Spatio-Temporal Analysis of Rainfall Distribution in Kaduna State, Nigeria

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Abstract

Monthly and annual rainfall data for Kafanchan, Kaduna and Zaria for the period 1961-2016 (56 years) were used in this study to analyse the spatio-temporal distribution of rainfall in Kaduna State. 10-year running mean, linear trend line equation, second order polynomial, Cramer's test and student's t-test were used to achieve this aim. The results revealed that the mean annual rainfall of the study area decreases from about 1659.44 mm in Kafanchan to about 1245.97 mm and 1016.66 mm in Kaduna and Zaria respectively. The linear trend line equation and the second order polynomial showed an increase in rainfall in recent years, while the 10-year running mean for the annual rainfall was above the long-term mean from the 1990s to 2016. Findings from the 10-year non-overlapping sub-period analysis (Cramer's test) of both the monthly and annual rainfall revealed an upward trend in the last three decades (1991-2000, 2001-2010 and 2011-2016) for Kafanchan and Zaria Stations and the present decade (2011-2016) for Kaduna. The result of the student's t-test for the two non-overlapping sub-periods (1961-1990 and 1991-2016) of each station showed that Kafanchan and Zaria were significantly wetter in the last 26 years (1991–2016) while Kaduna was having a normal condition. Further findings revealed that the increase in annual rainfall amount in recent years was as a result of increased rainfall in May, July, and September. It is recommended that agricultural planning, water resources management and government policies in Kaduna State should be based on recent rainfall trends.

Keywords: fluctuations, Kaduna State, rainfall, sub-periods, trends.

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Introduction

Rainfall is one of the most important fundamental parameters of climate as it determines the environmental condition of a particular region (Khavse *et al*, 2015). The amount of rainfall received in an area is an important factor in determining the amount of water available to meet various demands, such as agricultural, industrial, domestic water supply and for hydroelectric power generation; therefore, global climate changes may influence long-term rainfall patterns impacting the availability of water, along with the danger of increasing occurrences of droughts and floods (Jain and Kumar, 2012).

With specific reference to the continent of Africa, the IPCC (2007) report indicated that annual rainfall is likely to decrease in much of Mediterranean Africa and the Northern Sahara. Rainfall in Southern Africa is likely to decrease in much of the winter rainfall region and western margins. There is likely to be an increase in annual mean rainfall in East Africa (Christensen *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 rainfall deficit in this region during 1970 to 1990 was spatially uniform. 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 (Trenberth *et al*, 2007).

Rainfall in Nigeria has changed, and is currently changing due to a wide range of different natural and anthropogenic factors which operate over a variety of time scales (Abaje *et al*, 2015b). The pattern of rainfall in Northern Nigeria is highly variable in spatial and temporal dimensions with inter-annual variability of between 15 and 20% (Oladipo, 1993). An increase or decrease in rainfall has consequences on water resources, agriculture, soil conservations, and often results in extreme weather events such as floods or droughts, coupled with their devastating effects on food security and associated calamities and sufferings (Abaje *et al*, 2010; Ifabiyi and Ashaolu, 2015).

Most of the recent researches on rainfall trends in Northern Nigeria revealed that annual rainfall amounts have been on the increase especially from the late 1990s (Odekunle *et al*, 2008; Abaje *et al*, 2014; Abaje *et al*, 2015a). The increasing trend in rainfall totals may pose significant danger to areas that are prone to flooding as reservoirs could easily overflow leading to loss of lives and properties (Ati *et al*, 2008; Abaje *et al*, 2015a). This study therefore, examines the spatio-temporal distribution of rainfall in Kaduna State, along a geographic transect, from the Southern to the Northern parts of the State, for a period of 56 years (1961–2016) in order to point out the implications associated with such recent trend and distribution pattern.

Study Area

Kaduna State is located between latitude 09^{o} 02$'$ N to 11^{o} 32$'$ N and between longitude 06^{o} 15$'$ E to 08^{o} 38$'$ E (Figure 1).

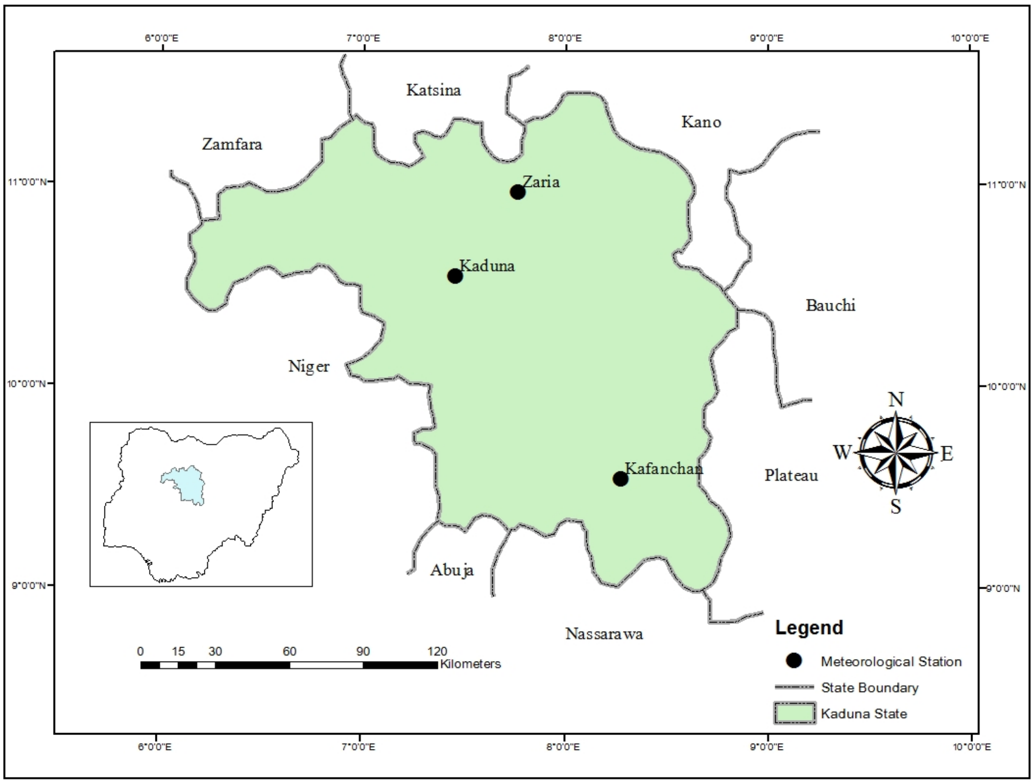


Figure 1: Kaduna State and the Selected Meteorological Stations

The climate is the tropical wet and dry type, classified as Köppen Aw (Abaje *et al*, 2015b). The wet season lasts from April through to mid-October with a peak in August; while the dry season extends from mid-October of one calendar year to April the next year (Abaje *et al*, 2016). The annual average rainfall in Kaduna State is about 1323 mm (Abaje *et al,* 2015b). The spatial and temporal distribution varies, decreasing from an average of about 1733 mm in the southern part of the State (Kafanchan) to about 1203 mm in the central part (Kaduna) and about 1032 mm in Zaria (northern part) (Abaje, 2016).

Seasonal variation in rainfall is directly influenced by the interaction of two 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, which is also associated with the dry, cool and dusty North-East Trades known as the Harmattan (Abaje *et al.,* 2015b; Atedhor, 2016a). The boundary zone between these two streams is called the Intertropical Discontinuity (ITD). The movement of the ITD northwards across the Kaduna State in August marks the peak of the rainy season in the whole State, while its movement to the southernmost part around January/February marks the peak of the dry season in the State (Abaje *et al.,* 2015b). The highest average air temperature occurs in April (28.9^{o}C) and the lowest in December (22.9ºC) through January (23.1ºC) (Abaje *et al.,* 2016). The mean atmospheric relative humidity ranges between 70-90% and 25-30% for the rainy and dry seasons respectively. The highest amount of evaporation occurs during the dry season (Abaje *et al.,* 2015b).

The bedrock geology is predominantly metamorphic rocks of the Basement Complex consisting of biotite gneisses and older granites; but in the south-eastern corner, younger granites and batholiths are evident (McCurry, 1989). Generally, soils of the study area are typical reddish-brown to reddish-yellow tropical ferruginous soils, which are mostly formed on granite and gneisses parent materials, also on aeolian and many sedimentary deposits (Abaje, 2007; Ishaya and Abaje, 2008).

Kaduna State lies within the Guinea Savanna Ecological Zone with the intensity of trees and other plants decreasing as one moves towards its northern part (Abaje *et al*, 2015b and 2016). The zone is significant, both as a major source of grains and tuber crops due to its relatively high rainfall compared to the more northerly Sudan and Sahel Savannas (Atedhor, 2016a).

Materials and Methods

Monthly rainfall data from three meteorological stations (Kaduna, Kafanchan and Zaria) in the study area were used for this study (Table 1). The data were obtained from the archive of the Nigerian Meteorological Agency (NIMET) and the Department of Hydrology (Meteorological Unit), Kaduna State Water Board for a period of sixty years (1961–2016). In this study, only rainfall totals for the months of May to October (growing season) as well as annually were used. This is because the study area received about 85% of its annual rainfall totals in these months.

Table 1: Meteorological Stations and Period of Data used.

Station	Latitude	Longitude	Period	No. of Years
Kafanchan*	09º 36' N	08º 18' E	1961 - 2016	56
Kaduna**	10º 36' N	07º 27' E	1961 - 2016	56
Zaria**	11º 08' N	07º 04' E	1961 - 2016	56

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

** Nigerian Meteorological Agency (NIMET), Lagos.

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 rainfall series for the study area. The standardized coefficient of Skewness (Z_1) was calculated as:

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

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 95% confidence level. Generally, the monthly and annual rainfall data have shown a great tendency towards normality. As a result, the data were used without any transformation.

To examine the nature of the trends and fluctuations in the rainfall series, 10-year running mean was calculated and plotted. Linear regression was used to determine the linear trends of the rainfall for the three stations. Also, changes in rainfall were calculated. The formula for the linear regression is given as:

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

where a the intercept of the regression 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, b_1, b_2), 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.

The rainfall series was sub-divided into decadal non-overlapping sub-periods (1961-1970, 1971-1980, 1981-1990 through to 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 statistic 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:

$$t_k = \left(\frac{n(N-2)}{N - n\left(1 + \tau_k^2\right)} \right)^{1/2} \tau_k \quad \text{...................................... eq. 10}$$

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

$$\tau_k = \frac{\bar{x}k - \bar{x}}{\delta} \quad \text{...................................... eq. 11}$$

the entire series respectively, and t_k is the value of the student *t*–distribution with *N–2* degrees of freedom. This 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.

The annual rainfall was further sub-divided into two non-overlapping sub-periods, 1961-1990 and 1991–2016. The student's t-test, t_d, was then used to analyse the relative contribution of the two sub-periods to the rainfall characteristics of each station. The statistics, t_d, is determined as:

$$t_d = \frac{\left(\bar{X}_2 - \bar{X}_1\right) - \left(\mu_2 - \mu_1\right)}{\left[\frac{N_2 S_2^2 + N_1 S_1^2}{N_2 + N_1 - 2} \cdot \frac{1}{N_2} + \frac{1}{N_1} \right]^{1/2}} \quad \text{.................................. eq.12}$$

where ($\bar{X}_2$ - $\bar{X}_1$) represents the difference in group means, ($\boldsymbol{\mu}_2 - \boldsymbol{\mu}_1$) is the expected differences (set equal to 0), N_2 and N_1 are the number of cases within each sub-sample, and S_2 and S_1 are their standard deviations respectively. When t_d is outside the bounds of the Gaussian distribution, equal to 1.96 at 95% confidence level, a significant shift from the mean is assumed.

Results and Discussion

Rainfall Normality

The general statistics of the monthly (May to October) and annual rainfall of the 3 meteorological stations are presented in Tables 2 to 4. The results of Z_1 and Z_2 for the three meteorological stations in Kaduna State show that all the monthly and annual rainfall are indicative of normality at $p<0.05$ with the exception of Z_2 for the annual total in Kaduna, and Z_2 for the month of May in Zaria.

Spatial Variation of the Rainfall Distribution

In Kafanchan, the mean annual rainfall for the 56 years (1961-2016) is 1659.44 mm while the highest mean monthly rainfall distribution is 352.05 mm (August) and the lowest mean monthly rainfall is 133.91 mm (October) as indicated in Table 2. The annual standard deviation is 345.71 mm. The maximum value of annual rainfall of 2333.40 mm was record in 1994, while the minimum value of 969.30 mm was recorded in 1971 which coincided with the Great Sahelian Drought of the 1970s that ravaged the country (Oladipo, 1993). The month with the highest amount of rainfall at this station is August.

Table 2: General Statistics and Trends of Rainfall (1961- 2016) for Kafanchan Station

Statistics	May	Jun	July	Aug	Sep	Oct	Annual
Mean ($\bar{x}$)	184.91	219.64	316.26	352.05	310.45	133.91	1659.44
Standard Dev. (δ)	72.76	66.46	123.49	102.41	91.63	81.98	345.71
Skewness (Z_1)	0.37	0.49	0.77	0.83	0.16	0.77	0.13
Kurtosis (Z_2)	-0.56	0.11	0.68	0.92	-0.92	0.54	-0.55
Minimum Value	69.0	91.7	79.5	170.6	144.6	11.3	969.3
Maximum Value	359.6	392.0	649.2	652.4	523.24	387.0	2333.4
Trend (mm/year)	2.29	1.35	2.81	1.74	1.98	1.40	11.64
Total Change (mm/56 yrs)	128.24	75.80	157.61	97.47	111.11	78.56	651.95

In Kaduna, the mean annual rainfall is 1245.97 mm. The highest monthly mean rainfall of 301.46 mm was recorded in August while the lowest monthly mean rainfall of 71.12 mm was recorded in October (Table 3). The annual standard deviation is 231.70. The maximum value of annual rainfall of 2246.90 mm was recorded in 1966, while the minimum value of 848.90 mm was recorded in 2008. The month with the highest amount of rainfall at this station is August.

Table 3: General Statistics and Trends of Rainfall (1961- 2016) for Kaduna Station

Statistics	May	Jun	July	Aug	Sep	Oct	Annual
Mean ($\bar{x}$)	118.72	177.82	233.57	301.46	259.75	71.12	1245.97
Standard Dev. (δ)	49.06	52.60	77.74	93.63	90.05	55.84	231.70
Skewness (Z_1)	0.57	0.73	0.10	0.60	-0.21	1.13	1.36
Kurtosis (Z_2)	0.06	1.69	-0.44	0.03	-0.07	1.08	5.10*
Minimum Value	15.40	80.90	54.30	146.80	24.60	0.00	848.9
Maximum Value	248.2	358.7	406.6	548.8	444.3	253.5	2246.9
Trend (mm/year)	-0.31	-0.27	0.06	0.76	-0.20	0.54	-1.55
Total Change (mm/56 yrs)	-17.45	-14.88	3.24	42.32	-10.90	30.50	-87.05

***Significant at p<0.05**

The mean annual rainfall in Zaria is 1016.66 mm. The highest mean monthly rainfall of 271.65 mm was in August, while the lowest mean monthly rainfall of 40.29 mm was in October (Table 4). The annual standard deviation for the period of study is 165.66. The highest value of annual rainfall of 1406.3 mm was recorded in 2012 which coincided with the 2012 flood disaster that ravaged the northern part of the country. The lowest value of 660.10 mm was recorded in 1977 which also coincided with the decade of the Great Sahelian Drought. The month with the highest amount of rainfall at this station is August.

Table 4: General Statistics and Trends of Rainfall (1961- 2016) for Zaria Station

Statistics	May	Jun	July	Aug	Sep	Oct	Annual
Mean ($\bar{x}$)	106.64	148.67	226.38	271.65	178.12	40.29	1016.66
Standard Dev. (δ)	61.32	53.10	63.83	91.28	77.62	43.49	165.66
Skewness (Z_1)	1.38	0.47	0.19	-0.20	0.24	1.21	0.01
Kurtosis (Z_2)	2.66*	0.61	0.82	0.56	-0.01	0.92	-0.50
Minimum Value	7.20	31.4	59.0	12.0	23.9	0.00	660.1
Maximum Value	323.1	295.1	407.2	473.1	381.0	166.1	1406.3
Trend (mm/year)	0.89	0.50	0.75	2.00	-0.28	0.02	4.04
Total Change (mm/56 yrs)	50.09	28.23	41.82	112.01	-15.89	1.22	226.16

***Significant at p<0.05**

A closer examination of the spatial distribution of rainfall using the three meteorological stations in the State (Tables 2-4) showed that, as one moves from the southern part of the State (Kafanchan) towards the northern part (Zaria), rainfall amount decreases. This is in agreement with Abaje *et al* (2015b and

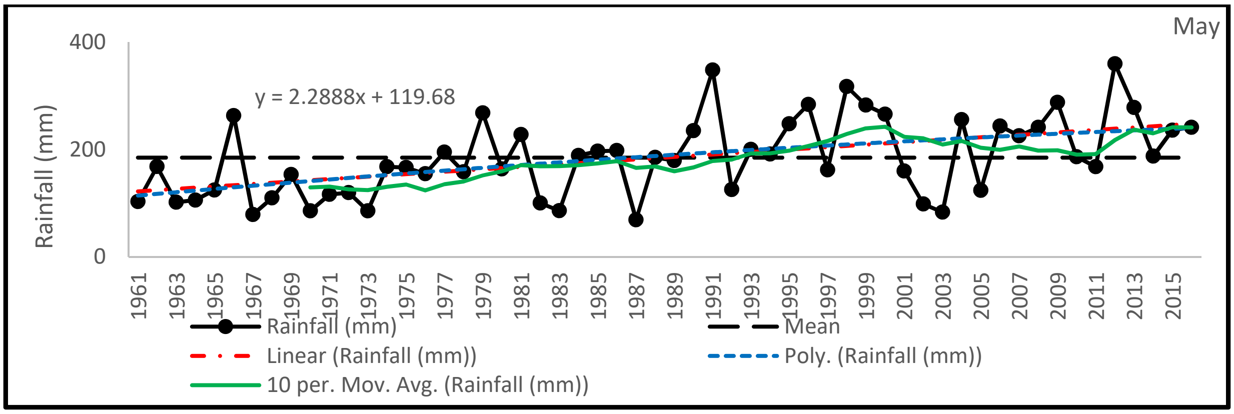
2016) using rainfall data of the same 3 stations for a study period of 40 years (1975–2014), where the result revealed that the mean annual rainfall decreases from about 1733 mm in Kafanchan to about 1203 mm and 1032 mm in Kaduna and Zaria respectively. The month of August which is having the highest amount of rainfall in the Kaduna State is in line with the findings of Atedhor (2016b) using 8 selected synoptic stations in the Sudano-Sahelian region of Nigeria in which all the stations witnessed their highest monthly distribution of rainfall peaks in the month of August.

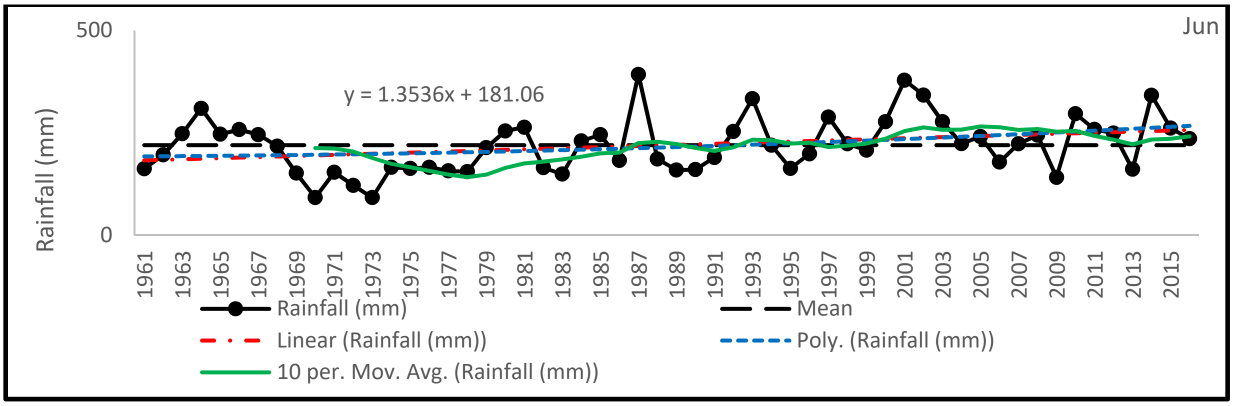
Rainfall Trend and Fluctuation

Monthly and Annual Rainfall Trends and Fluctuations for Kafanchan

Figure 2 and 3 show the graphical presentation of the monthly (May to October) and annual trends and fluctuation of the rainfall series of Kafanchan respectively, smoothened out with the 10-year running means. The 10-year running means for the month of May was below the long-term mean from the beginning of the study period up to the early 1990s and above it afterwards, indicating increasing rainfall for May. In June, the 10-year running mean was below the long-term mean from the beginning of the study period to the late 1980s, from there, it was above the long-term mean up to the early 2016. The linear trend lines for the two months also indicate an increase of 128.24 mm for the 56 years at a rate of 2.29 mm year^{-1} for May and an increase of 75.80 mm at a rate of 1.35 mm year^{-1} for June (Table 2).

All the 10-year running means for the months of July, August, September and October were above the long-term mean from the early 1990s to the end of the study period. This is a clear indication that the rainfall amount is increasing in recent years. The linear trend lines for the 56 years also indicate an increase of about 157.61 mm at a rate of 2.81 mm year^{-1} in July; an increase of 97.47 mm at a rate of 1.74 mm year^{-1} in August; an increase of 111.11 mm at a rate of 1.98 mm year^{-1} in September; and an increase of 78.56 mm at a rate of 1.40 mm year^{-1} in October. Based on the second order polynomial curve fitting, the trend showed that all the months experienced increasing trend from the beginning of the data (1961 to 2016).




Jun
500
0
Rainfall (mm)
y = 1.3536x + 181.06
1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
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Mean
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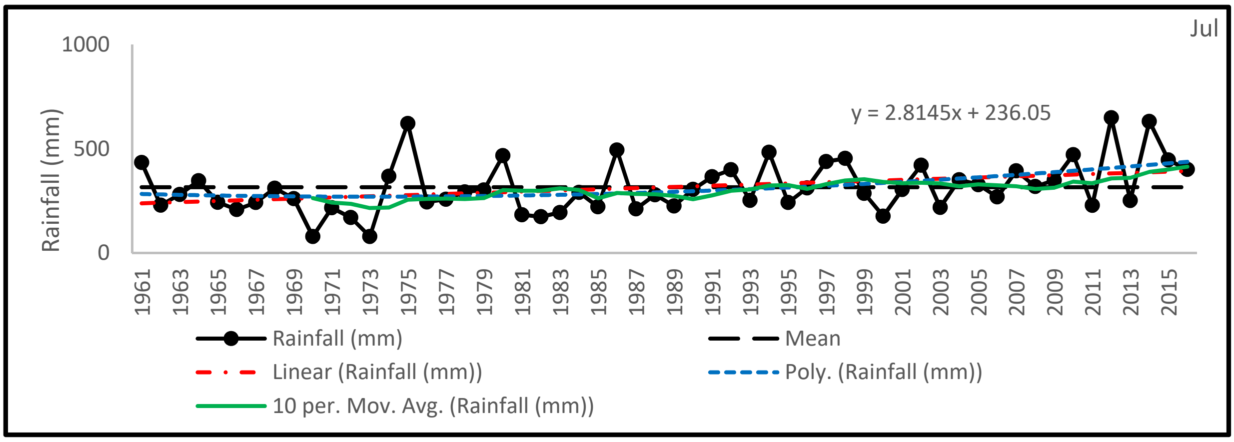
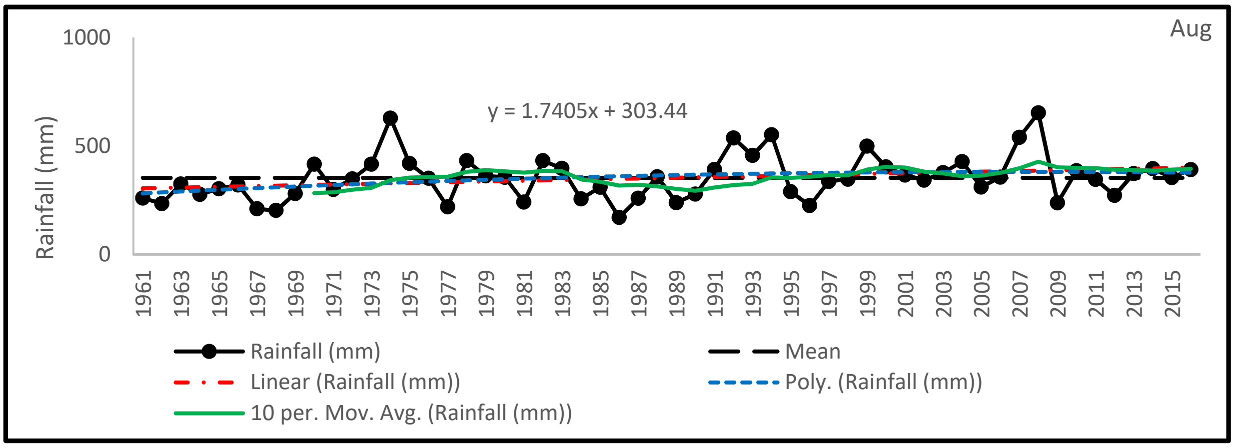
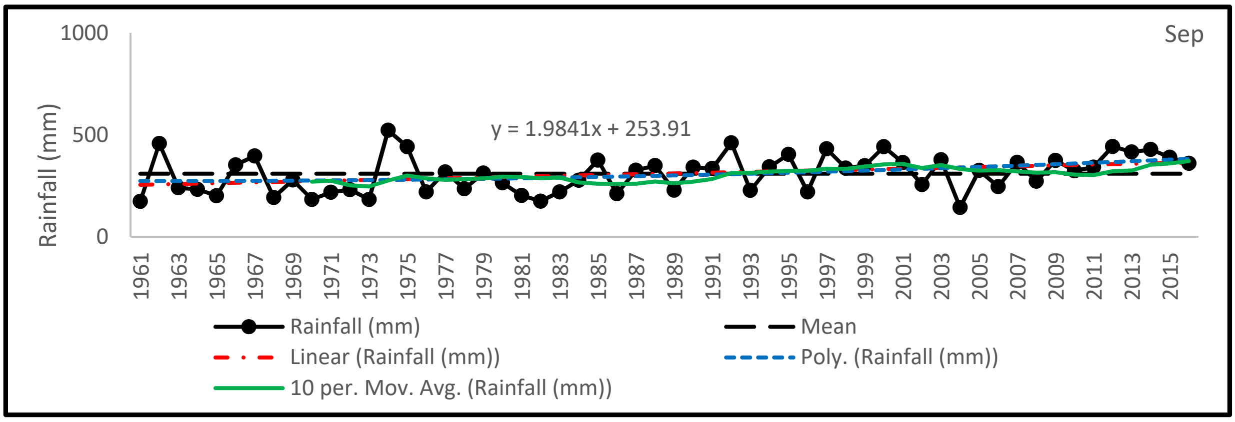

Jul
1000
500
0
Rainfall (mm)
y = 2.8145x + 236.05
1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Rainfall (mm)
Mean
Linear (Rainfall (mm))
Poly. (Rainfall (mm))
10 per. Mov. Avg. (Rainfall (mm))


Aug
1000
500
0
Rainfall (mm)
y = 1.7405x + 303.44
1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Rainfall (mm)
Mean
Linear (Rainfall (mm))
Poly. (Rainfall (mm))
10 per. Mov. Avg. (Rainfall (mm))


Sep
1000
500
0
Rainfall (mm)
y = 1.9841x + 253.91
1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Rainfall (mm)
Mean
Linear (Rainfall (mm))
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10 per. Mov. Avg. (Rainfall (mm))

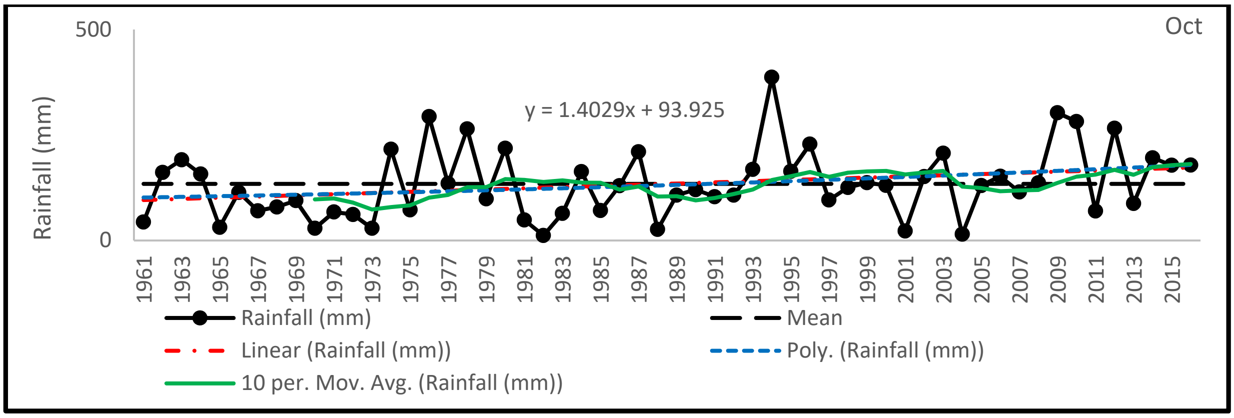


Figure 2: Rainfall Trends and Fluctuation of Kafanchan for May; June; July*;* August; September; and October.

For the annual total as shown in Figure 3, the 10-year running means was below the long-term mean from the beginning of the study period up to the early 1990s. It then rose above the long-term mean up to the end of the study period (2016). The linear trend line shows an increase of approximately 651.95 mm at a rate of 11.64 mm year^{-1}. This means that the annual rainfall keeps increasing in recent years. The second order polynomial curve fitting also showed that the annual rainfall experienced increasing trend from 1961 to 2016. This result is in conformity with other studies (Odekunle *et al,* 2008; Abaje *et al,* 2014; Abaje *et al,* 2015a) in Northern Nigeria in which rainfall was found to be increasing in recent years. The general increase in the annual rainfall yield is as a result of a substantial increase in the rainfall amount in May, July and September, which may be attributed to climate change.

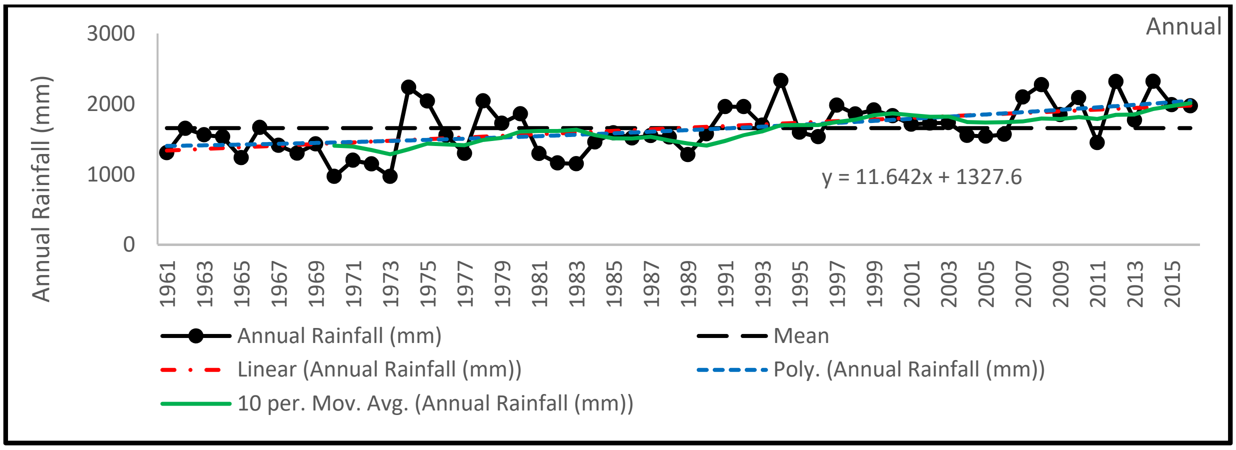
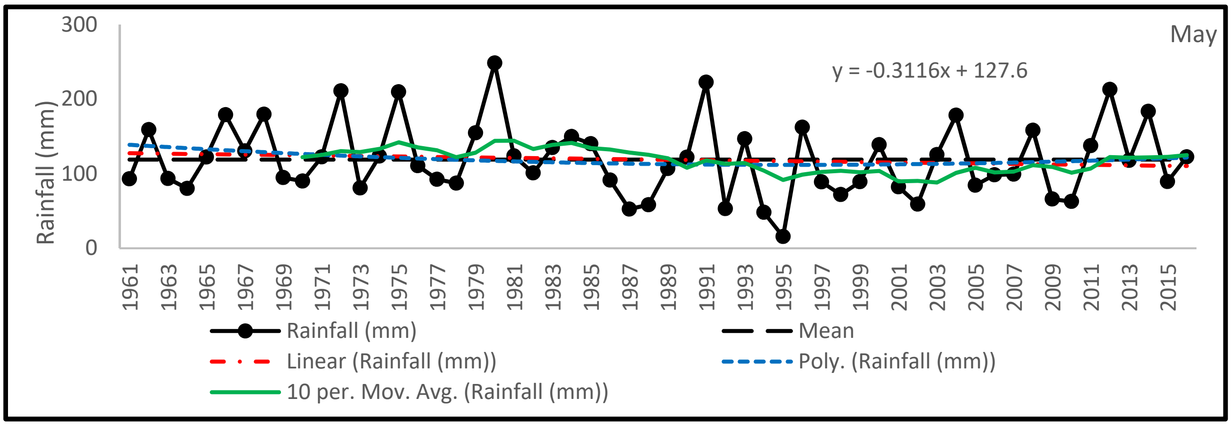


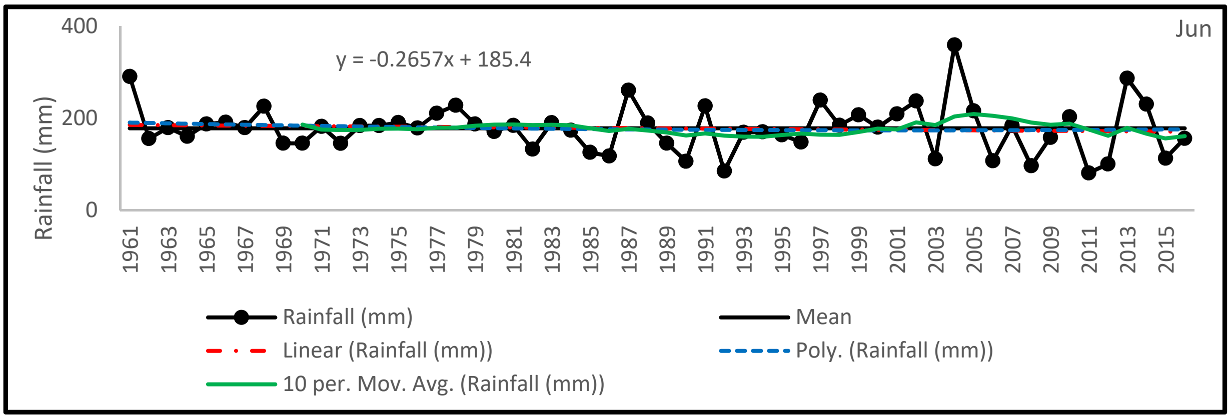
Figure 3: Rainfall Trends and Fluctuation of Kafanchan for Annual Total

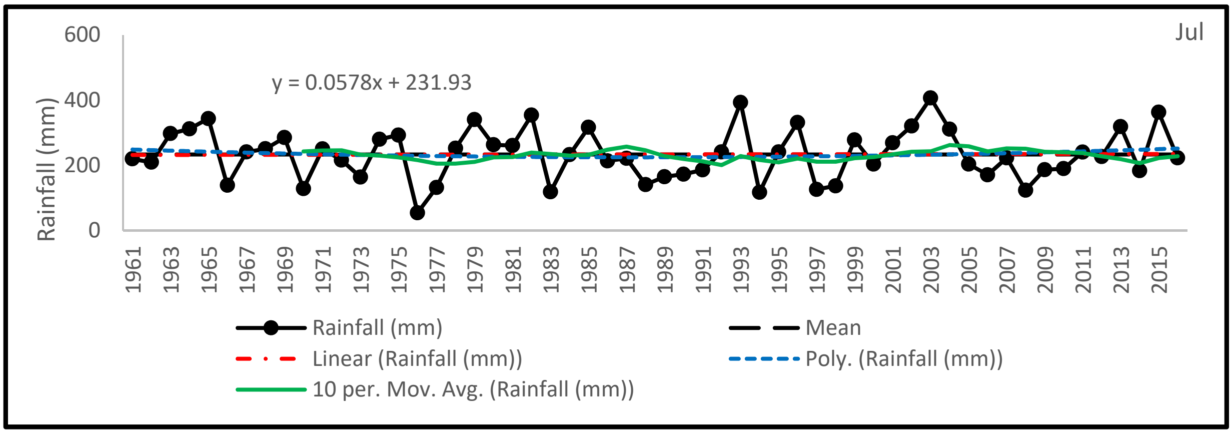
Monthly and Annual Rainfall Trends and Fluctuations for Kaduna

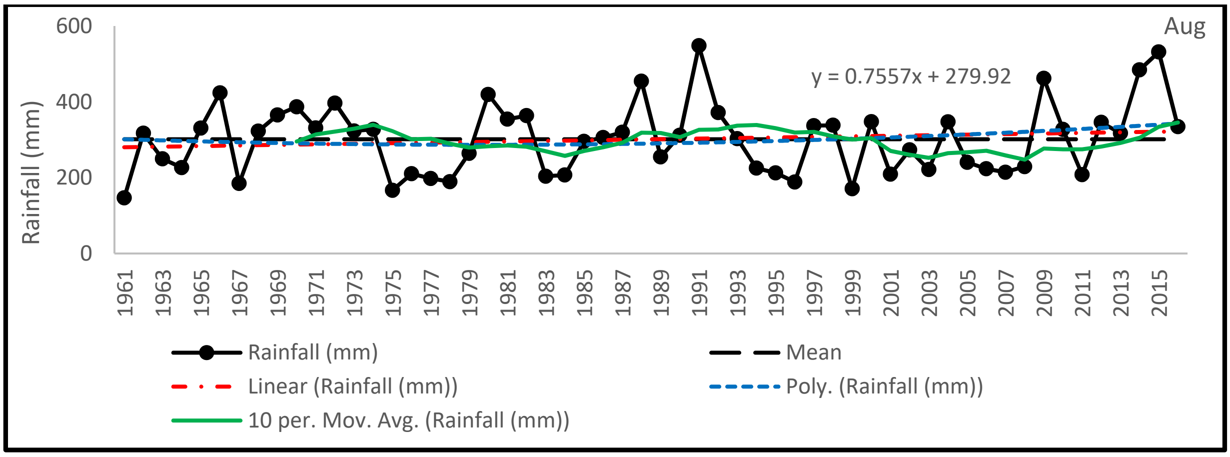
Figure 4 and 5 show the graphical presentation of the monthly (May to October) and the annual trends and fluctuation of the rainfall series of Kaduna synoptic station respectively, smoothened out with the 10-year running means. In May, the running mean was above the long-term mean from the beginning of the study period up to early 1990s and moved below the long-term mean from early 1990s up to 2012 and then rose above it again till 2016. For the month of June, the running mean was along the long-term mean from the beginning of the data recording to the late 1980s. From the early 1990s up to 2000, the running mean was below the long-term mean and rose above it from 2001 up to 2010. All the linear trend lines for May and June indicated a decrease in rainfall (see Table 3). In July, August and October, the running mean was fluctuating along the long-term mean from the beginning the data was recorded to the end; and all the linear trend lines show a little increase in rainfall (see Table 3).

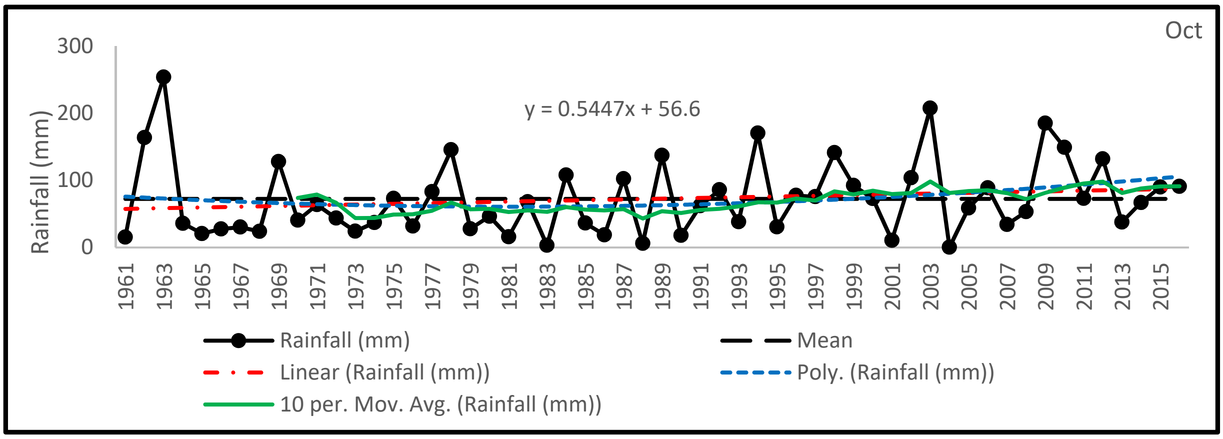
The second order polynomial for all months, with the exception of June, showed a decreasing trend from 1961 to the late 2000s and a little upward increase till 2016. For the month of June, there was an insignificant decrease in rainfall amount from 1961 to 2016. A closer examination of the second order polynomial curve fitting for the monthly rainfall (see Figure 4) shows that low rainfall was experienced in the 1970s and 1980s. These periods correspond with the drought that ravaged the country especially the northern part of Nigeria.











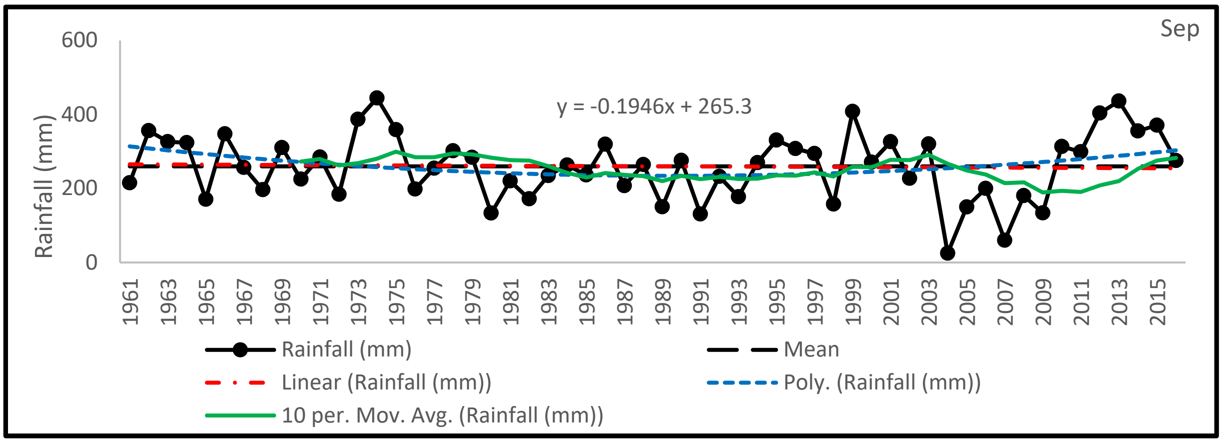


Figure 4: Rainfall Trends and Fluctuation of Kaduna for for May; June; July; August; September; and October.

The annual rainfall total shows that the 10-year running means was above the long-term mean from the beginning of the data to the early 1980s. From that point to 2016, the rainfall was below the long-term mean. The linear trend line shows a little decrease of 64.2 mm at a rate of 1.07 mm year^{-1}. The second order polynomial curve fitting for the annual rainfall exhibited a little high degree of curvilinear pattern. The annual rainfall showed a downward trend from the beginning of the data (1961) to the lowest, starting from around the late 1970s to the late 1990s. This is followed by an increasing trend thereafter.

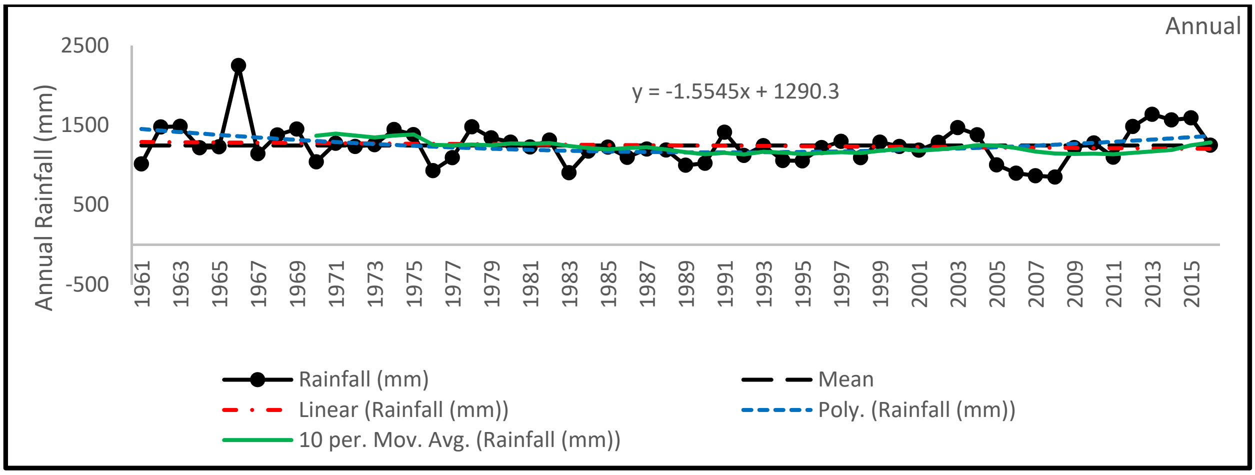
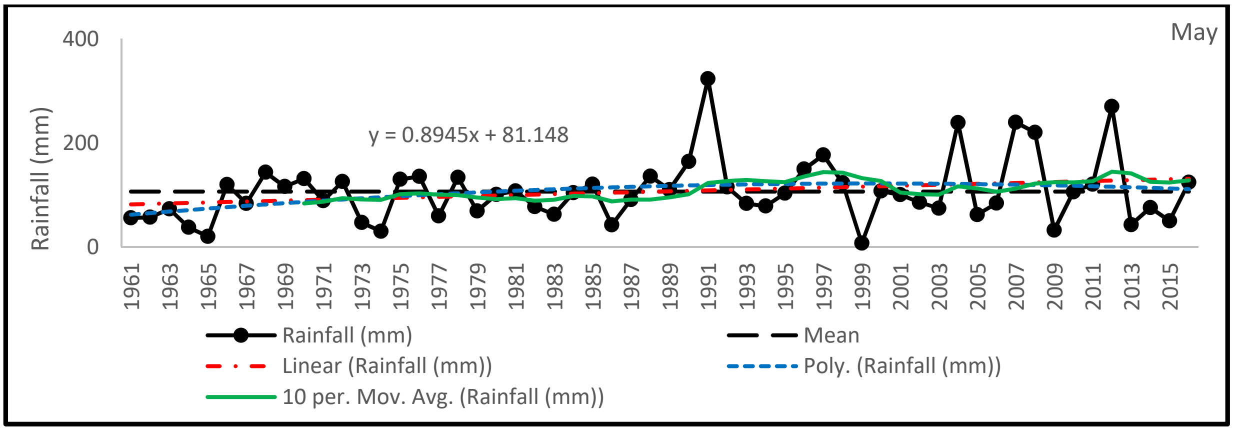
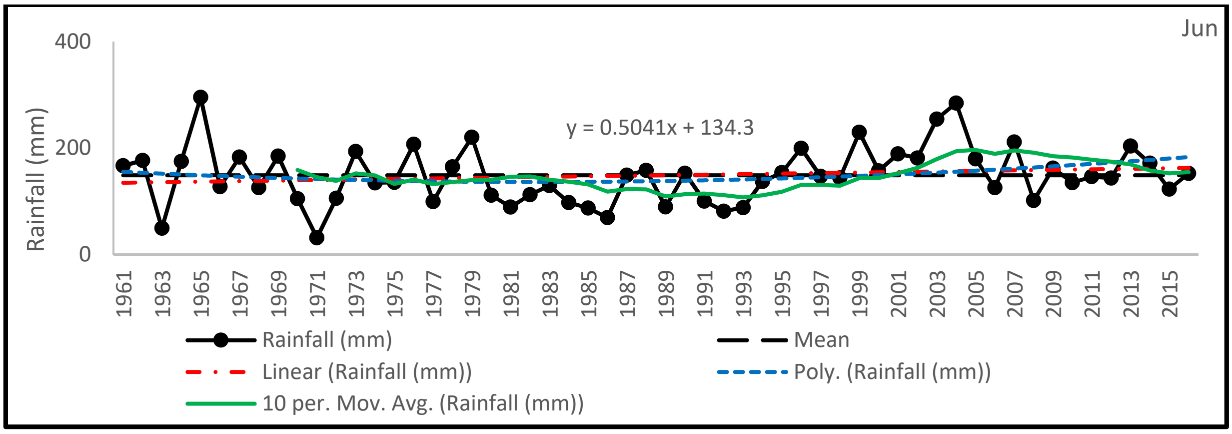


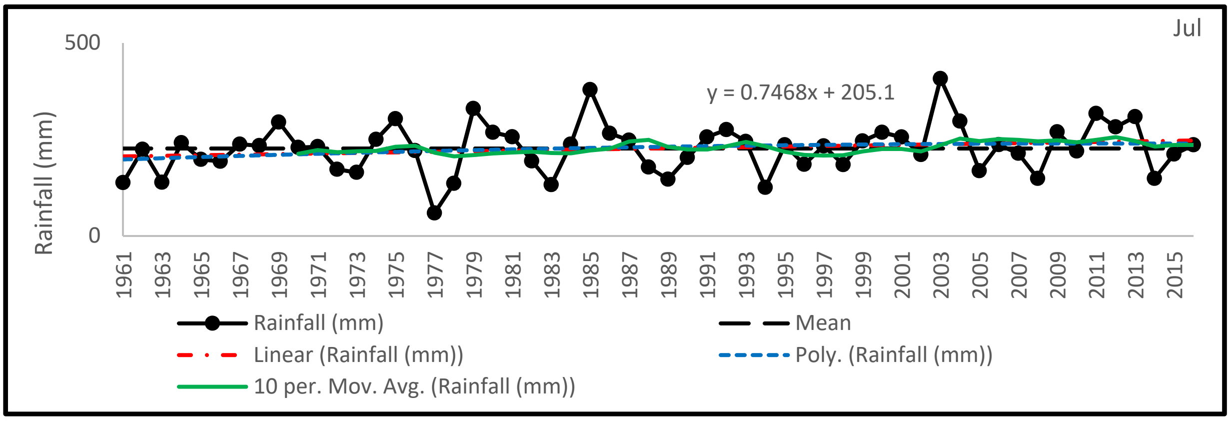
Figure 5: Rainfall Trends and Fluctuation of Kaduna for the Annual Total

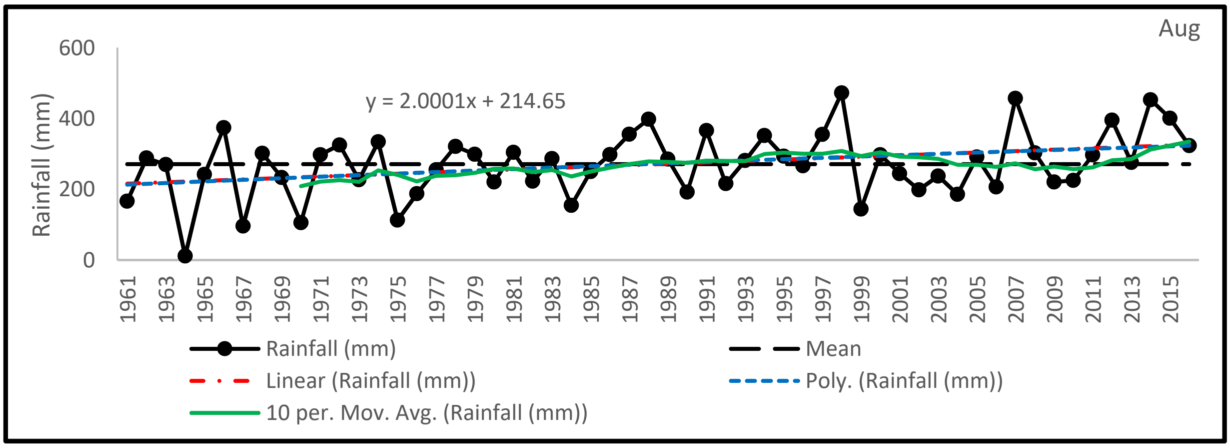
Monthly and Annual Rainfall Trends and Fluctuations for Zaria

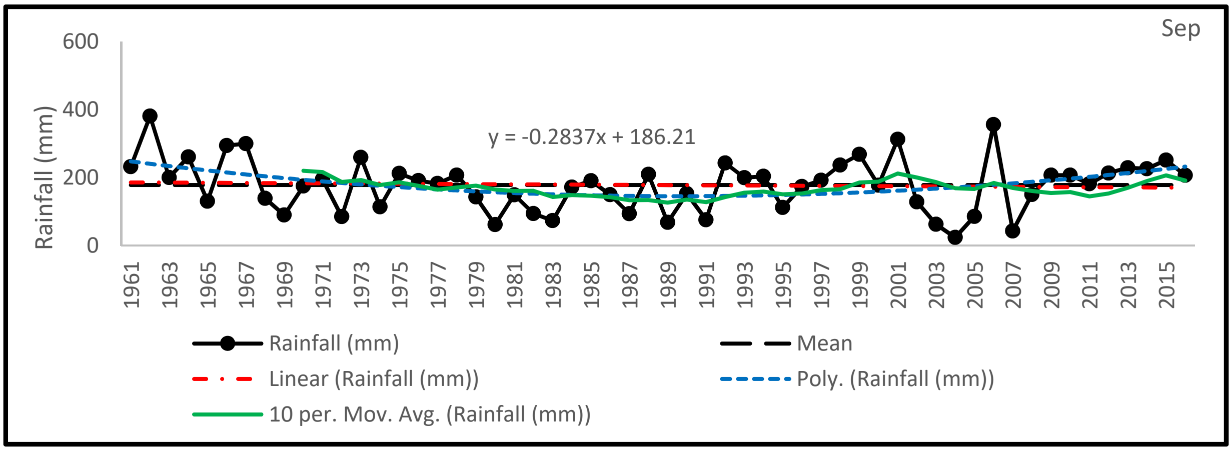
The graphical presentation of the monthly (May to October) and annual trends and fluctuations of the rainfall series of Zaria synoptic station smoothened out with the 10-year running means as shown in Figure 6 and 7 respectively. The 10-year running means for the months of May, June, July, and August (Figure 6) were generally above the long-term mean from the late 1990s to the end of the data recording (2016). All the linear trend lines for those months showed an increase in rainfall. The second order polynomial for the above months also experienced an upward trend from 1961 to 2016. The running mean for September was below the long-term mean from the early 2000s to the end of the data was recorded; the linear trends indicated a general decrease in rainfall for that month (see Table 4). On the other hand, the second order polynomial exhibited a downward trend from the beginning of recording the data (1961) to the lowest in the 1980s. From that point, there was an increasing trend.




Jun
400
200
0
Rainfall (mm)
y = 0.5041x + 134.3
1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Rainfall (mm)
Mean
Linear (Rainfall (mm))
Poly. (Rainfall (mm))
10 per. Mov. Avg. (Rainfall (mm))


Jul
500
0
Rainfall (mm)
y = 0.7468x + 205.1
1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Rainfall (mm)
Mean
Linear (Rainfall (mm))
Poly. (Rainfall (mm))
10 per. Mov. Avg. (Rainfall (mm))


Aug
600
400
200
0
Rainfall (mm)
y = 2.0001x + 214.65
1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Rainfall (mm)
Mean
Linear (Rainfall (mm))
Poly. (Rainfall (mm))
10 per. Mov. Avg. (Rainfall (mm))


Sep
600
400
200
0
Rainfall (mm)
y = -0.2837x + 186.21
1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Rainfall (mm)
Mean
Linear (Rainfall (mm))
Poly. (Rainfall (mm))
10 per. Mov. Avg. (Rainfall (mm))

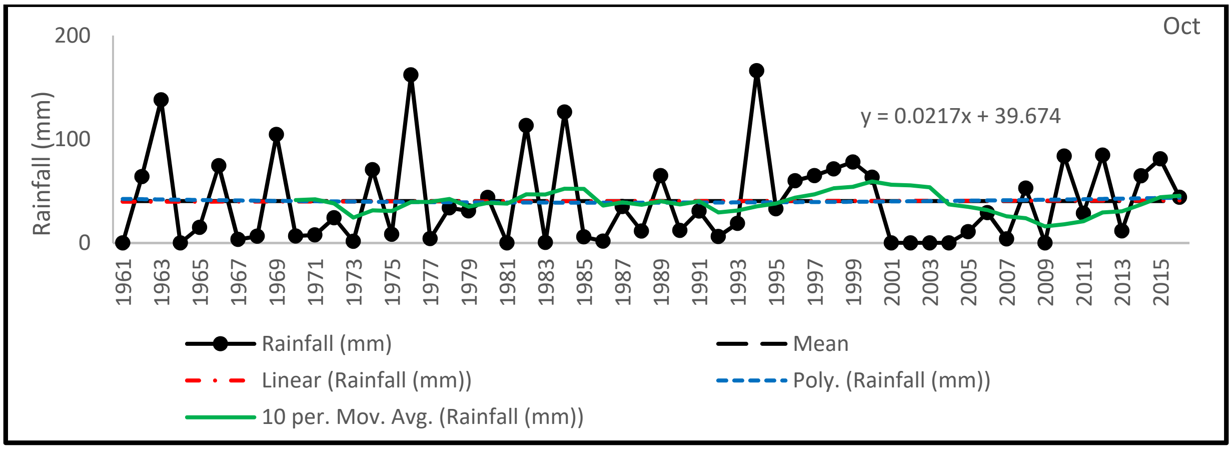


Figure 6: Rainfall Trends and Fluctuation of Zaria for May; June; July; August; September; and October.

The 10-year running means for the annual rainfall series as shown in Figure 7, was below the long-term mean from the beginning of the data to the mid-1990s. From that point to the end of the data (2016), the rainfall was above the long-term mean. The linear trend line indicated an increase in rainfall of about 226.16 mm at a rate of 4.04 mm year^{-1}. The second order polynomial curve fitting also indicated an increasing trend from the 1960 to 2016. The increase in annual rainfall amount of Zaria in recent years is as a result of substantial increase in the rainfall amount in July and August.

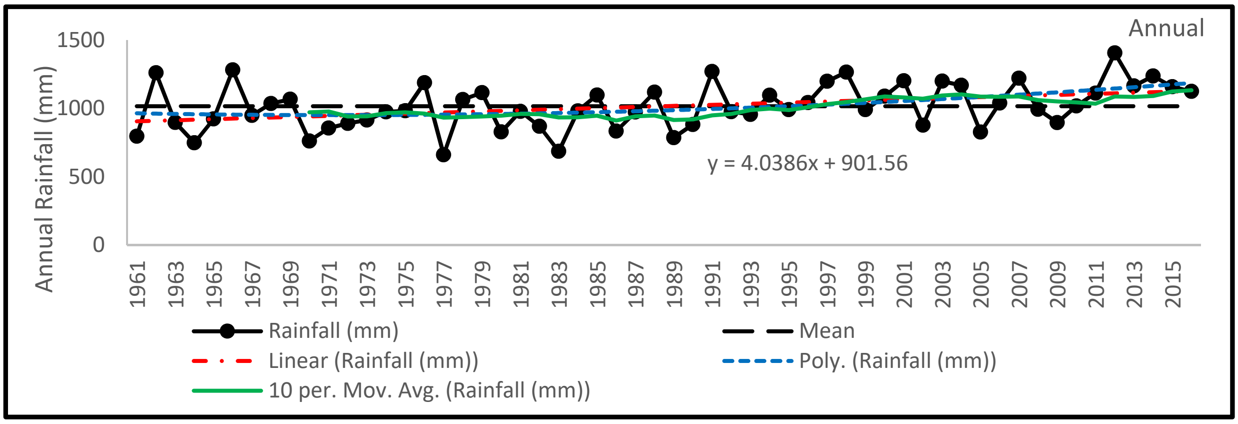


Figure 7: Rainfall Trends and Fluctuation of Zaria for the Annual Totals

Decadal Sub-Period Analysis

The results of the 10-years decadal sub-period analysis (Cramer's test) for the monthly and annual rainfall for Kafanchan, Kaduna, and Zaria are presented in Table 5, 6, and 7 respectively. In Kafanchan (Table 5), the t_k values for the monthly rainfall showed that the month of May in the sub-period (1961-1970), and the month of June in the sub-period (1971-1980) were significantly drier ($p<0.05$) than the long-term conditions. However, the month of May in the decade, thus 1991-2000, was significantly wetter ($p<0.05$) than the long-term condition. The t_k values for the annual rainfall showed a decrease in rainfall in the first three decades (1961-1970, 1971-1980 and 1981-1990) with significant cases (drier than long-term conditions) in the decades 1961-1970 and 1981-1990. These two decades coincided with the Great Sahelian Drought of the 1970s that ravaged the country (especially Northern Nigeria), and the drought of the 1980s that was more severe than the Catastrophic Sahelian Droughts (Oladipo, 1993). The last three decades, even though not significant, were very wet. This is a clear indication that the annual rainfall amount is increasing in recent years.

Table 5: Decadal Sub-Periods Analysis for Kafanchan Station

Sub-Period	May	Jun	Jul	Aug	Sep	Oct	Annual
1961-1970	-2.09*	-0.36	-1.33	-1.94	-1.34	-1.41	-1.97*
1971-1980	-1.11	-2.20*	-0.08	0.97	-0.55	0.46	-0.49
1981-1990	-0.82	-0.36	-1.45	-1.72	-1.37	-1.47	-1.96*
1991-2000	2.11*	0.75	0.70	1.53	1.51	1.18	1.73
2001-2010	0.28	1.55	0.73	1.43	-0.19	0.70	1.38
2011-2016	1.62	1.07	1.76	0.05	1.74	0.82	1.68

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

In Kaduna (Table 6), the t_k values for all the months in the six sub-periods were normal at $p<0.05$ with exception of the month of September in the decade 2001-2010, which was significantly drier than the long-term conditions. But the positive cases in the last sub-period (2011-2016) are indication of increasing rainfall amount. The annual rainfall for the whole period of study was also normal at $p<0.05$. The last sub-period (2011-2016), with a t_k value of 1.62 is still an indication of increasing rainfall in recent years.

Table 6: Decadal Sub-Periods Analysis for Kaduna Station

Sub-Period	May	Jun	Jul	Aug	Sep	Oct	Annual
1961-1970	0.21	0.51	0.39	-0.22	0.49	0.12	1.58
1971-1980	1.56	0.51	-0.44	-0.68	0.85	-0.89	0.37
1981-1990	-0.75	-0.99	-0.61	0.18	-0.95	-1.20	-1.49
1991-2000	-1.00	-0.06	-0.39	0.11	-0.08	0.72	-0.67
2001-2010	-1.18	0.64	0.26	-0.95	-2.05*	1.00	-1.39
2011-2016	1.16	-0.78	0.78	1.51	1.86	0.40	1.62

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

In Zaria (Table 7), the tk values for the monthly rainfall showed that the month of September in the sub-period 1961-1970, was significantly wetter (p<0.05) than the long-term condition. All other months in all the sub-periods were having a normal condition. The tk values for annual rainfall in the last three decades were all positive with the last sub-period, 2011-2016, having a value of 1.89. This is another clear evidence that the rainfall is increasing in recent years.

Table 7: Decadal Sub-Periods Analysis for Zaria Station

Sub-Period	May	Jun	Jul	Aug	Sep	Oct	Annual
1961-1970	-1.21	0.64	-0.68	-1.95	2.61*	0.08	-0.90
1971-1980	-0.82	-0.57	-0.68	-0.48	-0.56	-0.08	-1.32
1981-1990	-0.28	-1.93	-0.11	0.11	-1.65	-0.23	-1.72
1991-2000	1.07	-0.32	-0.05	1.17	0.44	1.36	1.35
2001-2010	0.92	1.81	0.83	-0.52	-0.84	-1.53	0.55
2011-2016	0.29	0.38	0.89	1.75	1.16	0.67	1.89

***Significant at p<0.05**

The significant increase in rainfall amount in the study area is in agreement with previous researches by Odekunle et al (2008) and Abaje et al (2014), that is, there is increase in rainfall supply in the northern part of the country in recent years.

Non-overlapping Sub-Period Analysis for Temporal Changes in the Rainfall Amount

The results of the student's t-test (td), for the temporal changes in the rainfall amount between the two non-overlapping sub-periods (1961-1990 and 1991-2016) in the three stations are presented in Table 8. The results indicated that Kafanchan and Zaria stations were having significant positive td values of 5.09 and 3.71 respectively at p<0.05, meaning that they were wetter than the long-term period. This implies that the recent sub-period (1991–2016) for the two stations were wetter than the sub-period for 1961–1990. In Kaduna, a normal condition existed throughout the study period.

Table 8: Student's t-test (td) Analysis for the Annual Rainfall

Stations	Sub-Periods	Mean (mm)	Standard Deviation (mm)	td
Kafanchan	1961–1990	1470.90	303.94	5.09*
	1991–2016	1871.67	261.43	
Kaduna	1961–1990	1257.46	248.69	-0.39
	1991–2016	1232.70	214.51	
Zaria	1961–1990	946.85	157.22	3.71*
	1991–2016	1097.22	138.22	

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

Generally, the findings of this research clearly indicated that Kaduna State has been experiencing increasing rainfall in recent years. This result does not concur with some of the earlier conclusions drawn by Oladipo (1993) and Sawa (2002) that the area was experiencing decreasing rainfall. However, these previous studies (Oladipo, 1993 and Sawa, 2002) were based on data covering up to the early 1990s and 2000 respectively. Studies using recent rainfall data covering up to 2016 will arrive at the same result with this present study.

Conclusion and Recommendations

The study examined the spatio-temporal distribution of rainfall in Kaduna State along a geographic transect, from the southern to the northern parts of Kaduna State, for a period of 56 years (1961 – 2016). The result revealed that rainfall in the Kaduna State is unevenly distributed. It decreases from the southern part to the northern part. Changes in rainfall amount of Kaduna State from the various statistical methods used—that is, the 10-year running means, the linear trends, the second order polynomial curve fitting, the decadal non-overlapping sub-period analysis, and the student's t-test for the temporal changes in the rainfall amount between the two non-overlapping sub-periods (1961-1990 and 1991-2016)—in all the three stations (Kafanchan, Kaduna and Zaria) generally showed that rainfall amount is increasing in recent years. The increase in the annual rainfall is as a result of a substantial increase in rainfall amount in May, July, August and September. Findings also revealed that the southern part of Kaduna State (Kafanchan) is having the highest rate of increase in annual rainfall for the 56-year period. This is followed by the northern part (Zaria), and the least is the central part (Kaduna).

Based on the findings, this study recommends the analysis of existing series of observed rainfall data in order to provide useful information on the onset, cessation and length of the rainy season, and the amount of available water during the season; crop varieties that can withstand much water should be planted in areas of high rainfall; and government policies related to agriculture and water resources development should be based on increasing rainfall trends.

Acknowledgement

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