IS THE CHANGING RAINFALL PATTERNS OF KANO STATE AND ITS ADVERSE IMPACTS AN INDICATION OF CLIMATE CHANGE?

Abaje, I.B.
Department of Geography and Regional Planning,
Federal University, Dutsin-Ma, Katsina State, Nigeria
Ndabula, C.
Garba, A.H.
Department of Geography, Taraba State University, Jalingo, Nigeria

Abstract

Annual and monthly rainfall data for Kano from the period 1911 to 2010 (100 years) were used in this study to determine the changing patterns of rainfall and its adverse impacts on transport infrastructures. The Relative Seasonality Index of the rainfall series revealed that the rainfall is in 3 months or less. In order to identify trends, the rainfall series was divided into 10-year non-overlapping and 30-year overlapping sub-periods and the Cramer's test was then used to compare the means of the sub-periods with the mean of the whole record period. The results of the 10-year non-overlapping sub-period analysis revealed a recent increase in the annual rainfall series in the last two sub-periods (1991-2000 and 2001-2010). The results of the 30-year overlapping sub-periods analysis also revealed that the recent sub-period, 1981-2010, was significantly wetter than the long-term conditions. Findings revealed that the increase in annual rainfall amount in recent years is as a result of the increased in June, July and August rainfalls. This may be responsible for the frequent occurrences of floods in the months of July and August which is an indication of climate change. The 10-year running mean shows that the increasing yield of the annual rainfall started from the mid 1990s to the end of the study period. The major implication of this increased in amount and intensity of rainfall on transport infrastructures is that models built on the perceived decreasing rainfall, such as drainages, bridges, etc, have to be reviewed. It is recommended that planning and designing of transport infrastructures should take into account the recent increasing nature of rainfall.

Keywords: Climate change, droughts, flooding, infrastructures, trends

1 Introduction

Climate change is real, and is brought about by a complex, interactive system consisting of the atmosphere, the oceans, the cryosphere, the surface lithosphere and the biosphere, which comprise the climate system (Le Treut *et al.*, 2007).

Human activity, particularly deforestation and the burning of fossil fuels, is driving this change by increasing atmospheric concentrations of carbon dioxide and other greenhouse gases (GHGs). As a result, the world is experiencing greater weather extremes, changes in rainfall patterns, heat and cold waves, and increasing droughts and floods. These phenomena have a negative impact on the environment and on people's lives and livelihoods. Marginalized groups in the poorest regions are particularly affected, even as they are least responsible for these changes (United Nations Development Programme, 2009).

Globally, it has been observed that changes are occurring in the amount, intensity, frequency and type of rainfall. In Africa, rainfall exhibits high spatial and temporal variability. Mean annual rainfall ranges from as low as 10 mm in the innermost core of the Sahara region to more than 2000 mm in parts of the equatorial region. The rainfall gradient is largest along the southern margins of the Sahara (i.e. the Sahel) where the mean annual rainfall varies by more than 1000mm over about 750km. As a result of the tight rainfall gradient, a small change in the position of the ITCZ can have large consequences for rainfall in the Sahel region; thus, this region is a sensitive indicator of climate change in Africa. The coefficients of rainfall variability in Africa is above 200% in the deserts, about 40% in most semi-arid regions and between 5% and 20% in the wettest areas (Watson, Zinyowera, Moss, & Dokken, 2001).

In Nigeria, climate change is one of the most serious threat to poverty eradication and sustainable development. This is because the country has a large rural population that is directly depending on the natural resources for their subsistence and livelihood which are climate-sensitive (Oladipo, 2008). Studies have shown that since the beginning of the 19th Century, the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria has suffered decrease in rainfall in the range of about 3-4% per decade (Federal Republic of Nigeria, 2003), and is subject to frequent floods and droughts as a result of the large inter-annual variability of the rainfall. Records have equally shown that severe flooding in this zone has become an almost annual occurrence.

Kano State has suffered severe droughts especially the droughts of the early 1970s and the 1980s that ravaged northern Nigeria. Conversely, flood disasters as a result of heavy rainfall have been recorded. In August, 1988 for example, severe flooding in Kano State resulted in the loss of 146 lives, destruction of 180,000 houses, washing away of 14,000 farms, displacement of 200,000 people, collapsed of the Bagauda dam and damage to residences and infrastructure worth 560 million naira (NEST, 1991). Similarly, in June 2011, 24 people lost their lives and many others injured, about 100 houses were destroyed, and more than 300 people were displaced after torrential rains flooded the highly populated Fagge area of Kano city (Ibrahim, 2011). On August 28, 2012, some Local Government Areas (Bagwai, Bebeji, Gabasawa, Garun-Mallam, Karaye, Nasarawa and Sumaila) were affected by floods as a result of heavy rainfall in which 15 lives were claimed. The August 11, 2013 flood also claimed a live and destroyed 434 houses in Kano metropolis.

Much attention, especially in the transportation sector, has been given to the subject of reducing greenhouse gas emissions (Cochran, 2009). Increase in temperature, precipitation and extreme events such as flooding, storm surges, among others have significant impacts on transportation infrastructure (Regmi & Hanaoka, 2009).

In Kano State, limited analyses have been conducted on how changes in rainfall would affect the infrastructures necessary to fill current mobility needs. The aim of this study, therefore, is to determine the changing patterns of rainfall in Kano state using long-term data and to identify some of the adverse impacts on transport infrastructures.

2 Study Area

Kano State (Figure1) lies approximately between latitudes 10^0 33’N and 12^0 23’N and longitudes 7^0 45’E and 9^0 29’E, with a population of 9,401,288 during the 2006 census (Federal Republic of Nigeria, 2010). It has an estimated land size of 21,276.872 km^2 with 1,754,200 hectares agricultural and 75,000 hectares forest vegetation and grazing land (African Institute for Applied Economics, 2007).

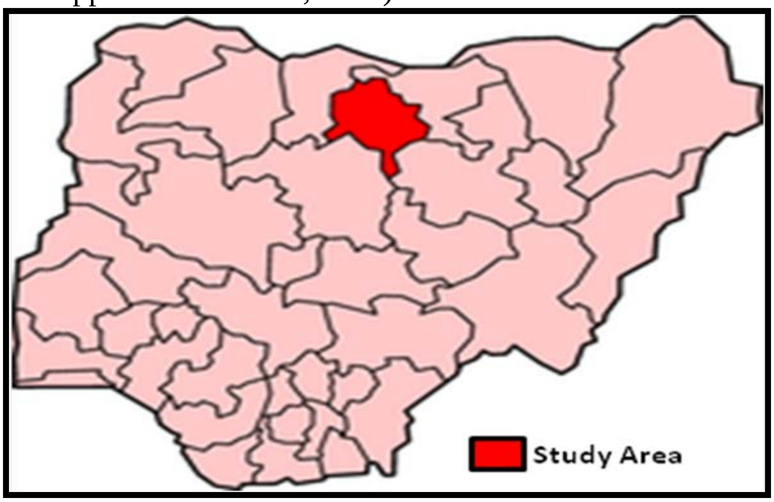


Figure 1. Map of Nigeria showing the study area (Kano State)

The climate of the study area is the tropical dry-and-wet type, classified by Koppen's as Aw. The movement of the Inter-Tropical Discontinuity (ITD) gives rise to two seasons (wet and dry seasons). The wet season lasts from May to mid-October with a peak in August while the dry season extends from mid-October of one calendar-year to mid-May of the next. The annual mean rainfall is between 800 mm to 900 mm; and variations about the annual mean values are up to $\pm 30\%$. The mean annual temperature is about 26^0C (Falola, 2002; Olofin, 2008).

The area is characterized by rocks of the Basement Complex of pre-Cambrian age to the west and south, and the Chad formation to the northeast. The relief can be described under three types which are found in three zones. These are: the south and southeastern highlands, the middle and western high plains and the northeastern low Chad plains. The first two types are part of the High plains of Hausaland and the third is part of the Chad plains (Olofin, 2008).

3 Materials and Methods

Rainfall data for Kano from the period 1911 to 2010 (100 years) were used in this study. These are secondary data that were sourced from the archive of Nigerian Meteorological Agency (NIMET), Oshodi-Lagos.

Only rainfall totals for the monthly growing season (April-October) and the annual were used in this study. The main reason is that 85% of the total annual rainfall received in the study area are within these months. The normality in the rainfall series was tested using the standardized coefficients of Skewness (Z_1) and Kurtosis (Z_2) statistics as defined by Brazel and Balling (1986). The standardized coefficient of Skewness (Z_1) was calculated as:

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

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

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

where $\bar{x}$ is the long term mean of x_i values, and N is the number of years in the sample. These statistics were used to test the null hypothesis that the individual temporal samples came from a population with a normal (Gaussian) distribution. 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.

The Relative Seasonality Index (*SI*) of the rainfall series was equally calculated using the Walsh and Lawler (1981) statistic. This was done in order to show the class into which the climate of Kano State can be classified. This index is calculated as:

$$SI = \frac{1}{\overline{R}} \sum_{n=1}^{n=12} \left| \overline{x}_n - \frac{\overline{R}}{12} \right| \text{--} (3)$$

where $\overline{x}_n$ is the mean rainfall for month n and $\overline{R}$ is the mean annual rainfall. This index can vary from zero (if all the months have equal rainfall) to 1.83 (if all the rainfall occurs in a single month). Table 1 shows the seasonality index classes as proposed by Walsh and Lawler (1981).

Table 1. Seasonality index classes

Rainfall Regime	*SI* Class Limits
Very equable	≤ 0.19
Equable but with a definite wetter season	0.20-0.39
Rather seasonal with a short drier season	0.40-0.59
Seasonal	0.60-0.79
Markedly seasonal with a long drier season	0.80-0.99
Most rain in 3 months or less	1.00-1.19
Extreme, almost all rain in 1-2 months	≥1.20

The rainfall series was sub-divided into 10-year non-overlapping sub-periods (1911-1920, 1921-1930 through 2001-2010) and 30-year overlapping sub-periods (1911-1940, 1921-1950 through 1981-2010). This was done in order to identify trends. The Cramer's test (Lawson, Balling, Peters, & Rundquist, 1981) was then used to compare the means of the sub-period with the mean of the whole record period. The *t*-statistic is computed as:

$$t_k = \left(\frac{n(N-2)}{N - n\left(1+\tau_k^2\right)} \right)^{1/2} \tau_k \text{-------------------------------------} (4)$$

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

$$\tau_k = \frac{\overline{x}k - \overline{x}}{S} \text{--} (5)$$

where $\overline{x}k$ is the mean of the sub-period of n-years. $\overline{x}$ and S 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 0.95 confidence level appropriate to a two-tailed form of test, it is accepted that the difference between the overall mean and the mean certain parts of the record are significant.

To examine the nature of the trend, linear trend lines and moving mean were calculated and plotted using Microsoft Excel statistical tool (2007) for both the monthly (April to October) and annual rainfall totals (mm) for the station. In this work, the 10-year moving mean was used in order to smoothing the time series, thereby reducing the irregular fluctuations and highlighting those that are regular. The standard deviation which has the potential to provide a result of deviation from normal was equally determined and plotted. The standard deviation (δ) is given by the formula:

$$\delta = \sqrt{\sum \frac{\left(X - \overline{X}\right)^2}{N}} \text{ -- (6)}$$

4 Results and Discussion

4.1 Rainfall Trends and Variability

The general statistics of the monthly (April to October) and annual rainfall of the study area are presented in Table 2. The results of Z_1 and Z_2 show that all the months and the annual were accepted as indicative of normality at the 95% confidence level with the exception of Z_1 and Z_2 for the months of April and October and Z_2 for the month of July that shows a significant deviation from normal. As a result, the data were used without any transformation. The calculated *SI* was 1.14, which means that most of the rainfall in the study area is within 3 months or less.

Table 2. General statistics of rainfall (1911-2010) for Kano State

Statistics	April	May	June	July	August	September	October	Annual
$\overline{X}$	13.13	59.72	123.75	226.75	303.44	142.26	13.18	883.47
SD	23.29	45.78	59.20	102.85	113.04	78.43	18.91	259.02
CV	177.38	76.66	47.84	45.36	37.25	55.13	143.47	29.32
Z_1	2.64*	0.99	0.79	1.20	0.70	0.88	2.26*	0.95
Z_2	7.88*	0.83	0.89	2.44*	1.52	1.29	7.35*	1.51

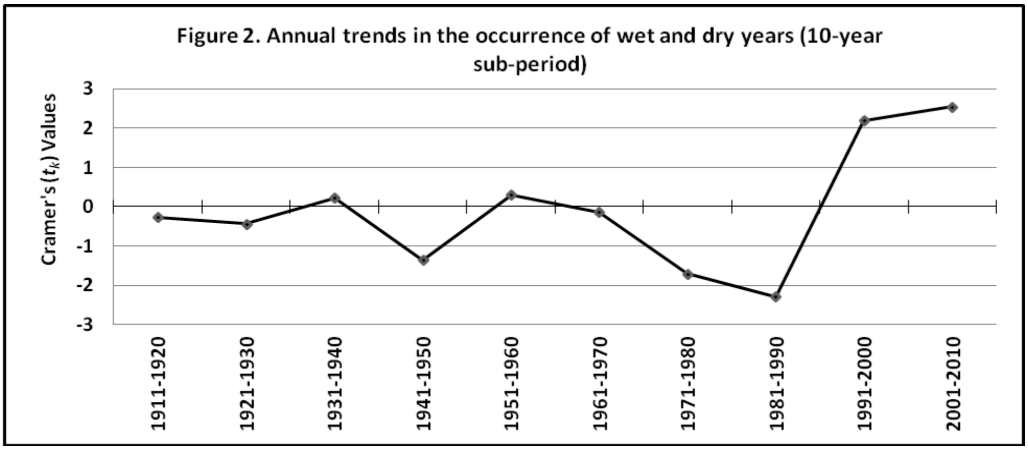
*Statistically significant at 95% confidence level

The results of the 10-year (decadal) non-overlapping sub-period analysis (Cramer's test) for the monthly and annual rainfall are presented in Table 3 and graphically (for the annual) in Figure 2. The t_k values for the annual rainfall shows that all the statistically significant cases occurred in three sub-periods (1981-1990, 1991-2000 & 2001-2010) while the other sub-periods do not show any significant changes from long-term conditions. This means that they were having a normal condition. The sub-period 1981-1990 was statistically drier at 95% confidence level than the long-term conditions. This finding corresponds to Oladipo (1993) that the 1983 and 1987 droughts were more severe than in 1973 which was the peak of the catastrophic Sahelian droughts of 1968-1973. The sub-periods 1991-2000 & 2001-2010 were significantly wetter than the long-term conditions. This is in agreement with O. Ati, Muhammed, and M. Ati, (2008); Ati, Stigter, Iguisi and Afolayan,(2009) and Abaje, Ati, Iguisi and Jidauna (2013) that the late 1990s have been witnessing increasing annual rainfall totals. The increase in the annual rainfall yield in the last two decades was predominantly as a result of the substantial increase in August rainfall for the decade 1991-2000 and in June and July rainfall for the decade 2001-2010 as indicated by the statistically significant wetter conditions of those months. The increase in rainfall supply of these three months, especially in August, corresponds with the frequent occurrences of August floods in the study area. This general annual trend is clearly depicted by the graph in Figure 2.

Table 3. Results of 10- year non-overlapping sub-period analysis (Cramer's Test)

Sub-Period	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1911-1920	0.10	0.20	-0.39	0.65	-0.89	0.26	-2.23*	-0.26
1921-1930	-0.86	-0.39	-1.55	-1.01	1.50	-0.55	0.30	-0.43
1931-1940	-0.46	0.13	0.46	-0.13	-0.13	0.83	1.06	0.23
1941-1950	0.43	0.03	-1.03	-1.30	-0.16	-1.57	-1.03	-1.35
1951-1960	-0.68	1.38	0.23	0.65	-0.26	-0.16	0.07	0.30
1961-1970	1.59	-0.07	1.17	-0.80	-0.43	-0.10	0.30	-0.13
1971-1980	0.16	-0.86	-0.49	-1.43	-1.57	-0.92	0.46	-1.70
1981-1990	-0.80	-1.55	-1.76	-0.45	-1.89	-1.63	-0.83	-2.29*
1991-2000	0.55	0.43	0.39	1.93	2.00*	1.89	0.65	2.19*
2001-2010	-0.20	0.80	2.39*	2.59*	1.59	1.72	0.49	2.54*

*Significant at 95% confidence level



The results of the 30-year overlapping sub-period analysis (Cramer's test) for the monthly and annual rainfall are presented in Table 4 and graphically (for the annual) in Figure 3. An examination of the result (Table 4) reveals that all the significant cases occurred in two sub-periods (1961-1990 & 1981-2010). The t_k values for the annual rainfall shows that the sub-period 1961-1990 was statistically drier at 95% confidence level than the long-term conditions, whereas, the sub-period 1981-2010 was statistically wetter at 95% confidence level than the long-term conditions. The decline in the annual rainfall yield between 1961 and 1990 was due to the decrease in the rainfall supply in the months of July and August as indicated by the statistically significant drier conditions of those months whereas, the recent rainfall increased in the last sub-period is as a result of increase in July rainfall. This implies that Kano has been experiencing decreasing number of dry conditions and consequently, increasing wetness over the recent years which is an indication of climate change (see Figure 3).

Table 4. Results of 30- year overlapping sub-period analysis (Cramer's Test)

Sub-Period	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1911-1940	-0.84	-0.06	-1.09	-0.32	0.39	0.39	-0.02	-0.26
1921-1950	-0.58	-0.13	-1.51	01.63	0.90	-0.96	0.13	-1.09
1931-1960	-0.45	0.39	-0.26	-0.58	-0.39	-0.71	-0.02	-0.64
1941-1970	1.02	0.96	0.26	-1.02	-0.58	-1.33	-0.52	-0.84
1951-1980	0.84	0.39	0.64	-1.15	-1.57	-0.77	-0.52	-1.15
1961-1990	0.77	-1.75	-0.84	-2.41*	-2.91*	-1.86	-0.06	-3.03*
1971-2000	-0.06	-1.39	-1.39	-0.52	-1.02	-0.32	0.19	-1.39
1981-2010	-0.32	-0.32	1.15	2.90*	1.27	1.57	0.19	2.30*

*Significant at 95% confidence level

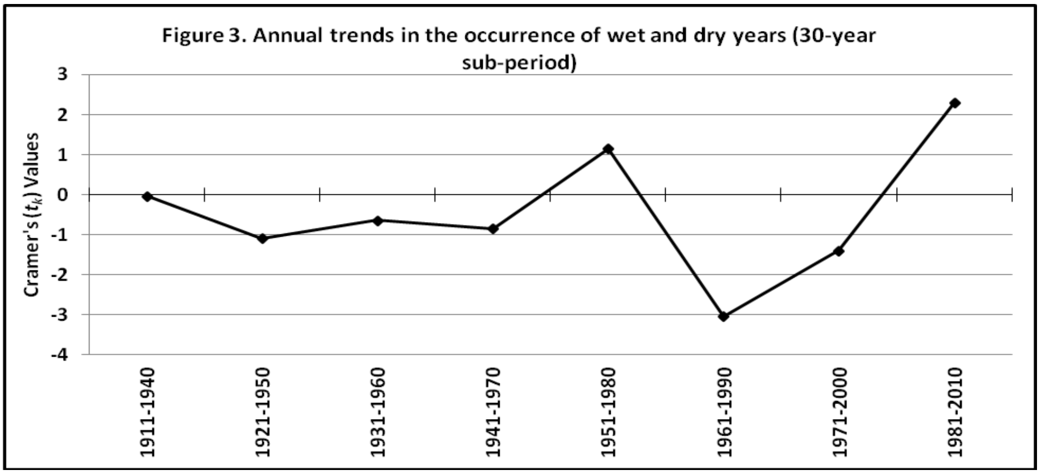


Figure 4 shows the graphical presentation of the monthly and annual trends and variability of the rainfall series for the period 1911 to 2010 smoothened out with the 10-year running mean. A general examination of the monthly running means (Figure 4a-g) shows that rainfall has been increasing from the mid 1990s to the end of the study period. A thorough examination of the annual rainfall (Figure 4h) shows that rainfall was along the long-term mean up to 1941. From that year it was below the long-term mean up to the late 1950s and again above the long-term mean from the early 1960s to the mid 1960s. From the mid 1960s, there was a substantial reduction in rainfall up to the early 1990s. This also coincides with the period of the great droughts of the 1970s and the 1980s in the region. The annual rainfall started increasing from the mid 1990s to the end of the study period. It is also clear from the results of the linear trend lines that the increase in the annual rainfall yield is predominantly as a result of the increase in June and July rainfall.

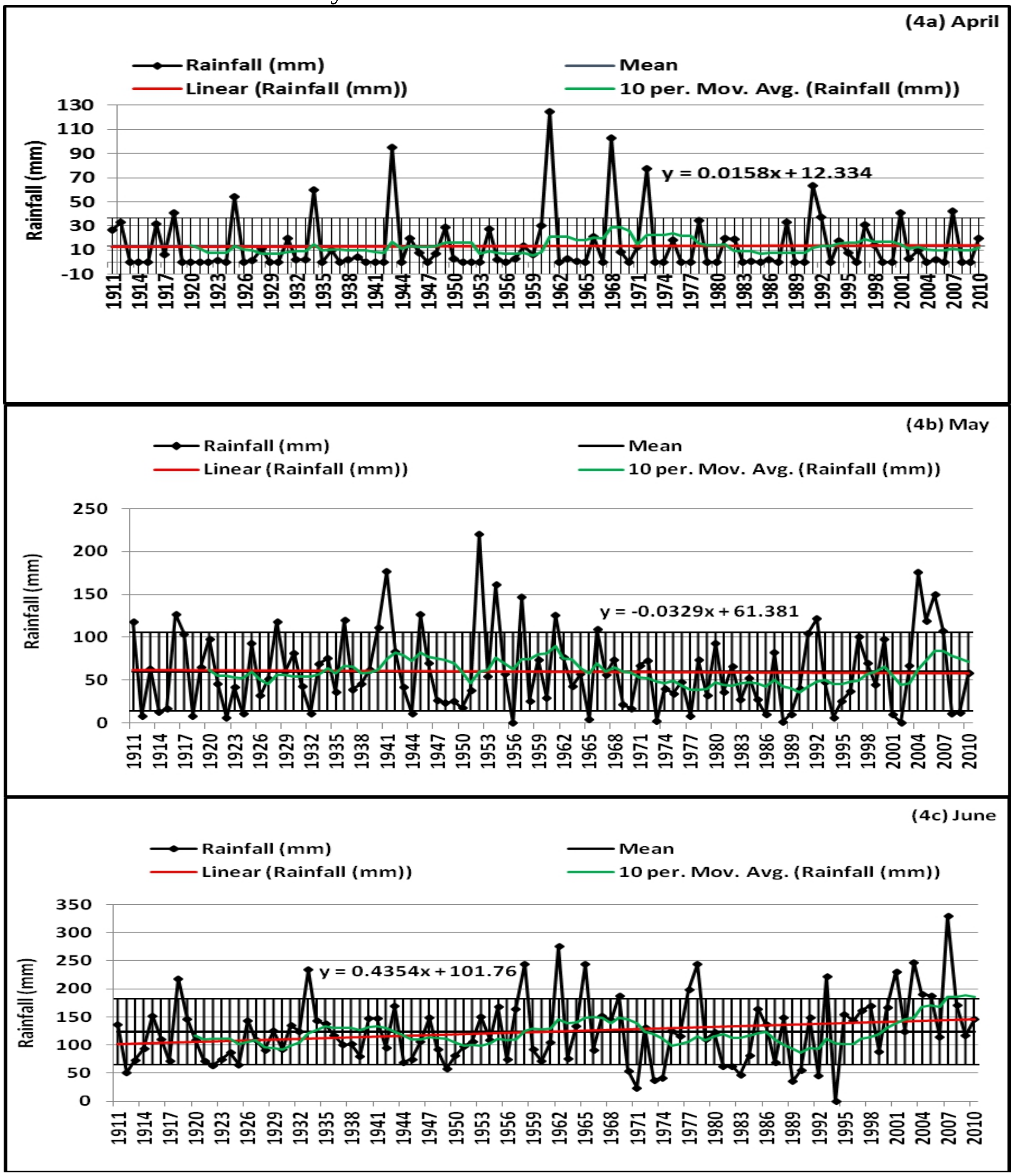


Figure 4. Rainfall Trends and Variability for (a) April; (b) May; (c) June; (d) July; (e) August; (f) September; (g) October; and (h) Annual Totals

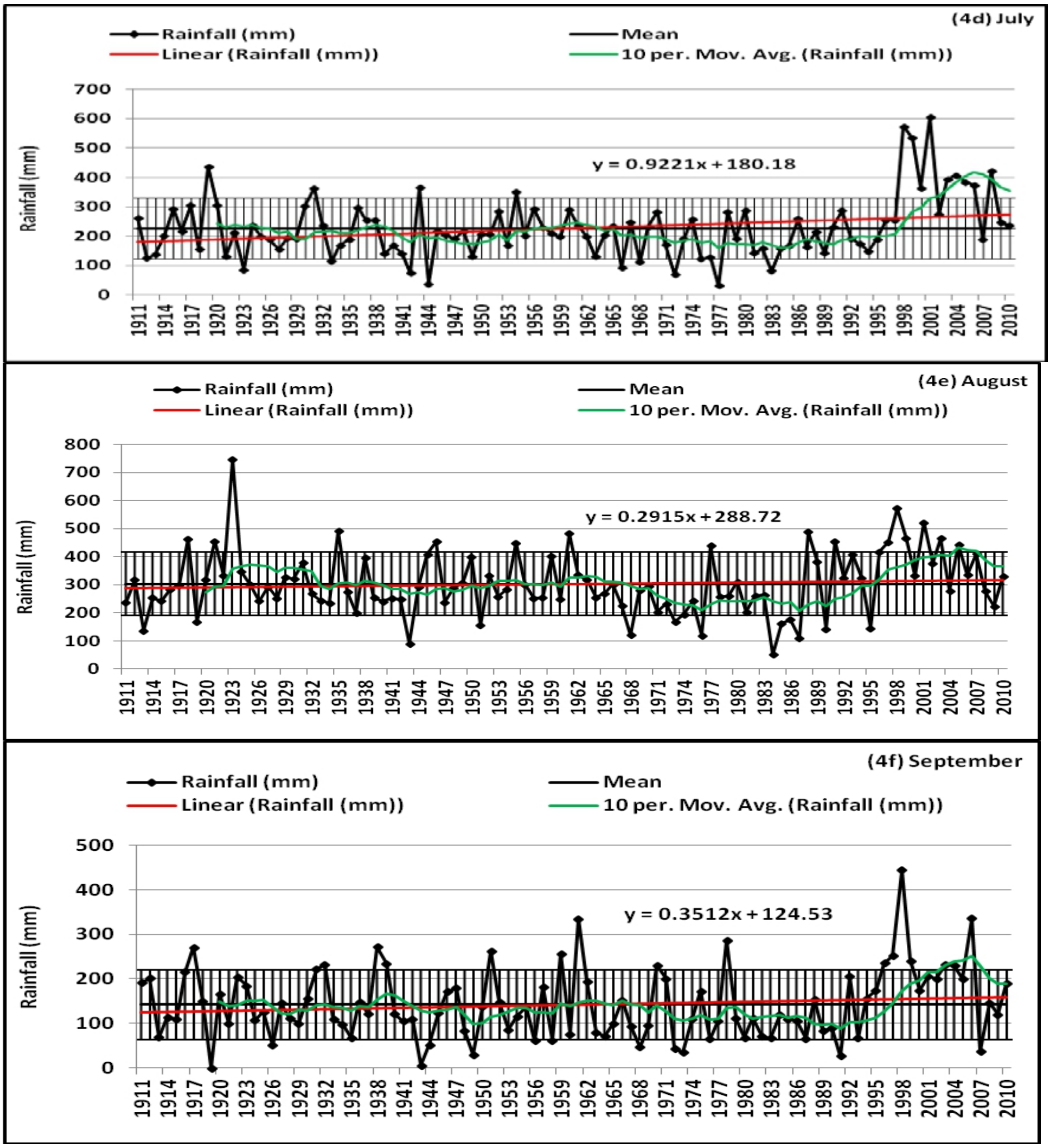


Figure 4 Continued

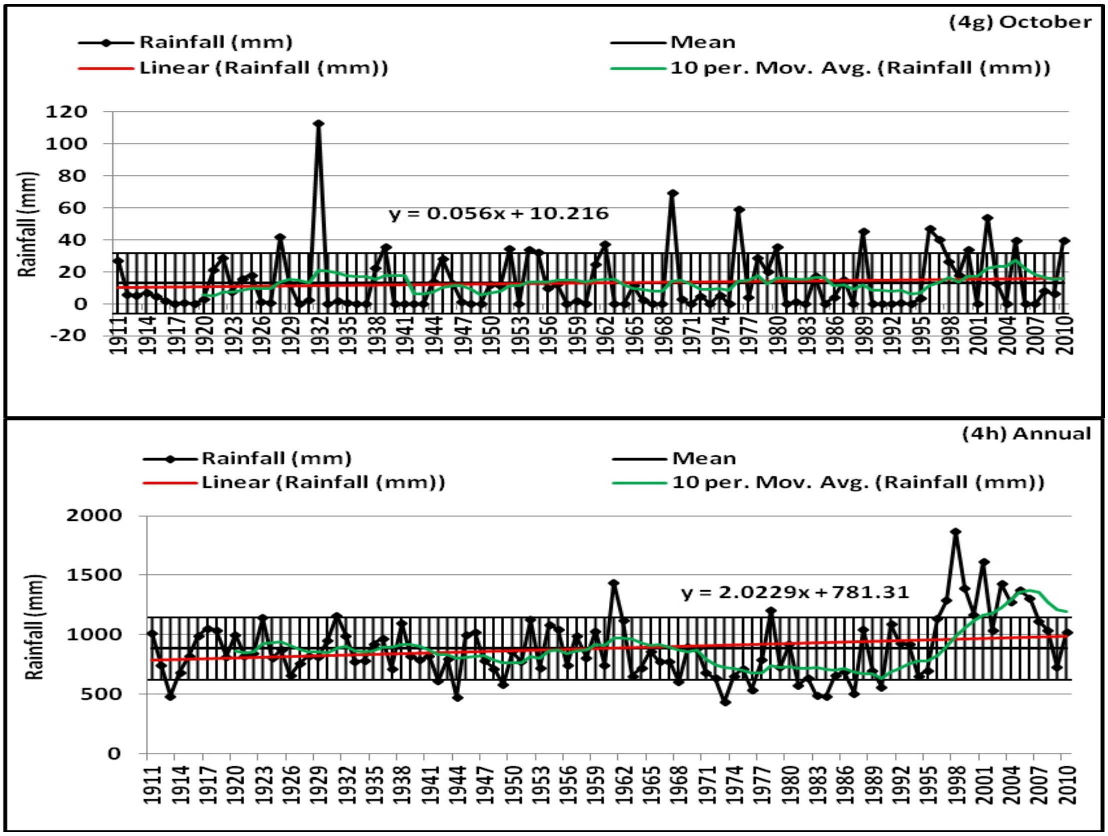


Figure 4 Continued

The plotted standard deviation for the monthly rainfall anomalies (Figure 4a-f) generally shows that years of rainfall above the mean standard deviation were more than below the mean standard deviation from the early 1990s to the end of the study period. The annual rainfall (Figure 4h) shows 24 anomaly years (12 below the mean standard deviation and 12 above it) of the 100 years of study. Out of the 12 years of rainfall below the mean standard deviation, 7 years (1973, 1976, 1981, 1983, 1984, 1987, & 1990) occurred between the decades 1971-1980 and 1981-1990. These years of rainfall below the mean standard deviation coincides with the droughts of the 1970s and 1980s that ravaged the country. On the other hand, out of the 12 years of rainfall above the mean standard deviation, 9 years (1997, 1998, 1999, 2000, 2001, 2003, 2004, 2005, & 2006) occurred between the decades 1991-2000 and 2001-2010. The findings is also in good agreement with the observations made by Ati, Iguisi, and Afolayan (2007), Odekunle, Andrew and Aremu (2008), Ati *et al.* (2008 & 2009), Abaje, Ati and Iguisi (2012a&b) and Abaje *et al.* (2013) that the area has been experiencing decreasing number of dry conditions and consequently, increasing wetness from the 1990s to the recent years. The increasing wetness appears to be accounted for by significant northward shifts in the surface location of the ITD over the country.

Generally, there is a clear indication of an increase in rainfall amounts over time in the study area. It is also clear from the results that the increase in the annual rainfall yield is predominantly as a result of the increase in June, July and August rainfall. The increase in rainfall for these months may be responsible for the frequent occurrence of floods within those months, especially the month of August, with adverse impacts on transport infrastructures which is an indication of climate variability and change.

4.2 Impacts of Increasing Rainfall on Transport Infrastructures

Roads, railways, airport runways, bridges and culverts are examples of the facilities and structures that are required to provide transportation services that enable the movement of passengers and freight. Transport networks are vital to economic and societal development. They are not only constructed to foster trade and the delivery of goods, but also to provide access to basic needs and services such as work, medical, education, etc (Cochran, 2009).

Increasing trends in rainfall totals and the magnitude of flooding events play a major role in driving the impacts of climate variability and change on transport infrastructure, especially the road network which is the largest, fastest-growing and the most heavily used transport infrastructure in the area and Nigeria at large. These impacts depend greatly on the geophysical setting, level of socio-economic development, infrastructure characteristics and other stressors.

Flooding as a result of increased in the amount and intensity of rainfall would therefore pose a threat to the transportation networks in the area. These include localized street-flooding, flood damages to roads and railways system, and in extreme cases, the submerged and collapse of bridges. Increase in the amount and intensity of rainfall will further triggers deterioration of roads pavements causing potholes and loss of surface chips due to high temperature and thus, increase in the number of road accidents in the area.

Increase in rainfall amount will lead to increase ground movement and changes in groundwater would accelerate degradation of materials, structures and foundations of transport infrastructure. The result would be reduction in life expectancy, increased maintenance costs and potential structural failure during extreme events such as flooding.

Increased rainfall may also affect the frequency of land slides and slope failures that could damage road and rail infrastructure and force greater levels of maintenance. This is likely to be most problematic in the mountainous regions of the study area.

The implications on transport infrastructure are that models built on the perceived decreasing rainfall, such as drainages, bridges, etc, have to be reviewed. This will lead to increase burden of the recurrent cost of repair/replacement.

5 Conclusion

This paper has examined the changing rainfall patterns of Kano State using annual and monthly data from the period 1911 to 2010. The impacts resulting from these changes on transport infrastructures were identified. Findings from the 10-year non-overlapping and 30-year overlapping sub-periods analysis (Cramer's test) and the plotted standard deviation for the monthly and annual rainfall revealed that Kano has been experiencing decreasing number of dry conditions and consequently, increasing wetness over the recent years. The increase in the annual rainfall yield in recent periods is predominantly as a result of the increased in the June, July and August rainfall as indicated by the statistically significant wetter conditions of those months. Observations show that flood occurrences which is an indication of climate change corresponded with months of increased in rainfall amount in the area. The 10-year monthly and annual running mean showed that the increasing yield of the rainfall started from the mid 1990s to the end of the study period.

This paper has also highlighted the vulnerability nature of transport infrastructures to extreme weather events especially increasing in amount and intensity of rainfall in the area. This would accelerates deterioration, degradation, damage, and in very extreme conditions, the collapse of infrastructures. The implication is the increase burden of the recurrent cost of repair/replacement.

It is recommended that: 1) policy, standards and design for new and existing infrastructure should ensures that the long-term impacts of extreme weather events are considered; and 2) climate change projections, science and impacts are better understood by those in the planning, investment and asset management for infrastructure so that appropriate measures are incorporated into the decision making process.

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