Temporal Changes Evaluation of Extremes Rainfall

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Abstract: - The knowledge of climate variability on temporal and spatial scales is vital to understand the nature of climate system. The study evaluated temporal changes in extreme rainfall and over the middle-belt of Nigeria by computing indices of extreme rainfall over the middle belt of Nigeria represented by Jos, Lokoja and Makurdi using the RclimDex software. Daily rainfall data in the three stations were collected for period of 35 years. Analyses of indices of extreme rainfall events depicted a decreasing and increasing trends in the variables considered. The results of Rx 5-day, SDII, R10, R20, R95P, and PRCPTOT showed decrease at Jos. Likewise, Rx5-day, R10, CDD, and CWD showed decrease at Lokoja. In Addition, Rx1-day, R10, CDD, CWD, R95P, R99P and PRCPTOT also showed decline at Makurdi. The findings provided vital information on extreme rainfall events indices which can be used for weather forecast, disaster emergency and weather prediction.

Key-Words: - temporal changes; extreme rainfall; middle belt; spatial; rainfall; climate

1 Introduction

Rainfall has been the most important determinant of the climate and crop yields in Nigeria as well as in other part of West Africa [1]. Inter-annual variability in rainfall has been the key climatic element that determines the success of agriculture in the sub-region. Different studies have carried out the climate related research in different parts of the world with such studies considering the relationship between climate variability and agricultural productivity in order to establish the impact of the former on the latter [2. 3. 4, 5, 6, 7].

IPCC [3] depicted clearly the between climate variability and climate change. Climate fluctuates naturally on all time scales from days, years and few decades to many decades. Thus, climate variability is short-to-medium term fluctuations around mean climate state on time scales, varying from less than annual to multi-decadal time scales such as 30 years.

Climate change, on the other hand is a fundamental shift in the mean state of climate. It pertains generally to longer-term trends than that of climate variability [6, 3, 4]. WMO [8] discussed the impacts of rainfall variability on agricultural productivity in Asia, Africa and Latin America with suitable examples. In tropical Asia and Africa, agricultural productivity is sensitive to rainfall variability that eventually causes environmental and social stresses. The arid and semi-arid tropics of Africa are already having difficulty in coping with environmental stress [8]. Inter-annual rainfall variability is resulting in increased frequencies of drought and poses the greatest risk to crop yield. Climate variability and change contribute immensely to vulnerability to economic loss, hunger and famine. Hence, it is imperative that these aspects are well understood in order to formulate more sustainable policies and strategies to promote food production in Nigeria. In the report titled “Climate Variability and Change: A Challenge for Sustainable Agricultural Production”, [9] examined the effects of rainfall variability on food production, the study showed that rainfall variability is one of the main determinants of agricultural production in both developing and developed countries. In general, changes in rainfall variability as well as in the mean value of climate variables influence the yield of cereal crops, but because the pattern of rainfall variability is not necessarily harmful, the problems arise from extreme events and the uncertainty, which derives from the difficulty of predicting weather beyond a week or so [9]. It is essential to note that although these extreme events are inherently abrupt, random and disastrous, the risks can be reduced through improved preparedness and planning, better information, stronger institution and new technologies to minimize human and material losses [9]. Agricultural productivity in Nigeria is strongly linked to rainfall variability because farmers rely on rain-fed agriculture. Climate variability has been, and continues to be, the principal source of fluctuations in global food production, particularly in the semi-arid tropical countries of the developing world, Nigeria inclusive [10, 11]. It determines not only where and when to plant a crop but also whether the crop will yield effectively or not. Theoretically, there are three different forms of rainfall variability: (a) spatial (b) inter-annual (c) intra-annual variability. Spatial variability has to do with differences in total rainfall received between places structurally located within a given region. Inter-annual rainfall variation can be defined as the annual deviation from long-term averages or the differences in rainfall between years. Intra-annual rainfall variability refers to the distribution of rainfall within a year [11]. In the last decade, inter-annual rainfall variations are causes of great stress to the farming activities, crop production and crop yield in the Guinea Savanna of Nigeria [7].This study was based on the analysis of rainfall data obtained from some meteorological stations and evaluated temporal changes in rainfall extremes over the middle belt of Nigeria for 35 years (1971 to 2005).

2 METHODOLOGY

2.1 Study Area

The north central Nigeria consists of seven states, which are Kogi, Kwara, Niger, Nassarawa, Plateau, Benue and F.C. T. This region, due to its location are characterized by tropical continental dry climate. The climate is characterized by alternate wet and dry seasons in response to the changes in pressure patterns and high temperature throughout the year at about 270^{o}C. Agriculture is the most dominant economic activity in the belt; crops like groundnut, cotton, millet, beans, guinea corn, cassava, yam and maize are cultivated in the belt, which also has the highest concentration of cattle in the country [7].

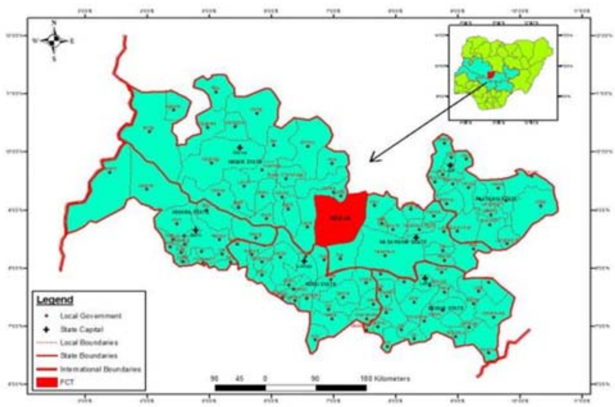

Figure 1: Map of the study area (adapted from: [12].

2.2 Indices of rainfall extremes in study area

2.2.1 Data Collection

Daily rainfall data from year 1971 to 2005 were obtained from the Nigerian Meteorological Agency (NIMET). The stations are Jos, Lokoja and Markurdi, representing; Plateau, Kogi and Benue State, respectively in the Middle Belt of Nigeria.

2.2.2 Data Analysis

Rainfall data was used to generate several indices using the RClimDex software. RClimDex is a Microsoft Excel based program that provides an easy-to-use protocol for the calculation of indices of climate extremes for monitoring and detecting climate change. It was developed by Byron Gleason at the National Climate Data Centre (NCDC) of NOAA, and has been used in CCI/CLIVAR workshops on climate indices from 2001. The data was processed by checking the homogeneity with the result for the analysis, while the trend in index of rainfall extreme was calculated using the Mann-Kendall test, a non-parametric test recommended by the World Meteorological Organization (WMO), to explore trends in hydro-climatological time series[13, 14, 15, 16]. This test is applicable in cases when the data values *X* of a time series can be assumed to obey the model;

$$\chi = f(t) + ei \quad (1)$$

Where *f(t)* is a continuous monotonic increasing or decreasing function of time and the Residual e_i can be assumed to be from the same distribution with zero mean Mann-Kendall test statistic S is given by Salami *et al.*, (2002) as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \quad (2)$$

where n is the length of the time series X_j…… X_n, and Sgn (·) is a sign function, X_j and X_k are values in years j and k, respectively. The expected value of S equal zero for series without trend and the variance is computed as:

$$\sigma^2(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \quad (3)$$

Here q is the number of tied groups and t_p is the number of data values in p^{th} group. The test statistic Z is then given as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\sigma^2(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{\sigma^2(S)}} & if \quad S < 0 \end{cases} \quad (4)$$

As a non-parametric test, no assumptions as to the underlying distribution of the data are necessary. The Z statistic is then used to test the null hypothesis, H_o, which the data is randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. A positive (negative) value of Z indicates an upward (downward) monotone trend. H_o is rejected at a particular level of significance if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. It should be noted that the Mann-Kendall test is non-dimensional and does not quantify the scale or the magnitude of the trend in the units of the time series under study, but is rather a measure of the correlation of xi with time and, as such, simply offers information as to the direction and a measure of the significance of the observed trends. [17] noted that Mann-Kendall test is non-dimensional and does not quantify the scale or the magnitude of trend but the direction of trend. The Sen.'s non parametric method will be use to estimate the slope of an existing trend. This method is good as it tends to bring out the true slope of any existing trend and researchers often use it [13, 18]. The Sen's method can be used in cases where the trend can be assumed to be linear. This means that $f(t)$ in equation (2) is equal to:

$$f(t) = Qt \pm B \quad (5)$$

Where Q is the slope and B is a constant. To get the slope estimate Q in equation (6) we first calculate the slopes of all data value pairs as:

$$Q_i = \frac{\chi_j - \chi_k}{j - k} \quad (6)$$

Where $j > k$.

If there are n values x_j in the time series, we get as many as $N = n(n-1)/2$ slope estimates Q_i. The Sen's estimator of slope is the median of these N values of Q_i. Both trend and slope test are calculated with software called MAKESENS 1.0.

3 RESULTS AND DISCUSSION

3.1 Patterns and Variations in some indices of extreme rainfall events

3.1.1 Patterns and Variations over Jos

The patterns and variations in some indices of extreme rainfall events over Jos, which represents Plateau state, are as shown in Figures 2 to 11. Figure 2 presented the patterns and variations in Maximum 1-day rainfall (Rx 1 day) over Jos. It shows that Rx 1 day ranges between 45.4 and 105.3 mm, while it stood at an average of 64.9 mm of rainfall at Jos. Figure 3 showed that maximum 5-days consecutive rainfall amount (Rx 5-day) stood at an average of 103.9 mm, while it ranges from 60.8 to 174.4 mm. Simple daily intensity index (SDI I) is displayed in Figure 4 which stood at an average of 12.95 mm/day, while it ranges from 9.81 to 16.4 mm/day. Furthermore, Figure 5 showed that number heavy rainfall days when rainfall is greater or equal 10 mm (R10) over Jos stood at an average of 44.3 days, while it ranges between 25 and 53 days. Figure 6 depicted that number heavy rainfall days when rainfall is greater than or equal to 20 mm (R20) over Jos stood at an average of 19.91 days, while it ranges between 11 and 28 days. Figure 7 showed that maximum number of consecutive dry days when rainfall is less or equal to 1 mm (CDD) over Jos ranges between 60 and 109 days, and stood at an average of 85.63 days. In the trend, Figure 8 showed that maximum number of consecutive wet days when rainfall is greater or equal to 1mm (CWD) over Jos ranges between 6 and 20 days, and stood at an average of 10.8 days. In addition, Figure 9 shows that annual total rainfall from days greater than 95^{th} percentile (R95P) ranges between 129.9 and 395.5 mm, with an average of 274.74 mm over Jos. Likewise, Figure 10 revealed that annual total rainfall from days greater than 95^{th} percentile (R99P) ranges between 45.4 and 161.2 mm, with an average of 103.8 mm over Jos. Finally, Figure 11 showed that annual total rainfall from days greater than or equal to 1mm (PRCPTOT) over Jos stood at an average of 1245.5mm, and ranges between 809.1 and 1574.8 mm. The patterns and variations in rainfall event indices were as presented in the figures.

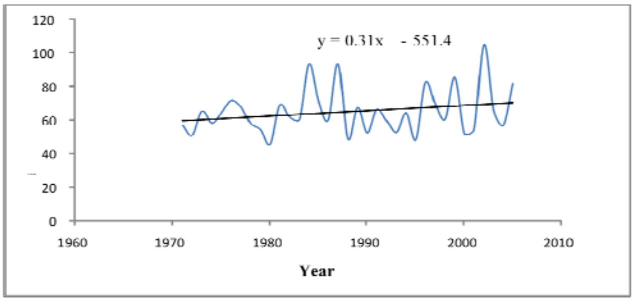

Figure 2: patterns and variations in Maximum 1-day rainfall (Rx 1 day) over Jos

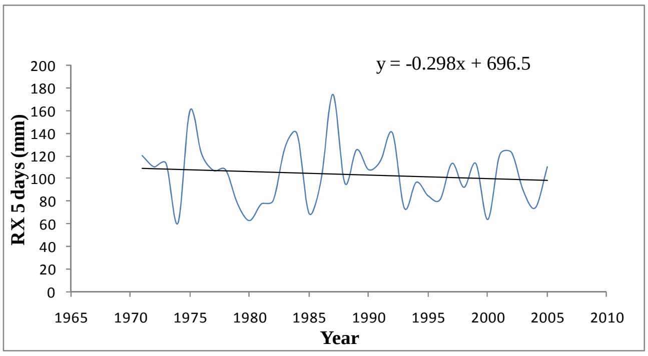

Figure 3: maximum 5-days consecutive rainfall amount (Rx 5-day) over Jos

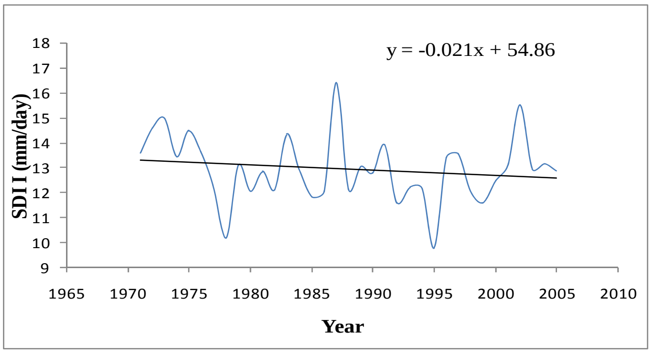

Figure 4: daily intensity index (SDI I) over Jos

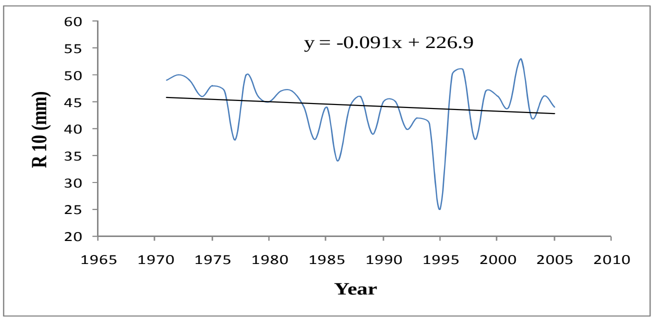

Figure 5: Presents number of heavy rainfall days when rainfall is greater or equal 10mm (R10) **over** Jos.

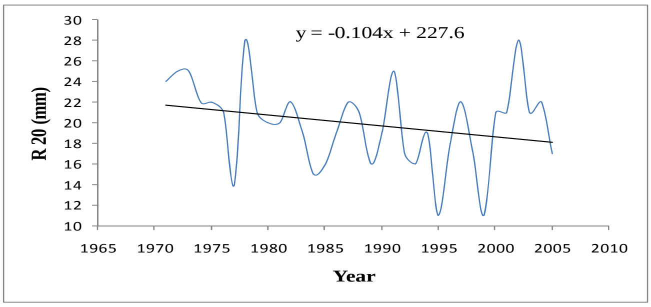

Figure 6: number heavy rainfall days when rainfall is greater or equal to 20mm (R20) over Jos.

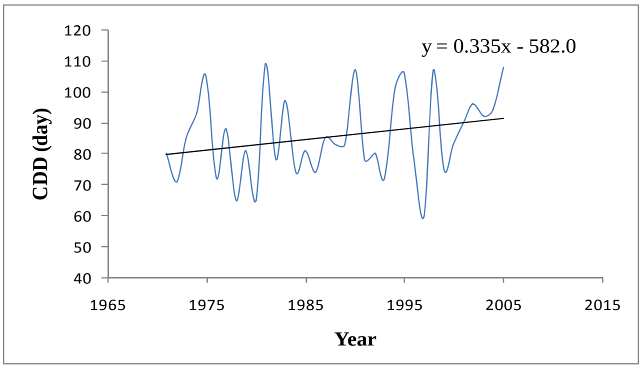

Figure 7: maximum number of consecutive dry days when rainfall is less or equal to 1mm (CDD) over Jos

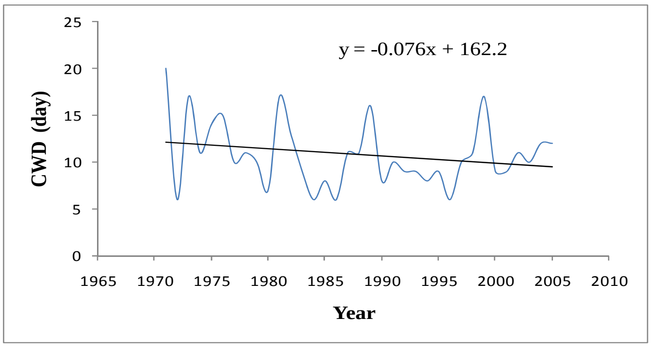

Figure 8: maximum number of consecutive wet days when rainfall is greater or equal to 1mm (CWD) over Jos.

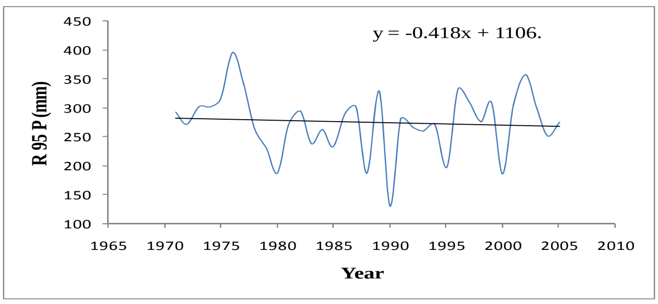

Figure 9: annual total rainfall from days greater than 95^{th} percentile (R95P) over Jos

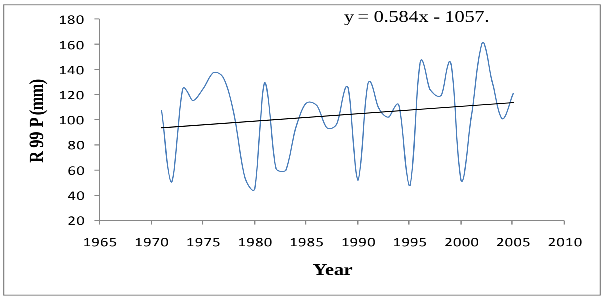

Figure 10: annual total rainfall from days greater than 99th percentile (R99P) over Jos

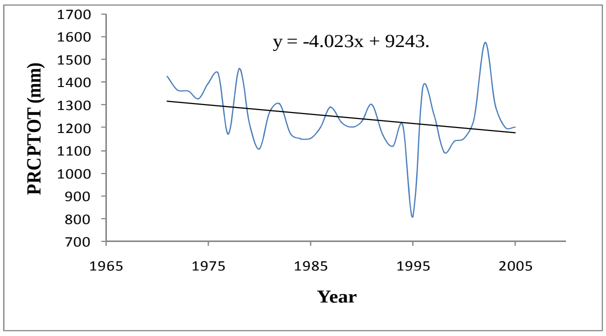

Figure 11: annual total rainfall from days greater than or equal to 1mm (PRCPTOT) over Jos

3.1.2 Patterns and Variations over Lokoja

For Lokoja, the patterns and variations in some indices of extreme rainfall events over Lokoja, which represents Kogi state, are presented in Figures 12 to 21. Figure 12 presents patterns and variations in Maximum 1-day rainfall (Rx 1 day) over Lokoja. The figure shows that Rx 1 day ranges between 54 and 154.4 mm, while it stood at an average of 80.38 mm of rainfall at Lokoja. Figure 13 showed that maximum 5-day consecutive rainfall amount (Rx 5-day) stood at an average of 70.55 mm, while it ranges from 0 to 256.2 mm. Simple daily intensity index (SDI I) in Figure 14 stood at an average of 15.8 mm/day, while it ranges from 11.7 to 20.2 mm/day. Furthermore, Figure15 showed that number heavy rainfall days when rainfall is greater or equal 10 mm (R10) over Lokoja stood at an average of 37.13 days, while it ranges between 25 and 51 days. Figure 16 showed that number heavy rainfall days when rainfall is greater than or equal to 20 mm (R20) over Lokoja stood at an average of 20.83 days, while it ranges between 11 and 36 days. Figure 17 showed that maximum number of consecutive dry days when rainfall is less or equal to 1 mm (CDD) over Lokoja ranges between 44 and 107 days, and stood at an average of 73.43 days. With the same trend, Figure 18 depicted that maximum number of consecutive wet days when rainfall is greater or equal to 1mm (CWD) over Lokoja ranges between 3 and 10 days, and stood at an average of 6.43 days. In addition, Figure 19 showed that annual total rainfall from days greater than 95th percentile (R95P) ranges between 163.5 and 436.7 mm, with an average of 283.17 mm over Lokoja. Likewise, Figure 20 revealed that annual total rainfall from days greater than 95th percentile (R99P) ranges between 454 and 242.5 mm, with an average of 85.53 mm over Lokoja. Finally, Figure 21 depicted that annual total rainfall from days greater than or equal to 1mm (PRCPTOT) over Lokoja stood at an average of 1163.57mm, and ranges between 767.4 and 1761 mm.

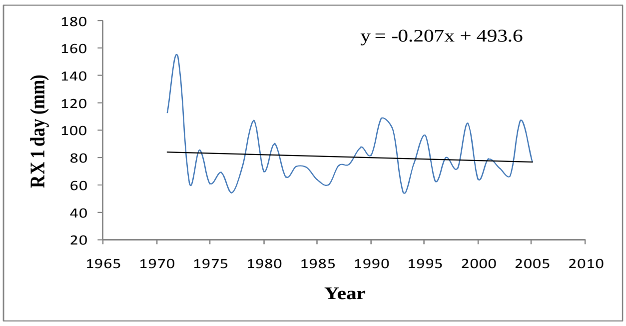

Figure 12: patterns and variations in Maximum 1-day rainfall (Rx 1 day) over Lokoja

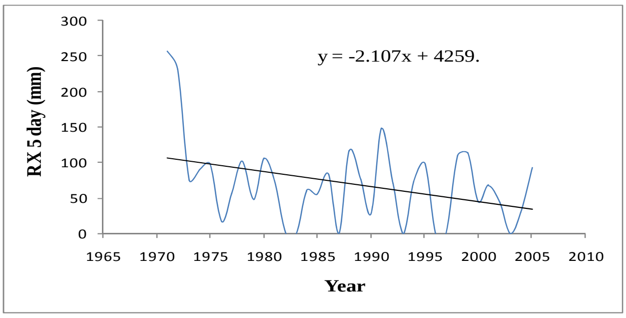

Figure 13: maximum 5-days consecutive rainfall amount (Rx 5-day) over Lokoja

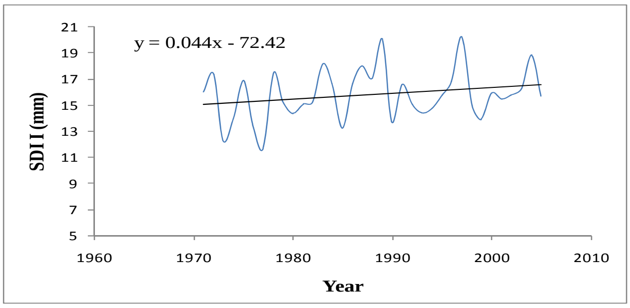

Figure 14: daily intensity index (SDI I) over Lokoja

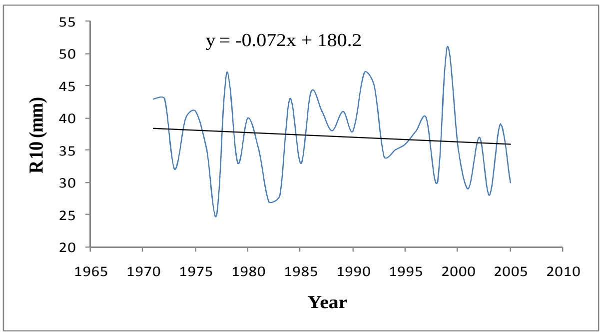

Figure 15: number heavy rainfall days when rainfall is greater or equal 10mm (R10) over Lokoja

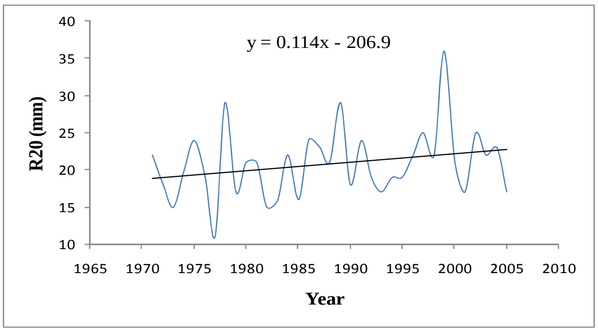

Figure 16: number heavy rainfall days when rainfall is greater or equal to 20mm (R20) over Lokoja

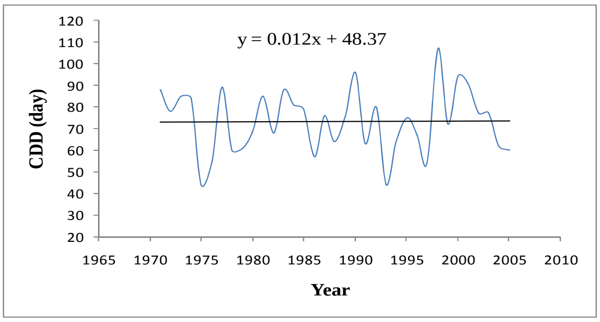

Figure 17: maximum number of consecutive dry days when rainfall is less or equal to 1mm (CDD) over Lokoja

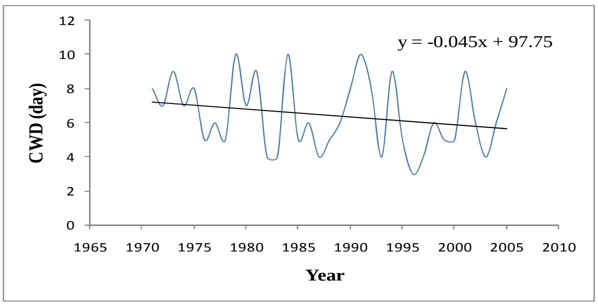

Figure 18: maximum number of consecutive wet days when rainfall is greater or equal to 1mm (CWD) over Lokoja

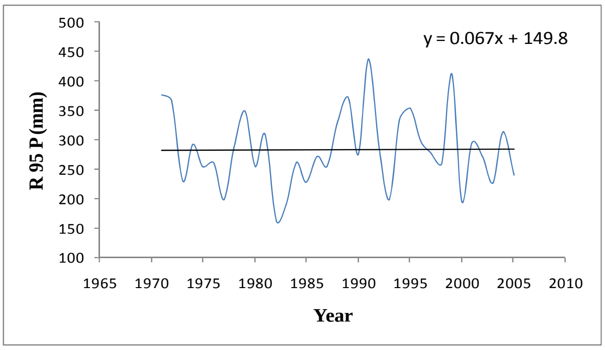

Figure 19: annual total rainfall from days greater than 95th percentile (R95P) over Lokoja

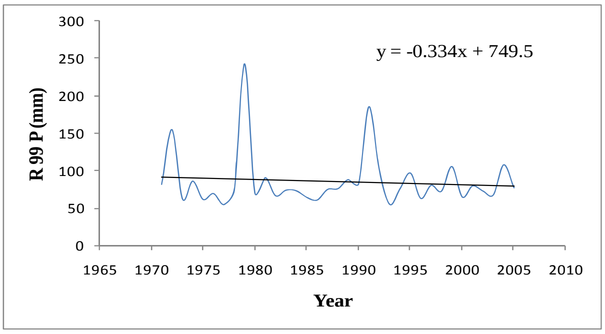

Figure 20: annual total rainfall from days greater than 99th percentile (R99P) over Lokoja

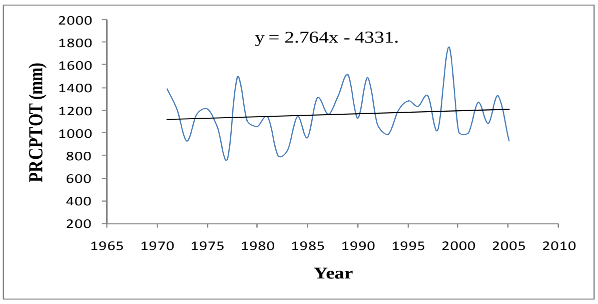

Figure 21: annual total rainfall from days greater than or equal to 1mm (PRCPTOT) over Lokoja

3.1.3 Patterns and Variations over Makurdi

The patterns and variations in some indices of extreme rainfall events over Makurdi, which represents Benue state, is as presented in Figures 22-31. Figure 22 presented patterns and variations in Maximum 1-day rainfall (Rx 1 day) over Makurdi. The Figure 23 showed that Rx 1 day ranges between 45.2 and 125.3 mm, while it stood at an average of 82.8 mm of rainfall at Makurdi. Figure 24 showed that maximum 5-days consecutive rainfall amount (Rx 5-day) stood at an average of 67.4 mm, while it ranges from 0 to 144.6 mm. Simple daily intensity index (SDI I) in Figure 25 stood at an average of 16.35 mm/day, while it ranges from 12.47 to 21.96 mm/day. Furthermore, Figure 26 displayed the number of heavy rainfall days with rainfall greater or equal 10mm (R10) over Makurdi stood at an average of 35.97 days, while it ranges between 21 and 50 days. Figure 27 showed that number of heavy rainfall days when rainfall is greater than or equal to 20 mm (R20) over Makurdi stood at an average of 20.47 days, while it ranges between 9 and 31 days. Figure 28 displayed that maximum number of consecutive dry days when rainfall is less or equal to 1 mm (CDD) over Makurdi ranges between 52 and 107 days, and stood at an average of 75.10 days. In the same vein, Figure 29 showed that maximum number of consecutive wet days when rainfall is greater or equal to 1mm (CWD) over Makurdi ranges between 3 and 12 days, and stood at an average of 6.17 days. Also, Figure 30 depicted that annual total rainfall from days greater than 95th percentile (R95P) ranges between 74 and 412.1 mm, with an average of 266.2 mm over Makurdi. Likewise, Figure 31 revealed that annual total rainfall from days greater than 95th percentile (R99P) ranges between 45.2 and 125.3 mm, with an average of 82.83 mm over Makurdi. Finally, Figure 31 showed that annual total rainfall from days greater than or equal to 1mm (PRCPTOT) over Makurdi stood at an average of 1153.9 mm, and ranges between 556.4 and 1608.2 mm.

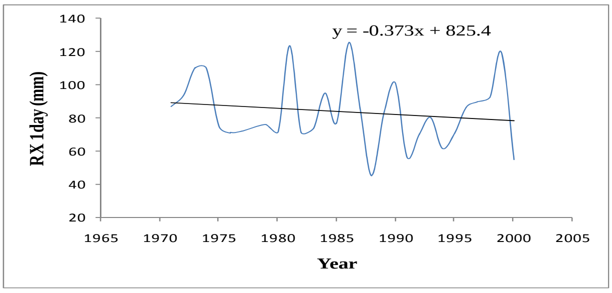

Figure 22: patterns and variations in Maximum 1-day rainfall (Rx 1 day) over Makurdi

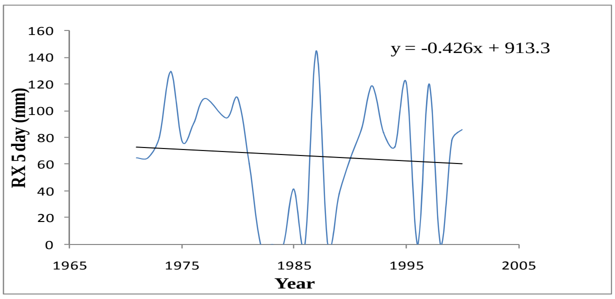

Figure 23: maximum 5-days consecutive rainfall amount (Rx 5-day) over Makurdi

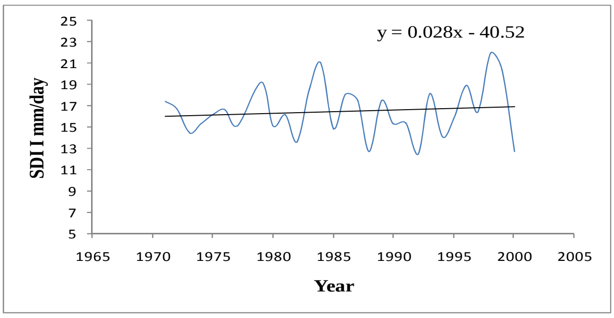

Figure 24: daily intensity index (SDI I) over Makurdi

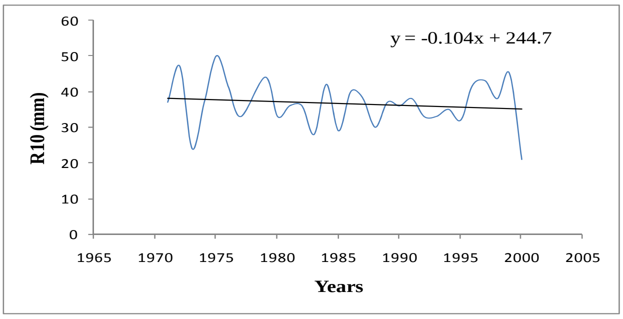

Figure 25: number heavy rainfall days when rainfall is greater or equal 10mm (R10) over Makurdi

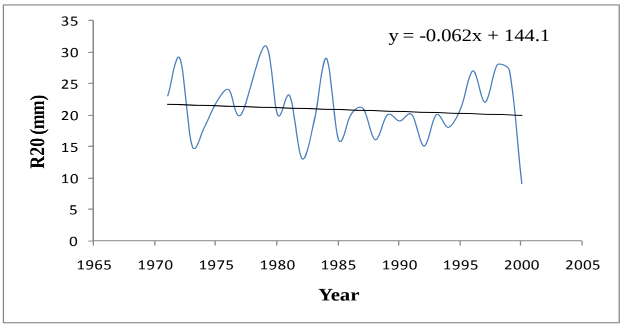

Figure 26: number heavy rainfall days when rainfall is greater or equal to 20mm (R20) over Makurdi

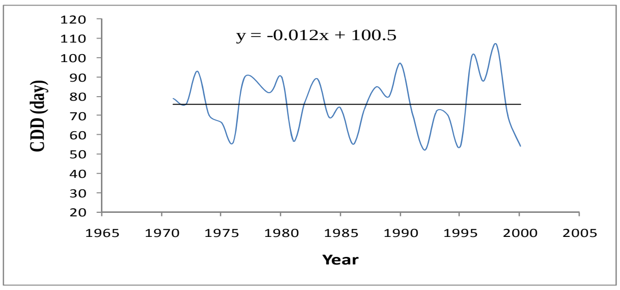

Figure 27: maximum number of consecutive dry days when rainfall is less or equal to 1mm (CDD) over Makurdi

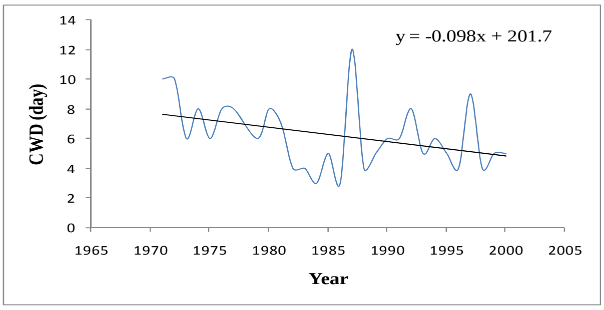

Figure 28: maximum number of consecutive wet days when rainfall is greater or equal to 1mm (CWD) over Makurdi

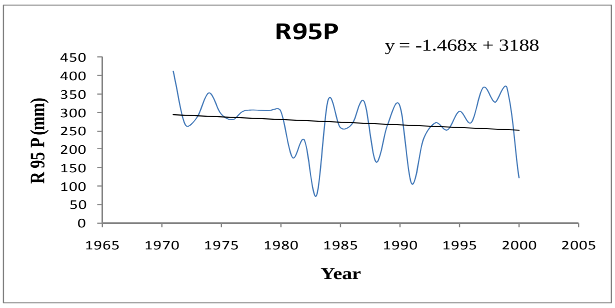

Figure 29: annual total rainfall from days greater than 95th percentile (R95P) over Makurdi

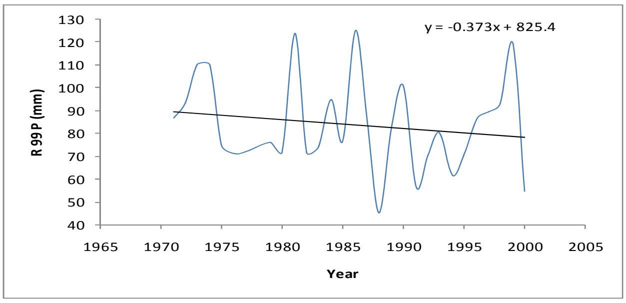

Figure 30: annual total rainfall from days greater than 99th percentile (R99P) over Makurdi

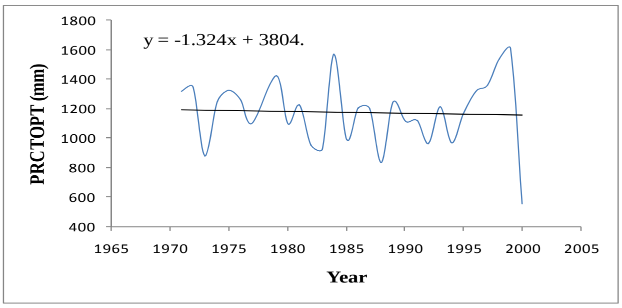

Figure 31: annual total rainfall from days greater than or equal to 1mm (PRCPTOT) over Makurdi

3.2 Discussion

To gain an insight into the nature of climatic variability within the climate system, it is necessary to study its components in a systematic way. In this study, emphasis was placed on precipitation, which was analyzed in terms of changes in the statistical distribution of the local rainfall. The study identified decreasing trends in some indices of extreme rainfall event across the middle-belt of Nigeria. At Jos, the study specifically found significant negative trends in R20, and PRCPTOT, while other indices: Rx5-day, SDII, R10, and R95P also showed decreasing trend. Furthermore, at Lokoja, the study identified decline trend in Rx5-day, R10, CDD and CWD although none of these indices was statistically significant. At Makurdi, significant negative trend was specifically found in CWD. While other indices: Rx1day, R10, CDD, R95P, R99P, and PRCPTOT also showed negative trend but not at a significant decrease rate. This finding is in line with the study of Abdukadri *et. al*. (2009) who had earlier reported that ‘’decline trend was identified in moisture effectiveness that intensified moisture stress across the belt in the last six decades signifying the fact that decrease moisture effectiveness is a prime aridity factor in the sub-region. By this result, the Sudan-sahelian belt is increasingly vulnerable to crops failure due to increased aridity (AI), late onset, and early retreat of rainfall resulting to shorter hydrologic growing season already obvious across the belt. The trend confirm the effect of climate change and is disastrous to agriculture, as delayed onset often leads to late planting of crops, while premature cessation leads to wilting and dryness of the crops before maturity, there by endangering food security in the belt’’.

5 CONCLUTION

The information provided by the indices not only includes how the mean values changed over time but how the statistical distribution of the data changed. In addition, the analysis gives us very important information about the trends in extremes. The results showed that Rx 5-day, SDII, R10, R20, R95P, and PRCPTOT have decreased at Jos. Likewise, Rx5-day, R10, CDD, and CWD have decreased at Lokoja. In the same vein, Rx1-day, R10, CDD, CWD, R95P, R99P and PRCPTOT have also declined at Makurdi. The results from the analysis, presented scientific information on magnitude, departures from long-term conditions and trends in rainfall in all the three stations but with a varying value due to population and size distribution, these inevitable climate effects, which needs to be adapted to may cost excessive spending in order to make life and environment worthwhile. To monitor indices of any extreme events accurately across each state in Nigeria, the Nigerian Government needs to invest in setting up weather station in every local government to cover for the lags in accuracy of data acquired when showing the spatial distribution of weather parameters. In addition, results of rainfall studies in any region can help the decision maker to manage their water resources, agricultural, environment and other water related projects.

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