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# Rainfall Trends in the Niger-South Basin, Nigeria, 1948-2008

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## ABSTRACT

Understanding rainfall trend can be a first step in the planning and management of water resources especially at the basin scale. In this study, standard tests are used to examine rainfall trends based on monthly, seasonal and mean annual series at the Niger-South Basin, Nigeria, between 1948 and 2008. Rainfall variability index showed that the decade 2000s was the driest (-2.1), while 1950s was the wettest (+0.8), with the decade 1980s being the driest in the second half of the last century, whereas the year 1983 was the driest throughout the series. Over the entire basin, rainfall variability was generally low, but higher intra-monthly than inter-annually. Annual rainfall was dominated by August, contributing about 15%, while December contributed the least (0.7%). On a seasonal scale, July-August-September (JJA) contributed over 40% of the annual rainfall, while rainfall was lowest during December-January-February (DJF) (4.5%). The entire basin displayed negative trends but only 15% indicated significant changes ($\alpha < 0.1$), while the magnitudes of change varied between -3.75 and -0.25 mm/yr. Similarly, only JJA exhibited insignificant upward trend, while the rest showed negative trends. About eight months of the year showed reducing trends, but only January trend was significant. Annual downward trend was generally observed in the series. The trend during 1948–1977 was negative, but it was positive for the 1978–2008 period. Hence, water resources management planning may require construction of water storage facilities to reduce summer flooding and prevent possible future water scarcity in the basin.

*Keywords*: Rainfall, trend analysis, statistical tests, variability index, Niger-South Basin

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## INTRODUCTION

Adequate understanding of the behaviour of climate variables is important in climate research and agricultural water resources management given that climate change is now one of the most debated environmental issues all over the world. This is especially so at basins where the phenomenon of climate changes has the potential to confound water resources planners and make management of resources a herculean task. However, despite the diversity of the field of climate change, change in rainfall pattern has received serious and systematic attention as an area within this field, owing to its impacts on both the availability of freshwater and food production (Dore, 2005). According to Oguntunde et al. (2011), detecting trends in rainfall time series provides vital information for the understanding of climate. Hence, detection of trends in rainfall becomes an important study capable of giving a clear direction of change in future climate in basins, apart from providing crucial information useful in planning and designing regional water resources management (Karpouzos et al., 2010).

Many studies have been carried out in different parts of the world to assess the impacts of climate change on hydro-meteorological processes. However, trend analyses provide the first step towards blaming such changes on factors such as variability, greenhouse gases and changes in the municipal environment (Blake et al., 2011). Meanwhile, studies of time series data across the globe have shown either decreasing or increasing rainfall trend (Mondal et al., 2012). In Europe, for example, Brunetti et al. (2006) studied the trend in Italian long precipitation records and reported a strong decreasing trend, with a decrease in rainfall of about 135 mm in the southern regions over the last 50 years. However, a study by Janssen (2013) over the contiguous United States detected an increasing trend in precipitation with variation among seven sub-regions in the area. Zhang et al. (2011) also observed significantly increasing precipitation trends over Canada since 1950 in the majority of stations used for their study; trend toward increasing precipitation was in addition to the rises in the amount of extreme daily precipitation during the growing season.

Meanwhile, mixed results have also been obtained by scientists in China and other parts of Asia. Zhao et al. (2008) studied monotonic trends and abrupt changes for major climatic variables in the headwater catchment of Yellow River basin, China, and observed an insignificant trend in annual precipitation, though a dry tendency was also detected. In a related study in China by Yang et al. (2012), a not so obvious downward trend in annual precipitation, with large decreases in summer, was observed. However, there was a strong continuity in the annual mean precipitation series in the basin, indicating a similar trend between the future and the past. In India, Kumar et al. (2010) studied the trend in rainfall data for the period 1871-2005 and found insignificant trend for monthly, seasonal and annual series over the entire landscape. While both monsoon and annual rainfall reduced, there was increased pre-monsoon, post-monsoon and winter rainfall over the years, with the highest increase in the pre-monsoon season. Meanwhile, there was a reduction in rainfall during the monsoon months of June, July and September, while August revealed an upward trend.

Studies which dealt with spatial and temporal rainfall trend and variability are not many within Africa, especially in the West Africa sub-region. However, in the context of Nigeria, diverse results have been documented by many researchers (see for instance, Ikhile, 2007; Abaje et al., 2010; Salami et al., 2014), depending on the geographical zone and the temporal scale covered. Many of the studies have also reported extreme weather events like floods and droughts, attributable to the current climate change. Nonetheless, Oguntunde et al. (2011) found a decrease in rainfall that was significant over the last three decades of the previous century, with a spatial distribution that was highly dependent on latitude. Granted that the foregoing study dealt broadly on the trend of rainfall over the country, but given the geographical spread of Nigeria, analysis of rainfall trend within a specific geographical zone can be a valuable effort. Again, the study was limited to the last century even as IPCC (2007) has predicted increased drying for the 21$^{st}$ century. In addition, recent flood events within the present study area have attracted the attention of both local and foreign experts, considering the attendant human and material losses. Thus, to confirm if this is due to climate change or human activities and for the purpose of planning, further investigation is needed. Therefore, the aim of the study is to detect the trend of rainfall in the Niger-South Basin, Nigeria.

## THE STUDY AREA

The Niger-South Basin (NSB), located in Nigeria between Latitudes 5.8° – 8.0° N and Longitudes 6.0° – 7.8° E, has a total area of about 26,324 km$^2$. It is the last part of the Niger River Basin (NRB) before its final exit to the Atlantic Ocean and falls within the Nigerian Hydrological Area V, excluding the Niger Delta (Figure 1). The basin covers three Nigerian agro-ecological zones, namely, Tall grass Savanna, Rain forest and Fresh water swamp, but with the greater part in the rainforest. The climate of the area is highly influenced by three major wind currents; the tropical maritime (MT) air mass, the tropical continental (CT) air mass and the equatorial easterlies (Ojo, 1977). The onset of rainfall is usually around March/April, attaining its highest between July and September and finally ceases in November/December. Mean annual rainfall ranges between 1000 mm and 2000 mm with a maximum temperature of 37.9 °C, and a relative humidity of 60%. Since the early 1990s, both environmental and hydrological processes in the area have been severely altered by anthropogenic factors, which amongst others include urbanisation, river dredging and road constructions. Recently, devastating floods of high magnitudes have been experienced in the area which many have attributed to climate and perhaps, rapid changes in land use. The population of the people living under the basin is about 12.9 million (NPC, 2006), while their major means of livelihood is agriculture, including fish farming with maize and other grain crops being the dominant products. There are about 20 dams of different sizes constructed for various purposes within the study area and the possibilities of additional ones in future as the population continues to rise and demands for water for different purposes increase.

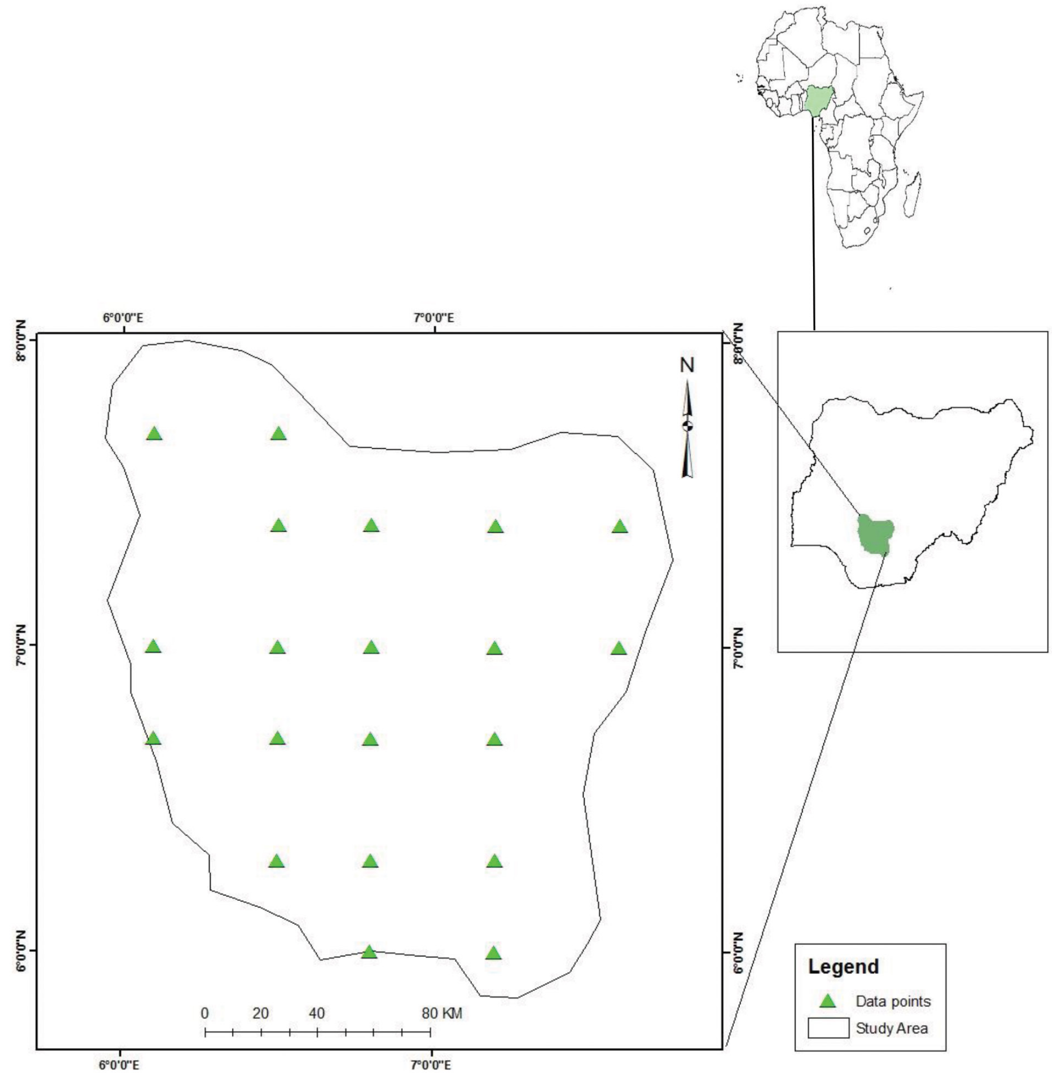



*Figure 1.* Location of the Niger-South Basin in Nigeria and Africa with the data points used for the study

## MATERIALS AND METHODS

Rainfall data for this study were acquired from Global Gridded Climatology (CRU TS 2.1) obtainable at a new high resolution and made available by the Climate Impacts LINK project, Climate Research Unit, University of East Anglia, Norwich, UK (Mitchell & Jones, 2005). The Climatic Research Unit (CRU) data set comprises of monthly 0.5$^{o}$ latitude/longitude gridded series of climatic parameters over the periods of 1901-2008. There is a general poor coverage of meteorological stations in Africa, therefore full information on quality control and interpretation of CRU data are available in related publications (e.g., New et al., 2000; Conway et al., 2009). Kahya and Kalayci (2004) argued that a time series of 30-year is long enough for the evaluation of climatic trend so as to arrive at any realistic conclusion. In this regard, the use of 61-year data (1948-2008) for this analysis is assumed to be long enough to arrive at a realistic conclusion for the present study. The characteristics of the data points used in terms of spatial spread are presented in Table 1.

Table 1
*Description of the dataset*

| Grid no | Code | Latitude | Longitude | Altitude (m) |
|---|---|---|---|---|
| 1 | Prec_47 | 6.0 | 6.8 | 28.32 |
| 2 | Prec_48 | 6.0 | 7.2 | 113.51 |
| 3 | Prec_59 | 6.3 | 6.5 | 257.73 |
| 4 | Prec_60 | 6.3 | 6.8 | 23.89 |
| 5 | Prec_61 | 6.3 | 7.2 | 42.40 |
| 6 | Prec_77 | 6.7 | 6.1 | 331.07 |
| 7 | Prec_78 | 6.7 | 6.5 | 138.45 |
| 8 | Prec_79 | 6.7 | 6.8 | 26.02 |
| 9 | Prec_80 | 6.7 | 7.2 | 221.51 |
| 10 | Prec_97 | 7.0 | 6.1 | 178.28 |
| 11 | Prec_98 | 7.0 | 6.5 | 51.99 |
| 12 | Prec_99 | 7.0 | 6.8 | 32.53 |
| 13 | Prec_100 | 7.0 | 7.2 | 129.47 |
| 14 | Prec_101 | 7.0 | 7.6 | 395.86 |
| 15 | Prec_123 | 7.4 | 6.5 | 186.08 |
| 16 | Prec_124 | 7.4 | 6.8 | 92.91 |
| 17 | Prec_125 | 7.4 | 7.2 | 285.14 |
| 18 | Prec_126 | 7.4 | 7.6 | 396.98 |
| 19 | Prec_148 | 7.7 | 6.1 | 431.29 |
| 20 | Prec_149 | 7.7 | 6.5 | 145.32 |

## DATA ANALYSIS

### Exploratory Data Analysis and Descriptive Statistics

The use of exploratory data analysis (EDA) can help in gaining an insight into the direction and pattern of change in hydro-climatic variables. Aside the formal mathematical methods, it is often included in comprehensive trend detection (Anghileri et al., 2014). EDA refers to any technique of data analysis besides formal statistical methods. It uses graphical tools such as time series plots and scatter plots, and it is aimed at better understanding of the available data and underlying processes. In addition, simple descriptive statistics like the mean, range, standard deviation (SD), coefficient of variation (CV) and determination of maximum and minimum values are also employed to gain preliminary understanding of the data.

## Rainfall Variability Index

Rainfall index is normally calculated as the standardised precipitation departure and it provides the metric to classify the rainfall time series into various climatic regimes such as very dry climatic year, normal climatic year and wet or very wet climatic years. Rainfall variability index was computed as:

$$\delta_i = (P_i - \mu)/\sigma \quad [1]$$

where, $\delta_i$ is rainfall variability index for year $i$, $P_i$ is annual rainfall for year $i$, $\mu$ and $\sigma$ are the mean annual rainfall and standard deviation for the period between 1948 and 2008. According to World Meteorological Organisation (WMO, 1975), rainfall time series can be grouped into different climatic regimes as indicated below.

$P < \mu - 2.\sigma$ – extremely dry

$\mu - 2.\sigma < P < \mu - \sigma$ – dry

$\mu - \sigma < P < \mu + \sigma$ – normal

$P > \mu + \sigma$ – wet

## Trend Analysis

The rank-based non-parametric Mann–Kendall (M-K) test (Mann, 1945; Kendall, 1975) has been widely used to assess the significance of monotonic trends in hydro-meteorological time series. The use of M-K test has also been suggested for detecting trends in climatic data by WMO (1988). It is preferred over other techniques because of its benefits which include (1) ability to handle non-normality, outliers and missing values in series or seasonality, and (2) its high asymptotic efficiency (Fu et al., 2004). Therefore, the M-K test is used in this study. For the estimation of an existing trend slope, the Sen's non-parametric method, which has been widely commended for its strength (Salmi et al., 2002; Kahya & Kalayci, 2004; Zhao et al., 2008; Gocic & Trajkovic, 2013a), is used and further detail can be found in Xu et al. (2007).

## Trend free pre-whitening

A major requirement of the Mann-Kendall (M–K) test is that time series should be without serial correlation. If serial correlation is positively significant, the strength of M–K is hampered and thus leads to uncertainty. In order to remove or reduce this effect, it is suggested that the original dataset be pre-whitened before applying the M–K test (Abdul Aziz & Burn, 2006). The procedure has been well-documented in Kumar et al. (2010) and many other authors. The final (or pre-whitened) series is then subjected to the M–K test to detect the presence of trend.

### Change Point Detection

First, we plotted the residual mass curve, a statistical technique that is widely used in the studies of climatic variations. It is a plot of cumulative deviations from a given reference such as mean, against time or date. In addition, detection of abrupt change point in the series was done using the cumulative sum (CUSUM) technique. The change points in the rainfall series for monthly, seasonal and annual time scales were detected following Kiely (1999), as follows:

$$S_i = \sum_{i=1}^{N} (y_i - \bar{y}) \quad [2]$$

where, $\bar{y}$ is the average value of the time series. With this, possible change has occurred when $S_i$ is at the maximum. When the CUSUM chart follows a fairly straight line, it signals a period during which the average does not change, whereas an abrupt shift in the average is indicated by an abrupt change in the direction of the CUSUM (Gocic & Trajkovic, 2013a).

## RESULTS AND DISCUSSION

### Summary of EDA and Descriptive Statistics

The scatter plots of the annual and seasonal series showed the evolution of rainfall over the entire basin for the whole period of study (Figure 2). A visual inspection of the plots shows a decreasing mean annual rainfall. Similarly, on the basis of four season's classification-December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON) - except for JJA which exhibited marginal increase, rainfall declined in all other seasons. However, the rate of decrease was highest in annual series followed by SON, MAM and DJF, respectively.

A summary of the descriptive statistics computed for the long-term (temporal) series is presented in Table 2. Mean annual rainfall varied from 1418.3 mm/yr to 2108.0 mm/yr, while the mean for the entire basin was 1719.2 mm/yr. Similarly, standard deviation (SD) ranged between 162.7 and 286.7mm/yr, with basin-wide SD obtained as 198.0 mm/yr. Maximum and minimum rainfall ranges were 1806.9-2235.0 mm/yr and 1038.4-1207.0 mm/yr, respectively, while the maximum and minimum rainfall for the entire basin were 1255.2 and 2199.5 mm/yr, respectively. For the coefficient of variation (CV), the highest was 15.2%, while the lowest was 11.5%, with the basin-wide CV of 11.5%. This shows that rainfall variability was relatively low within the basin. Similar statistics computed on annual and monthly bases are shown in

Table 3. The minimum rainfall of 0.0 mm/yr was received in December and January, while the maximum rainfall of 461.4 mm/yr was received in August. However, annual minimum and maximum were 1255.2 and 2202.4 mm/yr, respectively. Mean rainfall was highest in August (263.4 mm/yr) and lowest in December (11.2 mm/yr), while the annual mean was 1719.8 mm/yr. SD was highest in July (70.4 mm/yr) and lowest in December (21.5 mm/yr), with the annual SD obtained as 200.7 mm/yr; CV was highest in December (192.9%) and lowest in June (23.1%), whereas annual CV was (11.7%). The results show that rainfall variability was higher on intra-monthly basis than inter-annual in the basin.

In addition, the distribution of the rainfall series plotted as cumulative distribution function (cdf) revealed an overall reduction in rainfall over the basin (Figure 3a). It shows that close to 17% of the entire basin received about 1500 mm/yr of rainfall, 40% experienced about 1750 mm/yr, 90% received about 2000 mm/yr, while just another 20% had above 2000 mm/yr. Further analysis was done to characterise the period of decrease using the cdf by dividing the data set to the periods of 1948-1970 and 1971-2008, based on the assumption that drying in the West African sub-region actually started in the early 1970s (Nicholson et al., 2000). The results also showed that for the period of 1948-1970, less than 15% of the whole basin received about 1500 mm/yr of rainfall, 40% experienced about 1800 mm/yr, 95% received about 2000 mm/yr (Figure 3b), while just 10% had above 2000 mm/yr. However, a decline of the foregoing was noticed for the period of 1971-2008 as the results showed that 18% of the whole basin experienced about 1500 mm/yr of rainfall, 40% experienced about 1700 mm/yr, 99% received about 2000 mm/yr, while less than 2% had above 2000 mm/yr (Figure 3c). These findings actually suggest that rainfall of high amount may have reduced since 1970s in the study area.

Likewise, the percentage contributions on monthly basis are shown in Figure 4. Expectedly, the highest was August (15.3%), followed by July (14.6%) and September (14.2%). Surprisingly, the contribution of June (12.9%) was slightly less than that of May (13.1%), whereas January (1.2%) and February (2.6%) which are generally taken as the driest months in the geographical zone, each contributed more than December (0.7%). On a seasonal basis (not shown), JJA had about 42.9%, MAM, 28.7%; DJF contributed the least (4.5), while SON shared (23.9%). Additional analysis based on two-time slices of 1948-1977 and 1978-2008, showed similar pattern of seasonal contributions except that while only JJA increased from 40.3 to 45.5%, MAM (29.6 to 27.9%), DJF (5.4 to 3.5%) and SON (24.7 to 23.2) had reduced contributions. In general, the long-term rainfall of the basin was dominated by the JJA seasonal intensity.

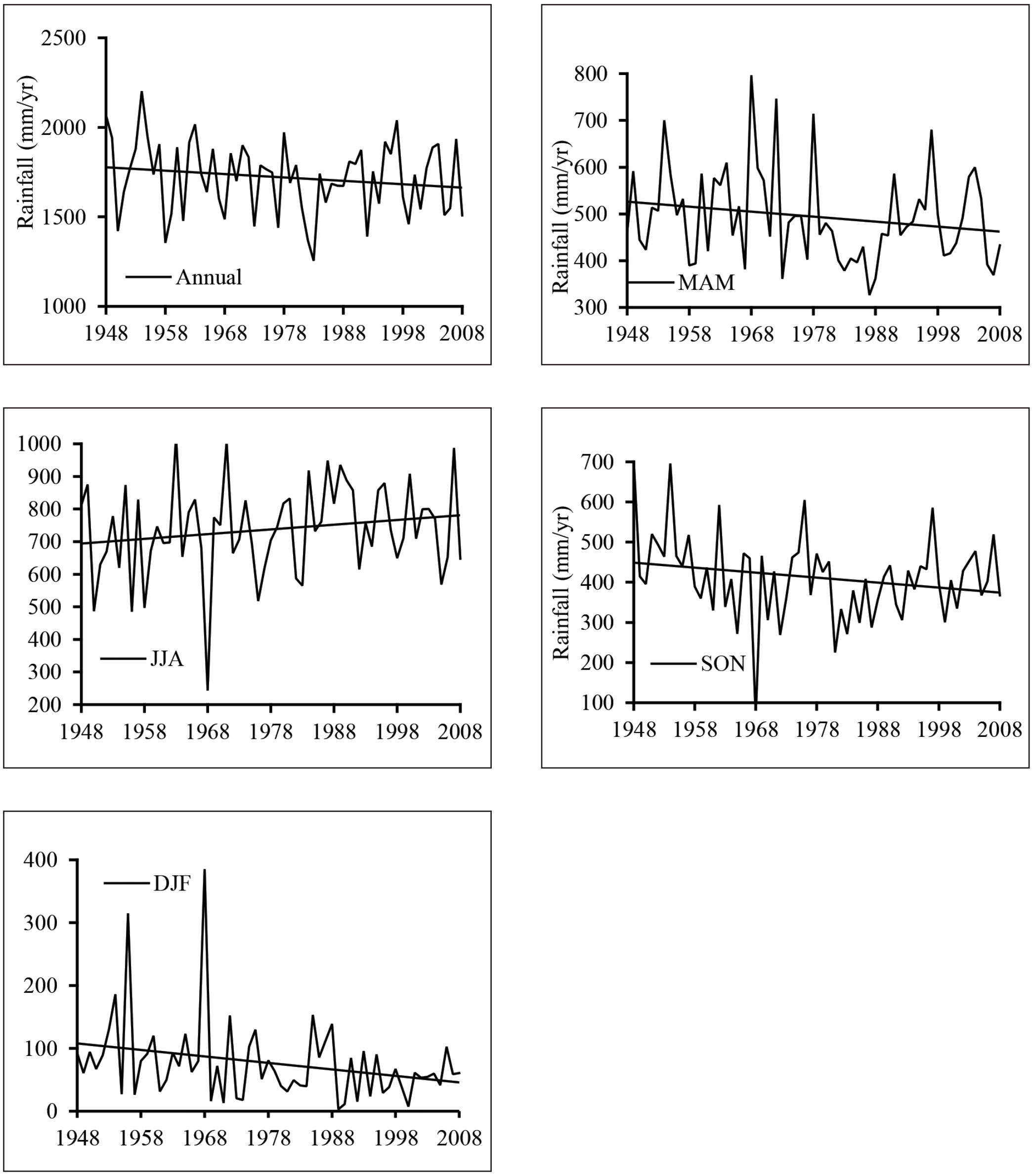



*Figure 2*. Times series plots of annual and seasonal rainfall data averaged over the basin

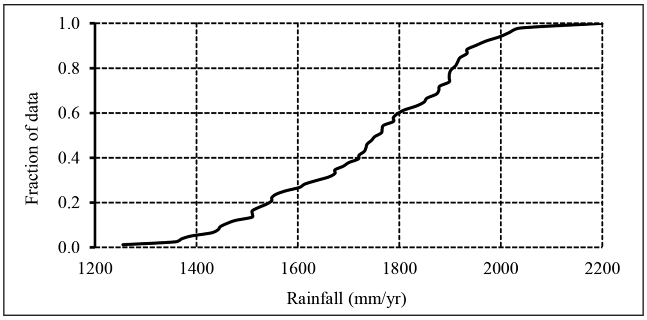
Table 2
*Descriptive statistics and trend analysis (M-K) for the entire basin*

| Code | Minimum (mm/yr) | Maximum (mm/yr) | Mean (mm/yr) | SD (mm/yr) | CV (%) | Z (mm/yr) | Slope (mm/yr) |
|---|---|---|---|---|---|---|---|
| Prec_47 | 1386.9 | 2677.2 | 2101.7 | 286.0 | 13.6 | -1.25 | -2.98 |
| Prec_48 | 1424.7 | 2712.6 | 2108.0 | 286.7 | 13.6 | -1.46 | -3.44 |
| Prec_59 | 1333.2 | 2523.0 | 1996.9 | 257.6 | 12.9 | -0.85 | -1.96 |
| Prec_60 | 1281.0 | 2548.6 | 1981.1 | 269.2 | 13.6 | -0.94 | -2.22 |
| Prec_61 | 1331.1 | 2541.7 | 1981.8 | 276.0 | 13.9 | -1.69 | **-3.62** |
| Prec_77 | 1231.5 | 2285.7 | 1791.1 | 234.4 | 13.1 | -0.50 | -1.03 |
| Prec_78 | 1235.5 | 2286.0 | 1771.1 | 223.7 | 12.6 | -0.68 | -1.18 |
| Prec_79 | 1256.4 | 2264.9 | 1742.7 | 217.2 | 12.5 | -0.85 | -1.23 |
| Prec_80 | 1299.1 | 2253.4 | 1727.2 | 230.5 | 13.3 | -1.57 | -2.56 |
| Prec_97 | 1194.7 | 2145.7 | 1677.7 | 219.1 | 13.1 | -0.27 | -0.57 |
| Prec_98 | 1207.5 | 2130.4 | 1656.0 | 206.2 | 12.5 | -0.57 | -0.61 |
| Prec_99 | 1205.6 | 2099.9 | 1627.5 | 199.3 | 12.2 | -0.57 | -1.16 |
| Prec_100 | 1202.9 | 2158.0 | 1617.6 | 216.9 | 13.4 | -1.57 | -2.56 |
| Prec_101 | 1128.7 | 2301.3 | 1632.5 | 247.5 | 15.2 | -1.92 | **-3.75** |
| Prec_123 | 1118.9 | 1983.3 | 1547.2 | 190.7 | 12.3 | -0.47 | -0.59 |
| Prec_124 | 1089.8 | 1943.6 | 1518.3 | 184.5 | 12.2 | -0.70 | -1.04 |
| Prec_125 | 1056.4 | 2023.3 | 1514.5 | 204.7 | 13.5 | -1.60 | -2.63 |
| Prec_126 | 1053.9 | 2169.1 | 1526.8 | 232.2 | 15.2 | -1.81 | **-3.37** |
| Prec_148 | 1072.9 | 1846.5 | 1446.4 | 170.9 | 11.8 | -0.18 | -0.24 |
| Prec_149 | 1038.4 | 1806.9 | 1418.3 | 162.7 | 11.5 | -0.38 | -0.54 |
| Basin | 1255.2 | 2199.5 | 1719.2 | 198.0 | 11.5 | -1.19 | -2.07 |

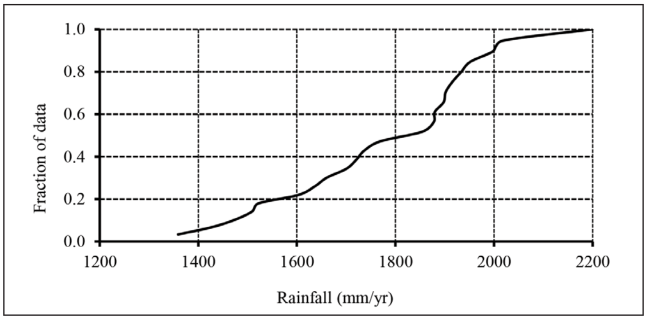
Bold font significant at 90%

Table 3
*Descriptive statistics of basin average monthly and annual time series*

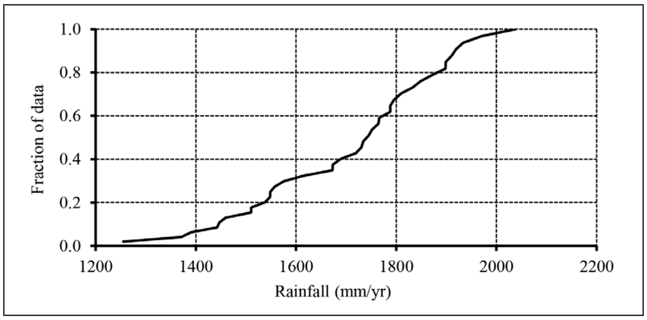
| Series | Minimum (mm/yr) | Maximum (mm/yr) | Mean (mm/yr) | SD (mm/yr) | CV (%) |
|---|---|---|---|---|---|
| January | 0.0 | 107.2 | 21.0 | 24.4 | 116.2 |
| February | 0.8 | 220.1 | 44.5 | 38.2 | 85.8 |
| March | 21.0 | 315.7 | 97.3 | 50.0 | 51.4 |
| April | 38.5 | 408.0 | 171.2 | 63.1 | 36.9 |
| May | 110.3 | 392.0 | 225.6 | 53.2 | 23.6 |
| June | 108.9 | 381.3 | 222.5 | 51.5 | 23.1 |
| July | 67.9 | 443.2 | 251.6 | 70.4 | 28.0 |
| August | 0.7 | 461.4 | 263.4 | 69.0 | 26.2 |
| September | 0.3 | 402.0 | 246.4 | 57.2 | 23.2 |
| October | 8.0 | 253.4 | 133.8 | 52.4 | 39.1 |
| November | 0.1 | 140.9 | 31.3 | 31.4 | 100.5 |
| December | 0.0 | 121.5 | 11.2 | 21.5 | 192.9 |
| Annual | 1255.2 | 2202.4 | 1719.8 | 200.7 | 11.7 |




(a)




(b)




(c)

*Figure 3*. Rainfall distribution (a) 1948-2008; (b) 1948-1977; and (c) 1978-2008 plotted as cumulative distribution function over the basin

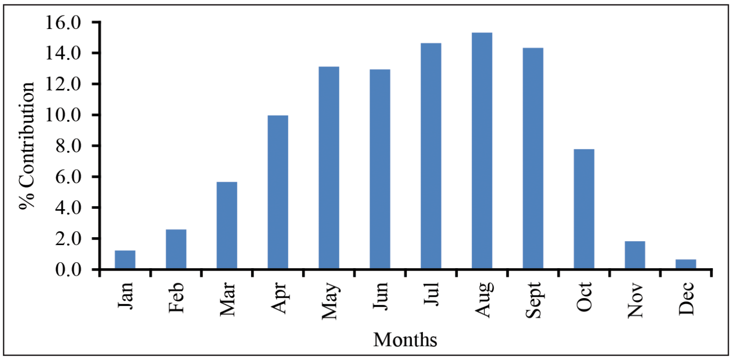
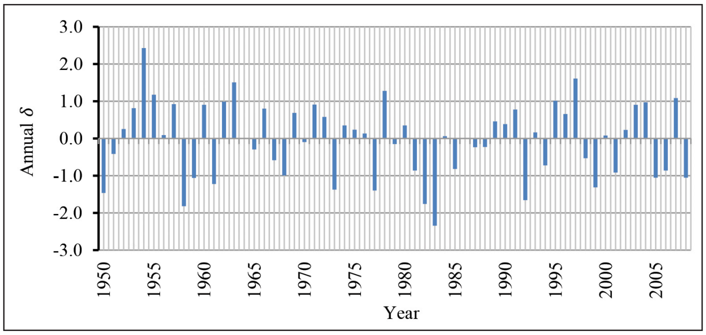


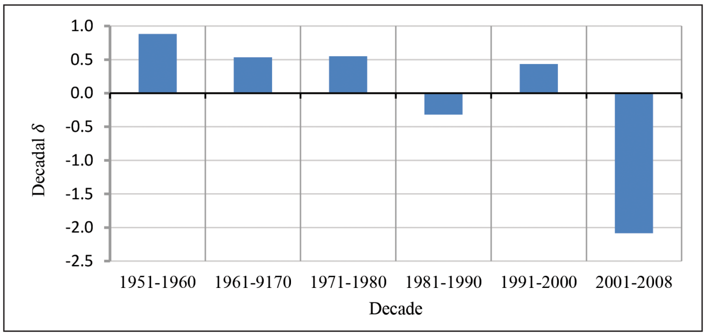

*Figure 4*. Percentage monthly contribution to annual rainfall

## Rainfall Variability

Rainfall variability indices on annual and decadal bases covering 1950 to 2008 are presented in Figures 5a & 5b. The results show three series of distinctive periods which may be described for the basin as: (1) from 1950 to 1965 (16 years), a seemingly random succession of six dry years, five ‘‘normal’’ years and 3 wet years; (2) from 1966 to 1980 (15 years), a series of 4 dry years, 8 ‘‘normal’’ years, and one wet year; (3) from 1981 to 2008 (28 years) of 12 dry years, 11 ‘‘normal’’ years and two wet years. Throughout the second half of the 20th century, the decade 1980s was the driest, while decade 1950s the wettest (Figure 5b). Nevertheless, for the entire 61-years period of study, the decade 2000s was the driest. Moreover, following WMO (1975) classification, as applied by Gocic and Trajkovic (2013b), only 12 years can be classified as “dry”. The dry years were 1950, 1958, 1959, 1961, 1968, 1973, 1977, 1982, 1992, 2005 and 2008, amounting to about 18% of the entire series. On the other hand, eight other years exhibited “normal” conditions; the years were 1948, 1949, 1954, 1955, 1963, 1978, 1997 and 2007, while the rest were “wet”. Throughout the whole length of period under study, “extremely dry” condition was only experienced in 1983.




(a)




(b)

*Figure 5*. Rainfall variability (a) annual; and (b) decadal

## Mann-Kendall (M-K)

The M-K trend test was done using a spreadsheet (Makesen 1.0) developed at the Finnish Meteorological Institute (Salmi et al., 2002). The results presented in Table 2 for all the 20 data points and the entire basin showed negative trends with only three significant ($\alpha < 0.1$). Trend slopes ranged from -3.75 to -0.24 mm/yr and for the entire basin were -1.29 mm/yr and -2.23 mm/yr, respectively. Analysis based on the monthly series also showed predominantly decreasing trends that are not significant (Table 4, columns 2, 3 & 4). For example, out of the 7 months which showed downward trends - January, February, March, April, June, September, October, only January (-0.18 mm/yr), March (-0.64 mm/yr) and September (-0.73 mm/yr) trends were significant. Except for August that showed a significant increasing trend (0.79 mm/yr), the other four months exhibited positive insignificant trends of varied magnitudes. The rate of change ranged between -0.73 mm/yr (September) and 0.78 mm/yr (August). On the seasonal basis, aside from DJF which showed a significant downward trend ($\alpha < 0.1$), trends were generally not significant; however, JJA recorded an upward trend (1.43 mm/yr), whereas slope magnitude ranged between -1.04 mm/yr (SON) and 1.42 mm/yr (JJA).

Moreover, analysis based on the two time slices (1948-1977 and 1978-2008) showed an insignificant decreasing trends (-7.03 mm/yr) with the magnitude -210.8 mm/yr between 1948 and 1977, while an insignificant increasing trend (2.64 mm/yr) was experienced during 1978-2008, with the magnitude of change reaching 81.69 mm/yr. Nevertheless, over the whole series length, an insignificant decreasing trend (slope = -2.25 mm/yr) with the magnitude of -137.07 mm/yr was observed. Similarly, while the trends were generally downward in all the seasons between 1948 and 1977, it was only significant ($\alpha < 0.1$) during SON (not shown). However, between 1978 and 2008, there was no significant trend in all seasons; nonetheless, while both DJF and JJA depicted downward trends, MAM and SON showed upward trends. Obviously, there have been sorts of redistribution in the annual rainfall amongst the seasons between the two time periods which favoured MAM and SON. This agrees with the finding of Wang et al. (2011) who stated that in the event of decreased annual precipitation, which is probably due to the change in global climate or elevation; monthly rainfall would not just decrease as a consequence, but is re-distributed to smoothen the seasonality. This result has implications for dry season farming as farmers may be able to extend their farming season to the usually dry months of SON if the trend persists in the area. With respect to the change point for all cases, the results determined using the CUSUM plot are shown in column 5 of Table 4 below.

Table 4
*Change points and M-K trend results based on monthly, annual, seasonal and two time slices*

| Series | Test Z | M-K | Change magnitude | Change .Point |
|---|---|---|---|---|
| January | -1.70 | -0.18$^{+}$ | -10.88 | 1970 |
| February | -1.52 | -0.34$^{+}$ | -21.03 | 1986 |
| March | -1.65 | -0.63 | -38.72 | 1972 |
| April | -1.13 | -0.44 | -26.97 | 1981 |
| May | 0.13 | 0.07 | 4.35 | 1972 |
| June | -0.27 | -0.13 | -7.84 | 1949 |
| July | 0.94 | 0.49 | 29.93 | 1968 |
| August | 1.92 | 0.79$^{+}$ | 47.90 | 1983 |
| September | -1.90 | -0.73$^{+}$ | -44.78 | 1962 |
| October | -1.11 | -0.43 | -26.49 | 1955 |
| November | 0.09 | 0.01 | 0.74 | 1963 |
| December | 0.30 | 0.00 | 0.28 | 1968 |
| Annual | -1.29 | -2.25 | -137.07 | 1957 |
| DJF | -2.00 | -0.62$^{+}$ | -37.51 | 1968 |
| MAM | -1.35 | -0.94 | -57.56 | 1972 |
| JJA | 1.19 | 1.43 | 87.17 | 1962 |
| SON | -1.57 | -1.04 | -63.68 | 1983 |
| 1948-1977 | -1.53 | -7.03 | -210.79 | 1957 |
| 1978-2008 | 0.41 | 2.64 | 81.69 | 1980 |

$^{+}$ significant at 90%

## DISCUSSION

In the present study, a complete picture of rainfall analysis covering the period between 1948 and 2008 over the NSB was undertaken. Generally, there have been reductions in rainfall over the entire landscape since the beginning of the period under study (Figure 2(a)). Unlike the results of Oguntunde et al. (2011), the average annual rainfall series between 1948 and 1970 were not significantly higher than that between 1971 and 2008, while variability was higher temporally than spatially. However, the result of the low spatial variability might be due to the smaller spatial coverage of the present study as compared with the previous. Conversely, the observed annual variability (Figure 5a) was not significantly different from that of L'Hóte et al. (2002). Based on the cdf, a greater portion of the basin also received mean annual rainfall higher than 2000 mm/yr between 1948 and 1977 as compared to between 1978 and 2008, and for the whole length of period. The increasing amount of mean annual rainfall combined with the rapid change in land cover in the basin could be the reason for floods that have been ravaging the area recently.

Rainfall variability also showed that there were many more dry years between 1981 and 2008, with only 1983 being extremely dry as compared with the period between 1948 and 1980. With respect to decadal variability, the decade 2000s was the driest, while decades 1950s was the wettest. The results agree with the findings of earlier studies (e.g., Nicholson et al*.,* 2000; Oguntunde et al., 2011); however, the decade 1980s was reported as the driest in the study by the second authors. Apparently, the emergence of the last decade as the driest in the present study is in agreement with the projection of increased drying during the 21st century (IPCC, 2001; 2007). Nonetheless, it should be noted that the temporal scale covered by the present study differs from that of the earlier authors, although the study still showed the decade 1980s as the driest of the last century.

On the seasonal time scale, rainfall has been declining in all seasons except in JJA, which showed a relative increase. Similar to the findings of Miao et al. (2012), who found an increase in summer rainfall in their study of seasonal precipitation for Beijing in China, there was also an increase of about 5% in the contribution of JJA during 1978 to 2008 as compared with 1948 to 1977. The increasing rainfall amount in JJA was mostly caused by the rise in the rainfall amount in August. In addition, of the 12 months of the year, December has been the driest and most varied while August was the wettest. Thus, this suggests that flood events which have been witnessed in the area during September months may have stemmed from the heavy rainfall in August and could persist intermittently for a while in the coming years.

In comparison with the findings of Oguntunde et al. (2011) in their study over Nigeria, decreasing trend dominated the entire basin and mean annual rainfall. Similar insignificant downward trend in rainfall was found by Salami et al. (2014) in their application of M-K test to hydro-meteorological variables at Lokoja, a location in the basin. Elsewhere in India, Jain and Kumar (2012) reported that basin-wise trend analysis carried out over the country showed that 15 basins experienced downward trend in annual rainfall, while one basin depicted a significant decreasing trend at 95% confidence level. Similarly, Longobardi and Villani (2010) also found a predominantly decreasing trend in their study in the Mediterranean area, both at the annual and monthly scale, with over 97% of the total stations significant.

Seasonally, an upward trend that is insignificant was observed in JJA, while other seasons showed a downward trend. In the same vein, 8 of the 12 months in the basin have shown downward rainfall trends, while the other four showed increasing trends. Once again, this also agrees with the results of Hess et al. (1995), who linked rainfall reduction in the northeast arid zone of Nigeria between 1961 and 1990 to decreases in August and September rainfalls, while Adefolalu (2007) attributed the destructive flood events in southern Nigeria to the rapid rise in August rainfall over the region during the last 50 years of the century.

## CONCLUSION

The study examined trends in monthly, seasonal and annual rainfall time series between 1948 and 2008 over the NSB. The overall results of this study showed that the general drying in the entire basin, which started since the last 30 years of the 20th century, has intensified into the present. Generally, rainfall in the summer months, especially August, has also been persistent leading to floods in the basin. Meanwhile, given the projection of the IPCC (2007) for the present century, the drying that has been observed in this study might be linked directly or indirectly with climate change. However, considering the rapid rate of urbanisation in the basin, impacts of land cover/use change might have also contributed to the intermittent floods being witnessed in the area. Nonetheless, water resources management efforts may require the construction and expansion of water storage facilities within the basin to reduce the impacts of summer flooding and possible water scarcity in the future.

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