Analysis of Rainfall Distribution, Temporal Trends, and Rates of Change in the Savannah Zones of Nigeria

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ABSTRACT *The impact of climate change is often demonstrated by rainfall and its attributes. Consequently, this study analyzes rainfall concentration, temporal trends, and rates of change in the savannah zones of Nigeria. Rainfall data were acquired from the archives of the Environmental Management Programme, Federal University of Technology, Minna, for 13 synoptic stations at annual, seasonal, and monthly time scales for the 1970–2016 period. The precipitation concentration index (PCI), Mann–Kendall trend test, Theil–Sen's slope estimator (β), and relative percentage change methods were adopted for data analysis. The findings reveal that PCI calculated on an annual scale falls into three categories 11–15, 16–20, and PCI > 20. Two distinct patterns emerged from the calculated PCI indicating that stations in the Guinea savannah zone (Bida, Yola, Minna, Jos, Bauchi, and Kaduna) have moderate, irregular, and strongly irregular rainfall concentrations, whereas stations in the Sudano-Sahelian savannah zone (Kano, Gusau, Maiduguri, Yelwa, Nguru, Sokoto, and Katsina) have irregular and strongly irregular rainfall concentrations. The Mann–Kendall analysis of the PCI values reveals that 8 of the 13 stations (62%) experienced downward trends. This implies that rainfall is sliding toward a moderate to uniform distribution. The trends, and consequently the variability in the annual and seasonal rainfall, reveal that, with the exception of Yola and Jos stations, where the trends were downward, the overall rainfall was increasing significantly in some areas and insignificantly in others. The magnitude of the significant upward trends in the annual rainfall was found to be 3.59 mm yr*$^{-1}$ *at Yelwa station, 9.84 mm yr*$^{-1}$ *at Bauchi station, 17.13 mm yr*$^{-1}$ *at Kano station, 3.98 mm yr*$^{-1}$ *at Sokoto station, and 3.11 mm yr*$^{-1}$ *at Katsina station. It is understood that the changes in rainfall distribution and trends have positive effects on water availability for crops, and this should facilitate enhanced productivity in rain-fed farming.*

RÉSUMÉ *[Traduit par la rédaction] Les effets des changements climatiques se démontrent souvent à l'aide des précipitations et de leurs attributs. Ainsi nous analysons la concentration, les tendances temporelles et les taux de changement des précipitations dans les savanes du Nigeria. Nous avons extrait les données de pluie des archives du Programme de gestion de l'environnement de la Federal University of Technology (Minna), pour 13 stations synoptiques, et ce, à des échelles annuelle, saisonnière et mensuelle pour la période de 1970 à 2016. Nous analysons les données à l'aide de l'indice de concentration des précipitations (ICP), du test de tendance Mann-Kendall, de l'estimateur de pente de Theil-Sen (β) et de calculs de changement relatif de pourcentage. Les résultats révèlent que l'ICP calculé sur une échelle annuelle se répartit en trois catégories : 11 à 15, 16 à 20 et ICP > 20. Deux répartitions distinctes émanent de l'ICP calculé. Ce qui indique que les stations de la savane guinéenne (Bida, Yola, Minna, Jos, Bauchi et Kaduna) possèdent des concentrations de pluie modérées, irrégulières et fortement irrégulières, tandis que les stations de la savane soudano-sahélienne (Kano, Gusau, Maiduguri, Yelwa, Nguru, Sokoto et Katsina) ont des concentrations de pluie irrégulières et fortement irrégulières. L'analyse Mann-Kendall des valeurs de l'ICP révèle que 8 des 13 stations (62%) ont connu une tendance à la baisse. Les précipitations tendent donc vers une répartition modérée à uniforme. Les tendances, et par conséquent la variabilité des précipitations annuelles et saisonnières, révèlent qu'à l'exception des stations de Yola et de Jos, où les tendances se révélaient à la baisse, les précipitations ont globalement augmenté, de façon significative dans certaines régions et de façon non significative dans d'autres. L'ampleur des tendances à la hausse significatives des précipitations annuelles atteint 3,59 mm an*$^{-1}$ *à la station de Yelwa; 9,84 mm an*$^{-1}$ *à la station de Bauchi; 17,13 mm an*$^{-1}$ *à la station de Kano; 3,98 mm an*$^{-1}$ *à la station de Sokoto et 3,11 mm an*$^{-1}$ *à la station de Katsina. Il est entendu que la modification de la répartition et des tendances des précipitations engendre des effets positifs sur la disponibilité de l'eau pour l'agriculture. Cette augmentation devrait faciliter le renforcement de la productivité de la culture sous pluie.*

KEYWORDS PCI; rainfall trends; Mann–Kendall test; savannah zones

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1 Introduction

The climate science community is in agreement that a number of hydroclimatic parameters are changing as a result of global warming caused by an increase in greenhouse gases. Based on a recent study, the average temperature of the Earth has increased by about 0.6°C over the twentieth century (Tabari & Hosseinzadeh, 2011). The increase in the amount of evaporation is one of the effects of climate change, as are extreme precipitation events. Rainfall is considered to be one of the important variables associated with monsoons in any part of the world. Previous studies suggest that the quantity of rainfall at weekly, monthly, and annual time scales varies widely (Valli, Sree, & Krishna, 2013). The variability in rainfall is expected to be exacerbated by climate change leading to intensification of water fluxes, with more evaporation and more precipitation (Some'e, Ezani, & Tabari, 2013). Similarly, precipitation amount has been unequally distributed around the globe, and several areas are expected to see significant reductions or major changes in the timing of wet and dry seasons. It has also been asserted that unbalanced distribution of rainfall may evoke periods of rainfall excess and periods of drought, which may make plant and crop growth difficult (Michiels, Gabriels, & Hartmann, 1992).

The impact of climate change is commonly evidenced by rainfall attributes (intensity, amount, duration, and timing), and the best indicators of these impacts are precipitation irregularities (Shi, Yu, Liao, Wang, & Jia, 2013). In tropical Africa, previous studies revealed that rainfall variability and associated droughts led to food shortages (Tadross, Hewitson, & Usman, 2005; Usman, Archer, Johnston, & Tadross, 2005). The worrisome issue about rainfall attributes is that their changes are expected to continue, particularly in the Sahel and sub-humid areas of Africa. This has led previous researchers to recommend continued monitoring and detailed study of rainfall phenomena (Tadross et al., 2005; Hachigonta, Reason, & Tadross, 2008; Bayer et al., 2014). Additionally, understanding the changes in rainfall patterns remains an important climatic problem that needs continued study. Two important indices in this regard are the precipitation concentration index (PCI) and trends. The PCI index describes the precipitation time distribution frequently used at the annual time scale. An increase in the PCI index implies that the precipitation concentration has led to irregular distribution in a region (Khalili, Tahoudi, Mirabbasi, & Ahmadi, 2015).

This study covers all (Guinea and Sudano-Sahelian) the savannah zones of Nigeria where more than 65% of the population is directly or indirectly engaged in a wide range of agricultural activities. Rainfall is the most important physical factor in determining the agricultural production in this area, which spans 3° to 15°E and 8° to 14°N. It is for this reason that Usman and Reason (2004) argued that application of rainfall studies to fields such as agriculture and water resource management needs more detailed information. Even though some work has been done on precipitation variability over the study area, most of the earlier studies, for example, Abaje, Ishaya, and Usman (2010), Abubakar and Adesola (2012), and Ifabiyi and Ojoye (2013), were limited in temporal coverage, methodologies, and geographic area (the Sudano-Sahelian savannah zone of Nigeria only). Thus, there is room for additional studies over all the savannah zones of Nigeria, utilizing more appropriate methodologies and longer time series. The use of more appropriate analytical methodologies examining intra-annual as well as longer-term variability is important because it has been established, for example, that crops are more likely to do well with uniformly spread light rains than with a few high intensity rainfall events concentrated in a short time period (Usman & Reason, 2004). Rasel, Ismal, and Keramat (2017) and de Luis, Gonzalez-Hadalgo, Brunetti, and Longares (2011) added that the information derived from a thorough understanding of the spatial and temporal characteristics of rainfall is very important for agricultural planning and flood frequency analysis. Consequently, in this study, PCI, PCI trend, rainfall trends, and relative changes are determined and their implications on rain-fed agriculture are discussed.

2 Materials and methods

a *Data Used*

Daily rainfall data from 13 globally referenced meteorological stations (Bida, Yola, Minna, Jos, Bauchi, Kaduna, Yelwa, Maiduguri, Kano, Gusau, Nguru, Sokoto, and Katsina) were acquired from the archives of the Environmental Management Programme, Federal University of Technology, Minna, for the 1970–2016 period.

b *Data Analysis*

1 PRECIPITATION CONCENTRATION INDEX

The PCI was designed by Oliver (1980) as an indicator of rainfall concentration over specified time scales. For the purpose of this study, the PCI is calculated on an annual scale for each station as in Eq. (1):

$$\mathrm{PCI}_{\mathrm{annual}} = \left[\frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \right] 100, \qquad (1)$$

where p_i is the monthly precipitation in month i.

TABLE 1. Classification of PCI adapted from Oliver (1980).

PCI Value	Distribution of Precipitation
< 10	Uniform precipitation distribution (i.e., low precipitation concentration)
11–15	Moderate precipitation concentration
16–20	Irregular distribution
> 20	Strongly irregular distribution (i.e., high precipitation concentration)

The interpretation of the PCI classification as suggested by Oliver (1980) is represented in Table 1. Recently, many researchers (e.g., Michiels et al., 1992; Adegun, Balogun, & Adeaga, 2012; Hänsel et al., 2013; Shi et al., 2013; Valli et al., 2013; Khalili et al., 2015; Rasel et al., 2017) have adopted this method in precipitation analysis.

In addition to the above, the frequency count of PCI classes in each station is carried out.

2 SERIAL CORRELATION EFFECT

The Mann-Kendall test is a non-parametric test commonly used to detect significant trends in hydrological and meteorological time series (Oguntunde, Lischeid, Abiodun, & Dietrich, 2014; Huang et al., 2014; He, Ye, & Yang, 2015; Kundu, Khare, Mondal, & Mishra, 2015). It is a simple and robust test and can cope with missing values and values below a detection limit. The application of the Mann–Kendall test to the time series of annual rainfall levels was done after subjecting the rainfall data to serial correlation investigation. This was to meet the Mann-Kendall test requirement for a time series to be serially independent. The suggestion being that the presence of serial correlation frequently leads to rejection of the null hypothesis of no trend (Tabari, Somee, & Zadeh, 2011). In this study, the presence of serial correlation in the annual rainfall was investigated graphically with the help of the autocorrelation function (ACF) in the R software, which computes the autocorrelation corresponding to the time series of annual rainfall. Similar studies (Tabari et al., 2011; Vousoughi, Dinpashoh, Aalami, & Jhajharia, 2013; Jhajharia, Dinpashoh, Kahya, Choudhary, & Singh, 2014) adopted the serial correlation test as a standard.

3 TREND ANALYSIS

The trend analysis was performed on the annual value of the PCI to determine whether the PCI is moving toward a strongly irregular distribution or a uniform precipitation distribution. Similarly, the annual and monthly rainfall values were subjected to the trend test to determine increases or decreases in the rainfall.

The analyses were carried out using the Mann-Kendall test (Mann, 1945; Kendall, 1975) with significant levels at $\alpha = 0.001$, 0.01, 0.05, and 0.1 taken as thresholds to classify the significance of upward and downward trends. The Mann-Kendall test is

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

where

$$\text{sign}(x_j - x_k) = \begin{Bmatrix} 1 & if (x_j - x_k) > 0 \\ 0 & if (x_j - x_k) = 0 \\ -1 & if (x_j - x_k) < 0 \end{Bmatrix}, \text{ and} \quad (3)$$

$$\text{VAR}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18}, \quad (4)$$

where n is the number of data points; t_i are the ties of the sample time series; and m is the number of tied values (a tied group is a set of sample data having the same value).

Then Eqs (3) and (4) were used to compute the test statistic Z from the following equation:

$$Z = \begin{Bmatrix} \frac{S-1}{\sqrt{\text{VAR}(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}} & f\ S < 0 \end{Bmatrix}. \quad (5)$$

A positive value of Z indicates an upward trend; a negative value indicates a downward trend, and a zero value indicates no trend.

4 THE MAGNITUDE OF RAINFALL TREND CHANGES

The Theil-Sen slope estimator (β) measures the magnitude of change (per unit time) using a non-parametric procedure developed by Sen (1968). The Theil-Sen slope approach is considered to give a robust estimate of the magnitude of a trend (Yue, Pilon, Phinney, & Cavadias, 2002), and for this reason it has been preferred over other regression slope approaches in recent hydrologic studies (e.g., Some'e et al., 2013; Huang et al., 2014; Jhajharia et al., 2015; Zhang, Zheng, Wang, & Yao, 2015). The trend magnitude using this method is computed as follows:

$$\beta = \text{Median}\left(\frac{x_j - x_k}{j - k}\right) \quad \forall k < j, \quad (6)$$

where β is the slope between data points x_j and x_k.

The magnitude of rainfall trend changes is analyzed with the aid of Excel template software developed by the Finnish Meteorological Institute MAKESENS 1.0.

5 RELATIVE PERCENTAGE CHANGE

Equation (7) was used to compute the relative percentage change (RPC) of the annual PCI, as well as monthly and annual rainfall:

$$\text{RPC} = \left(\frac{n\beta}{\bar{X}}\right)100, \quad (7)$$

where n is the length of the trend period (years); β is the magnitude of the trend slope of the time series determined by the Theil-Sen median estimator; and $\bar{X}$ is the absolute average value of the time series. This method was used in a similar study by Some'e et al. (2013) and Tabari and Talaee (2013)

3 Results and discussion

a *Autocorrelation Test on the Rainfall Data*

The results of the serial correlation tests on the rainfall data are depicted in Figs 1a and 1b. The plots suggest that the autocorrelation present in the rainfall series is not significant because most of the vertical spikes in the ACF plots fall within the horizontal band defined by the dotted lines beyond which serial correlations would be deemed to be significant. Consequently, the Mann-Kendall test was applied without any corrections for serial correlation.

b *PCI Values for the Stations*

The PCI values were estimated for all 13 stations throughout the savannah zone of Nigeria from 1970 to 2016. Figures 2a and 2d and Table 2 depict the values of PCI and the frequency of PCI across the study area respectively. The values of Z obtained through the Mann–Kendall test are presented in Table 3. The PCI values for the stations in the Guinea savannah zone (Bida, Yola, Minna, Jos, Yelwa, Bauchi, and Kaduna) range between 14 and 43, signifying a range between a moderate precipitation distribution and a strongly irregular distribution. The highest values of PCI were recorded at the Yelwa rain gauge station. The PCI values for the Sudano-Sahelian savannah stations (Maiduguri, Kano, Gusau, Sokoto, Nguru, and Katsina) were in the same range (between 13 and 75) in the savannah group of stations in Guinea but with a predominant occurrence of irregular and strongly irregular distributions. The highest values of PCI were recorded at the Maiduguri and Nguru rain gauge stations. As would be expected, these two stations are on the northeastern flank of the study area where the mean annual total rainfall is lowest in Nigeria.

The frequency counts for the PCI of the stations presented in Table 2 revealed that at the Kaduna station (10.60°N) and others to its south, rainfall demonstrated moderate, irregular, and strongly irregular rainfall distribution, with the exception of Minna and Bauchi stations that did not experience moderate rainfall distributions. The PCI frequency counts north of the Kaduna station indicate rainfall distribution was strongly irregular.

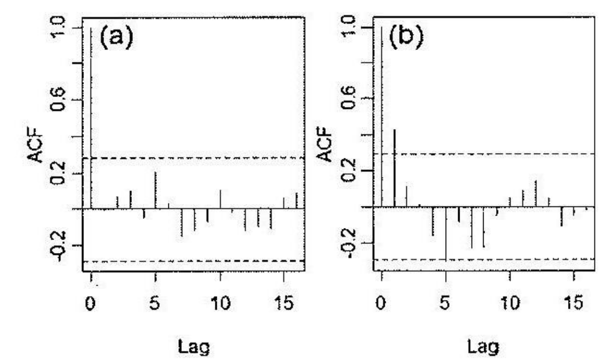

Fig. 1 Serial correlation test of rainfall data. (a) Bida, Yola, Minna, Jos, Bauchi, and Kaduna stations. (b) Yelwa, Maiduguri, Kano, Gusau, Sokoto, Nguru, and Katsina stations.

The climate system in this study region varies from semi-arid to sub-humid. The onset of rainfall is mainly determined by the position of the Intertropical Discontinuity (ITD; Abdulrahim, Ifabiyi, & Ismaila, 2013; Ifabiyi & Ojoye, 2013). The south-to-north movement in the position of the ITD influences the distribution of rainfall over Nigeria (Oguntunde et al., 2014). The rainfall begins around May in the southern parts of the study area (Bida, Minna, Jos, and Kaduna) and spreads northward, reaching its peak between July and September (Oguntunde, Abiodun, & Lischeid, 2011) in line with the movement of the ITD. The findings imply that the more southerly locations tend to have moderate to irregular rainfall distributions, whereas the more northerly parts tend to have irregular to strongly irregular rainfall distributions.

The Mann–Kendall trend analysis of the PCI values at Yola, Yelwa, Kaduna, Sokoto, Nguru, and Katsina stations revealed non-significant downward trends in the PCI values over the 1970–2016 period. The implication of this is that the rainfall over those stations is sliding toward a moderate distribution. At Bida, Bauchi, Maiduguri, Kano, and Gusau, the PCI values indicated non-significant increasing trends over the same period. On the other hand, the PCI values for Minna and Jos stations revealed significant decreasing trends at $\alpha = 0.1$ and $\alpha = 0.05$, respectively. The magnitudes of the change for these stations are −0.04 per year and −0.03 per year, respectively.

The spatiotemporal pattern of the mean annual PCI is represented in Fig. 3. The study area is generally typified by two major rainfall concentration patterns: an irregular distribution (central and eastern flanks of the study area) and a strongly irregular distribution (the bulk of the study area). Table 4 shows the mean PCI values and trends reported by other studies. The PCI values exhibited in the Andhra Pradesh, Jiangxi province, and Fudian were similar to those in this study, while those in Iran, Iraq, and northwestern Bangladesh are much less so. These indicate that although there are weather-producing features ranging in scale from the synoptic to the global that may similarly influence precipitation regimes, other factors from local to regional scales are also at play. It will be interesting to see how these patterns are depicted in other parts of the globe as more studies are conducted along these lines.

c *Trends in Rainfall*

The Mann-Kendall test and the Theil-Sen slope estimator (β) were applied to detect annual, seasonal, and monthly trends in the rainfall series. The results are depicted in Table 5 and reveal insignificant upward trends in seasonal rainfall at Bida, Minna, Kaduna, Maiduguri, Gusau, Nguru, and Katsina stations. Insignificant downward trends in seasonal rainfall were detected at Yola and Jos stations, while significant upward trends were detected at Yelwa, Bauchi, Kano, and Sokoto stations at various α levels. The annual rainfall series indicated insignificant upward trends at Minna, Kaduna, Maiduguri, Gusau, and Nguru, significant upward

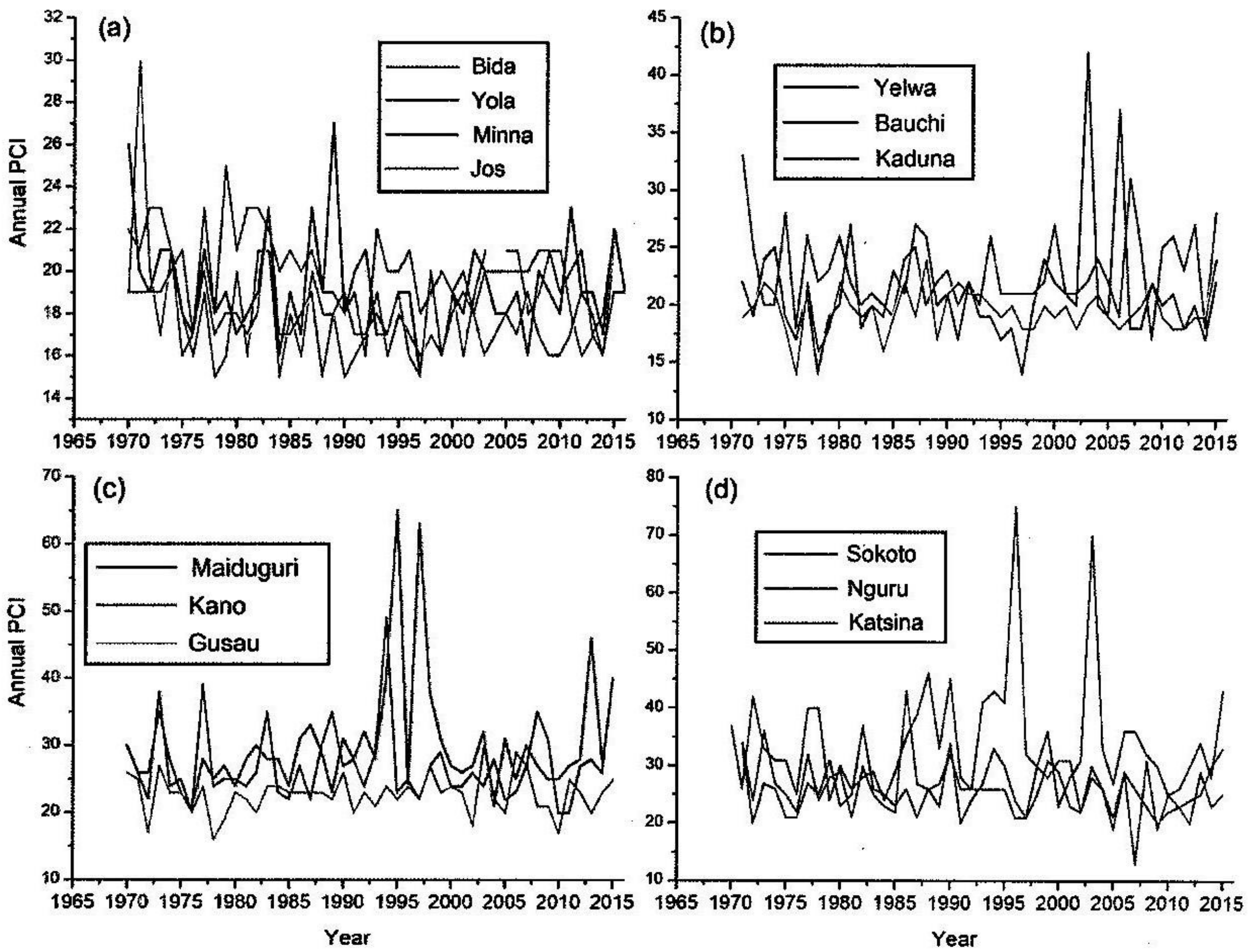

Fig. 2 Precipitation concentration index series for (a) Bida, Yola, Minna, and Jos; (b) Yelwa, Bauchi, and Kadina; (c) Maiduguri, Kano, and Gusau; and (d) Sokoto, Nguru, and Katsina.

trends at Yelwa, Bauchi, Kano, Sokoto, and Katsina, and insignificant downward trends at Bida, Yola, and Jos rain gauge stations. It is worth noting that, with the exception of Katsina, all stations that experienced significant upward trends in seasonal rainfall also experienced significant upward trends in annual rainfall. The results of the annual trend tests are consistent with Abaje, Ati, and Iguisi (2012), Ifabiyi and Ojoye (2013), and Usman and Abdulkadir (2014) who reported upward trends in rainfall in the Sudano-Sahelian savannah zones of Nigeria.

Based on the Theil–Sen estimator, the magnitudes of the significant trends at the $\alpha = 0.001$ confidence level is 17.29 mm yr^{-1} for seasonal rainfall and 17.13 mm yr^{-1} for

TABLE 2. PCI frequency count at the thirteen stations.

Stations	PCI < 10	11–15	16–20	PCI > 20
Bida	0	3	32	10
Yola	0	1	34	11
Minna	0	0	27	19
Jos	0	2	43	2
Yelwa	0	2	24	19
Bauchi	0	0	12	33
Kaduna	0	1	31	13
Maiduguri	0	0	1	44
Kano	0	0	3	42
Gusau	0	0	10	36
Sokoto	0	0	4	41
Nguru	0	0	0	46
Katsina	0	1	2	42

TABLE 3. PCI trends.

Stations	Z Test	β
Bida	0.62	0.0157
Yola	−0.15	−0.0031
Minna	−1.76⁺	−0.0433
Jos	−2.01*	−0.0330
Yelwa	−0.59	−0.0155
Bauchi	0.57	0.0179
Kaduna	−0.39	−0.0105
Maiduguri	1.24	0.0710
Kano	0.15	0.0049
Gusau	0.17	0.0043
Sokoto	−0.69	−0.0430
Nguru	−0.01	−0.0003
Katsina	−1.14	−0.0688

* Significant trend at $\alpha = 0.05$
\+ Significant trend at $\alpha = 0.1$

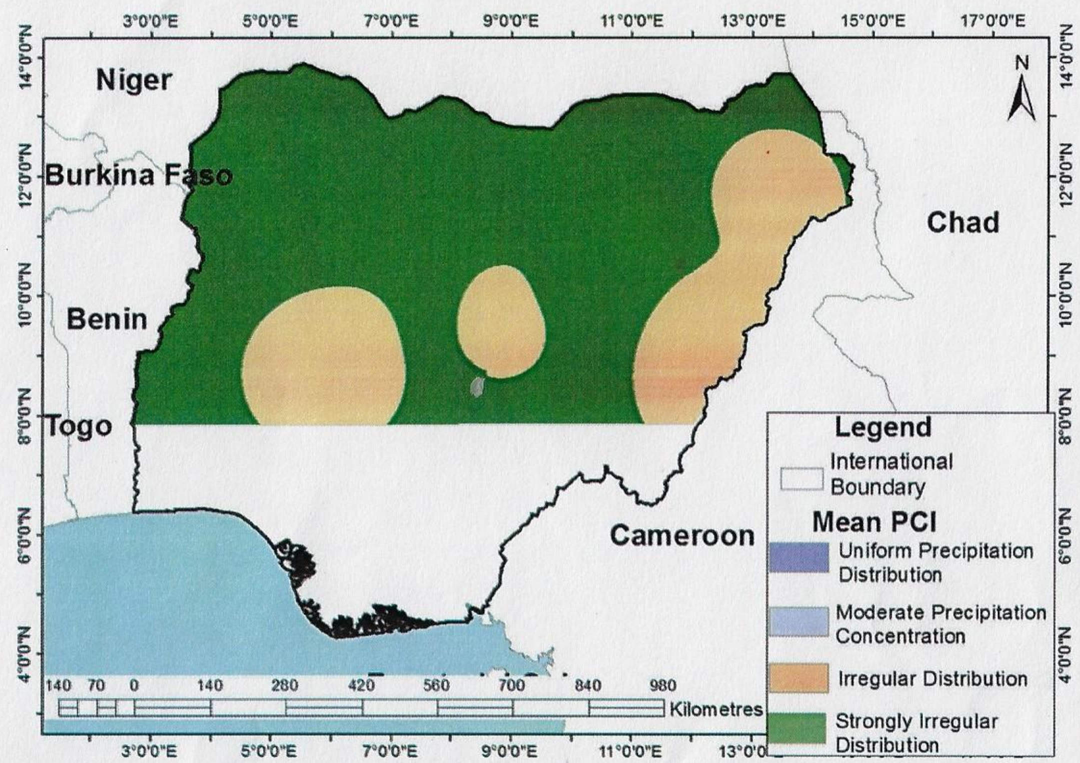

Fig. 3 Mean annual precipitation concentration index.

annual rainfall at Kano station. The magnitudes of the significant trends at the $\alpha = 0.01$ confidence level are 9.95 mm yr^{-1} for seasonal rainfall and 9.84 mm yr^{-1} for annual rainfall at Bauchi station. At Yelwa and Sokoto stations the magnitudes of the significant trends at $\alpha = 0.05$ are 4.10 mm yr^{-1} and 3.77 mm yr^{-1}, respectively, for seasonal rainfall and 3.59 mm yr^{-1} and 3.98 mm yr^{-1}, respectively for annual rainfall. Finally, the magnitudes of the significant trends at Katsina station at $\alpha = 0.1$ are 3.11 mm yr^{-1} for annual rainfall.

The RPC presented in Table 5 indicates that the annual RPC (% Δ-*A*) at Jos, Minna, Bauchi, Sokoto, and Katsina stations is greater than the seasonal RPC (% Δ-*S*). The positive seasonal RPC ranges between 0.70% at Bida and 83.07% at Kano stations, while the negative RPC ranges between −8.72% a Jos and −2.28% at Yola stations. The positive annual RPC ranges between 1.63% at Maiduguri and 81.23% at Kano stations, while the annual negative RPC ranges between −5.48% at Jos and −1.59% at Bida stations.

The spatiotemporal pattern of the RPC in annual and seasonal rainfall is depicted in Figs 4a and 4b. The changes in the patterns for annual and seasonal rainfall are similar.

d *Monthly Trends in Rainfall*

The investigation of changes in the monthly precipitation series provides a picture of the timing of significant changes in annual precipitation. The months of May to October are taken into consideration because they represent the growing season in the savannah zones of Nigeria. Table 7 shows that the changes in annual precipitation at the stations in the savannah zones are not uniformly distributed over different months. The monthly Mann-Kendall results show mixed (upward and downward) trends at different alpha (α) levels across the study area. The magnitudes of the trends are depicted in Table 7, and the relative rates of change in the monthly rainfall are presented in Table 8. Table 6 also illustrates significant and insignificant upward and downward trends at different

TABLE 4. Mean PCI values and trends reported by other studies.

Area	Country	Precipitation Period	PCI	Z	β	References
Andhra Pradesh	India	1981–2010	> 16	—	−1.2	Valli et al. (2013)
Jiangxi province	China	1960–2008	> 16	0.63	19.4	Huang, Sun, and Zhang (2013)
Fudian	China	1961–2010	17.3	0.33	—	Shi et al. (2013)
Iran	Iran	1961–2010	< 10	−1.33	—	Khalili et al. (2015)
Northwestern	Bangladesh	2000–2011	10.4–10.9	—	—	Rasel et al. (2017)
Iraq	Iraq	1980–2010	< 16	—	—	Al-shamarti (2016)

TABLE 5. Trends of seasonal (*Z-S*), annual (*Z-A*) rainfall, magnitudes of seasonal (β-*S*), annual (β-*A*) and their relative percentage change (% Δ).

Stations	(Z-S)	(Z-A)	(β-S)	(β-A)	% Δ-S	% Δ-A
Bida	0.06	−0.24	0.16	−0.40	0.70	−1.59
Yola	−0.25	−0.53	−0.41	−0.95	−2.28	−5.04
Minna	0.97	1.02	1.56	1.79	6.34	6.83
Jos	−1.43	−0.97	−2.12	−1.46	−8.72	−5.48
Yelwa	2.06*	2.04*	4.10	3.59	20.59	17.11
Bauchi	3.16*	3.32**	9.95	9.84	41.38	42.30
Kaduna	1.57	1.50	4.33	4.19	36.39	34.87
Maiduguri	0.30	0.28	0.60	0.44	2.32	1.63
Kano	4.49***	4.43***	17.29	17.13	83.07	81.23
Gusau	0.36	0.38	0.84	0.66	4.36	3.52
Sokoto	2.24*	2.30*	3.77	3.98	26.99	28.16
Nguru	0.45	0.32	1.02	0.70	11.87	8.08
Katsina	1.61	1.69+	2.91	3.11	23.85	24.85

***Significant trend at $\alpha = 0.001$
** Significant trend at $\alpha = 0.01$
* Significant trend at $\alpha = 0.05$
+ Significant trend at $\alpha = 0.1$

confidence levels. A significant upward trend is found at Yola in June; Minna in May, September, and October; Jos in October; Yelwa in September and October; and Bauchi from May to October; Maiduguri in July, August, and October; Kano in all months except May; and Kaduna, Gusau, Sokoto, Nguru, and Katsina in October. In July and August there is a significant downward trend at Jos. It should be noted that spatially consistent and significant upward trends

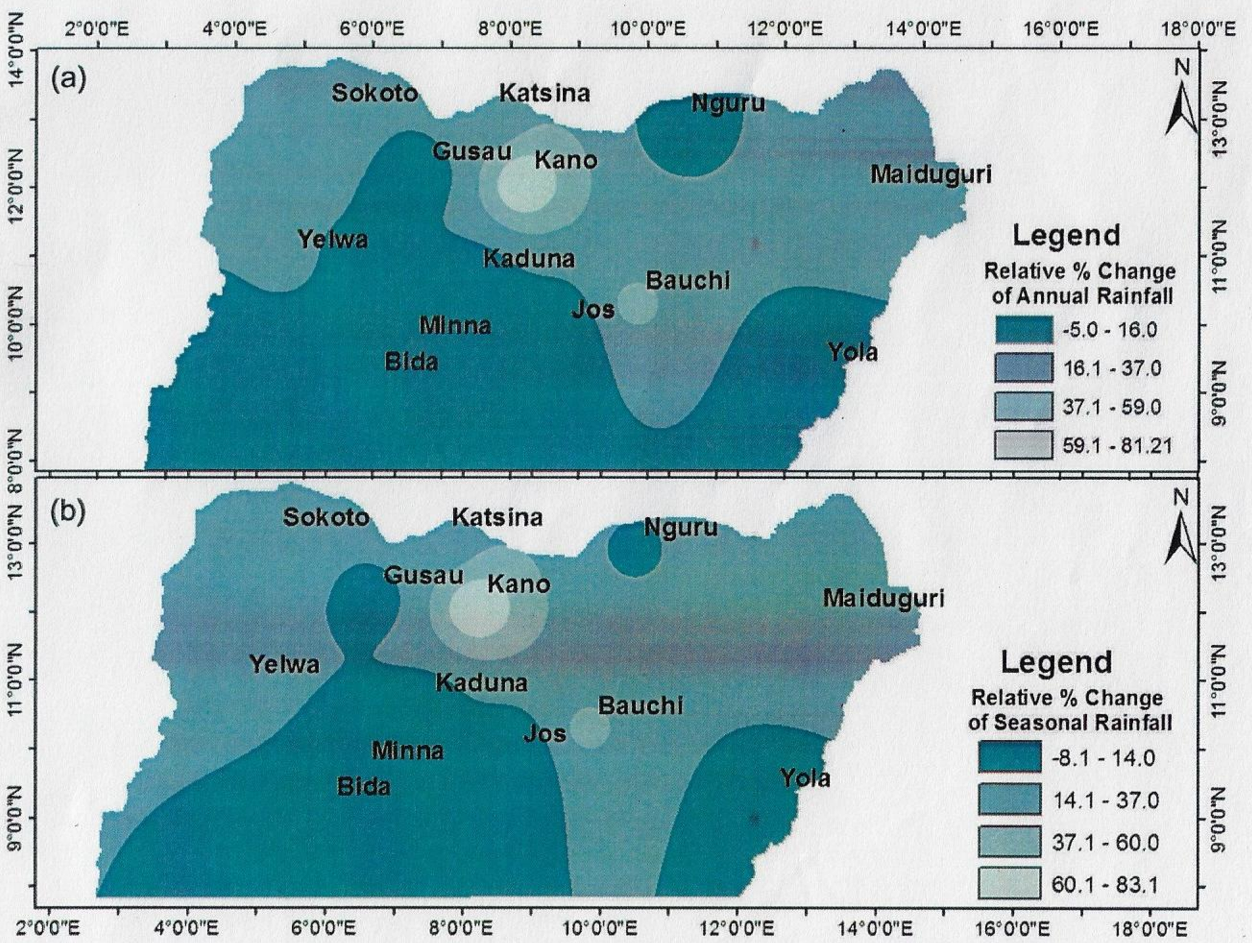

Fig. 4 Relative percentage change in (a) annual and (b) seasonal rainfall.

TABLE 6. Trends in monthly rainfall.

Stations	May	June	July	August	September	October
Bida	−0.89	1.44	−0.44	1.20	0.80	0.48
Yola	−1.74	1.33+	−1.97*	−1.54	1.56	0.77
Minna	1.72+	0.49	−0.25	0.02	1.69+	1.89+
Jos	0.18	0.75	−1.94+	−1.78+	−0.62	2.49*
Yelwa	0.69	0.69	0.11	1.55	2.40*	1.99*
Bauchi	2.30*	4.06***	3.04**	3.81***	4.29***	2.80**
Kaduna	−1.61	−0.26	0.34	−0.80	1.25	1.68+
Maiduguri	−0.44	0.52	1.88+	2.37*	−0.27	1.81+
Kano	1.12	1.92+	3.27**	3.83***	3.57***	1.66+
Gusau	0.80	0.09	−0.55	0.81	−0.64	1.71+
Sokoto	1.19	0.61	1.38	1.04	1.04	2.06*
Nguru	0.11	0.78	−1.03	1.08	0.54	1.72+
Katsina	0.30	1.64	1.27	1.12	−0.30	1.92+

***Significant trend at $\alpha = 0.001$
** Significant trend at $\alpha = 0.01$
* Significant trend at $\alpha = 0.05$
+ Significant trend at $\alpha = 0.1$

TABLE 7. Magnitudes of change (β) of monthly rainfall.

Stations	May	June	July	August	September	October
Bida	−0.674	1.439	−0.425	1.687	0.778	0.240
Yola	−0.883	1.056	−1.265	−1.176	1.316	0.241
Minna	1.571	0.314	−0.166	0.109	1.492	2.106
Jos	0.183	0.394	−1.579	−1.391	−0.500	0.922
Yelwa	0.475	0.506	0.068	2.049	1.562	0.752
Bauchi	1.536	4.031	5.247	7.067	4.732	0.851
Kaduna	−1.003	−0.138	0.292	−0.851	1.383	0.786
Maiduguri	−0.062	0.305	1.718	2.254	−0.100	0.103
Kano	0.482	1.703	4.416	6.409	3.107	0.161
Gusau	0.450	0.070	−0.344	0.587	−0.503	0.377
Sokoto	0.489	0.275	0.879	0.525	0.646	0.117
Nguru	0.000	0.225	−0.689	0.979	0.320	0.033
Katsina	0.065	0.881	0.938	0.953	−0.109	0.039

TABLE 8. Relative percentage changes in monthly trends magnitude (%).

Stations	May	June	July	August	September	October
Bida	−24.34	40.65	−9.03	37.69	16.68	12.89
Yola	−41.22	37.72	−34.00	−27.19	35.19	20.15
Minna	36.39	8.91	−2.01	0.77	28.95	26.95
Jos	4.97	9.52	−27.71	−0.30	−12.57	90.68
Yelwa	23.21	16.69	1.63	38.73	37.83	62.25
Bauchi	89.00	120.42	99.44	119.86	135.75	108.00
Kaduna	−36.88	−3.57	5.80	−12.29	23.66	50.17
Maiduguri	−9.88	18.68	50.71	56.01	−5.18	35.07
Kano	36.51	57.84	80.01	86.67	96.19	40.36
Gusau	26.99	2.69	−8.37	10.14	−12.93	52.59
Sokoto	49.77	14.99	23.21	11.57	26.99	27.74
Nguru	0.00	25.31	−25.08	28.75	24.15	20.40
Katsina	8.05	54.88	27.81	23.37	−5.53	11.24

in October were experienced across the study area. For three of the five stations with significant upward trends in October (Kaduna, Sokoto, and Katsina), the annual trends suggest that the end of the wet season is becoming increasingly wetter than usual. For the other two stations (Gusau and Nguru), however, the downward annual trends suggest that the upward trends in October are most probably countered by significant downward trends for the other months of the hydrologic growing season. This general finding indicating that rainfall shifts have occurred in different months should influence decision making with respect to changes in cropping and cropping calendars in the light of the current drive to achieve food security and attain sustainable development goals.

The magnitude of the monthly rainfall trends for the study period obtained from the Theil–Sen slope estimator (Table 7) shows variations across different stations. Most of the months have a positive rainfall magnitude with a maximum in August at Bauchi station ($7.07\ \text{mm yr}^{-1}$), while the lowest magnitude is noted in July at Jos station ($-1.58\ \text{mm yr}^{-1}$).

e *Relative Percentage Change in Monthly Rainfall*

The relative change in monthly rainfall is presented in Table 8, which shows that most stations in the study area indicated a positive RPC with a monthly increase in rainfall of 0.77% in August at Minna and 135.75% in September at Bauchi. Conversely, monthly rainfall decreased by 0.3% in August at Jos and 41.22% in May at Yola. Compared with annual and seasonal rainfall, the sample variation of monthly rainfall series is much larger.

4 Conclusions

The study adopted the PCI, Mann-Kendall trend test, Theil–Sen slope estimator, and RPCs to investigate rainfall concentration, spatiotemporal trends, and changes in rainfall at 13 synoptic stations in the savannah zones of Nigeria at annual, seasonal, and monthly time scales for the 1970–2016 period. The PCI test revealed that stations experienced alternating upward and downward trends. Two stations (Minna and Jos) showed significant decreases in PCI values implying marked tendencies toward a more evenly spread rainfall distribution. Eight other stations showed similar but insignificant tendencies.

The Mann-Kendall trends of annual and seasonal rainfall revealed that about one-third of the stations experienced significant upward changes. The rates of the significant upward trends in annual rainfall were 3.59 mm yr^{-1}, 9.84 mm yr^{-1}, 17.13 mm yr^{-1}, 3.98 mm yr^{-1}, and 3.11 mm yr^{-1} at Yelwa, Bauchi, Kano, Sokoto, and Katsina, respectively. The findings for annual rainfall trends are consistent with those of Abaje et al. (2012) and Ifabiyi and Ojoye (2013) who studied trends over the Sudano-Sahelian zone. The monthly Mann-Kendall trends indicate that both significant and insignificant negative and positive changes in rainfall have occurred across the savannah zones. The observed changes in rainfall distribution and trends are likely to have positive effects on water availability for crops, and this should facilitate enhanced productivity in rain-fed agriculture.

Disclosure statement

No potential conflict of interest was reported by the authors.

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