Recent Changes in the Temperature and Rainfall Conditions Over Kaduna State, Nigeria

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Abstract

This study examines the evidence of climate change in Kaduna State, Nigeria, from the analysis of temperature and rainfall data (1971-2016) of three meteorological stations along a geographic transect in the State. Linear regression, second order polynomial, standard deviation and Cramer's test were used to determine the changes in both the temperature and rainfall series. The result of the linear trend lines and second order polynomial revealed an increasing trend of temperature in recent years. The linear trend line revealed a mean increase in average temperature of 1.03°C for the State. The plotted standard deviation for the temperature anomalies generally showed that years of temperatures above the mean standard deviation in the last 16 years (2001-2016) were more than those below it. The Cramer's test generally revealed an increasing temperature trend in the last two decades. The linear trend line of the annual rainfall revealed a mean increase of 303.32 mm for the State. Findings also revealed that the second order polynomial generally showed a decreasing trend from 1971 to the late 1990s and an increasing trend afterwards up to 2016. The plotted standard deviation showed an increase in rainfall in recent years. The decadal analysis of rainfall in all the stations generally showed an increasing trend in the last two decades. The study recommends that awareness programs on recent changes in temperature and rainfall should be enhanced; greenhouse gases emission in the atmosphere that have warming effect should be reduced; and, government policies related to agriculture, water resources, and other related sectors should take into account the increasing nature of temperature and rainfall amount in recent years.

Keywords: Anomalies; curve fitting; linear trend; rainfall; sub-period; temperature.

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Introduction

Climate change is a global issue that impacts on every living being in the world. It refers to any significant change in the measures of weather elements such as temperature, rainfall, wind pattern etc. and lasting for an extended period of time (Nigerian Meteorological Agency (NiMet), 2017). Complex interactions in the climate system can give rise to strong feedback mechanisms that may lead to sudden climatic changes (Narisma *et al*, 2007; Tang and Zhang, 2018). Climate change, whether driven by natural or human forcing, can lead to changes in the likelihood of the occurrence or strength of extreme weather and climate events. Evidence of climate change from observations of the atmosphere and surface has grown significantly in recent years (Hartmann *et al*, 2013).

There is a general concern that global temperatures and sea levels are rising and will continue to do so throughout the 21st century (Trenberth *et al*, 2007). A large number of studies, for examples IPCC (2007), Trenberth *et al* (2007), Hartmann *et al* (2013), and Tang and Zhang (2018) among others, show that the trend of global warming has been remarkable in the past hundred years. Instrumental observations over the past 157 years show that temperatures at the earth's surface have risen globally, with regional variations (Trenberth *et al*, 2007). The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85°C, over the period 1880–2012, and about 0.72°C, over the period 1951–2012 (Hartmann *et al*, 2013). The warmest years in the instrumental record of global surface temperatures are 1998 and 2005 (IPCC, 2007; Trenberth *et al,* 2007).

The global increase in temperatures is as a result of increase in greenhouse gases (GHGs) due to human activities such as industrial pollution, destruction of nature (e.g. deforestation and bush burning), combustion of fossil fuel, gas flaring, used of chemicals among others (Manyatsi *et al*, 2010; Cubasch *et al,* 2013). These activities result in emissions of four long-lived GHGs. These are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons (IPCC, 2007). The rapid increase in these GHGs, since the great industrial revolution, has resulted in global warming. As a result of global warming, the world is experiencing greater weather extremes such as changes in rainfall patterns, heat and cold waves, and also increasing droughts and floods with a negative impact on the environment and on people's lives and livelihoods (IPCC, 2007).

As the climate changes, several direct influences alter precipitation amount, intensity, frequency and type. Widespread increases in heavy precipitation events have been observed, even in places where total amounts have decreased. These changes are associated with increased water vapor in the atmosphere arising from the warming of the world's oceans, especially at lower latitudes (Trenberth *et al*, 2007).

West Africa has experienced marked multi-decadal variability in rainfall. Wet conditions in the 1950s and 1960s gave way to much drier conditions in the 1970s, 1980s and 1990s. The decreasing rainfall and devastating droughts in the Sahel region during the last three decades of the 20^{th} century are among the largest climate changes anywhere else in the world (Trenberth *et al*, 2007).

In Nigeria, rising average temperatures as a result of global warming have been shown to be already affecting the environment and livelihood assets (Ishaya and Abaje, 2009). Temperature increases of about 0.2–0.3^{o}C per decade have been observed in the various ecological zones of Nigeria (Federal Republic of Nigeria (FRN), 2003). Precipitation increases of about 2-3% for each degree of global warming may be expected for the tropical humid zones (FRN, 2003; Oladipo, 2011). In the northern part, annual rainfall amounts have been on the increase especially from the late 1990s (Abaje *et al*, 2013).

Climate will continue to change at all scales and levels. Traditional coping and adaptation mechanisms may, therefore, not be sufficient to deal with impacts of climate change. Humanity will have no choice but to try to cope with it and in the long-term adapt to it. This calls for the recent changes in temperature and rainfall over Kaduna State in order to facilitate appropriate strategies to ameliorate the scourge of climate change. This is because the implications of these changes for agriculture, water resources, ecological systems, food security, and human health among others will certainly be different.

Literature Review

Climate change includes major changes in temperature, rainfall, or wind patterns among other effects, that occur over several decades or longer (Hartmann *et al*, 2013). The climate of Kaduna

State and Nigeria at large has shown considerable temporal and spatial shifts in its variability and change since the late 1960s and early 1970s through a careful study of meteorological data (FRN, 2003; NiMet, 2012).

Temperature Changes

Nigeria is generally characterized by a high temperature regime almost throughout the year. The far south has a mean maximum temperature of about 32°C while in the North (between February and May) it is about 42°C (NiMet, 2015). However, the mean minimum temperature in the South is 21°C and about 13°C in the North. Analysis of surface temperature data of Nigeria for the period, 1981 to 2017, shows an increasing trend in annual mean maximum and minimum temperature over the last few decades (NiMet, 2017).

Temperatures in Kaduna State and across Northern Nigeria show an increasing trend from the mid-20th century to date. The most significant increases in Northern Nigeria according to Building Nigeria's Response to Climate Change [BNRCC] (2011) were recorded in the extreme northeast (Nguru and Maiduguri) and extreme Northwest (Katsina and Sokoto) of the country. In the high ground areas of Jos, Kaduna, Yelwa and Ilorin, temperatures have increased from 0.2 to 0.5°C (NiMet, 2012).

In a study to unravel the certainty of climate change in Kafanchan town of Kaduna State using climate data from the period 1974 to 2007, Ishaya and Abaje (2009) revealed that the temperature values showed a fluctuating increase from 1974 to 1979 with a drastic fall in temperature in 1980. Thereafter, there was a stable but high temperature of above 25°C between 1994 and 1998. In another study, twelve selected climate indices for temperatures in Kaduna State based on Expert Team on Climate Change Detection and Indices (ETCCDI) definitions were computed for time series for the period 1971 to 2010 by Abdussalam (2015). The result of the study revealed that warmer days and nights have generally increased, and the general trends in all the temperature indices have shown a spatial coherence with mostly statistically significant increases at $p<0.05$.

Similarly, Abaje *et al* (2016) examined evidence of global warming in Kaduna State from the analysis of temperature data (1975-2014) using linear trend line equation, standard deviation which provides the deviation from normal, and Cramer's test in order to compare the means of sub-periods with the mean of the whole record period; the result of the analysis showed an increasing temperature trend in the last twenty years (1995-2014) in all the selected three stations.

Rainfall Changes

The annual rainfall in Nigeria is greater than 3500 mm from the very coastal area to less than 600 mm in the Northeastern (Nguru and Maiduguri) and Northwestern (Katsina and Sokoto) parts of the country (NiMet, 2012; Abaje *et al*, 2012). The length of the rainy season decreases from 9-12 months in the North, 6-8 months in the central part (Kaduna inclusive), to about 2-3 months in the extreme Northeastern part of the country (Odekunle *et al,* 2008; NiMet, 2012). The period of the rainy season in the country has being reduced from 1941 when the onset and cessation were generally normal to 1971 when signals of late onset and early cessation of the rainy season sets in. Since then, the length of the rainy season has remained shrinking while annual rainfall is about the same, thereby giving rise to high impact rainfall, resulting in flash floods (NiMet, 2012).

The mean annual rainfall anomalies over Nigeria from 1986 to 2015 according to the Nigeria Climate Review Bulletin showed that rainfall has been increasing, though not at a steady rate (NiMet, 2016). The report further revealed that there are some differences in the rainfall over the Southern and Northern parts of the country. Both parts show a deficit and excess in rainfall in 1986 and 2012 respectively. However, while the Northern part experienced droughts in 1987, 1990, and 2011, the southern part experienced normal rainfall in these years.

A study of rainfall trend and variation characteristics across Kaduna State using eleven selected stations in the Southern, Central and Northern parts of the State for a period of 50 years (1966-2015) was carried out by Yunusa *et al.* (2017). The study revealed that Kafanchan, in the Southern part of Kaduna State, has the highest total rainfall, yet there was not any significant trend in the five decadal periods that were analyzed. Some of the stations in the central and northern parts of the State revealed insignificant positive trend while others showed insignificant negative trend for the five decadal periods.

Similarly, Abaje *et al* (2018) examined the spatio-temporal distribution of rainfall in Kaduna State along a geographic transect, from the Southern to the Northern parts of State, for a period of 56 years (1961 – 2016). Findings revealed that rainfall is unevenly distributed. It decreases from the Southern part to the Northern part of the State, and that changes in rainfall amount of Kaduna State in all the three selected stations (Kafanchan, Kaduna and Zaria) from the various statistical methods used generally showed increasing wetness in recent years in Kafanchan and Zaria while Kaduna, there is an insignificant negative trend. The findings further revealed that the increase in the annual rainfall is as a result of a substantial increase in rainfall amount in the months of May, July, August and September.

From the above reviews, the climate of the State has indicated a tendency towards a wetter condition rather than the increasing dryness that was a feature of the 1960s to the 1980s; and the increasing temperature is an indication of increasing warming of the earth's atmosphere in recent years. Thus, a good understanding of the recent changes in temperature and rainfall is imperative to facilitating appropriate strategies to ameliorate the scourge of climate change at all levels.

Study Area

Kaduna State is located between Latitude 09^o 02'N and 11^o 32'N and between Longitude 06^o 15'E and 08^o 38'E (Figure 1). The climate of this area is under Koppen as Aw (tropical dry-and-wet climate). The wet season lasts for about six to seven months (April to October) with an average annual rainfall of about 1323 mm, with the month of August being the peak of the wet season (Ishaya and Abaje, 2008). The highest amount of rainfall of about 1733 mm per annum is recorded in the Kafanchan, the Southern part of the study area and decreases to about 1032 mm per annum in Zaria, the Northern part (Abaje *et al,* 2015). The rainfall intensity is very high within the months of July and August (ranging from 60mm hour^{-1} to 99mm hour^{-1}) (Oladipo, 1993b).

The highest average air temperature of about 28.9^{o}C normally occurs in April while the lowest (22.9 to 23.1^{o}C) occurs in December through January (NiMet, 2016). The mean atmospheric relative humidity ranges between 70-90% and 25-30% for the rainy and dry seasons respectively.

The low relative humidity experienced in the dry season is a product of the dry, dusty and cold harmattan air whose origin has been traced to the Sahara Desert (Abdulkarim and Sarki, 2013).

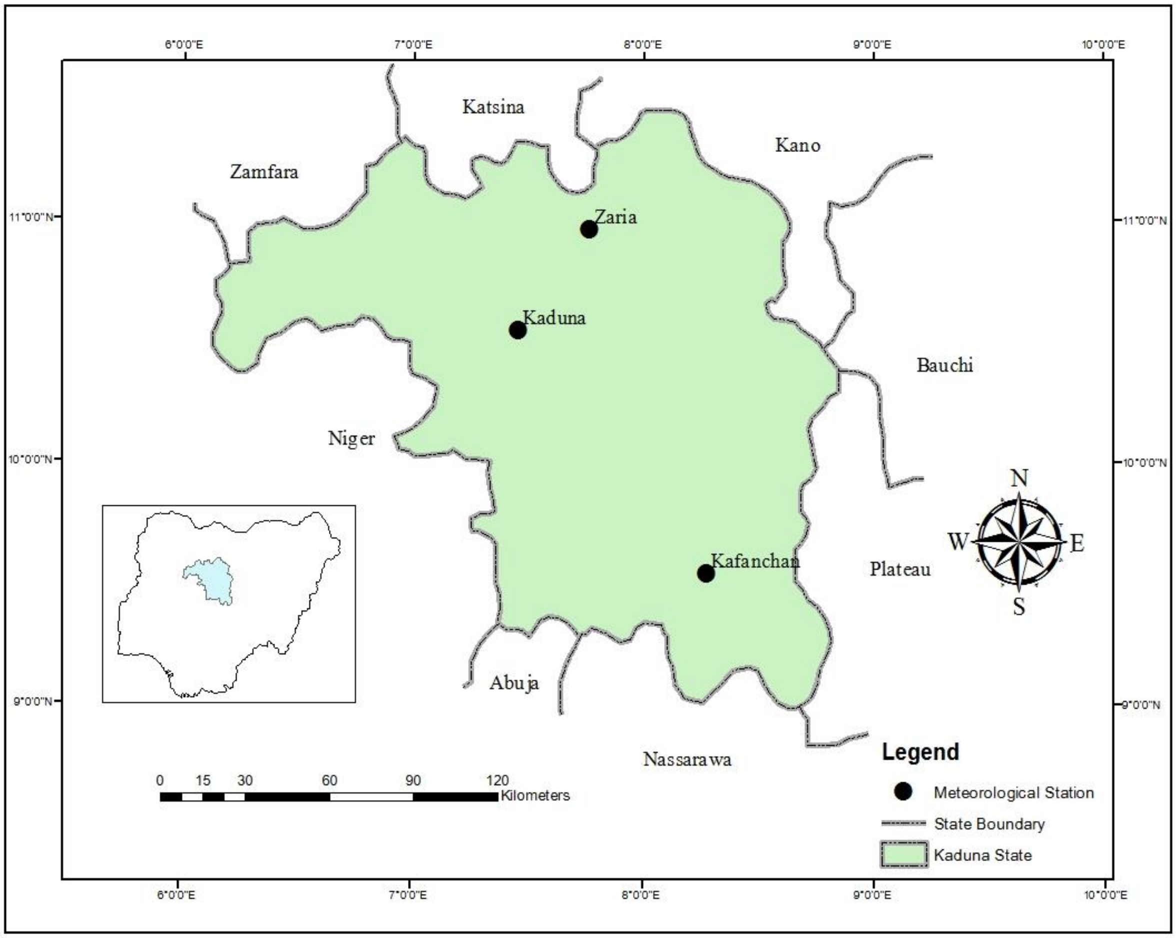

Figure 1: Kaduna State Showing the Three Meteorological Stations
Source: Adapted from Kaduna State Ministry of Lands and Surveys (2014)

The climate is dominated by the influence of two major air masses: the relative warm and moist tropical maritime (mT) air mass, which originates from the Atlantic Ocean associated with Southwest winds in Nigeria; and the relatively cool, dry and stable tropical continental (cT) air mass that originates from the Sahara Desert and is associated with the dry, cool and dusty Northeast Trades known as the Harmattan (Odekunle, 2010). These two air masses (mT and cT) meet along a slanting surface called the Intertropical Discontinuity (ITD). The movement of the ITD northwards across the State in August marks the height of the rainy season while its movement to the Southernmost part of the State around January/February marks the peak of the dry season (Abaje *et al*, 2018).

Materials and Methods

Data Collection

Forty-six years (1971-2016) of temperature and rainfall data were used for this study. These data were obtained from the archives of NiMet, Abuja, and Department of Hydrology (Meteorological Unit), Kaduna State Water Board, Kaduna. The Southern part of the study area was represented by data from Kafanchan Station, central part was represented by data from Kaduna Station, and Northern part was represented by data from Zaria Station (Table 1). These stations were selected based on the following criteria: 1) the stations have long period of recorded temperature and rainfall data that cover the period of study; 2) the stations have no significant missing data for the period under investigation; and, 3) the stations have not been relocated since their establishment.

Table 1: Meteorological Stations and Period of Data Used

Stations	**Latitude**	**Longitude**	**Period**	**No. of Years**
Kafanchan*	09° 36'N	08° 18'E	1971-2016	46
Kaduna**	10° 36'N	07° 27'E	1971-2016	46
Zaria**	11° 11'N	07° 38'E	1971-2016	46

Source: *Dept. of Hydrology (Meteorological Unit), Kaduna State Water Board, Kaduna (2017).

**Nigerian Meteorological Agency (NiMet), Abuja (2017).

Data Analysis

The standardized coefficients of Skewness (Z_1) and Kurtosis (Z_2) statistics as defined by Brazel and Balling (1986) were used to test for the normality in the temperature and rainfall series for the study area.

The standardized coefficient of Skewness (Z_1) was calculated as:

$$Z_1 = \left[\left(\sum_{i=1}^{N} (x_i - \bar{x})^{3/N} \right) \Big/ \left(\sum_{i=1}^{N} (x_i - \bar{x})^{2/N} \right)^{3/2} \right] \Big/ \left(6/N\right)^{1/2} \quad \text{……………..….……….. eq. 1}$$

and the standardized coefficient of Kurtosis (Z_2) was determined as:

$$Z_2 = \left[\left(\sum_{i=1}^{N} (x_i - \bar{x})^{4/N} \right) \Big/ \left(\sum_{i=1}^{N} (x_i - \bar{x})^{2/N} \right)^{2} \right] - 3 \Big/ \left(24/N\right)^{1/2} \quad \text{……………….….. eq. 2}$$

where $\bar{x}$ is the long term mean of x_i values, and N is the number of years in the sample. If the absolute value of Z_1 or Z_2 is greater than 1.96, a significant deviation from the normal curve is indicated at the 95% confidence level.

Linear regression was used to determine the linear trends of the temperature and rainfall for the three stations, and changes in temperature and rainfall were also calculated. The formula for the linear regression is given as:

$$y = a + bx \quad \text{……………………………..……… eq. 3}$$

where a the intercept of the regression is line on the y-axis; b is the slope of the regression line. The values of a *and* b can be obtained from the following equations:

$$a = \frac{\sum y - b\left(\sum x\right)}{n} \quad \text{…..………………………….…. eq. 4}$$

$$b = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{n\left(\sum x^2\right) - \left(\sum x\right)^2} \quad \text{……………………..…. eq. 5}$$

To further examine the nature of the trends, second order polynomial curve fitting was used to determine the non-linear trends of the rainfall. The equation is of the form:

$$y = a + b_1 x + b_2 x^2 \quad \text{............................eq. 6}$$

To evaluate the three unknowns (*a, b₁, b₂*), the normal equations become a set of 3 simultaneous equations:

$$\sum y = na + b_1\left(\sum x\right) + b_2\left(\sum x^2\right) \quad \text{.......................... eq. 7}$$

$$\sum xy = a\left(\sum x\right) + b_1\left(\sum x^2\right) + b_2\left(\sum x^3\right) \quad \text{..................... eq. 8}$$

$$\sum x^2 y = a\left(\sum x^2\right) + b_1\left(\sum x^3\right) + b_2\left(\sum x^4\right) \quad \text{.................... eq. 9}$$

Here $\sum xy$ is the sum of the products obtained by multiplying each value of *x* by the corresponding value of *y*, $\sum x^2 y$ is the sum of the products obtained by multiplying the square of each value of *x* by the corresponding value of *y*, and $\sum x^2$, $\sum x^3$, and $\sum x^4$ are the sums of the second, third, and fourth powers of the *x'*s respectively.

In ascertaining the nature of trends and measurement of variability of both rainfall and average temperature, the standard deviation, which provides the deviation from normal for rainfall amount and temperature, was equally determined and plotted using Microsoft Excel Statistical Tool (2013). From the plotted charts, extreme conditions were then detected. The standard deviation is given by the formula:

$$\delta = \sqrt{\frac{\sum (x - \bar{x})^2}{n}} \quad \text{.................................. eq. 10}$$

where: $x =$ value of rainfall or temperature observations.

$\bar{x}$ = mean value of rainfall or temperature observations.

$n =$ number of rainfall observations of sample.

δ = standard deviation.

To further identify trends, the temperature and rainfall series were sub-divided into decadal non-overlapping sub-periods (1971-1980, 1981-1990 through the present decade 2011-2016). Cramer's test as defined by Lawson *et al* (1981), was then used to compare the means of the sub-periods with the mean of the whole record period. In applying Cramer's test, the mean **(** $\bar{x}$ **),** and the standard deviation (δ *),* were calculated for each of the station in the study area for the total number of years, *N,* under investigation. The purpose of this statistics was to measure the difference in terms of a moving *t*-statistic, between the mean **(** $\bar{x}k$ **)**, for each successive n-year period and the mean ($\bar{x}$) for the entire period. The *t*-statistic is computed as:

$$t_k = \left(\frac{n(N-2)}{N - n(1+\tau_k^2)} \right)^{1/2} \tau_k \quad \text{.......................... eq. 11}$$

where τ_k is a standardized measure of the difference between means given as:

$$\tau_k = \frac{\bar{x}k - \bar{x}}{\delta} \quad \text{................................. eq. 12}$$

where $\bar{x}k$ is the mean of the sub-period of n-years. $\bar{x}$ and δ are the mean and standard deviation of the entire series respectively and t_k is the value of the student *t*-distribution with *N-2* degrees of freedom. It is then tested against the "students" *t*-distribution table, at 95% confidence level appropriate to a two-tailed form of test. When t_k is outside the bounds of the two- tailed probability of the Gaussian distribution (equal to 1.96 at 95% confidence level), a significant shift from the mean is assumed.

Results and Discussion

Trend Analysis of Temperature in the Southern Part

The result of the analysis of temperature data for the southern part of the study area represented by Kafanchan agro-climatological station is presented in Table 2; whereas Figure 2 shows the graphical presentation of the minimum, maximum and average temperature trends.

Table 2: Annual Summary Statistics of Temperature Data (1971-2016) for Kafanchan (Southern Part**)**

Temperature (°C)	**Min. Temp. (°C)**	**Max. Temp. (°C)**	**Average Temp. (°C)**
Mean	16.05	33.79	24.92
Standard Deviation	0.56	0.82	0.52
Skewness (Z_1)	0.21	0.40	0.22
Kurtosis (Z_2)	-0.45	-0.68	-0.92
Range	2.50	3.25	1.92
Minimum Value	14.75	32.50	24.04
Maximum Value	17.25	35.75	25.96
Trend (°C/year)	0.001	0.03	0.016
Total Change (°C/46 years)	0.04	1.45	0.75

Source: Field Survey (2017)

From the linear trend lines, estimation of changes of the minimum temperature (Figure 2a) expressed in °C for the 46 years period of study indicates an insignificant increase of approximately 0.04°C. The linear trend line for the maximum temperature (Figure 2b) indicates an increase of 1.45°C for the period of study at the rate of 0.03°C year^{-1}; while the average temperature (Figure 2c) showed an increase of 0.75°C for the 46 years period of study at the rate of 0.016°C year^{-1}. The second order polynomial curve fitting for the minimum temperature of Kafanchan (Fig. 2a) revealed an increase from 1982 to 2006. This was preceded by a decline at the end of the study period (2016). With respect to the maximum and average temperature (Fig. 2b&c), the second order polynomial showed an increase in temperature in the last 15 years.

The plotted standard deviation for the temperature anomalies in Figure 2(a-c) generally showed that years of temperatures above the mean standard deviation (hotter than the normal conditions) in the last two decades (1991-2000 and 2001-2016) were more than those below. This is a clear indication that the temperature is increasing in the southern part of the study area. The rise in temperature may not be unconnected with human activities taking place in the area such as widespread use of land, deforestation, bush burning, and combustion of fossil fuels among others (Ishaya and Abaje, 2009).

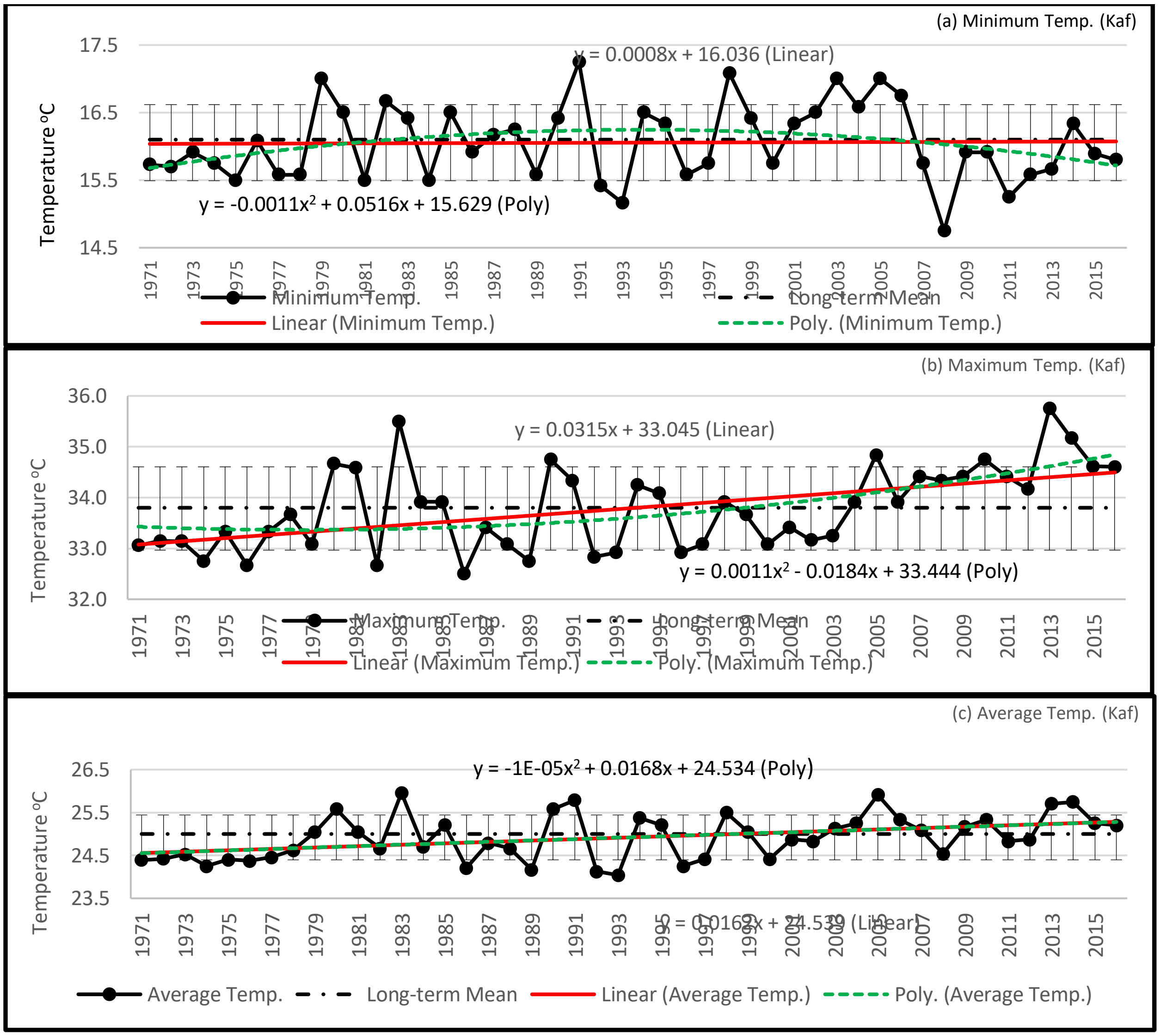

Figure 2: Temperature Trends of Kafanchan (Southern Part) for: (a) Minimum Temperature; (b) Maximum Temperature; and (c) Average Temperature

Source: Field Survey (2017)

The result of the decadal sub-period analysis for the average temperature series is presented in Table 3. The t_k values for all the months did not show any significant case in all the decades. The first decade (1971-1980) was generally colder than others as indicated by the negative t_k values. This is mainly caused by the decrease in temperature for the month of March, April, June, July and August. This month was significantly colder at $p<0.05$ than the long-term conditions. From there afterwards, there was an increase in temperature in the other decades, especially 2001-2010 and the present decade (2011-2016) as indicated by their positive values. Even though the values were not significant at $p<0.05$, but it is a clear evidence of increasing temperature in recent years.

Table 3: Decadal Sub-Period Analysis of Average Temperature **(°C)** of the Southern Part (Kafanchan)

Months	**Sub-Period**				
	1971-1980	**1981-1990**	**1991-2000**	**2001-2010**	**2011-2016**
January	-0.26	0.52	0.52	-0.26	0.00
February	-0.52	0.00	-0.26	0.00	1.32
March	-1.26	0.00	-0.66	1.60	1.06
April	-1.28	0.34	0.00	0.67	0.72
May	-0.67	0.67	-1.53	1.27	0.93
June	-1.59	0.70	-1.32	1.02	1.34
July	-1.90	-0.32	0.94	1.47	0.24
August	-1.20	0.63	0.63	0.63	-0.23
September	-0.40	0.40	-0.40	0.79	1.08
October	-0.32	-0.32	-0.92	0.63	1.51
November	-0.74	-0.74	-0.38	1.08	0.80
December	-0.34	-1.00	0.68	1.00	0.00

Source: Field Survey (2017)

Trend Analysis of Temperature in the Central Part

The result of temperature data analysis for the central part represented by Kaduna Meteorological Station is presented in Table 4, while Figure 3(a-c) shows the graphical presentation of the minimum, maximum and average temperature trends.

The linear trend line equations for the minimum, maximum and average temperature for the study period indicate an increase in temperature. Estimation of changes of the minimum temperature

(Fig. 3a) expressed in ^oC for the 46 years period of study indicates an increase of approximately 1.45^oC at the rate of 0.032^oC year^{-1}, whereas the linear trend line for the maximum temperature (Fig. 3b) indicates an increase of about 1.01^oC for the period of study. Based on that, the average temperature (Fig. 3c) therefore, increased by 1.23^oC for the 46 years period of study at the rate of 0.03^oC year^{-1}. The second order polynomial curve fitting for the minimum, maximum and average temperature (Fig. 3(a-c)) showed an increasing trend from the beginning of the data to 2016. This is an indication of increasing warming of the atmosphere. The increase in temperature in Kaduna, the capital city of Kaduna State, is largely attributable to human activities such as industrial pollution, combustion of fossil fuel, destruction of nature, urbanization and industrialization among others (Abaje *et al,* 2016).

Table 4: Annual Summary Statistics of Temperature Data (1971-2016) for Kaduna (Central Part)

Temperature (^oC)	**Min. Temp. (^oC)**	**Max. Temp. (^oC)**	**Average Temp. (^oC)**
Mean	19.58	31.74	25.66
Standard Deviation	1.18	0.50	0.67
Skewness (Z_1)	1.44	-0.15	0.34
Kurtosis (Z_2)	1.65	-0.96	-0.13
Range	4.68	1.83	2.69
Minimum Value	18.19	30.91	24.55
Maximum Value	22.88	32.73	27.24
Trend (^oC/year)	0.03	0.02	0.03
Total Change (^oC/46 years)	1.45	1.01	1.23

Source: Field Survey (2017)

The plotted standard deviation for the temperature anomalies (Figure 3(a-c)) equally shows that years of temperatures above the mean standard deviation in the last two decades were more than those below. The minimum temperature shows 8 years of anomalies. Two years (1975 and 1978) were colder than the normal conditions while 6 years were hotter than the normal conditions of the 46 years under study. Out of the 6 years that were hotter than the normal condition, 3 occurred in 1980, 1981 and 1983 while the other 3 occurred in 2007, 2008 and 2009. The maximum and average temperature have 16 and 15 anomaly years respectively. The maximum temperature has 6 anomaly years above (hotter than the normal temperature conditions) and 10 below the mean standard deviation (colder than the normal temperature conditions), whereas the average temperature has 6 anomaly years above and 9 below the mean standard deviation. A careful observation of both the maximum and average temperatures show that all the years that were below the mean standard deviation occurred between 1971 and 1989 while most of the years that were above the mean standard deviation occurred in the recent years (2005-2016). This is an indication of increasing temperature in the central part of the study area in recent years.

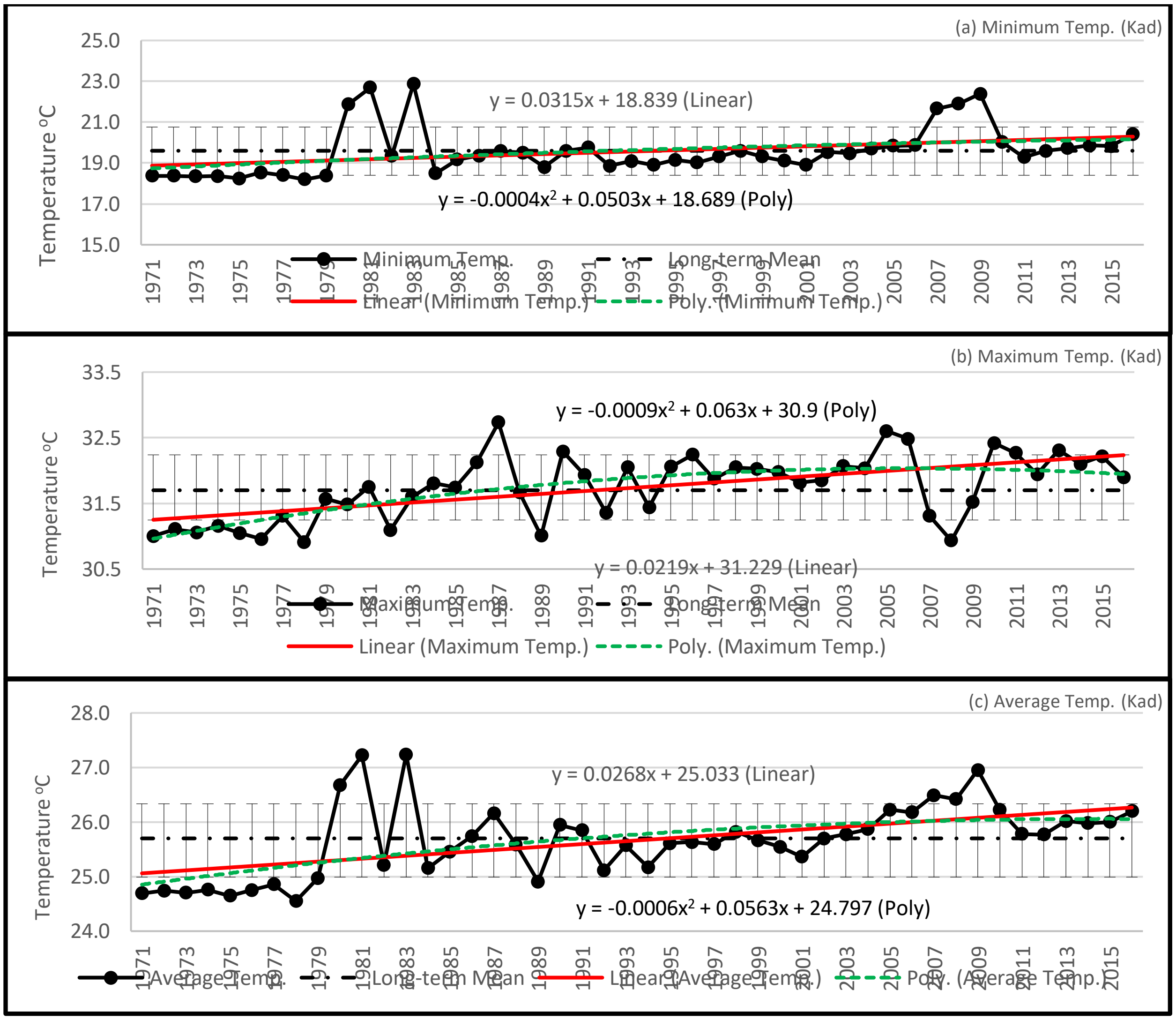

Figure 3: Temperature Trends of Kaduna (Central Part) for: (a) Minimum Temperature, (b) Maximum Temperature, and (c) Average Temperature

Source: Field Survey (2017)

The decadal sub-period analysis for the average temperature series of the central part is presented in Table 5. The Table shows that all the t_k values for the first decade (1971-1980) were negative and significantly colder than the normal conditions at $p<0.05$ with the exception of the months of January and February that were not significant. This is followed by increasing temperature. The *tk* values for the last two decades (2001-2010 and 2011-2016) were all positive with one significant case in September (2001-2010). This result further confirms that the temperature of the earth's surface is increasing (global warming) in the study area in the recent years.

Table 5: Decadal Sub-Period Analysis of Average Temperature **(°C)** of Kaduna (Central Part)

Months	**Sub-Period**				
	1971-1980	**1981-1990**	**1991-2000**	**2001-2010**	**2011-2016**
January	-1.94	0.29	0.00	0.85	0.62
February	-1.00	-0.62	-1.00	0.81	1.41
March	-2.21*	0.70	-0.35	1.59	0.97
April	-2.18*	1.56	0.35	1.56	0.50
May	-2.31*	1.30	0.00	1.30	0.41
June	-2.39*	0.71	-0.36	1.61	0.52
July	-2.16*	0.00	0.00	1.95	0.82
August	-1.98*	0.47	-0.92	1.68	0.00
September	-2.20*	0.00	-0.47	1.96*	0.34
October	-2.19*	0.78	0.00	1.46	0.84
November	-2.03*	0.90	-0.90	1.43	0.66
December	-2.00*	1.30	-0.35	1.30	0.00

*****Significant at $p<0.05$

Trend Analysis of Temperature in the Northern Part

Table 6 presents the result of the analysis of temperature data for the Northern part represented by Zaria Meteorological Station, while Figure 4(a-c) shows the graphical presentation of the minimum, maximum and average temperature trends of the Northern part. The results of the linear trend lines for the period of study (1971–2016) clearly indicate a rise in minimum, maximum and average temperature of approximately 1.24°C, 0.97°C and 1.11°C respectively (Table 6 and Fig. 4(a - c). Just like Kaduna Metropolis, the increase in temperature in Zaria (the second largest city in Kaduna State) is also connected to human activities such as industrial pollution, combustion of fossil fuel, destruction of nature, urbanization and industrialization among others. The second order polynomial shows that the minimum, maximum and average temperatures experienced increasing trend from 1971 to 2016. This gives another clear picture of the warming trend in the study area.

Table 6: Annual Summary Statistics of Temperature Data (1971-2016) for Zaria (Northern Part)

Temperature (°C)	**Min. Temp. (°C)**	**Max. Temp. (°C)**	**Average Temp. (°C)**
Mean	19.05	31.75	25.40
Standard Deviation	0.64	0.73	0.58
Skewness (Z_1)	-0.14	1.43	0.72
Kurtosis (Z_2)	-0.94	4.94*	1.28
Range	2.60	4.25	2.83
Minimum Value	17.73	30.16	24.41
Maximum Value	20.33	34.41	27.24
Trend (°C/year)	0.03	0.02	0.024
Total Change (°C/46 years)	1.24	0.97	1.11

*****Significant at $p<0.05$

Source: Field Survey (2017)

The plotted standard deviation for the average temperature anomalies (Figure 4c) shows that 8 years were colder than the normal conditions. Out of this 8 years, 6 years were found between 1971 and 1989. On the other hand, 5 years were hotter than the normal conditions; and incidentally, they are found in the recent years (1999-2016). This is another indication of increasing warming of the earth's atmosphere in recent years.

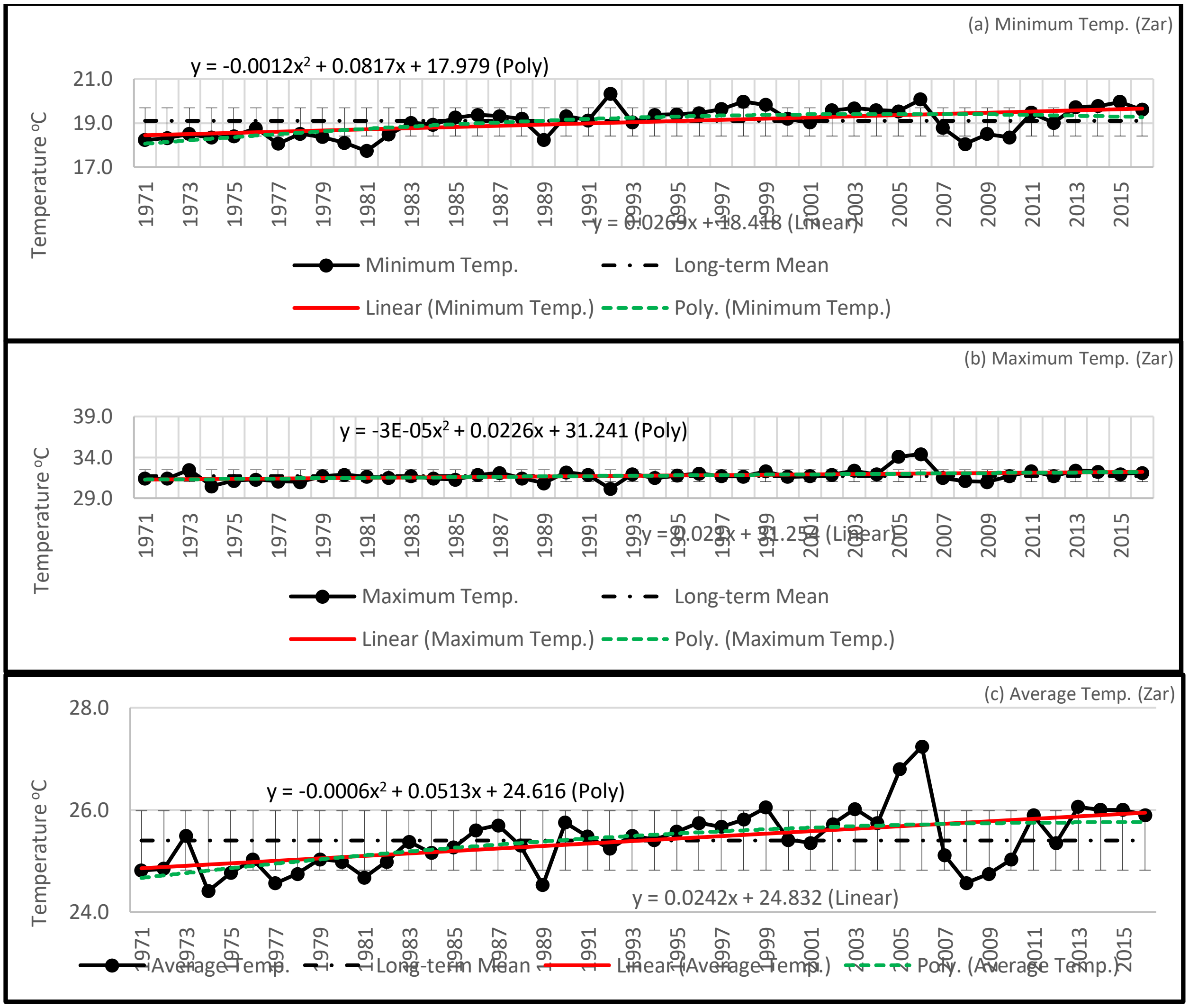

Figure 4: Temperature Trends of Zaria (Northern Part) for: (a) Minimum Temperature, (b) Maximum Temperature, and (c) Average Temperature

Source: Field Survey (2017)

The decadal sub-period analysis of the average temperature of the northern part (Table 7) showed an increasing trend from the first decade to the recent decade. All the monthly t_k values for 1971-1980 were negative with July, August, and September being significant colder at $p<0.05$ than the long-term condition. The last two sub-period (2001-2010 and 2011-2016) showed an increase in temperature. The months of August and September for the decade, 2001-2010, were significantly hotter at $p<0.05$ than the long-term condition. For the 2011-2016 sub-period, all the months indicate an increase in temperature. The result of the last two sub-periods is another clear picture that the earth's atmosphere is getting warmer in recent years.

Table 7: Decadal Sub-period Analysis of Average Temperature **(°C)** of Zaria (Northern Part)

Months	**Sub-Period**				
	1971-1980	**1981-1990**	**1991-2000**	**2001-2010**	**2011-2016**
January	-0.84	-1.21	0.64	1.21	0.00
February	-0.41	-1.63	-0.80	1.48	1.48
March	-1.75	-1.10	0.57	1.34	1.14
April	-1.64	-0.37	1.64	-0.37	0.53
May	-1.94	0.85	0.85	-0.29	0.99
June	-1.81	0.42	1.20	0.00	1.13
July	-2.37*	-0.46	0.89	0.89	1.41
August	-2.58*	0.60	0.00	2.31*	0.85
September	-2.35*	-1.01	0.00	2.11*	0.38
October	-1.77	-0.51	0.51	0.00	1.70
November	-1.81	-0.35	0.69	-0.35	1.91
December	-1.53	0.00	1.32	-0.28	0.00

*Significant at $p<0.05$

Source: Field Survey (2017)

In general, the mean increase in average temperature for the study area (Table 8) is 1.03°C. This warming trend collaborates reports of several researches carried out by IPCC (for example, IPCC, 2007; Trenberth *et al,* 2007; Hartmann *et al,* 2013) where their findings using the same method (linear trend) revealed a globally averaged temperature increase of 0.72°C over the period 1951–2012 (Hartmann *et al*, 2013). The plotted standard deviation for the temperature anomalies, and the decadal sub-periods analysis of temperature in the whole State also showed an increasing trend from the beginning of the data (1971) to the end of the study period (2016). This increase in temperature is a clear evidence of increasing warming of the earth's atmosphere. This study also conforms with the report of NiMet (2015 and 2016; Abaje *et al*, 2016) in which the trend analyses revealed a higher rate of temperature increase in the country. The study further tallies with the report of the Fifth Assessment of IPCC that in Africa the number of warm days and warm nights have increased in the last two decades (Niang, *et al*, 2014).

The increase in temperature in Kaduna State as earlier discussed is majorly due to human activities that either emits large amount of GHGs into the atmosphere or activities that reduce the amount of carbons absorbed from the atmosphere. Human activities such as gas flaring from Kaduna Refinery and Petro-chemical Company Limited, industrial pollution from manufacturing industries situated in Kaduna and Zaria, burning of fossil fuels in all the urban centers of the State, urbanization and agriculture result in emissions of four principal GHGs: CO_2, CH_4, N_2O and halocarbons (a group of gases containing fluorine, chlorine and bromine) such as chlorofluorocarbons (CFCs), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs) and sulphuric hexafluoride (SF_6) among others (IPCC, 2007), and thus increasing the warming effect of the atmosphere. On the other hand, human activities that reduce the amount of carbon sinks in the study area are deforestation, alterations in land use, water pollution and bad agricultural practices.

Due to the fact that the major occupation of the people of Kaduna State is crop and livestock production, temperature increases would have a detrimental sequential effects on agriculture and livelihood because of an increase in the number of extremely hot days, a reduction in soil moisture, and an acceleration of crop development that will lead to premature ripening and lower yields in crops such as cereals (FRN, 2003).

Table 8: Rate of Total Change in Temperature of the Three Zones (1971-2016)

Station	**Min. Temp. (°C)**	**Max. Temp. (°C)**	**Average Temp. (°C)**
Kafanchan (Southern Zone)	0.04	1.45	0.75
Kaduna (Central Zone)	1.45	1.01	1.23
Zaria (Northern Zone)	1.24	0.97	1.11
Mean	**0.91**	**1.14**	**1.03**

Source: Field Survey (2017)

Trend analysis of annual rainfall in the Southern part

The linear trend lines of the annual rainfall for the period of study (1971-2016) generally showed an upward increase in rainfall for the Southern part represented by Kafanchan Agro-climatological

Station (Figure 5). Changes in annual rainfall for the period of study indicates an increase of approximately 582.7 mm at the rate of 12.67 mm year^{-1} (Table 9). When compared with the long-term average total, it means that the annual rainfall was increasing at a rate of 0.74% year.$^{-1}$ The second order polynomial curve fitting showed an increasing trend from the beginning of the data (1971) up to the end of the data set (2016). It is, therefore, clear from the results of the linear trend line and the second order polynomial that the rainfall is increasing in recent years, an indication of climate change.

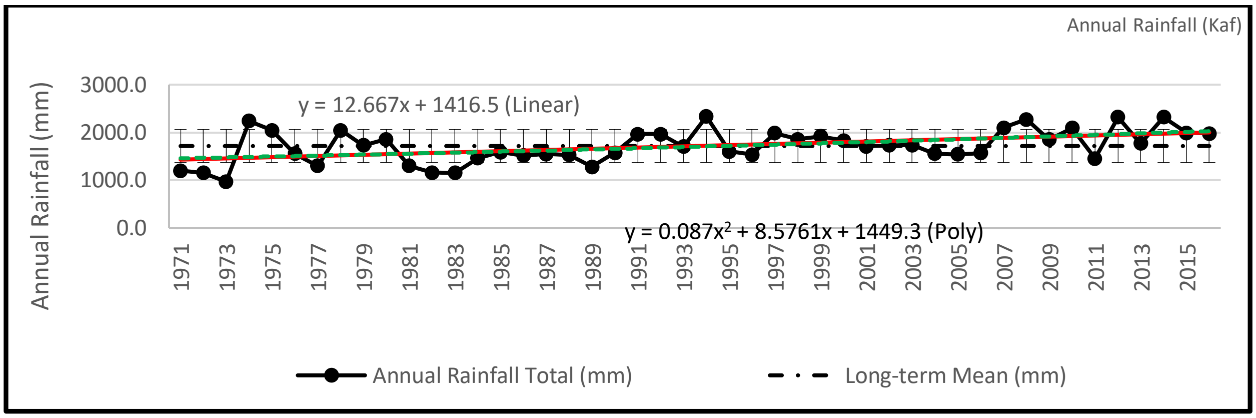

Figure 5: Annual Rainfall Trend for Kafanchan

Source: Field Survey (2017)

The plotted standard deviation for the annual rainfall (Figure 5) shows 15 anomaly years; 7 years (1974, 1994, 2007, 2008, 2010, 2012, and 2014) were wetter than the normal condition signifying floods while 8 years (1971, 1972, 1973, 1977, 1981, 1982, 1983, and 1989) were drier than the normal condition signifying droughts. These 8 years corresponded with the droughts of the 1970s and 1980s that ravaged the northern parts of Nigeria (Oladipo, 1993a). All the 8 years that were drier than the normal condition were found in the first 19 years (1971-1989) of the study period, while 6 out of the 7 years that were wetter than the normal condition are found in the last 23 years (1994-2016). With this result, it is also clear that the rainfall amount is increasing in recent years which is also an indication of climate change.

Table 9: Summary Statistics of Annual Rainfall (1971-2016)

Rainfall (mm)	**Kafanchan**	**Kaduna**	**Zaria**
Mean	1714.20	1225.77	1026.35
Standard Deviation	346.07	185.79	160.49
Skewness (Z_1)	-0.05	0.03	-0.09
Kurtosis (Z_2)	-0.60	-0.10	-0.21
Range	1364.1	787.4	746.2
Minimum Value	969.3	848.9	660.1
Maximum Value	2333.4	1636.3	1406.3
Trend (mm/year)	12.67	1.36	5.75
Total Change (mm/46 years)	582.7	62.74	264.51

Source: Field Survey (2017)

The results of the 10- year non-overlapping sub-period analysis (Cramer's test) for the annual rainfall (see Table 10) revealed that the annual rainfall for the first two decades (1971-1980 and 1981-1990) were having negative *tk* values which is an indication of dryness in which the 1981-1990 sub-period was statistically drier (drought) at $p<0.05$ than the long term condition. This result concurs with the findings of Abaje *et al* (2013) that it was the decade in which severe drought became more extensive. The *tk* values for the last 3 decades (1991-2000, 2001-2010 and 2011-2016) were all positive with 2011-2016 having a *tk* value of 1.53. Even though it was not statistically significant, but it further confirms the increasing nature of the rainfall amount in the recent decade.

Trend analysis of annual rainfall in the Central part

The result of the linear trend line of the annual rainfall for the central part, represented by Kaduna Meteorological Station, demonstrates a little increase in rainfall yield. Estimation of changes in rainfall expressed in mm for the period of study (1971-2016) showed an annual increase of 62.74 mm for the 46 years period of study at the rate of 1.36 mm $year^{-1}$ (Table 9 and Figure 6). The annual rainfall was, therefore, increasing at the rate of 0.11% $year.^{-1}$ The second order polynomial showed a decreasing trend from 1971 to the late 2000s and an increasing trend afterwards up to 2016.

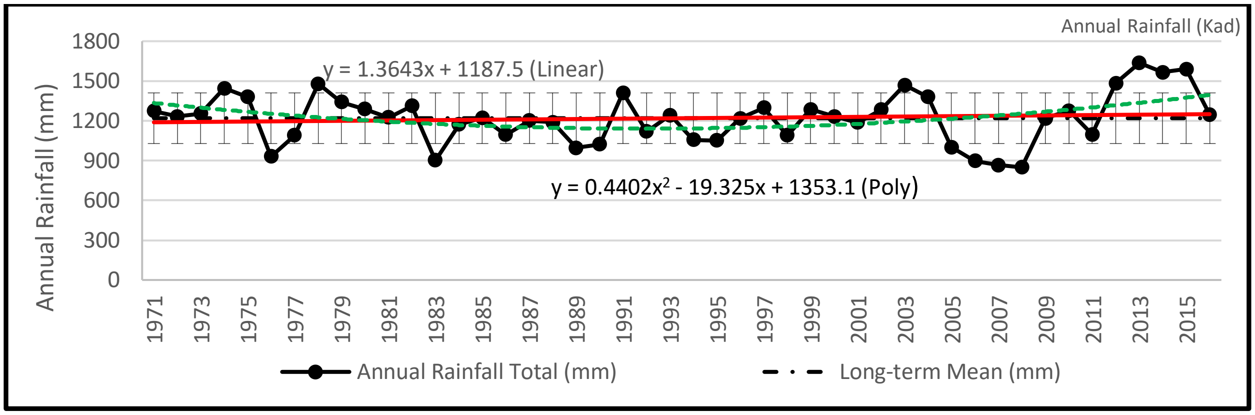

Figure 6: Annual Rainfall Trend for Kaduna

Source: Field Survey (2017)

The plotted standard deviation of the annual rainfall for the 46 years period of study (Figure 6) shows 14 anomaly years; 7 years (1974, 1978, 2003, 2012, 2013, 2014 and 2015) were wetter than the normal condition and also 7 years (1976, 1983, 1989, 2005, 2006, 2007 and 2008) were drier than the normal condition signifying droughts. Out of the 7 wetter years, 4 occurred continuously in the last 5 years (2012-2016). The result of the decadal analysis revealed that all the decades were normal at $p<0.05$ (Table 10), but the positive *tk* value of 1.93 for 2011-2016 is also a clear indication that the annual rainfall is increasing in recent years.

Table 10: Decadal Sub-Period Analysis of Annual Rainfall

Sub-Period	**Kafanchan**	**Kaduna**	**Zaria**
1971-1980	-1.03	1.29	-1.54
1981-1990	-2.30*	-1.55	-1.92
1991-2000	1.42	-0.47	1.25
2001-2010	0.98	-1.43	0.39
2011-2016	1.53	1.93	1.89

*****Significant at $p<0.05$

Source: Field Survey (2017)

Trend analysis of annual rainfall in the Northern part

The linear trend lines of the annual rainfall for the northern part represented by Zaria Meteorological Station (Figure 7), for the period of study indicates an increase of approximately 264.51 mm at the rate of 5.75 mm year^{-1} (Table 9). Compared with the long-term average total, it means that the annual rainfall was increasing at a rate of 0.56% year.$^{-1}$ The second order polynomial curve fitting also showed an increasing trend from the beginning of the data (1971) up to the end of the data set (2016).

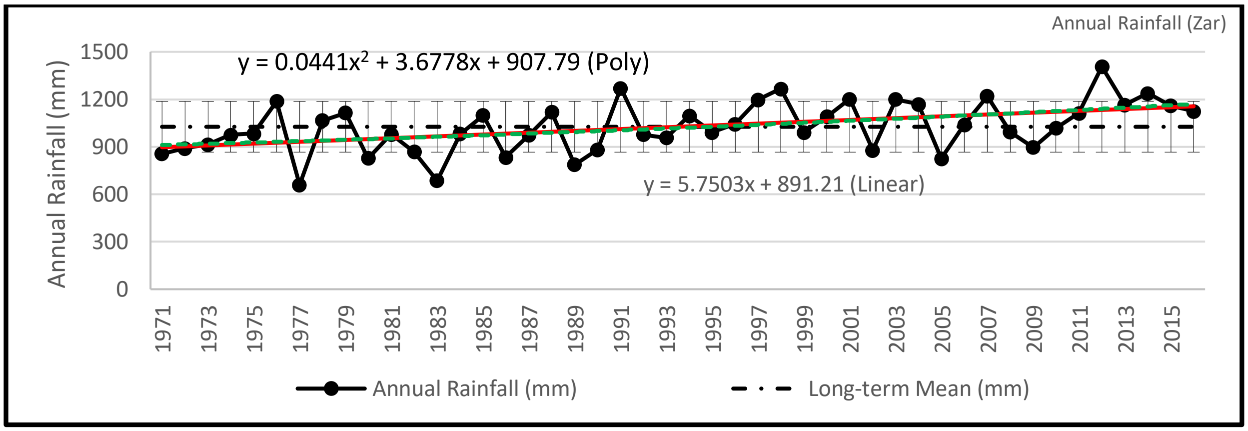

Figure 7: Annual Rainfall Trend for Zaria

Source**:** Field Survey (2017)

The plotted annual standard deviation for the rainfall anomalies (Figure 7) revealed that out of the 46 years of study, 8 years (1991, 1997, 1998, 2001, 2003, 2007, 2012, and 2014) experienced wetter rainfall (or floods) while 7 years (1971, 1977, 1980, 1983, 1986, 1989, and 2005) experienced drier conditions (or droughts). It is important to note that out of the 8 years that experienced wetter conditions, 5 years were in the last two decades, 2001-2010 and 2011-2016. On the other hand, out of the 7 years that experienced drier conditions, 6 years were in the first two decades, 1971-1980 and 1981-1990. With this result, just like the Southern and Central parts of the study area, it is clear that the rainfall amount is increasing in recent years.

The result of the 10-year analysis (Table 10) also revealed that the last 3 decades are having positive t_k values with 2011-2016 having the highest *tk* value of 1.89. This is another indication of increasing rainfall yield in recent years.

In summary, estimation of changes in the rainfall amount for the whole State from the linear trend line equations showed an average increase of 303.32 mm for the 46 years period studied. The plotted standard deviation for the rainfall anomalies, and the decadal analysis of the rainfall in all the three stations generally showed an increasing trend from the beginning of the data collection (1971) to the recent years. This is a clear indication that the study area has been experiencing increasing wetness over recent years and hence climate change. The increasing rainfall in recent times may be attributed to the rising atmospheric temperatures observed in the State in recent years, which has increased evapo-transpiration and consequently increased condensation and precipitation (NiMet, 2016). The increasing rainfall over recent years is in agreement with the findings of Odekunle *et al* (2008), Abaje *et al* (2012), and NiMet (2015 and 2017) that the Northern part of the country, especially the sudano-sahelian ecological zone is now experiencing wetter conditions in recent years. The study is at variance with some of the earlier conclusions drawn by Oladipo (1993a) and Sawa (2002) on the rainfall trends of this part of the country. This is because their studies were based on data covering early 1990s and 2000 respectively. However, studies using recent rainfall data covering up to 2016 are highly likely to arrive at the same result with the present study.

Conclusion and Policy Recommendations

Different methods of trend analysis of temperature and rainfall were used in this study to unravel the certainty of climate change in Kaduna State. Findings from the analyses of the observed temperature and rainfall data for the period under study, (1971-2016) generally showed that the frequency of climate change is increasing, both in terms of extreme weather events and gradual changes in climate. This will consequently aggravate the impacts of climate change on the major occupations of the people which is mostly crop and livestock production.

The study recommends the following:

- ✓ Awareness programs to be initiated to educate people on recent changes in temperature and rainfall as a process of enhancing people's adaptive capacities. This is important because the ability to effectively respond to increasing temperature and rainfall will be determined by the quality of information available to the people and how easily they can access it.
- ✓ Reduction of greenhouse gases emission in the atmosphere that have warming effect through fuel switching in the energy sector, and the direct reduction of their concentrations which could be through sequestration or enhancing the sink capacity of biological and other systems.
- ✓ One other way to reduce high temperature (global warming) is to reduce the amount of energy consumed or making sure it is used as efficiently as possible.
- ✓ Government policies related to agriculture, water resources development and other related sectors should take into account ways of tackling the recent increase in temperature and rainfall amount in recent years.

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