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Climate Change Incidence Analysis: Evidence from the Semiarid Zone Of North-Eastern Nigeria

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Abstract: *Climatic variability and change in the North-eastern Nigeria was evaluated using mean monthly temperature and rainfall data collected from the Nigerian Meteorological Agency for the period 1971 – 2010. The dataset was aggregated to obtain average yearly values and Mann Kendall test was used to assess the trend. The study revealed that the temperature at monthly scale for the months of March, April, May and December showed a significant positive trend at between 0.01 - 0.05 significance level, whereas temperatures in the remaining months showed no significant trend. More so, rainfall showed a significant positive trend between 0.1 - 0.5 level of significance for the months of June September and October while no significant trend in rainfall for the remaining months. It further indicated that increase in annual temperature of +0.76 °C from 1971 to 2010 has been recorded in the entire semiarid zone of North-eastern Nigeria, whereas annual rainfall has not exhibited any trend. The significant trends observed in temperature and rainfall seem to be consistent between the different data sources. The study showed a clear evidence of climate change in the study area. Hence suggest the need for adaptation in response to climate change.*

Keywords: *Climate change, Man-Kendal test, North-eastern Nigeria, Trend Analysis*

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I. Introduction

The African continent is controlled by complex maritime and terrestrial interactions that produce a variety of climates across different regions, for instance from the humid tropics to the hyper-arid Sahara [1]. The intergovernmental panels on climate change (IPCC) confirm an increase in world temperature since the beginning of the industrial period and an acceleration of warming since 1975 [2]. Furthermore, the report stressed the extreme anthropic cause of this warming. Although warming affects the whole world, however, African continent is more vulnerable as evidence has shown that climate change has already affected crop yields in many countries. This is particularly true in low-income countries, where climate is the primary determinant of agricultural productivity and with low adaptive capacities [3]. Many African countries economy is largely based on weather sensitive agricultural production system with Nigeria inclusive are particularly vulnerable to climate change. The Niger Delta region along the coast of the country is vulnerable to flood and the Northern region is susceptible to prolonged droughts [4].

According to the IPCC third assessment report, observed temperatures have indicated a greater warming trend since the 1960s. Although these observed trends seem to be consistent over the continent, with little regional variations. For instance, decadal warming rates of 0.29 °C in the African tropical forests [5] and 0.1 to 0.3 °C in South Africa [6] have been observed. In South Africa and Ethiopia, minimum temperatures have increased slightly than maximum or mean temperatures [6]. Between 1961 and 2000, there was an increase in the number of warm spells over southern and western Africa, and a decrease in the number of extremely cold days [7]. Also in Nigeria, temperature records between 1901-1938 and 1971-2008 have shown an increase of 1.78 ^{o}C [8]. However, major spatial shifts were observed in temperature, as southward shift in the divide between the double rainfall peak and single rainfall peak, and a temporal shift in the short-dry-season from August to July in Southern Nigeria [8].

For precipitation, the situation is more complicated in which the rainfall exhibiting notable spatial and temporal variability. Inter-annual rainfall variability is large over most of Africa and, in some regions; multi-decadal variability is also substantial. In West Africa (4°-20°N; 20°W-40°E), a decline in annual rainfall has been observed since the end of the 1960s, with a decrease of 20 to 40% noted between the periods 1931-1960 and 1968-1990 [10]–[12]. In the tropical rainforest zone of Africa there was a decline in the mean annual precipitation of around 4% in West Africa, 3% in North Congo and 2% in Southern Congo for the period 1960 to 1998 have been reported [5]. A 10% increase in annual rainfall along the Guinean coast during the last 30 years has, however been observed [11]. In other regions, such as the Southern Africa, no long-term trend has been noted. Increased inter-annual variability was observed in the post-1970 period, with higher rainfall anomalies and more intense and wide spread droughts reported [13]. However, a downwards shift of 8.8% rainfall from the long-term mean of 1968 to 2008 has been recorded in the North-western Nigeria [14], with a consistent decrease in annual rainfall of 8 mm year-1 in the North-eastern part has been reported [15]. Finally, uncertainties in climatic variability resulted to changes in extreme events, such as droughts and floods in the north-eastern Nigeria, as this have major implications for numerous Nigerians and further attention is required. Therefore, the aim of this article is to assess the trend of climatic variability such as change in temperature and rainfall regimes at different time scale in the semiarid zone of North-eastern Nigeria.

II. Materials and Methods

2.1 Study Area

The study area covers three states in the North-eastern Nigeria consisting of Bauchi (10.50°N, 10.00°E), Maiduguri (13°10', 11°50'), and Adamawa (9.33°N, 12.50°E) state, selected based on the availability of climatic data (Fig. 1). The area defined falls within the semiarid zone of the country [15], [16], with a land area of approximately 103,639 square miles, and represents 29.1% of the total area of Nigeria [17]. The region has a savannah climate with distinct wet and dry seasons, with the length of the rainy season from June to October. During the dry season in the North-eastern part, Maiduguri for example, the mean monthly maximum temperature used to exceed 100^{o}F (38 °C) during the hot months (April and May), while in the same season frost may occur at night. The humidity is generally high in the north, but it falls during the harmattan period [18]

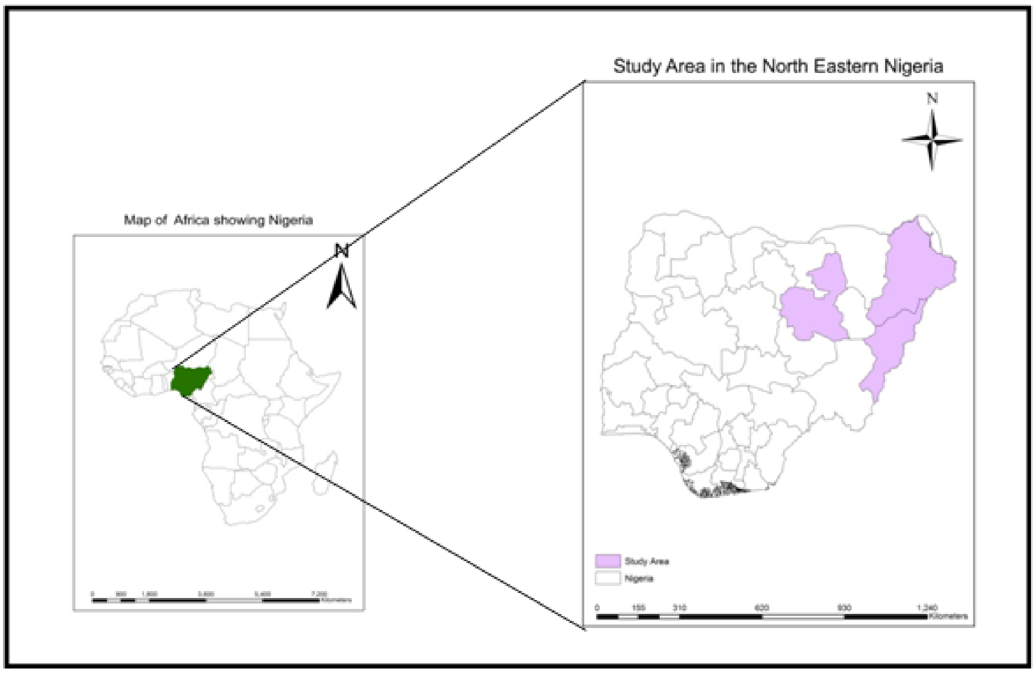

Figure. 1 Location of the study area in the North-eastern Nigeria

2.2 Data set

A time series monthly Average temperature and rainfall data spanning a period of 40 years (1971 - 2010) were analysed in this study (Table 1). The data series were collected from Nigerian Meteorological Agency (NIMET) three weather stations in Bauchi, Maiduguri, Yola and the aggregate for the entire North-eastern region. The selection of the stations was carried out based on the homogeneity, the length and completeness of records in which most of the study area were covered by the corresponding data. There is only one weather station with less than 2% of missing values in relation to the total data of the stations for the whole study period. Missing data was substituted with the corresponding monthly average value as recommended by [19]–[21]. Seasonal and annual series were calculated for each station using the seasonal Mann-Kendall Trend Test [21]–[24]. Seasons in these regions are classified as dry and wet seasons and were considered as follows: Dry season = November, December, January, February, March, and April; wet season= May, June, July August September and October.

Table 1 Descriptive summary of the data from 1971 to 2010

Variables	Statistics	1971-1980	1981-1990	1991-2000	2001-2010
Temperature	Minimum	33.62	33.80	33.78	34.08
	Maximum	35.05	35.07	34.80	35.32
	Mean	34.13	34.39	34.45	34.66
	V. Coefficient (%)	0.39	0.39	0.28	0.35
	SD	0.01	0.01	0.00	0.01
Rainfall	Minimum	87.10	77.00	90.90	96.50
	Maximum	136.70	127.90	143.00	136.20
	Mean	115.57	94.96	115.26	119.88
	V. Coefficient (%)	17.08	15.56	13.34	14.20
	SD	0.14	0.16	0.11	0.11

2.3 Methods

Trend analysis of monthly, seasonal and the annual temporal scale was carried out by applying linear and non-parametric models for each of the data series. Mann-Kendall test was conducted using XLSTAT software and MAKESENS Microsoft Excel template developed by the Finnish Meteorological Institute to calculate the statistical significance of the tendencies. Man-Kendall test was applied to examine the performance of a class of non-parametric trend test, and the relative magnitudes of the data rather than their measured values [22], [25], [26]. In this context, the method was used to detect long-term trend of the meteorological variables (e.g. temperature and rainfall) in the study area.

2.3.1 Mann-Kendall Trend Test

The basic principle of Mann-Kendall tests for trend is to examine the sign of all pairwise differences of observed values. The Mann-Kendall test is based on the statistics S. Each pair of observed values in the series is inspected to find out whether there is trend in the series. Let H_0 be "there is no trend in the series" null hypothesis to be tested against alternative hypothesis Hα "there is trend in the series". The test statistic, S, is the differences between these two cases and is written as

$$S = \sum_{k-1}^{n-1} \sum_{j=k=1}^{n} sgn\,(\mathrm{Xj} - \mathrm{Xk}) \qquad (1)$$

Where the xj and xk are the sequential data values and j>k, n is the length of the data set and

$$sgn(xj - xk) = \begin{cases} 1 \; if \; xj - xk > 0 \\ 0 \; if \; xj - xk = 0 \\ -1 \; if \; xj - xk < 0 \end{cases} \qquad (2)$$

which is the number of positive differences minus the number of negative differences. Variance of S, computed by

$$\mathrm{Var}\,(S) = \lfloor n\,(n-1)(2n+5) - \textstyle\sum_t (t-1)(2t+5) \rfloor / 18 \qquad (3)$$

And are asymptotically normal [27], where *t* is the extent of any given tie and the summation over all ties. For the case that *n* is larger than 10, the standard normal variate *z* is computed by using the following equation [28].

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \; if \; S > 0 \\ 0 \quad if \quad S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}} \; if \; S < 0 \end{cases} \qquad (4)$$

Thus, in a two-sided test for trend, at a selected level of significance α, the null hypothesis of no trend is rejected if the absolute value of *Z* is greater than $z_{a/2}$. In addition to identifying whether a trend exists, the magnitude of a trend was also estimated by a slope estimator b, which was extended by Hirsch [27] from that proposed by Sen [29], defined as

$$\beta = \mathrm{Median}\left(\frac{xj - xi}{j - i}\right) \; where \; 1 < i < j < n \qquad (5)$$

In other words, the slope estimator ß is the median over all possible combinations of pairs for the whole data set [27]. A positive value of β indicates an 'upward trend' (increasing values with time), while a negative value of β indicates a 'downward trend' [30].

III. Results and discussions

3.1 Annual Scale of Climatic Variability for Temperature

The results obtained at the annual scale for temperature are shown in Tables 2. Annual temperature displays significant changes, with an upward trend identified in Bauchi, Yola and the entire Northeast, with only Maiduguri showing a non-significant trend. The average trend calculated for the study area has a Senslope of +0.76, implying that an increase in annual temperature of +0.76 °C from 1971 to 2010 has been recorded in the entire North-eastern region which is in consistent with [8], who observed an increase of 1.78 °C from 1901 to 2008 with a more significant increase between 1971 to 2008 in Nigeria.

Table 2 Trend for annual temperature of North-eastern Nigeria 1971-2010

Stations	Kendall Statistic	Kendall's Tau	Senslope	P-value (two tailed)	Test Interpretation
Northeast	286	0.36	0.76	0.001	Reject H0
Bauchi	244	0.31	0.92	0.004	Reject H0
Maiduguri	162	0.20	0.06	0.061	Accept H0
Yola	210	0.27	0.56	0.014	Reject H0

Note: Alpha: 0.05, *H0*: There is no trend in the series, *Ha*: There is a trend in the series

Although these trends seem to be consistent over the country, the changes are not always uniform. Therefore, a certain spatial variability from the mean average and anomaly with a linear trend is observed in the annual temperature trend in most of the stations within the region which indicate increasing trend (Fig. 2a, b).

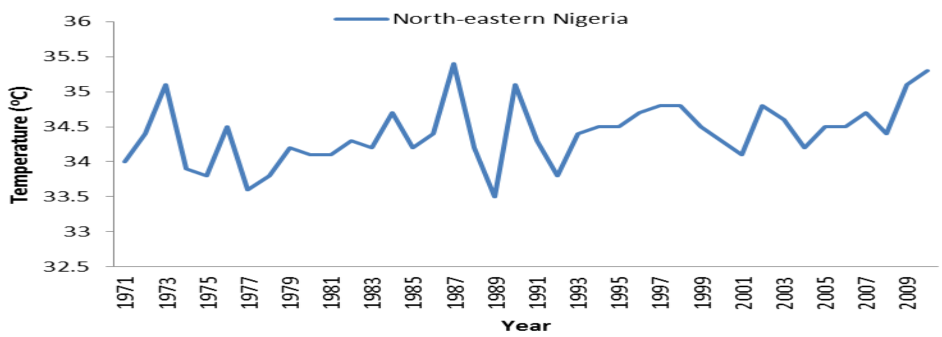

Fig. **2a** Temperature trend with anomalies in the North-eastern Nigeria

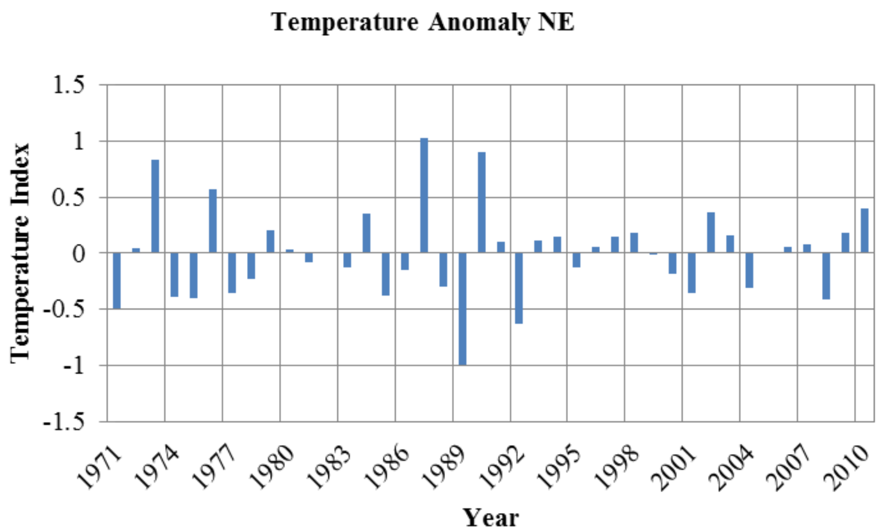

Fig. **2b** Temperature trend with anomalies in the North-eastern Nigeria

3.2 Annual Scale of Climatic Variability for Rainfall

For annual rainfall, no trends was observed in most of the stations (Table 3), hence these agrees with the conclusions of [8], [31], [32], they did not observe any significant trend for annual totals of different regions of the country. Nevertheless Bauchi station recorded an average increase of (+1.09 mm) from 1971 to 2010, which is in agreement with the findings of [33] who found significant upward trends for yearly total rainfall within a period of 1947 –1977.

Table 3 Average annual rainfall North-eastern Nigeria for the period of 1971-2010

Stations	Kendall Statistic	Kendall's Tau	Senslope	P-value (two tailed)	Test Interpretation
Northeast	158	0.20	0.55	0.067	Accept H0
Bauchi	202	0.25	1.09	0.019	Reject H0
Maiduguri	146	0.18	0.75	0.091	Accept H0
Yola	-72.0	-0.09	-0.22	0.411	Accept H0

Note: Alpha: 0.05, *H0*: There is no trend in the series, *Ha*: There is a trend in the series

However, significant negative trend in annual rainfall within the west African Sahel and the Northern Nigeria have been pointed out by [12], [34], [35]. Several authors have pointed out to that effect that the circulation in rainfall variability over West Africa exhibits the most basic characteristics of a monsoon: a pronounced seasonal wind shift that is produced by thermodynamic contrasts between the land (i.e., the Sahara) and ocean (i.e., the equatorial Atlantic). South-westerly flow is established between the Atlantic cold tongue (cool water close to the equator between the boreal spring and summer) and the Saharan heat low, bringing moisture into the continent [36], [37]. In general, the result show an insignificant increase in the annual rainfall scale of the region, that is especially pronounced by some authors previously mentioned (Fig. 3a, b).

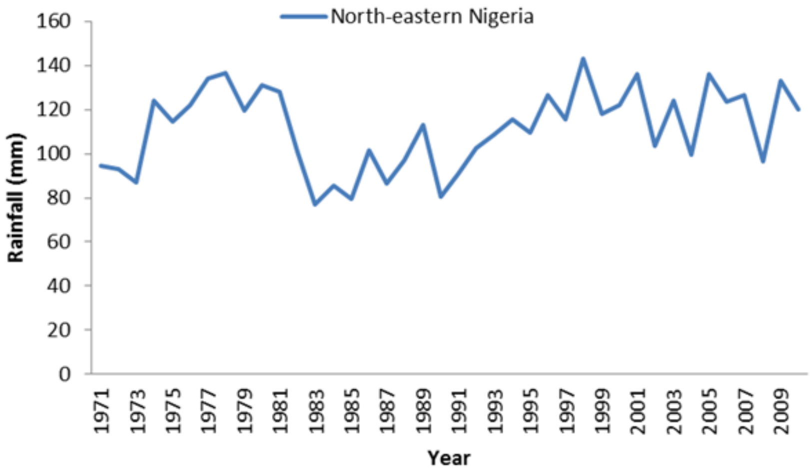

Fig. 3a Rainfall trend with anomalies in the North-eastern Nigeria

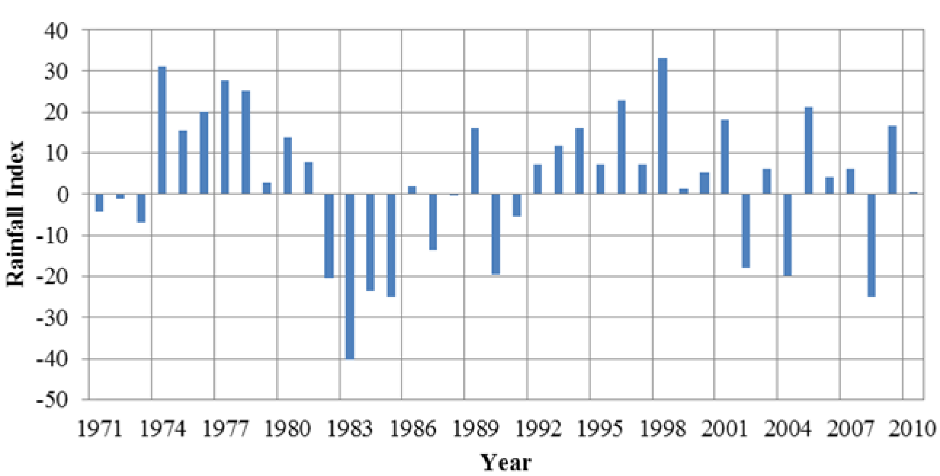

Fig. 3b Rainfall trend with anomalies in the North-eastern Nigeria

3.3 Monthly Scale Variability

The monthly scale variability, show an upward trend in temperature in most of the month for the entire region. A significant increase in trend at the level of α = 0.01 and 0.05 was observed in the months of March, April, May, and December with a Sen slope of (0.24 °C, 0.28 °C, 0.28 °C and 0.40 °C) for the entire four decades (Table 4). Positive significant trends in this month have been also pointed out by the previous studies recorded in Nigeria [2], [38], [8], [9]. In addition, a significant decrease in trend was observed in two stations; Maiduguri and Yola for the months of August (Sen-slope of -0.28 °C) and October (-0.24 °C), suggesting that the decrease in trend may be associated with an increase in rainfall intensity in those months in the stations.

Table 4 Monthly trends for annual temperature of Northeast during 1971-2010

Time series	n	Test Z	Sen- slope	Sig. level	Trend
Jan	40	1.10	0.02		NT
Feb	40	1.06	0.02		NT
March	40	2.44	0.24	*	↑
April	40	3.19	0.28	**	↑
May	40	2.16	0.28	*	↑
June	40	0.08	0.00		NT
July	40	1.25	0.01		NT
August	40	0.25	0.00		NT
Sep	40	-0.23	-0.01		NT
Oct	40	-1.42	-0.01		NT
Nov	40	1.35	0.01		NT
Dec	40	2.47	0.40	*	↑

Note: ↑- *upward trend*; NT: -*no trend*; *: α = 0.05; **: α = 0.01; +: α = 0.1

Increase in temperature is observed above all in the dry season from March to May and the month of December, with most significant increasing trend of 0.28 °C recorded in April for the four decades which is quite alarming, and justified the rampant cases of weather related diseases that were clinically recorded within the month. This findings is in agreement with the findings of [39] which reported that dry season temperatures range between 36 and 42 degrees Celsius across the country, indicating a likelihood for an outbreak of some diseases that are common with hot weather like meningitis, tuberculosis, malaria, dengue fever, measles, chicken pox, boils, skin rashes, and heart attack. More so, the report also found that simultaneous hot weather and high humidity could cause deadly disease epidemic and high mortality rate in the animal husbandry sub-sector. Therefore, the result shows that positive trends have clearly prevailed against negative tendencies in the study period.

Nevertheless the study have noted that the temperature over the period 1971–2010 has tended to increase in general at a lower level than the results reported by some authors previously mentioned. It also reveals that temperature in North-eastern Nigeria is increasing at monthly scale over the last four decades. Although the study found it challenging to compare the findings of monthly scale with many previous studies due to lack of literature from the study area, but they were in agreement with the studies of [21], [23] conducted in different regions. Monthly rainfall indicates a non-significant downward trend in the cumulated figures for March, April, May, and July. However, rain fall were not recorded between March and April in some years as a result of absent of rainfall within the period. In contrast, increasing monthly trends that are statistically significant were recorded in June, September and October in all of the stations. The averages of these trends in the study are having a Senslope of +1.16 mm June, +1.23mm September and October having +0.57 mm (Table 5).

Table 5 Monthly trends for average annual rainfall of Northeast during 1971-2010

Time series	n	Test Z	Sen- slope	Sig. level	Trend
March	14	-1.48	-0.08		NT
April	38	-0.98	-0.25		NT
May	40	-1.08	-0.45		NT
June	40	2.17	1.16	*	↑
July	40	-1.02	-0.63		NT
Aug	40	1.24	0.79		NT
Sept	40	1.71	1.23	+	↑
Oct	40	2.01	0.57	*	↑

Note: ↑- *upward trend*; NT: *no trend*; *: α = 0.05; **: α = 0.01; +: α = 0.1

Although the annual trend in rainfall exhibits a non-significant trend, positive tendencies in these months have also been found by [34], who reported an increase in monthly rainfall for the month of June at the rate of 2.29 mm. Similarly, the shift in variability for the peak months of rainfall from August to July in the Sahel reported by Nicholson [12] was not observed in the present work. However, monthly precipitations have increased practically everywhere in June and is significant at the regional scale.

IV. Change in Eco-environmental System of the Study Area

The changes in meteorological regimes could potentially result in many eco-environmental changes in the semi-arid environment such as the North-eastern Nigeria. This effect is more serious and usually irreversible, as evident in the reduction of stream flow in the Lake Chad Basin, the largest lake in the Chad basin of Africa which threatened the livelihood of over 30 million people in Chad, Nigeria, Niger and Cameroun, due to number of factors ranging from climate change to population explosion, poor conservation practices and other human activities. The Lake has shrunk dramatically in recent decades and has been labelled an ecological catastrophe by the UN Food and Agriculture Organization.

However, there is a general consensus that desertification is by far the most pressing environmental problem in the Northern parts of the country. The visible sign of this phenomenon is the gradual shift in vegetation from grasses, bushes and occasional tress, to grass and bushes and in the final stages, expansive areas of desert-like sand. It has been estimated that between 50% and 75% of Bauchi, Borno, Gombe, Jigawa, Kano, Katsina, Kebbi, Sokoto, Yobe, and Zamfara States in Nigeria are affected by desertification as a result of climate change. Therefore, the most viable option that is open to Nigeria and the entire sub-Sahara Africa to manage the impact of climate change in the region is through mitigation and adaptation to the changing climate.

V. Conclusion

The trends of climatic variability such as change in temperature and rainfall regime at different spatial scales in the North-eastern Nigeria have been examined in this study. The results at the annual scale for temperature show significant change with an upward trend identified in Bauchi, Yola and the entire Northeast, while Maiduguri shows a non-significant trend. The average trend calculated for the study has a Sen-slope of +0.76 °C, implying an increase in the annual temperature of 0.76 °C from 1971 to 2010 recorded in the entire North-eastern region. For annual rainfall, no significant trends were observed in most of the stations, with only Bauchi station recording an average increase of +1.09 mm, suggesting +1.09 mm from 1971 to 2010.

A significant increase in monthly trend at the level of $\alpha = 0.01$ and 0.05 is observed in the months of March, April May, and December with a Sen slope of (0.24 °C, 0.28 °C, 0.28 °C and 0.40 °C) for the entire four decades. Also, a significant decrease in the trend was observed in two stations; Maiduguri and Yola for the months of August (Senslope -0.02 °C) and October (-0.02 °C), suggesting that the decreasing trend may be associated with an increase in rainfall intensity in those months. The study found that positive trends prevailed over the negative trends in the study area. Nevertheless it has been noted that the North-eastern temperature over the period 1971–2010 has tended to increase in general at a lower level than the results reported by some authors previously mentioned. The changes in meteorological regimes have resulted in many eco-environmental changes in the semi-arid environment such as the North-eastern Nigeria, as evidenced in the shrinkage and disappearance of lakes (Lake Chad), declination of ground water level, decrease numbers of herbaceous species (Yankari game reserve), as well as the desert encroachment characterized by increased frequency of floating dust and sand-dust storms. This signifies a clear evidence of climate change in the study area, hence call for urgent means of addressing this issue through mitigation and adaptation to the changing climate.

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