Analysis of rainfall and temperature over a sub-basin of Lake Chad, Nigeria

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Abstract: Rainfall and temperature are two climatic variables that are indispensable for climate variability and change studies. This study aims to examine the trend pattern of rainfall and temperature over a sub-basin of Lake Chad Hydrological Area. To achieve this, rainfall and temperature datasets over 50 years (1970-2020) were analysed for variability and trends using descriptive statistics and Mann Kendal Trend Analysis. The results showed that the area has experienced a mean annual rainfall of 751.13 mm yr^{-1} with a standard deviation of 136.58 mm yr^{-1}. Rainfall variability was high (CV >30) in the early rainy but less (i.e., CV <20) in the annual and late rainy season. The highest mean value was noted for TMIN, TMAX and TMEAN in the months of April and May and their highest variability was in the months of January and February. Also, an increasing trend in rainfall pattern that is significant ($p<0.05$) had been recorded in the late rainy season and annual timescale. Except for the TMAX (i.e., the day temperature) that showed an upward but non-significant trend, the remaining temperatures (TMIN and TMEAN) showed upward trends of varying levels of significance on seasonal and annual bases. This implies that the area has been experiencing a warming trend with effects on rainfall that has probably attracted the flood witnessed in part of the Lake Chad Hydrological Area.

Keywords: Rainfall, temperature, trend, variability

1. Introduction

Climate change is a global menace that has posed a serious threat to virtually every nation of the world [1]. Studies have shown that the impact of climate change and environmental crisis has been felt through erosion, drying of the land and prevailing drought [2]. Drought and flood which are the worst climate disasters account for 85% of the world's natural disasters, with drought having more detrimental effects [3]. Rainfall and temperature are the most critical climatic variables influencing climate extreme events. The consequences of their variabilities are evident in Africa, especially Nigeria which is an agrarian hub, with most of its agricultural activities depending on rain. Therefore, understanding the pattern and trends of these climatic variables is essential not only to climate change studies but also for decision-making on adaptation strategies.

Regional-scale analysis of historical climate data is essential for understanding the unique challenges posed by climate change to different parts of Africa. It provides the foundation for developing effective management and mitigation plans to address the impacts of climate change on water resources and agricultural activities, which are critical for the continent's sustainable development and food security [4]. This is so as rainfall and temperature remain better variables for easy understanding of the climatic condition of a place [5]. Several studies have been conducted on changing patterns of rainfall and temperature in Africa. Although most of the studies were carried out separately, either on rainfall or temperature variability. Therefore, there are limited studies conjoining both variables for variability studies. For instance, [6] used Regression and Mann-Kendall trend analysis to study the trend of temperature and rainfall over Guinea during 1960–2016. The results of their study indicated that while trends of temperature had been on the increase, the trends of rainfall had been on the decrease. A study by [5], who observed the rainfall and temperature variability over Nigeria between 1971 and 2000, indicated an increase in precipitation and air temperature in most parts of Nigeria, especially during the last decade (1991–2000) of the study period. The two aforementioned studies showed that though temperature followed a similar trend pattern, the pattern for their rainfall differs. This suggests the uniqueness of each area and a need for each basin or sub-basin to be assesed [4]. Thus, this study aims to analyse the variability and trend of rainfall and temperature over a sub-basin of the Lake Chad hydrological area.

2. Method

2.1. Study area

The Study area is located on latitude 11.8 N and longitude 9.8 E. It is situated within Lake Chad Hydrological Area, which is one of the eight hydrological area in Nigeria (Fig. 1). It falls within Sudano-Sahelian region and characterized with moderate rainfall and tropical climate. It experiences two seasons namely dry and wet season.

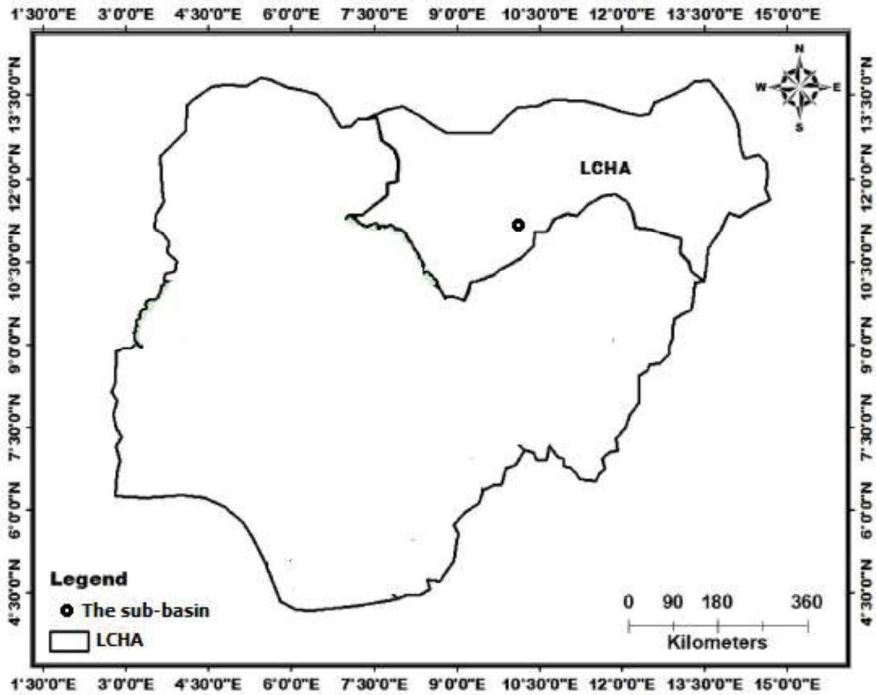

Fig. 1. Map of the study area

2.2. Details of data and data analysis

2.2.1. Dataset

The observation data used for the variability and trend analysis were obtained from the Climate Research Unit (CRU_TS 4.06), University of East Anglia, Norwich, UK. The CRU is a monthly dataset with 0.5 by 0.5 latitude and longitude resolution over the periods 1901–2021. However, this study uses a dataset between 1970 and 2020. The choice of the dataset is due to the unavailability of continuous long-term datasets. In Nigeria, CRU data has gained wide acceptance and its high correlation with Nigeria Meteorological Agency (NiMET) data has been reported by many researchers [8]. The obtained datasets are precipitation, minimum (TMIN) and maximum (TMAX) temperatures and the two were averaged to get the mean (TMEAN) temperature.

2.2.2. Data analysis techniques

In this study, descriptive statistics and Mann Kendall (MK) test have been adopted for the variability and trend studies respectively. The descriptive statistics carried out are the mean, standard deviation, coefficients of skewness (Cs), kurtosis (Ck), and variation (CV). The coefficient of skewness (Cs) is said to be right-skewed, if it has a positive Cs, left-skewed, if its Cs is negative Cs and a time-series is considered normally distributed if it has values of the coefficients of skewness and kurtosis of 0 and 3, respectively [4]. On the other hand, Mann Kendall (MK) and Sen Slope estimator were applied to determine the trend direction and magnitude.

2.2.3. Variability analysis

The CV was computed to evaluate the variability of the rainfall and temperature. The degree of variability is a function of the indicator, which implies that the higher the value of CV, the higher the variability and vice versa [7]. The value of CV obtained is used to categorize the degree of variability of rainfall events as less (CV < 20), moderate (20 < CV < 30), and high (CV > 30).

$$CV= (\sigma/\mu) \times 100 \quad (1)$$

where CV is the coefficient of variation, σ is standard deviation, and μ is the mean rainfall.

2.2.4. Mann-Kendall trend test

Mann-Kendall (MK) trend test is skillful in detecting the presence, direction (increasing or decreasing) and significance of changes in rainfall and temperature series.

The MK. test statistic ‘S’ is calculated using the equation below

$$S=\sum_{i=1}^{n-1}\sum_{j=i=1}^{n} sign(Xj - Xi) \quad (2)$$

where xi and xj are the sequential data values, n is the data set record length, and

$$Sign=\begin{cases} +1 & \theta > 1 \\ 0 \quad if & \theta = 0 \\ -1 & \theta < 0 \end{cases} \quad (3)$$

indicates positive differences, no differences, and negative differences, respectively, and S is computed as the sum of the integers. The expected value of S equals zero (E[S] = 0) for series without trend and the variance is computed as below:

expected value of S equals zero (E[S] = 0) for series without trend and the variance is computed as below:

$$\sigma^2 (s) = \frac{1}{18} [n (n-1) (2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5)] \quad (4)$$

where q is the number of tied groups and tp is the number of data values in pth group. The test statistics Z is then given as:

$$Z=\begin{cases} \frac{s-1}{\sqrt{\sigma\, 2\,(s)}} & S > 0 \\ 0 \quad if & S = 0 \\ \frac{s+1}{\sqrt{\sigma\, 2\,(s)}} & S < 0 \end{cases} \quad (5)$$

The Z statistic is used to test the null hypothesis, H0 that the data are randomly ordered in time, with the alternate hypothesis, H1, indicating an increasing or decreasing monotonic trend.

2.2.5. Sen’s slope estimator

Sen's Slope Estimator was used along with the MK test to quantify the magnitude of the trend. This provides information about the rate of change in the time series data. Sen’s slope estimation test computes both the slope (i.e., change per unit time) and intercepts. A positive value of Z indicates an ‘upward trend’ (increasing values with time), while a negative value of Z indicates a ‘downward trend’. Here, the slope (Q) of all data pairs was computed as presented below. The slope estimates of N pairs of data were first calculated using (6) below:

$$Q=\frac{x_J - x_k}{J-K} \text{ for } i = 1 \ldots\ldots\ldots N \quad (6)$$

where j > k.

Ranking of N values of Qi was done from the smallest value to the largest, and the Sen’s estimator is given as:

$$Q = Q_{[(N+1)/2]} \quad \text{if N is odd} \quad (7)$$

$$Q = \frac{1}{2}(Q_{(N/2)} + Q_{[(N+1)/2]}) \text{ if N is even} \quad (8)$$

For details on the analysis check [8] and [9].

3. Results and Discussion

3.1. Variability and trend of rainfall

The results of the statistical analyses of seasonal rainfall over the year (1970-2020) under study are presented in Table 1. The mean annual rainfall for the period was 751.13 $mmyr^{-1}$ having a standard deviation (SD) of 136.58 $mmyr^{-1}$. The minimum annual rainfall experienced was 425.2 mm while the maximum was 1061.60 mm. The coefficients of skewness and kurtosis were 0.37 and -0.03, respectively, which suggest that the data is right-skewed and not normally distributed. Similar pattern has been reprted by [4] for Niger Central Hydrological Area (NCHA), Nigeria. The temporal variability of annual rainfall was found to be 18.18%. The result of the Mk-test shows that it has an increasing annual trend that is significant ($P < 0.05$).

Table 1. Descriptive Statistics of monthly (mm/month), seasonal (mm/month), and annual (mm/year) rainfall over the sub-Basin (1970-2020).

Time series	Min	Max	Mean	SD	CV%	Cs	Ck	Z-value	Q
Apr	0.40	31.60	8.55	8.27	96.79	0.11	0.93	0.78	0.019
May	4.50	141.80	50.23	30.49	60.70	0.09	0.78	-0.19	-0.039
Jun	39.20	279.70	104.78	54.13	51.66	1.60	1.36	2.13*	0.986
Jul	118.00	324.70	199.97	44.99	22.50	0.32	0.34	0.90	0.459
Aug	115.00	399.40	249.68	54.11	21.67	0.69	0.02	2.75**	1.233
Sep	31.70	215.10	119.31	42.60	35.71	-0.60	0.09	1.66	0.771
Oct	0.60	90.70	18.16	18.45	101.63	4.17	1.80	2.14*	0.306
Early rainy	59.80	362.30	163.55	68.75	42.04	0.94	0.94	1.65	1.095
Late rainy	322.40	843.20	587.11	102.22	17.41	0.47	-0.30	2.78**	2.759
Annual	425.20	1061.60	751.13	136.58	18.18	0.37	-0.03	3.15**	4.168

The late rainy season was found to have a higher contribution to the total annual rainfall than the early rainy season. While the late rainy seaon contributed 78.16%, 21.77% was contributed by the early rainy season. This is not unexpected, as most of the rainfall events were recorded in the month of August followed by July with their joint contribution of 76.6% to the average late rainy season rainfall (JASO) and 59.86% to the average annual rainfall. The inter-annual variability was higher in the early rainy season having a CV of 42.04% than in the late rainy season which has a CV of 17.41%. The degree of variability can be classified as high (CV > 30) for the early rainy season, and less (i.e., CV < 20) for the annual and late season rainfall. The less variability for annual time series is in agreement with the finding of [10].

Also, seasonal and annual rainfall have experienced a positive trend which was significant (($P < 0.05$) for the annual and late rainy seasons. This evidence indicates that the late rainy season experiences greater fluctuations or variability from one year to the next compared to the early rainy season. This result contradicts what was reported in [4] that inter-annual variability was higher in the early rainy season than in the late rainy season over the NCHA. This variation in results could be attributed to a number of factors, such as climate patterns, weather conditions, or other environmental influences. This variability can have significant implications for agriculture, water resources, and ecosystems, among other things.

The peak of annual rainfall was in the month of August with a mean rainfall of 249.68 $mmyr^{-1}$, followed by the month of September with a mean rainfall of 119.31 $mmyr^{-1}$ (Fig. 2). The slope (Q) depicts the same pattern as that of the MK-test (Z-value).

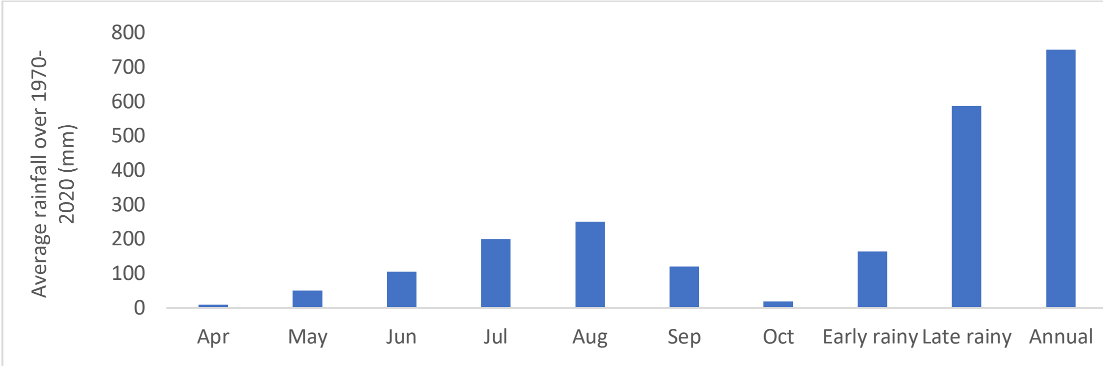

Fig. 2. Monthly and seasonal rainfall (mm)

3.2. Variability and trend of temperature

The results of descriptive statistics of the temperature over the study area is presented in Table 2. The result shows the variability analysis of monthly, seasonal and annual temperature time series (minimum, maximum, and mean) for the period 1970–2020. The mean value of TMIN ranged from 14.03 °C (in January) to 25.06 °C (in May). The coefficient of variation (CV) of the monthly datasets indicated the night temperature varied from 2.24% (in August) to 8.02% (in January). The TMAX showed that the day temperature over the region ranged from 30.29 to 39.36 oC and varied from 2.09 to 5.79%. Also, the mean temperature over the area ranged from 22.14-31.81°C and varied from 1.98-6.16%. It was found that TMIN, TMAX and TMEAN have high mean values in the month of April and May with their highest variability in the month of January and February. Relatively high temperature in the months preceding the onset of the rainy season ascribed to the intensification of convective precipitation at high temperatures and highest variability in January has also been reported in earlier studies [8, 11].

Table 2. Descriptive statistics of Temperature over the study area (1970–2020) CV in %

	TMIN			TMAX			TMEAN		
	Mean	STD	CV	Mean	STD	CV	Mean	STD	CV
Jan	14.03	1.13	8.02	30.25	1.75	5.79	22.14	1.36	6.16
Feb	17.01	1.35	7.93	33.47	1.83	5.46	25.24	1.55	6.13
Mar	21.26	1.28	6.00	37.18	1.41	3.80	29.22	1.26	4.30
Apr	24.25	0.90	3.73	39.36	0.90	2.29	31.81	0.82	2.57
May	25.06	0.69	2.76	38.20	0.80	2.09	31.63	0.63	1.98
Jun	24.35	0.58	2.37	35.77	0.81	2.26	30.06	0.64	2.14
Jul	22.90	0.54	2.37	32.37	0.95	2.94	27.63	0.72	2.59
Aug	22.13	0.50	2.24	31.39	0.85	2.72	26.76	0.64	2.40
Sep	22.01	0.51	2.32	33.18	0.82	2.47	27.60	0.63	2.28
Oct	21.10	0.76	3.58	35.37	0.76	2.14	28.23	0.62	2.20
Nov	17.10	1.07	6.24	34.11	1.20	3.51	25.61	1.06	4.12
Dec	14.69	1.05	7.11	31.30	1.41	4.52	23.00	1.15	5.00
NDJFM	16.82	0.66	3.95	33.26	0.84	2.53	25.04	0.72	2.87
AMJ	24.55	0.55	2.26	37.78	0.60	1.59	31.17	0.51	1.63
JASO	22.03	0.48	2.16	33.08	0.63	1.92	27.56	0.53	1.91
Annual	21.14	0.45	2.12	34.33	0.52	1.51	27.92	0.44	1.58

More so, on a seasonal basis, all the peak values for TMIN (24.55 ºC), TMAX (35.17 ºC) and TMEAN (28.03 ºC) were recorded in the early rainy season (AMJ). This shows that while the early rainy season was the warmest, the coldest was the late rainy season The high temperature experienced in the early rainy season, despite it being associated with rain, can be attributed to several factors, including intense land preparation activities, increased insolation, moisture levels in the soil, and local climate and geographical features [8]. The activity tends to expose the area to extreme daylight heating and thus increases the temperature [11]. The highest seasonal variability was recorded for the TMIN (3.95%). TMAX (2.53%) and TMEAN (2.97%) in the dry season (NDJFM). The high variance of the temperatures in the dry season indicated a probable extension of the dry season.

The result of the Mann-Kendall trend presented in Table 3 showed the trend of TMIN, TMAX and TMEAN for all the time series. The monthly time series of the TMIN showed that only January and February were insignificant, the remaining months showed increasing trends at various levels of significance. The results for TMAX showed that increasing trend in 50% of the months were not significant, while four months (April, May, July and October) were significant at $P < 0.05$, the remaining two months (March and November) recorded an increasing trend that significant at $P < 0.01$. The TMEAN also recorded an increasing trend that were significant in all months, except January, February, August and September which experienced positive but not significant trends. The trend pattern reported for TMEAN in this study is similar with the report of [8].

The trends for annual TMIN, TMAX and TMEAN all showed increasingly significant trends ($P < 0.01$). On a seasonal scale, both TMIN and TMEAN showed a significant increasing trend ($P < 0.01$) in both the dry and the rainy seasons, while TMAX showed a significant trend only in the dry ($P < 0.01$) and early rainy ($P < 0.05$) seasons. The late rainy season (JASO) was insignificant. In both monthly, seasonal and annual scales, sen's slope showed the same pattern as that of the Men-Kendal estimator in both magnitude and direction. This could be due to the close lag-1 serial correlation observed in the data [12].

Table 3. MK statistic for monthly and seasonal of temperatures over the area (1970–2020)

	TMIN		TMAX		TMEAN	
	Test Z	Q	Test Z	Q	Test Z	Q
Jan	1.29	0.01	1.00	0.017	1.210	0.015
Feb	1.88	0.03	0.87	0.015	1.081	0.020
Mar	3.00**	0.03	2.86**	0.034	3.129**	0.035
Apr	2.47*	0.02	2.54*	0.023	2.936**	0.023
May	2.80**	0.02	2.49*	0.015	3.073**	0.019
June	3.64***	0.02	1.52	0.014	2.651**	0.015
July	3.19**	0.02	2.24*	0.020	2.684**	0.019
Aug	2.66**	0.01	0.36	0.002	1.284	0.008
Sep	2.08*	0.01	1.20	0.011	1.577	0.012
Oct	3.23**	0.02	1.97*	0.014	3.016**	0.017
Nov	3.55***	0.04	3.17**	0.035	3.690***	0.037
Dec	2.85**	0.03	1.65	0.025	2.332*	0.027
NDJFM	4.85***	0.03	3.42***	0.026	4.257***	0.028
AMJ	3.98***	0.02	2.89**	0.017	4.176***	0.020
JASO	3.75***	0.02	1.62	0.011	2.551*	0.013
ANNUAL	5.43***	0.02	4.06***	0.019	5.117***	0.022

4. Conclusion

In this study, variability and trends of the monthly, seasonal and annual timescale of rainfall and temperature over 50 years (1970 - 2020) were analysed. The peak monthy and seasonal rainfall were in August (249.68 mm) and late rainy season (587.11 mm) and the average annual rainfall over the period was 751.13 mm. The highest monthly and seasonal variability were noted for October (101.63%) and early rainy season (42.04%) respectively. The TMIN and TMAX have high mean values in April and May with their highest variability were in January and February. A significantly positive rainfall had been experienced in the late rainy season and annual timescale. Also, the positive trends for the annual tempertures (TMIN, TMAX and TMEAN) were all significant. On a seasonal timescale, both TMIN and TMEAN showed trends that were positive and significant for both seasons while the trend of TMAX was though positive for both season, the trend was not significant in the late rainy season. This finding suggested that drought resistance growth with a shorter growth period should be planted in the early rainy season and a need for mitigation plan for probable flood as indicated by an increasing trend of the annual and late rainy season.

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