TIME SERIES ANALYSES OF MEAN MONTHLY RAINFALL FOR DROUGHT MANAGEMENT IN SOKOTO, NIGERIA

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Abstract

This paper analyses the time series characteristics of rainfall data for Sokoto metropolis for 40 years with a view to understanding drought management. Data for this study was obtained from the Nigeria Metrological Agency (NIMET), Sokoto Airport; Sokoto. The data was subjected to time series tests (trend, cycle, seasonal and decomposition analyses) using additive and multiplicative modeling approach. The results showed an increasing trend of rainfall amount over the metropolis within the period under review. Analysis of seasonality in monthly precipitation showed a concentration of rainfall in the months of June, July and August while it decreases in September; however, the months of March, April, and October do experience some showers of rainfall sometimes. Obviously, result of the seasonality analysis showed that January, February, March, April, May, November and December are dry months. This implies that growing season in Sokoto do end around September. The implication is that farmers in the study area need to stream line their farming activities with a view to making effective use of the available rainfall. The paper also suggests a need for building micro dams, developed underground water resources and or adopts conjunctive water management as part of drought management efforts.

Keywords: *Rainfall, seasonality, cycle, decomposition, multiplicative modeling, drought*

Introduction

According to Fidelis (2003) drought refers to protracted deficiency in precipitation. It is an insidious hazard of nature that originated from a deficiency of precipitation over an extended period of time, usually a season or more. In United Kingdom, drought is considered as 15 consecutive days without rains as threshold value, while in USSR drought is considered as 10 consecutive days without rains as threshold value.

Drought has several negative consequences; it causes extensive damages to crops and loss of agricultural produce. Droughts results in water shortage for human activities and the functioning of physical environment. Drought leads to water scarcity due to insufficient precipitation, high evapo-transpiration and over-exploitation of water resources or combination of both (Mosaad, *et al.,* 2009). It is pertinent to note that meteorological drought will eventually trigger other forms of droughts. This is because rainfall as the main input into the hydrological cycle provides water for recharging surface runoff, which in turn serve as a source of water for irrigation and subsequently such water will be required for various socio-economic activities which will in turn create wealth.

Drought has three distinguishing features, namely: intensity, duration and spatial coverage. Intensity is the degree of precipitation shortfall and severity is the impact associated with the shortfall; duration refers temporal patterns, while spatial coverage involves the spread of the affected areas (WMO, 2006). Drought varies in space, time, and intensity. It has been estimated that drought results in annual economic losses of about 86 to 88 billion dollars in the United States (Jesslyn *et al.,* 2002). Accurate monitoring of drought has always been a challenge. This is because drought has neither distinct start nor end (Oladipo, 1985). Extreme drought destroyed food crops, caused famine, animal's death and forced people to migrate in search of means of livelihood (Akeh *et al.,* 1999).

Nigeria is the most populous country in Africa with an estimated population of over 140 million and a total land area of 923,773 km^2 (Odiogor, 2010). It is currently losing about 351,000 ha annually to desert encroachment which is estimated to be advancing southwards at the rate of about 0.6 km per year (Medugu *et al.*, 2009). FGN (1999) and Odiogor, (2010) also reported that Nigeria loses about 351,000 hectares of land every year to desert encroachment a condition which has resulted to demographic displacements in villages in the North. In these same reports, it was estimated

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that Nigeria loses about $5.1billion every year owing to rapid encroachment of desert in most parts of the north, out of which land degradation alone (including desertification and soil erosion) accounts for about 73%. Odiogor (2010) further estimated that over 70 million Nigerians have direct and indirect experiences of the negative impacts of drought and desertification; and that between 50% and 75% of Bauchi, Borno, Gombe, Jigawa, Kano, Katsina, Kebbi, Sokoto, Yobe, and Zamfara States in Nigeria are being affected by desertification. These states, with a population of about 35 million people account for about 35% of the country's total land area. About 42 million people are believed to have been affected by this development. This has led to gradual disappearance of fertile lands and steady decline in food production. There is massive death of persons, cattle and vegetation in Northern Nigeria and other parts of West African countries in 1973-1975, which became an international issue at that time. This condition has forced people in the affected villages to migrate to more favorable areas, thereby creating new settlements where they have to compete with the indigenous population for the scarce resources. In Yobe state sand dunes are encroaching at a rate of 30 hectares a year, taking over villages (Medugu, 2009). Populations in eight local government areas are also under severe threat as surface and underground water sources are gradually drying up. Meanwhile, apart from the frontline states in the north, other parts of the country have also been threatened by the drop of the water level caused by the global climate change. More worrisome is that, seven adjacent states to the south are reported to have about 10% to 15% of their land areas threatened by processes of desertification (Akeh, et. al. 1999; Fidelis, 2013; Medugu, 2009). In Nigeria, population pressure, compounded by consistent influx of migrants from neighboring countries, results in over grazing and continuous over-exploitation of marginal lands. This has in turn aggravated the twin problems of drought and desertification. Villages and major access roads have been buried under sand dunes in Borno, Jigawa, Katsina, Sokoto and Yobe States. The pressure of migrating human and livestock populations from these areas are being absorbed by pressure point buffer states such as Adamawa, Benue, Kaduna, Kwara, Niger, Plateau and Taraba. This condition calls for an understanding of the characteristics of rainfall in the study area. This present study will examine the temporal characteristics of rainfall in Sokoto with a view to assisting agricultural planning.

Study Area

Geographically, Sokoto metropolis (Figure1) lies on the geographical coordinates of 13° 3' 5" North, and 5° 13' 53" East.

The climate is largely influenced by the interactions between two air masses: the tropical maritime air mass from the Atlantic Ocean and the tropical continental air mass from Sahara Desert. The climate is characterized by rapid changes in temperature and humidity. Temperatures are generally high in the months of March-May, with highest recorded mean monthly temperature of about 40°C in April (Ayoade, 2004). The lowest temperatures occur in the months of December and January due to the influence of harmattan. Seasonal rainfall prediction by NIMET (2013) shows that the northern Nigeria region will have a range of mean annual rainfall that is between 300mm-1200m. The relative humidity is very high during rainy season reaching about 65 to 70%.

The vegetation of the study area falls under the Sudan savannah type of classification, with the presence of grasses and shrubs less than one meter in height. The forest vegetation in some parts of the State comprises neem (*Dogonyaro*) and baobab trees (*Kuka*) (Adefolalu, 1990). Most part of the state lies within the Sudan Savanna zone where trees and short grass species of less than one meter co-dominate (Davis 1982 p12).

The study area has two major rivers (Figure 2); River Rima and River Sokoto. The river Rima has it source from Kano, Katsina and neighboring Niger Republic, while river Sokoto has its major source from Katsina state around Funtua and Dan'dume. River Bunsuru and river Gangare are the two major tributaries that flow in a northern direction where they meet and flow in to river Rima (Davis, 1982). The study area lies on a sedimentary formation which is made up of unconsolidated sediments believed to have been formed or deposited in a syncline during the Cretaceous and Tertiary era (Davis, 1982). The relief of Sokoto State is generally plain though interrupted by spot of plateau, sandstone with resistant layer of lateritic material in some parts of the state. The Sokoto plain on the one hand form monotonous lowland derived from softer sedimentary rock with an average height of 300m compared with 700m (Davis, 1982). The study area is characterized by loess and sandy soils. They are formed directly from the

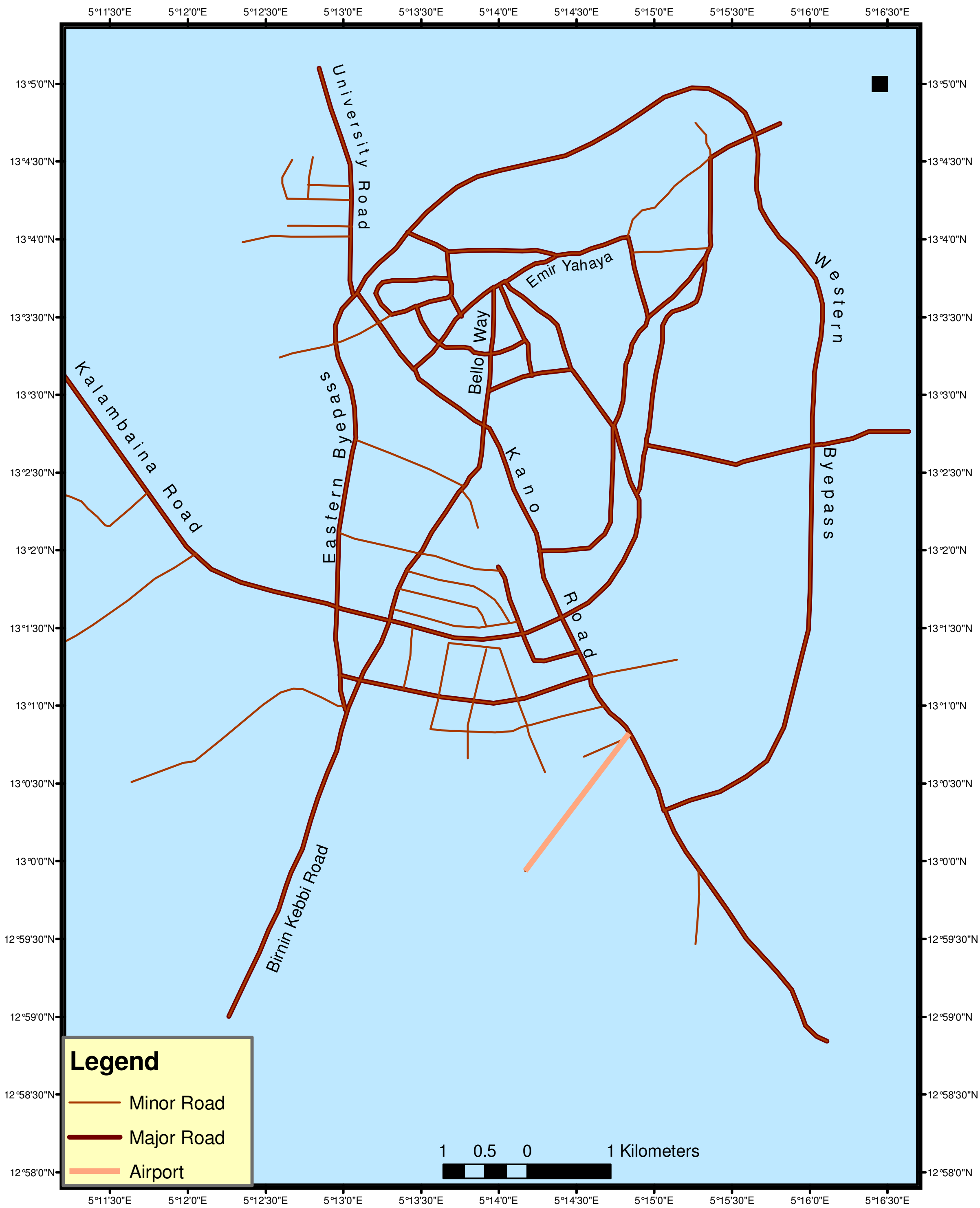

Figure 1 Major Road Network and Street Layout in Sokoto Metropolis, Nigeria

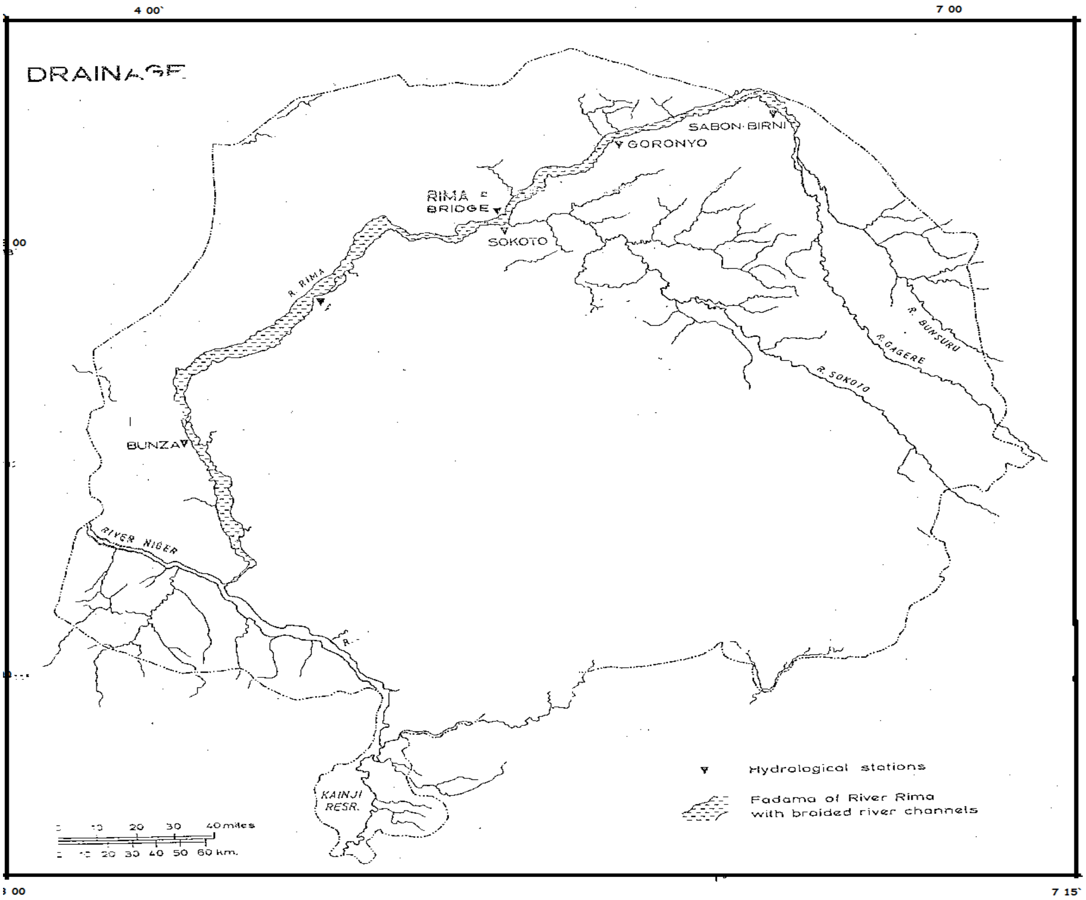

Figure 2 Drainage System of the study area
Source: (Adapted from Davis, 1982)

Methodology

Method of Study

The data required for this work include daily rainfall and rain days for Sokoto over the period of 1970- 2009. Other sets of data are in form of common crops cultivated in the study area. They are mainly data from secondary sources; collected from the Nigerian Meteorological Agency (NIMET); Sultan Abubakar III Airport Sokoto.) Rainfall data collected from NIMET were of daily record of 40 years. The rationale behind 40 year rainfall data is to conform to the World Meteorological Organization standard, which is a stipulated period of 30 to 35 years. According to Raghunat (2006) rain gauge data provide accurate information on rainfall around the immediate vicinity of the instrument.

Time Series Analysis (TSA)

The mean monthly rainfall was estimated by dividing the accumulated rainfall for a month by total number of days it rains in that month using mean equation. and transposed to make a sum of 480 months (40 years).The analysis was carried out using Minitab software.

Decomposition Method was used with additive and multiplicative Model to identified trend cycle and seasonal analysis (ref.). Decomposition modeling was arrived at using equation 1 to 4

Decomposition Model = $Y_t = f(S_t, T_t, E_t)$ Equ …………(1)

Where: =

Y_t = is the times series data value (actual data)

S_t = is the seasonal component

T_t = is the trend cycle component and

E_t = is the irregular component

t = is the time or period

f = is the frequency of the observations

Additive Model = $Y_t = S_t + T_t + E_t$ Equ …………….. (2)

Multiplicative Model = $Y_t = S_t \times T_t \times E_t$ Equ……………… (3)

For Multiplicative decomposition, the seasonally adjusted data are computed by dividing the original observation by the seasonal component.

$$\frac{Y_t}{S_t} = T_t + E_t$$

Seasonally adjusted data = Equ ...…….(4)

The trend line equation is presented as follow.

Linear trend equation = Yt = 5.14675+ 4.40E-30*t …………………equ 6

Coefficient of Variation (C.V)

The inter- annual and inter-decadal variability of rainfall in Sokoto over the period of 1970-2009 were examined using the coefficient of variation. It is defined as follow:

$$C.V = \frac{\sigma}{\bar{x}} \times 100$$ Equ…………..(5)

Where:

$C.V$ = Coefficient of Variation

σ = Standard deviation

$\bar{x}$ = Mean of the Time series

Results and Discussion

Pattern of Mean Monthly rainfall in Sokoto (1970 -2009)

The descriptive statistics of the pattern of mean monthly rainfall in Sokoto (1970-2009) is presented in Table 1. It was observed that highest mean monthly rainfalls were recorded in May 1983, and August 1978 with 44.8mm and 40.7mm respectively. This Table further showed that May 1971 and September 1973 recorded the lowest mean monthly rainfall values of 0.43mm. This trend coincides with the Sudano Sahelian drought of 1970s as noted by several scholars (Motimore, 1989, Olaniran, 2002, and Fidelis 2003). Further analyses, also showed that October rainfall was experienced with the highest mean monthly of 18.5mm in 1978 and 25.0mm in 2009. The lowest values recorded range from 0.43mm (1971) and 1.6mm (2008). This implies that there were late cessation periods of rainfall relevant for planting double season crops. Mean monthly rainfall is relevant to plant water requirement and it also gives insight to the nature of agricultural management in an area.

Table 1 Mean Monthly rainfall in Sokoto (1970-2009)

YEAR	JAN	FEB	MAR	APRIL	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC
1970	0.00	0.00	0.00	0.00	6.97	6.76	24.8	13.4	14.3	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	11.9	8.50	16.6	13.1	0.43	0.00	0.00	0.00
1972	0.00	0.00	0.00	17.5	19.1	13.2	14.6	14.1	9.28	18.4	0.00	0.00
1973	0.00	0.00	0.00	2.05	0.43	9.22	8.12	9.21	11.5	0.00	0.00	0.00
1974	0.00	0.00	0.00	2.00	8.15	1.98	10.1	10.8	8.69	21.4	0.00	0.00
1975	0.00	0.00	0.00	0.60	12.7	10.6	11.4	11.4	9.46	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.30	9.77	10.9	12.3	20.4	15.3	14.3	0.00	0.00
1977	0.00	0.00	0.00	0.00	8.83	9.65	27.2	22.3	8.69	0.00	0.0	0.00
1978	0.00	0.00	0.00	5.05	0.00	17.5	14.9	40.8	12.6	18.5	0.00	0.00
1979	0.00	0.00	0.00	0.00	3.70	11.4	14.3	18.9	9.50	0.00	8.90	0.00
1980	0.00	0.00	0.00	7.20	29.7	19.2	11.8	12.1	9.83	6.80	0.00	0.00
1981	0.00	0.00	0.00	0.00	16.9	14.4	14.9	12.1	8.47	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	6.00	12.8	16.1	18.7	25.5	4.90	0.00	0.00
1983	0.00	0.00	0.00	0.00	44.7	30.7	28.6	11.7	9.54	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	15.8	17.6	15.8	11.5	0.00	0.00	0.00
1985	0.00	0.00	0.00	20.5	16.7	13.1	9.15	12.7	10.2	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	12.1	18.2	15.1	12.7	12.7	0.00	0.00	0.00
1987	0.00	0.00	31.0	0.00	2.25	7.01	7.81	21.5	8.97	12.8	0.00	0.00
1988	0.00	0.00	0.00	2.90	0.00	13.4	18.5	13.6	18.8	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	8.90	13.1	8.84	7.62	7.50	8.30	0.00	0.00
1990	0.00	0.00	0.00	0.00	13.3	10.3	23.2	10.9	11.8	0.00	0.00	0.00
1991	0.00	2.80	10.2	6.10	16.3	14.6	13.3	13.2	8.53	4.03	0.00	0.00
1992	0.00	0.00	0.00	0.00	9.73	12.3	12.6	11.0	20.6	0.00	0.00	0.00
1993	0.00	0.00	0.00	5.00	27.4	9.93	15.8	19.9	9.98	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	7.40	14.9	19.8	15.5	5.50	0.00	0.00
1995	0.00	0.00	0.00	2.70	5.93	5.80	15.4	10.7	9.13	2.40	0.00	0.00
1996	0.00	0.00	0.00	0.00	9.57	23.5	17.3	12.9	10.3	7.55	0.00	0.00
1997	0.00	0.00	2.80	1.80	15.7	21.8	12.5	14.6	5.25	5.43	0.00	0.00
1998	0.00	0.00	0.00	10.0	1.70	9.86	13.9	13.1	34.1	1.70	0.00	0.00

1999	0.00	0.00	0.00	0.00	9.00	10.6	9.58	20.6	11.2	7.60	0.00	0.00
2000	0.00	0.00	0.00	0.00	6.23	11.9	32.9	19.9	9.11	8.10	0.00	0.00
2001	0.00	0.00	0.00	0.00	11.4	5.11	14.8	12.9	13.8	0.00	0.00	0.00
2002	0.00	0.00	0.00	1 6.7	8.42	18.9	19.0	13.2	17.3	10.1	0.00	0.00
2003	0.00	0.00	0.00	9.20	5.83	14.0	23.9	22.2	20.8	2.95	0.00	0.00
2004	0.00	0.00	0.00	10.0	19.3	11.4	13.1	18.1	8.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	11.9	26.9	12.7	18.2	13.2	12.7	5.20	0.00	0.00
2006	0.00	0.00	0.00	0.00	4.80	10.1	12.3	16.9	15.5	14.9	0.00	0.00
2007	0.00	0.00	0.00	3.30	15.2	13.1	18.3	13.6	9.91	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.70	8.10	11.6	20.9	8.14	10.4	1.60	0.00	0.00
2009	0.00	0.00	0.00	2.70	21.5	17.1	24.4	13.2	14.4	25.0	0.00	0.00

Trend in Mean Monthly Rainfall in Sokoto (1970-2009)

The result of the mean monthly rainfall for 40 years (1970-2009) was subjected to time series analysis. The result shows slight level of variation especially in the monthly mean rainfall between 1970-2009 (Figure 3). The result of time series analysis indicates that Mean Absolute Percentage Error (MAPE) is 181.173, Mean Absolute Deviation (MAD) is 6.706 and the Mean Square Deviation (MSD) is 63.015. The MAPE, MAD, MSD values measures the accuracy level for the time series.

The above equation implies that slight increase has been recorded in monthly values of rainfall in the period under study. Thus the mean monthly rainfall in Sokoto suggests that the rainfall has been increasing on monthly basis. Indeed equation 6 shows that for every 5.1mm monthly mean in Sokoto, rainfall will increase by 0.0044mm. The trend suggests an increase in rainfall in the near future, which is an evidence of climate change as predicted by NIMET (2011).

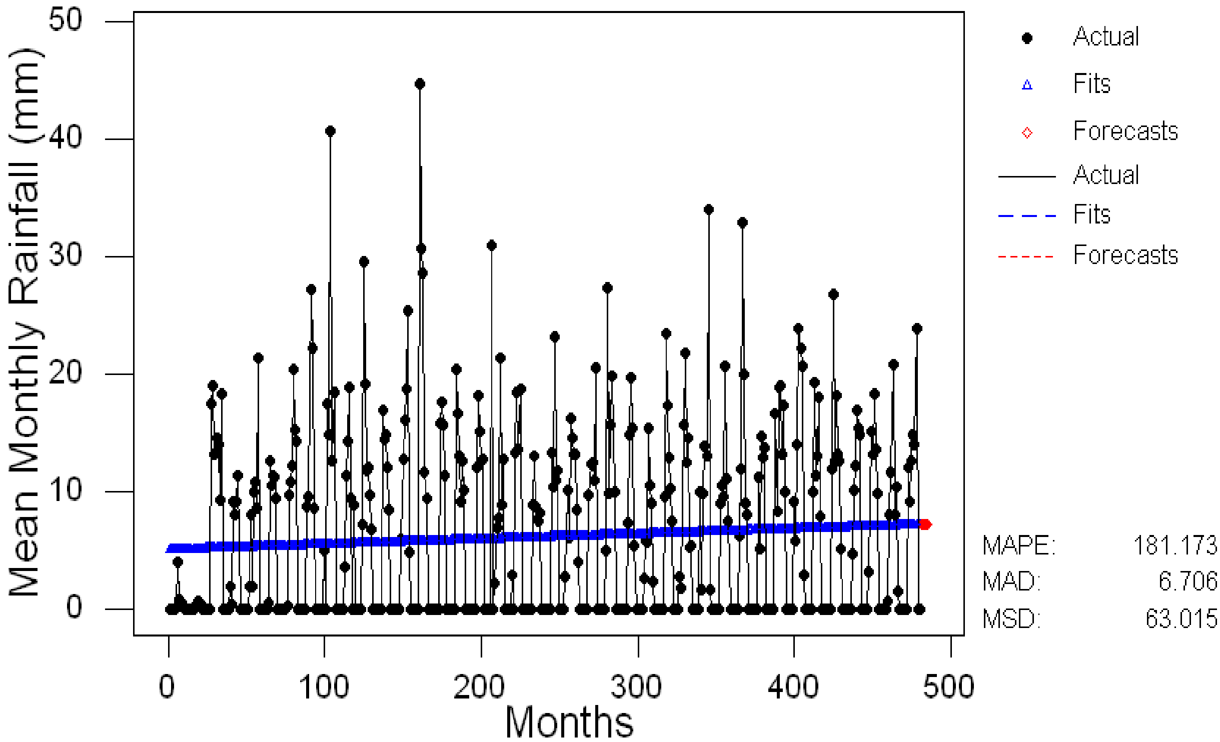

Figure 3 Trend Analysis for Mean Monthly Rainfall.

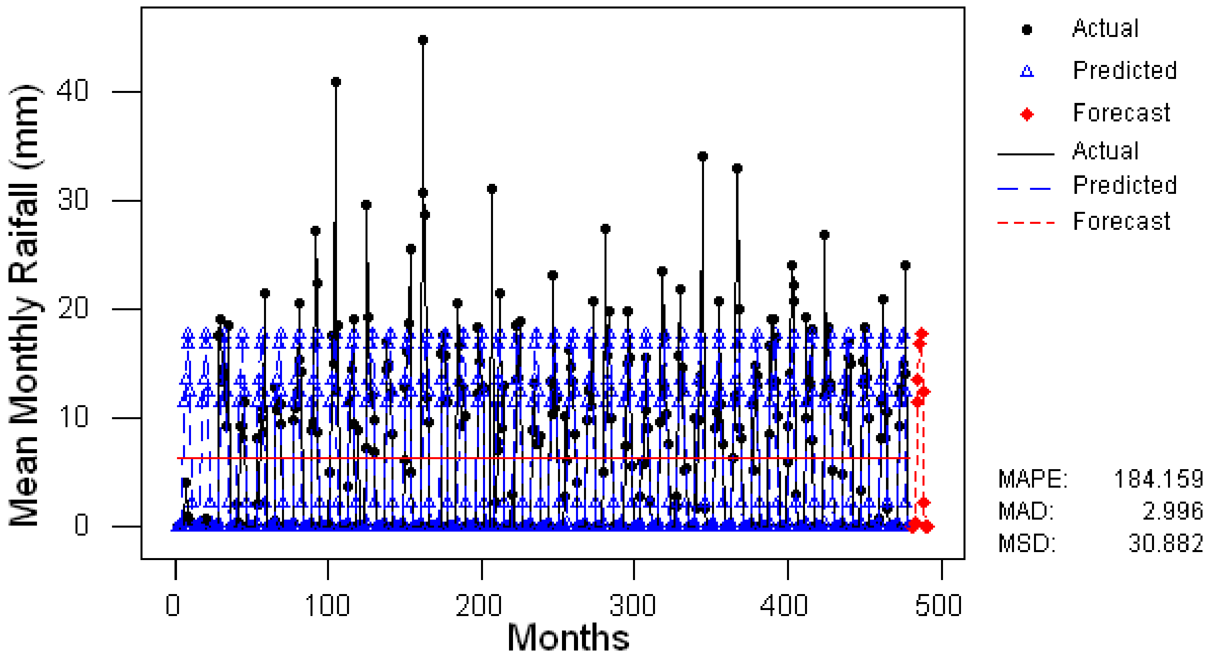

Figure 4 Decomposition of Trend with Multiplicative Model

Further analysis of the trend is presented in Figure 4 and 5 in a multiplicative and additive model. The measures of accuracy for the multiplicative model (Figure 4) are presented as follows: Mean Absolute Percentage Error (MAEP) of 184.159, Mean Absolute Deviation (MAD) of 2.996 and Mean Square Deviation (MSD) of 30.882. The results of additive model are: MAEP 187.569, MAD 3.194, and MSD 38.755 (Figure 5). The MAEP, MAD, MSD measures the accuracy of the models. It was observed that the multiplicative model has measures of accuracy value lower than the additive model and suggesting that the multiplicative model is a better method for prediction.

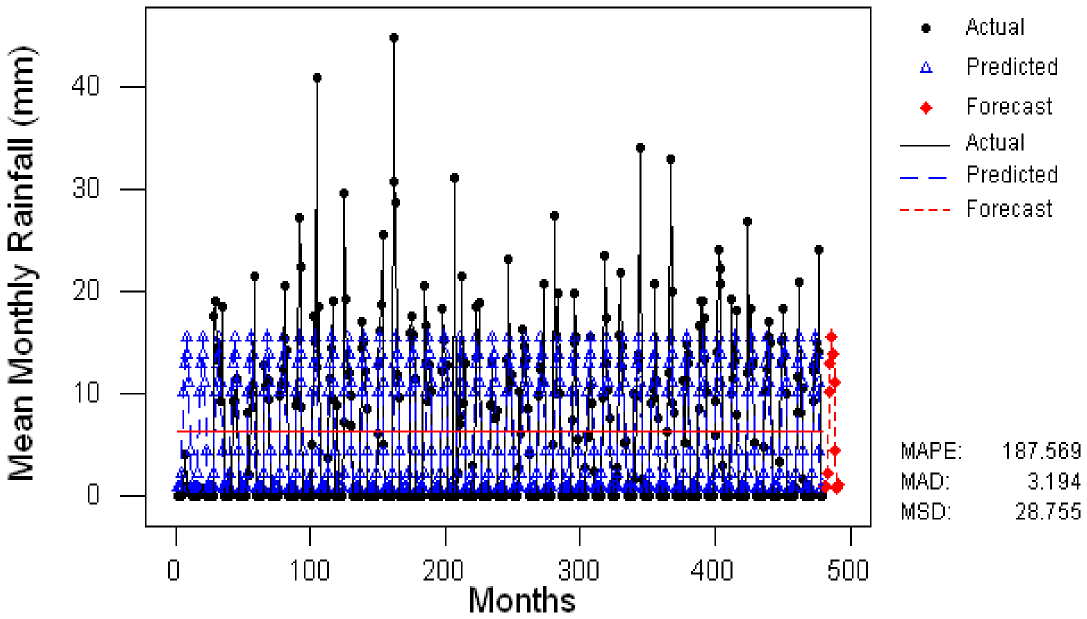

Figure 5 Decomposition of Trend with Additive Model

The essence of decomposition is for separation of the time series characteristics into its component parts. A complete decomposition separates the time series into four, when the trend has been removed the result is called deseasonalized or seasonally-adjusted data.This analysis clearly indicates the pattern of trend analysis of mean monthly rainfall after the trend line has been removed. Figure 6: indicates original data, seasonally adjusted data, detrended data and combined seasonally adjusted and detrended data.

Analysis of seasonality in monthly precipitation showed a concentration of rainfall in the months of June, July, and August and it decreases in September (Table 1). These have been characterised by Omogbi (2010) as a one rainfall season formed in northern Nigeria.

However months of March, April, and October recorded rainfall in some years as indicated in Table 1. In February 1991 mean monthly rainfall of 2.8mm was recorded in Sokoto. In November 1979, 8.9mm was recorded. The result of the seasonal analysis showed, January, February, March, April, May, November and December as dry months. This implies that growing season in Sokoto do end around September. The implication is that farmers in the study area need to stream line their farming activities with a view to making effective use of the available rainfall for efficient agricultural practices.

The result of Seasonal indices is presented Figure 7. This result shows the patterns of dry and wet season in Sokoto, it shows high variation in January, February, May, November, and December. These months have low seasonality indices, suggesting intense drought, which mark a period of acute water shortage (Table 2).

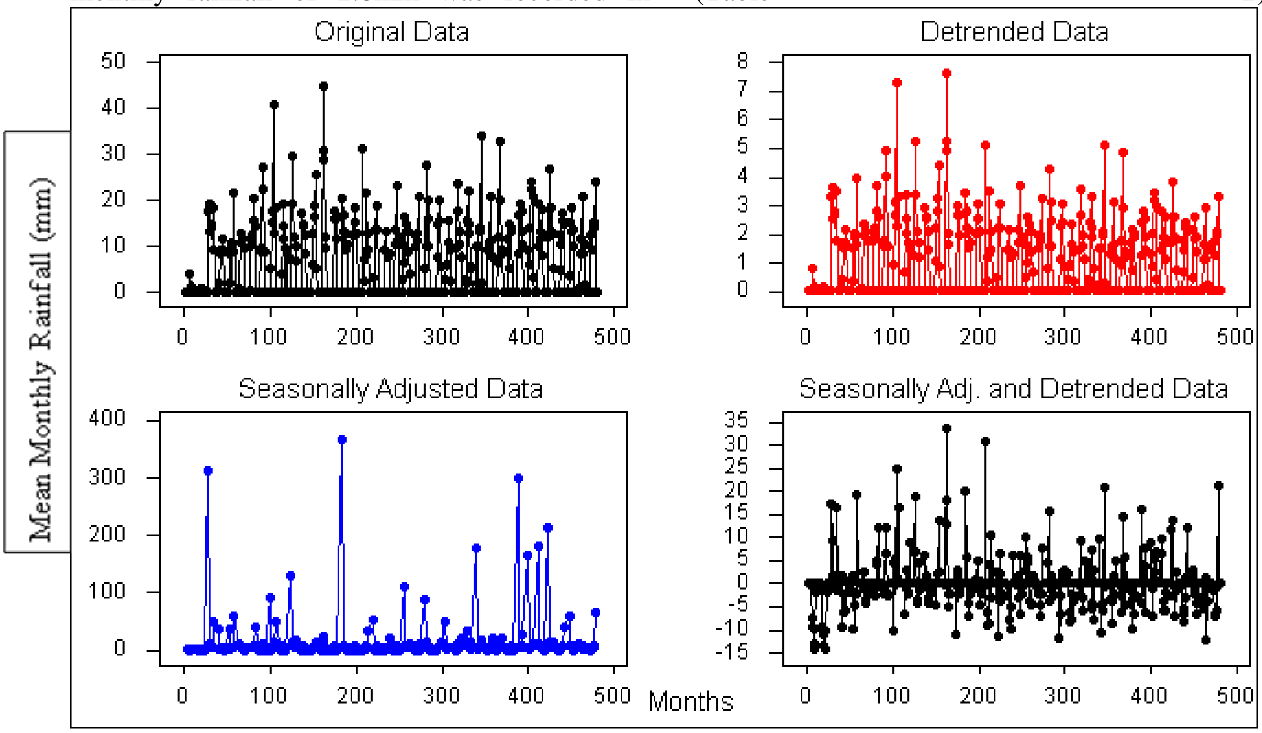

Figure 6 Component Analysis of Decomposition for Mean Monthly.

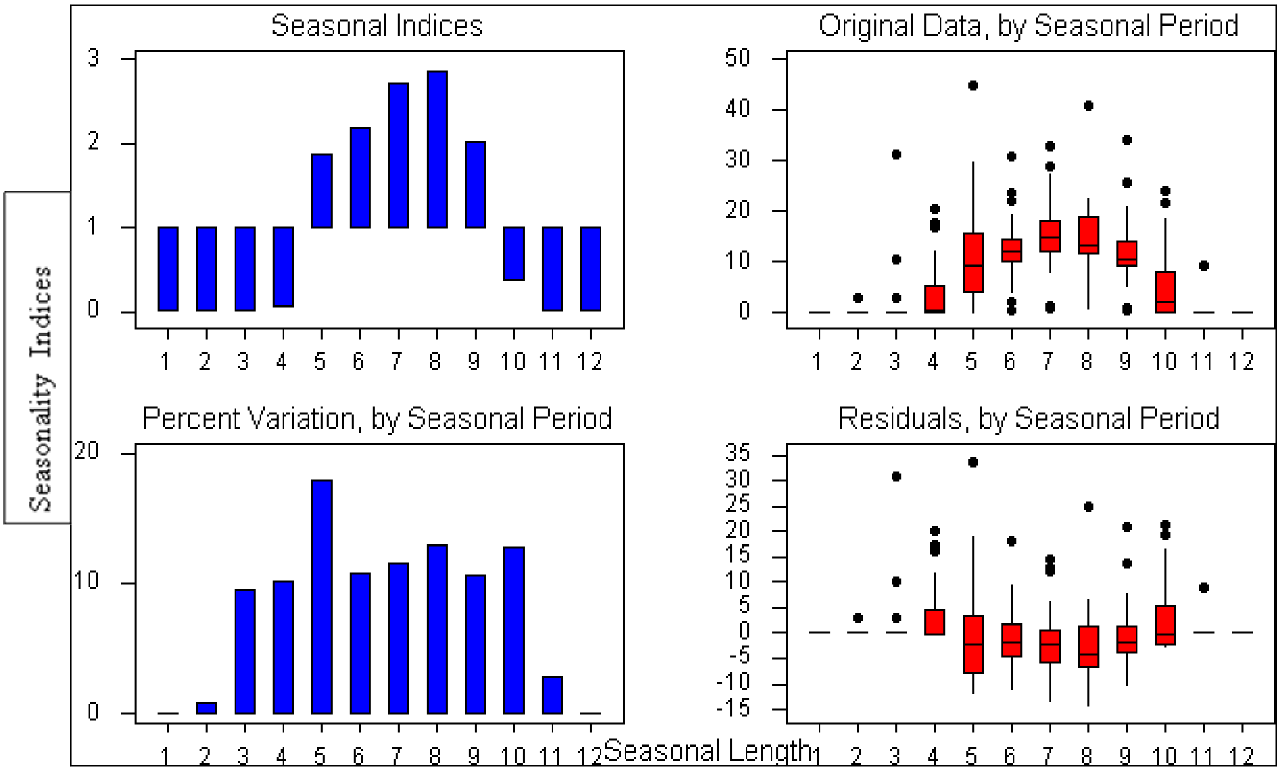

Figure 7 Seasonal Analysis of Mean Monthly Rainfall.

Table 2 Seasonal Indices

	Seasonal Period	Index
i.	January	0.00000
ii.	February	0.00000
iii.	March	0.00000
iv.	April	0.00000
v.	May	0.05561
vi.	June	1.85657
vii.	July	2.17278
viii.	August	2.70266
ix.	September	2.84347
x.	October	2.00121
xi.	November	0.36771
xii.	December	0.00000

Implication to Drought Management

The paper predict increasing rainfall trend in Sokoto metropolis. The increasing trend agrees with the recent NIMET prediction of increasing rainfall trend for northern Nigeria. This increasing trend has culminated into floods in the region. A case in point is the 2010 flooding events in Sokoto and the entire Rima basin, which claimed lives and properties.

The result of the seasonal analysis showed, January, February, March, April, May, November and December as dry months. This implies that growing season in Sokoto do end around September. The implication is that farmers in the study area need to stream line their farming activities with a view to making effective use of the available rainfall for efficient agricultural practices.

According to the result presented in this study, the excess water of 5 months rainy season (May to September) could be better utilized by developing new irrigation dams, particularly micro irrigation schemes, in many sections of the Rima water course. These dams should be designed to take into cognizance the high rate evaporation in the region. For example, they should be deep and should have smaller surface areas. Micro dams will be appropriate in the Sokoto environment because of their numerous advantages over the largely underutilized large dams which are common in the study area.

Meanwhile, during the 7 months of dry season (October to April), dry farming should be encouraged. This would only be sustained in the face of appropriate government incentives on appropriate farm inputs, water pump subsidy programme, fair access to fertilizers, storage and preservation facilities, among others.

For the purposes of potable water supply in the period of dry season, a bigger reservoir will be required to store excess water of the rainy season. This could be done by increasing the dam size and by constructing more underground reservoirs in strategic areas of the metropolis. These reservoirs will be for strategic use in the 7 months of dry season. In addition, conjunctive water use approach is recommended, whereby the vast groundwater resources of the Sokoto basin will be used simultaneously with the surface water resources of the River Rima.

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