

## Spatiotemporal variability of rainfall and drought characterization in Kaduna, Nigeria

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### Abstract

Rainfall variability and drought events can affect food security globally. This study aimed to assess the spatial and temporal trends and variability of rainfall in Kaduna State, Nigeria. Gridded rainfall data were obtained from the Climate Research Unit (CRU\_TS 4.07) (1952–2022) for Birnin Gwari, Kaduna, Kafanchan and Zaria towns. The rainfall data were subjected to the Anderson–Darling normality test and found to be normally distributed. The data were analysed using the coefficient of variation (CV), rainfall anomaly index (RAI) and precipitation concentration index (PCI). The trend was assessed using the Mann–Kendall trend test, and finally, meteorological drought was computed using the standardized precipitation index (SPI). The results revealed that all four locations had low to moderate variability, with CVs < 15%. The rainfall anomaly index revealed that 1983 was the driest year for Birnin Gwari, Kaduna and Kafanchan, with RAI values of – 4.863, – 4.474 and – 4.316, respectively, while in Zaria, the driest year was 1974, with a RAI value of – 4.065. The PCI showed that there was a high concentration of rainfall in Birnin Gwari, Kaduna, and Kafanchan. However, Zaria experienced 41 years of high concentrations and 30 years of very high concentrations of precipitation. The Mann–Kendall trend test revealed that all four locations experienced a significant downward trend in rainfall within the study period. The Z statistics for Birnin Gwari, Kaduna, Kafanchan and Zaria were – 1.112, – 0.357, – 0.556 and – 0.764, respectively, all indicating decreasing rainfall amounts. Finally, the SPI Birnin Gwari and Kaduna experienced 18 months of severe drought, with maximum intensities of – 2.671 and – 3.111, respectively. Kafanchan experienced 25 months of drought with a maximum intensity of – 2.643, while Zaria experienced 30 months of drought with a maximum intensity of – 3.069. These severe droughts occurred from the 1970s to the 1990s. The study concluded that rainfall concentrations were mostly high and very high, and severe, catastrophic drought events occurred in the 1970s and 1980s.

**Keywords** Rainfall variability · Precipitation concentration index · Rainfall anomaly index · Kaduna State · SPI

## 1 Introduction

Globally, an increasing number of small-scale farmers are being impacted by the environmental and socioeconomic effects of climate change, which is typically linked to fluctuations in rainfall [1]. In Northern Nigeria, these changes in the quantity and length of rainfall have been a source of grave concern to farmers, water resource managers and other stakeholders. This variability becomes more frequent as the concentration of greenhouse gases continues to increase [2]. Changes in rainfall variability can be ascribed to various climate mechanisms [3–6]. Generally, rainfall is the most significant climate variable

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affecting hydrological and climatic changes that affect the environment and human life both directly and indirectly [7] because the majority of hydrological processes depend on rainfall, and its spatial and temporal distribution and fluctuations can have a significant influence on ecosystems and the management of water resources [8]. Long-term climate change related to changes in the patterns of rainfall, variability, and temperature in sub-Saharan Africa is anticipated to increase the periodicity of droughts and flooding [9]. Additionally, rainfall-related natural disasters have increased in intensity and frequency in recent decades [10, 11].

Rainfall influences the availability of water for agriculture and crop yield [12, 13]. Thus, rainfall variability threatens the sustainability of millions of people whose livelihoods rely on agriculture in sub-Saharan Africa [11, 14], especially people with low adaptive capacity. In Nigeria, similar to most other African countries, there is mounting evidence that the region will be severely impacted by rainfall variability, particularly in arid regions. This may lead to a decline in agricultural production [15], adversely affecting food security. This can significantly impact the continent's target of reducing poverty (SDG1) [16], ending hunger, and achieving food security (SDG2) [17, 18] while taking steps to enhance resilience to rainfall-related disasters (SDG13) [19].

Apart from agriculture and natural disasters, studies have shown that rainfall influences different aspects of human endeavors. Rainfall variability has been identified as a factor responsible for the seasonal migration of people [20, 21] and a factor influencing communal conflicts in sub-Saharan Africa [22]. Similarly, the quantity, length, and intensity of rainfall, as well as its geographic distribution, have direct and substantial impacts on human health [23, 24]. It is a critical factor influencing the spread of infectious diseases such as cholera and meningitis [25, 26] and contributes significantly to malaria outbreaks [23]. Rainfall also influences natural systems and processes. For example, rainfall affects the quality and amount of runoff in a basin [27] and determines the quality and quantity of groundwater [28, 29], the hydrological regime of rivers [8], and the health and functions of ecosystems [30].

Several studies related to precipitation in the Kaduna River Basin have been carried out [31–34]. However, none of these studies focused on Kaduna State, a state covered by Guinea and Sudan Savanna. Additionally, several methods have been used to assess rainfall trends, variability and meteorological drought worldwide. These include the Mann–Kendall trend test [35, 36], innovative trend analysis [37], standardized anomaly index (SAI) [30, 38], precipitation concentration index (PCI) [1, 39, 40], and coefficient of variation [14, 41], among others. Thus, this study will use different methods to gain insight into the spatial and temporal variability of rainfall in Kaduna State.

However, because of the paucity of rainfall data, we used gridded rainfall datasets from CRU (CRU\_TS, v4.7). Furthermore, indices such as rainfall anomalies, precipitation concentrations, and standardized precipitation indices will be used to assess climate variability and meteorological drought in Kaduna State, Nigeria. Specifically, this study aims to analyse the trends in rainfall and characterize droughts in Kaduna between 1952 and 2022. The objectives of this study were to assess the variability of rainfall in Kaduna State, to examine the trend of rainfall in Kaduna State, and to assess drought in Kaduna State between 1952 and 2022.

Kaduna State is a major agricultural hub in northern Nigeria, with a variety of crops grown across the state. Kaduna is the highest producer of corn in the country, and it produces 10% of groundnuts consumed in Nigeria [42]. Additionally, Nigeria is the second largest exporter of ginger in the world after India, and Kaduna accounts for about 95% of the country's production [43]. Furthermore, according to the bureau, 1.3 million households in Kaduna are agricultural, with almost 90% of them relying on rainfed agriculture for their livelihoods. This study will bridge this gap and help governments and relevant stakeholders in agriculture and food production understand the trend and variability of rainfall, especially with regard to agricultural production, such as the amount of rainfall, and determine the length of the growing season. Additionally, the findings from this study will help disaster risk managers understand the occurrence of hydrological disasters resulting from droughts, which are covered under SDG 15, especially in Sub-Saharan Africa. Additionally, this study will help in understanding the impacts of excess rainfall, which can lead to floods, to develop early warning systems that are vital for achieving SDG 6.

## 2 Materials and methods

### 2.1 Description of study area

Kaduna State is composed of twenty-three (23) local government areas [44]. It lies between latitudes 8° 59' 9" N and 11° 31' 53" N and longitudes 6°4' 28" E and 8° 49' 54" E, with an area of 46,053 km<sup>2</sup> (see Fig. 1). According to the Köppen classification, Kaduna has a tropical savanna climate (Aw) characterized by alternating wet and dry conditions [45]. The dry season runs from October to April of the next year, while the rainy season runs from April through mid-October,

peaking in August [46, 47], with an annual average of 1323 mm [48]. There is variation in the spatiotemporal distribution of rainfall in Kaduna State; the average rainfall is approximately 1733 mm around Kafanchan, 1203 mm in Kaduna town, and 1032 mm in the Zaria axis [47].

The southern part of Kaduna State has a typical Guinea savannah vegetation [49, 50], while the northern part is the Sudan savannah [51]. The underlying geology of Kaduna is mainly metamorphic rocks, which include biotite gneisses and older granites. However, Jurassic ring complexes and batholiths may be observed around Sanga in the southeast [52]. Generally, soils in Kaduna are mostly ferruginous and are developed primarily from granites and gneisses, as well as from sedimentation [51].

## 2.2 Data

This study used gridded monthly rainfall data from the Climate Research Unit (CRU), University of East Anglia (UEA). The data were obtained from <https://crudata.uea.ac.uk/cru/data/hrg/index.htm#current> (accessed 29th December, 2023). Version 4.07 was released in April 2023 and has a duration of 101 years (1901 to 2022), with a spatial resolution of 0.5° by 0.5° [54]. Although the CRU is reported to have relative errors in precipitation, especially in regions close to the Sahara Desert [54], it has been accepted worldwide [55], and a number of studies have used these datasets to conduct studies related to rainfall [40, 56–58]. The coordinates and elevations of the various locations used in this study are shown in Table 1.

These locations are the major agricultural hubs in the state and can be affected by rainfall variability. Additionally, the locations were selected because of their geographical spread. For example, Kafanchan is located in Guinea Savanna, while Zaria is located in the Sudan Savanna.

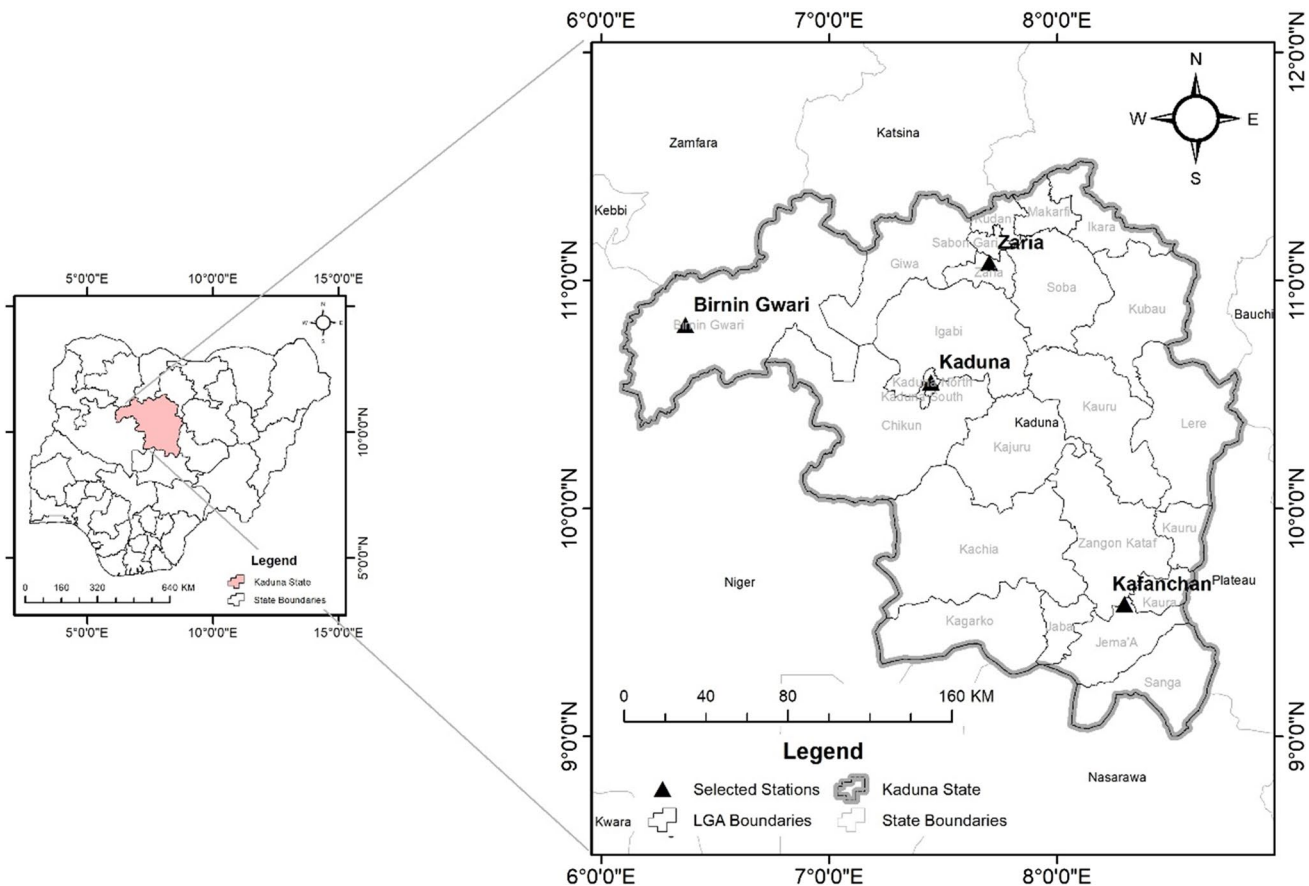


Fig. 1 Kaduna state showing the local government areas (Source: Adapted from [53])

## 2.3 Data processing

Rainfall data were collected from the Climate Research Unit (CRU\_TS 4.07) from 1952 to 2022. The climate data were subjected to a normality test using the Anderson–Darling test (AD) [59]. The formula is given in Eq. (1):

$$A_n^2 = \int_{-\infty}^{\infty} |F_n(x) - F(x)|^2 \varphi(x) f(x) dx, \quad (1)$$

where:

$$\psi(x) = n/F(x)\{1 - F(x)\},$$

$n$  = total number of data points;  $F(x)$  = distribution function of the fitted distribution;  $f(x)$  = density function of the fitted distribution.

$$F_n = \frac{i}{n},$$

$i$  = the cumulative rank of the data point.

The AD statistic is more suitable for measuring fitness than other statistics, such as the Kolmogorov–Smirnov (KS) test, particularly when fitting a distribution at both the tails and the main body is considered. The hypothesis for the Anderson–Darling normality test is  $H_0$ , and the data are from a set that is regularly distributed.

The probability that the data are from a normally distributed population is evaluated by the  $p$  value obtained from the AD test. The AD statistics will be low, and the corresponding  $p$  value will be higher than the selected alpha-level (0.05 and 0.10) in cases when the distribution fits the data. In this study, the AD normality test procedure was employed and performed using XlStat in Microsoft Excel.

## 2.4 Data analysis

### 2.4.1 Coefficient of variation

To calculate the spatiotemporal variability of rainfall in Kaduna State, the coefficient of variation (CV) was calculated using Eq. (2) below.

$$CV = \frac{\sigma}{\bar{X}} * 100, \quad (2)$$

where  $\sigma$  is the standard deviation and  $\bar{x}$  is the average rainfall data. Often, CV values below 20% are considered low, values between 20 and 30% are considered moderate, values between 30 and 40% are considered high, and values above 40% are considered very high [60, 61].

### 2.4.2 Rainfall anomaly index (RAI)

Van Rooy [62] created the rainfall anomaly index (RAI), which is used to categorize rainfall anomalies into positive and negative severities. According to [7], the RAI responds to changes in precipitation that are abnormally wet or abnormally dry. The RAI is a procedure with remarkable simplicity because only precipitation data are needed.

**Table 1** Station name, longitude, latitude and elevation of the four locations considered in this study

| Station name | Longitude (°E) | Latitude (°N) | Elevation (m) |
|--------------|----------------|---------------|---------------|
| Birnin Gwari | 6.25           | 10.75         | 366           |
| Kaduna       | 7.25           | 10.75         | 623.54        |
| Kafanchan    | 8.25           | 9.75          | 648           |
| Zaria        | 7.75           | 11.25         | 646.9         |

The years with low rainfall values indicate a negative departure from the mean seasonal rainfall, which is further denoted as drought years. It has been used in studies related to changes in soil moisture conditions [62, 63]. The various levels of the RAI are shown in Table 2.

The formula below (Eq. 3) was used for calculating the RAI:

$$RAI = (R - \mu) / \sigma, \quad (3)$$

where RAI = rainfall anomaly index;  $R$  = rainfall;  $\mu$  = long-term average rainfall;  $\sigma$  = standard deviation.

#### 2.4.3 Precipitation concentration index (PCI)

To assess the seasonality of rainfall, the PCI was used. It is an index that displays the monthly rainfall data distribution and can be used to predict droughts and floods [35], and it was calculated using the formula in Eq. (4) below [65]:

$$PCI = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} * 100, \quad (4)$$

where  $P_i$  is the monthly rainfall amount in the  $i$ th month.

According to [66], a PCI under 10 indicates a uniform distribution of monthly rainfall, while a PCI between 11 and 16 indicates a moderate distribution. PCIs between 16 and 20 are considered irregular, while PCIs above 20 are considered very high rainfall concentrations.

#### 2.4.4 Mann–Kendall trend test (MK)

To examine the spatiotemporal trend of rainfall in Kaduna State, the Mann–Kendall trend test was used. The Mann–Kendall method [67, 68] is frequently used to identify pattern time series data, especially in hydroclimatic studies [32, 35, 36, 40, 69]. It is used to identify data that are not normally distributed and insensitive to outliers [70]. The null or alternate hypotheses are accepted or rejected. The null hypothesis states that there is no trend, while the alternative hypothesis states that there is an increase or decrease in the time series. The test statistic  $S$  is given as follows (Eq. 5):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i), \quad (5)$$

where  $n$  is the number of observations,  $x_i$  and  $x_j$  are the  $i$ th and  $j$ th ( $j > i$ ) observations in the time series, respectively, and  $\text{sgn}(x_j - x_i)$  is the sign function computed as (Eq. 6):

$$\text{sgn}(x_j - x_i) = \begin{cases} +1, & \text{if } (x_j - x_i) > 0 \\ 0, & \text{if } (x_j - x_i) = 0 \\ -1, & \text{if } (x_j - x_i) < 0 \end{cases} \quad (6)$$

**Table 2** RAI classification.  
Source: [64]

| Level          | Value          |
|----------------|----------------|
| Extremely wet  | > 300          |
| Very wet       | 2.0 to 2.99    |
| Moderately wet | 1.00 to 1.99   |
| Slightly wet   | 0.50 to 0.99   |
| Near normal    | −0.49 to 0.49  |
| Slightly dry   | −0.99 to −0.50 |
| Moderately dry | −1.99 to −1.00 |
| Very dry       | −2.99 to −2.00 |
| Extremely dry  | < −3.00        |

For the series where sample size  $n > 10$ , the test statistic  $S$  is considered to be asymptotically normally distributed, with mean  $E(S)$  and variance  $Var(S)$  as:

$$E(S) = 0, \text{ and}$$

$$Var(S) = \frac{n(n-1)(2n+5)}{18}. \quad (7)$$

The distribution of the statistics  $S$  tends toward normalcy when  $n$  is greater than 10, and there is a chance of a tie in the value of  $x$  [68]; thus, the variance is calculated using Eq. (8):

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^m t_k(t_k-1)(2t_k+5)}{18}, \quad (8)$$

where  $m$  is the number of tied groups and  $t_k$  is the number of ties of extent  $k$ . The standard normal test statistic  $Z$  used for identifying a monotonic trend is given as Eq. (9):

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & \text{if } S < 0 \end{cases}. \quad (9)$$

In a two-tailed test, the null hypothesis of 'no trend' is accepted at the  $\alpha$  significance level for  $-Z_{1-\alpha/2} \leq Z \leq Z_{1-\alpha/2}$ , where  $Z_{1-\alpha/2}$  is the standard score (z score) of the standard normal distribution with a cumulative probability of  $1 - \alpha/2$ . Otherwise, the null hypothesis is rejected if a trend is detected at the  $\alpha$  significance level. Hence, positive  $Z$  values indicate an upwards trend, while negative values indicate a downwards trend.

#### 2.4.5 Sen's slope estimator test (SSE)

Sen's slope estimator is a nonparametric method that has been widely applied to determine slope trends in hydroclimatic time series [35, 36]. It was developed by [71] and calculated using Eq. 10:

$$f(t) = Qt + B. \quad (10)$$

In Eq. (9) above,  $Qt$  is the slope, and  $B$  is a constant. To estimate the slope ( $Q$ ), the slopes (values) of the time series were computed using Eq. (11):

$$Q_i = \frac{X_j - X_k}{j - k}, \quad (11)$$

where  $X_j$  and  $X_k$  are the values of the data at periods  $j$  and  $k$  ( $j > k$ ). If each period has a single datum, then  $N = n(n-1)/2$ , where  $n$  is the number of data points. If there are multiple observations in one or more periods, then  $N < (n(n-1))/2$ . Sen's slope estimator is calculated using Eq. (12):

$$Q_{med} = \begin{cases} Q * \left[ \frac{(N+1)}{2} \right], & \text{if } N \text{ is odd} \\ \frac{Q * \left[ \frac{N}{2} \right] + Q * \left[ \frac{(N+2)}{2} \right]}{2}, & \text{if } N \text{ is even} \end{cases}. \quad (12)$$

Finally,  $Q_{med}$  is applied using a nonparametric model to determine the trend and slope magnitude. A positive  $Q_i$  indicates an upwards trend, and a negative  $Q_i$  indicates a downwards trend. Likewise, if the value is zero, there is no trend.

#### 2.4.6 Standardized precipitation index (SPI)

To determine the occurrence of meteorological droughts in Kaduna State, the standardized precipitation index (SPI) was applied. It was calculated using Eq. (13) and levels developed by [72]. Rainfall records were obtained from the Climate

**Table 3** SPI classification. Source: [72]

| SPI value     | Category       |
|---------------|----------------|
| > 2.0         | Extremely wet  |
| 1.5 to 1.99   | Very wet       |
| 1.0 to 1.49   | Moderately wet |
| −0.99 to 0.99 | Near normal    |
| −1.0 to −1.49 | Moderately dry |
| −1.5 to −1.99 | Very dry       |
| < −2.0        | Extremely dry  |

**Table 4** Normality test using the Anderson–Darling (AD) test

| Anderson–Darling test | Birnin Gwari | Kaduna | Kafanchan | Zaria  |
|-----------------------|--------------|--------|-----------|--------|
| A <sup>2</sup>        | 53.80        | 55.64  | 49.25     | 66.13  |
| p value (two-tailed)  | 0.0001       | 0.0001 | 0.0001    | 0.0001 |
| Alpha                 | 0.05         | 0.05   | 0.05      | 0.05   |

Research Unit, and the SPI was calculated to determine the spatial and temporal scales of meteorological drought events in Kaduna. The values of the SPI are shown in Table 3. The SPI is calculated as Eq. (13):

$$Z = \frac{X_j - \mu_m}{\sigma_m}, \quad (13)$$

where  $x$  is the average rainfall duration, which depends on span  $j$ , and  $j$  is the 3-, 6-, 12- or 24-month time period depending on the scenario. However, we used a 12-month time period for this study.

$\mu$  = the long-term average for the duration covered  $m$  in an area.  $\sigma$  = Standard deviation of rainfall for the area during the period under study  $m$  and is the aggregate of months of historical data that should not be less than 30 years.

The gamma distribution is given as Eq. (14):

$$g(x) = \frac{x^{\alpha-1} \cdot e^{-\frac{x}{\beta}}}{\beta^\alpha \cdot \Gamma(\alpha)} \text{ for } x > 0, \quad (14)$$

where  $\alpha > 0$  is a shape parameter,  $\beta > 0$  is a scale parameter,  $\chi$  is the precipitation amount and  $\Gamma(\alpha)$  is the gamma function.

### 3 Results and discussion

#### 3.1 Spatial and temporal variability in rainfall in Kaduna State

The rainfall data were subjected to a normality test using the Anderson–Darling (AD) test. The results are shown in Table 4 below.

The computed  $p$  values for all the stations are less than the significance level of  $\alpha = 0.05$ , which indicates that the distribution of rainfall does not follow a normal distribution.

#### 3.2 Coefficient of variation (CV)

This study analysed the variability in rainfall across the four stations selected for analysis. The minimum, maximum and mean annual rainfall records were also assessed. Additionally, the standard deviation and CV were calculated. The results are shown in Table 5 below:

From Table 5, the results revealed that Birnin Gwari experiences low variability, with a CV of 0.111 (11.1%). The highest amount of rainfall is 1432 mm, while the lowest is 832.40 mm. The mean annual rainfall is 1129.34 mm, and the standard deviation is 125.64 mm. The highest rainfall in Kaduna town during the study period was 1530.10 mm, the lowest was



**Table 5** Coefficient of variation

| Station      | Min    | Max     | Mean    | Std. deviation | CV    |
|--------------|--------|---------|---------|----------------|-------|
| Birnin Gwari | 832.40 | 1432.90 | 1129.34 | 125.64         | 0.111 |
| Kaduna       | 859.00 | 1530.10 | 1173.47 | 139.97         | 0.119 |
| Kafanchan    | 935.50 | 1526.40 | 1230.59 | 128.68         | 0.105 |
| Zaria        | 726.10 | 1344.60 | 1033.89 | 144.69         | 0.140 |

859.00 mm, and the average rainfall was 1173.47 mm. The standard deviation is 140 mm, and the coefficient of variation is 0.119 (11.9%).

In Kafanchan, the highest amount of rainfall within the study period was 1526.40 mm, the lowest was 935.50 mm, and the mean annual rainfall was 1230.59 mm. The standard deviation is 127.68 mm, and the coefficient of variation is 0.105 (10.5%), which indicates low variability. Finally, the highest amount of rainfall in Zaria is 1344.60 mm, the lowest is 726.10 mm, and the mean annual rainfall is 1033.89 mm. The standard deviation is 144.69 mm, and the coefficient of variation is 0.140 (14.0%), indicating low variability.

### 3.3 Rainfall anomaly index (RAI)

To compute the RAI, thresholds of +3 and –3 were applied to the average of the 10 highest positive and negative irregularities, respectively.

From the analysis, 1983 was the driest year for Birnin Gwari, Kaduna and Kafanchan, with RAI values of –4.863, –4.474 and –4.316, respectively. On the other hand, Zaria experienced its driest period in the year 1973, with RAI value of –4.065. Compared to other locations under study, Zaria is farther up north, within the Sudan Savannah best.

The wettest period under study was observed in Birnin Gwari, Kaduna and Zaria town are 1957, with RAI values of 4.299, 4.638 and 4.071, respectively. Kafanchan recorded its wettest year in 1954, with RAI value of 4.120 (Fig. 2).

### 3.4 Precipitation concentration index (PCI)

The precipitation concentration index (PCI) revealed the distribution of precipitation concentrations in Kaduna State. The results are shown in Table 6 below.

Table 6 shows that the annual PCI in Birnin Gwari is high (85.92%). Moderate concentrations (1.41%) and very high concentrations (12.67%) were also recorded. Kaduna town also experienced moderate concentrations (1.41%), high concentrations (85.92%) and very high concentrations (12.67%). The PCI results for Kafanchan revealed moderate (14.08%) to high concentrations (85.92%). The lowest concentration was recorded in 1978, and the highest was recorded in 1973. For Zaria, the PCI was high (57.75%) and very high (42.25%). Zaria had the highest concentration in 1977 and the lowest in 1978.

### 3.5 Trend of rainfall in Kaduna State

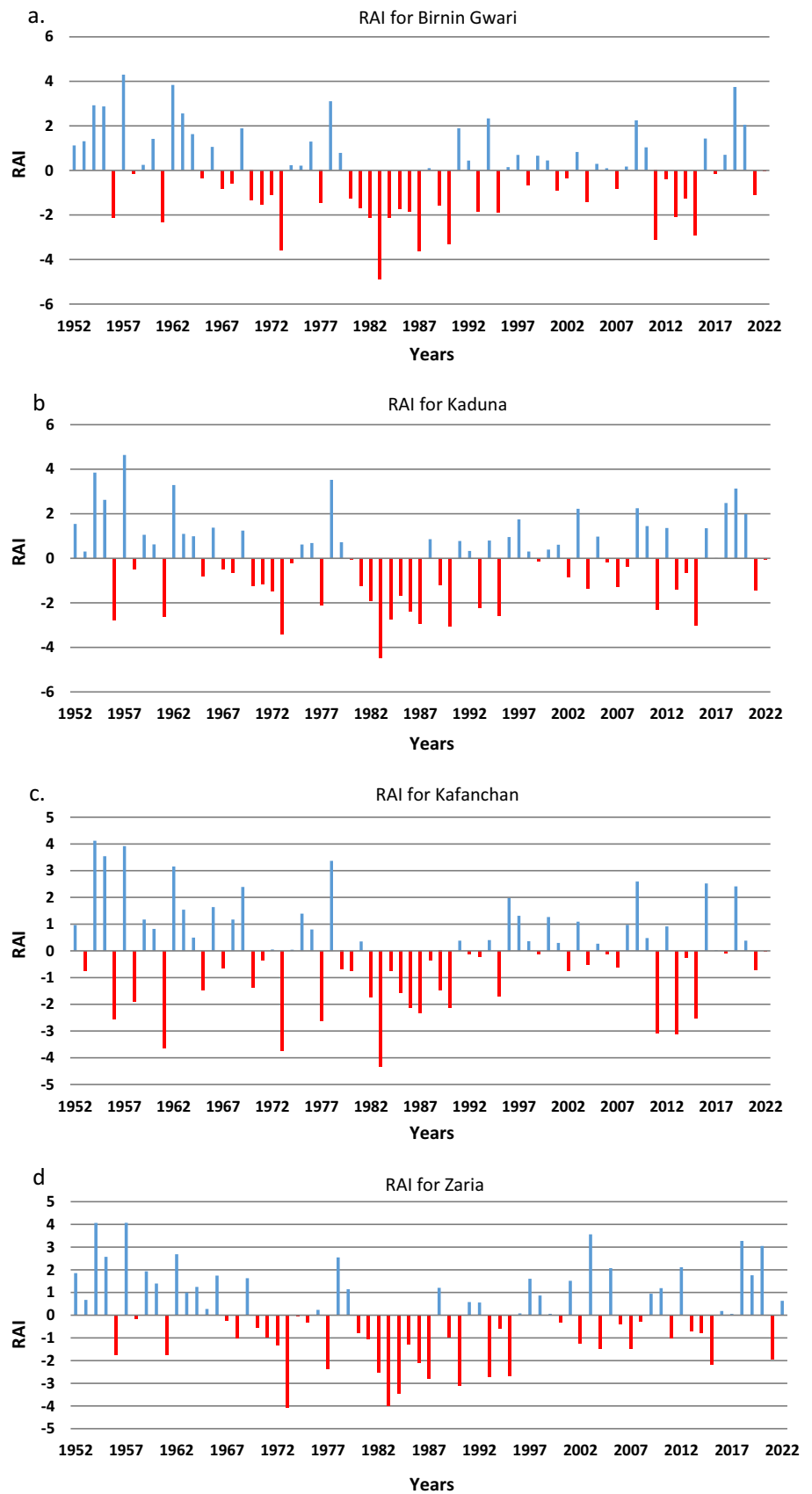
To determine the trend of rainfall in Kaduna State, the Mann–Kendall trend test was used. The annual trends of rainfall for all four stations were computed, and the results are shown in Table 7 and Fig. 3.

Table 7 reveals that Birnin Gwari experienced a monotonic downwards trend in rainfall, with a Z-statistic of –1.112. However, the trend is not statistically significant given that the p value (0.264) is greater than the alpha (0.05). Kaduna town also showed a decreasing trend in rainfall, with a Z statistic of –0.357. However, the trend is not statistically significant, given that the p value (0.717) is greater than the alpha (0.05).

Additionally, in Kafanchan town, the rainfall exhibited a downwards trend, but it was not significant. The Z-statistic is –0.556, the p value is 0.575, and the significance level is 0.05. Finally, the rainfall in Zaria town exhibited a decreasing trend, with a Z-statistic of –0.764. The p value is 0.442, and the significance level is 0.05, which indicates that the trend is not statistically significant. The Sens's slope is –0.757, which is the magnitude of the trend. The results of the Mann–Kendall trend test are shown in Fig. 3.



**Fig. 2** Rainfall anomaly indices for **a** Birnin Gwari, **b** Kaduna, **c** Kafanchan and **d** Zaria



**Table 6** Precipitation concentration index (PCI) of Kaduna State (1952–2022)

| Index | Description             | Birnin Gwari | Kaduna | Kafanchan | Zaria |
|-------|-------------------------|--------------|--------|-----------|-------|
| < 10  | Low precipitation       | 0            | 0      | 0         | 0     |
| 11–15 | Moderate concentration  | 1            | 1      | 10        | 0     |
| 16–20 | High concentration      | 61           | 61     | 61        | 41    |
| > 20  | Very high concentration | 9            | 9      | 0         | 30    |

**Table 7** Summary of the Mann–Kendall trend test results

|                      | Birnin Gwari | Kaduna     | Kafanchan  | Zaria      |
|----------------------|--------------|------------|------------|------------|
| Kendall's tau        | −0.091       | −0.029     | −0.045     | −0.062     |
| S                    | −225.000     | −73.000    | −113.000   | −155.000   |
| Var(S)               | 40,588.333   | 40,586.333 | 40,588.333 | 40,588.333 |
| p value (two-tailed) | 0.264        | 0.717      | 0.575      | 0.442      |
| Alpha                | 0.05         | 0.05       | 0.05       | 0.05       |
| Z                    | −1.112       | −0.357     | −0.556     | −0.764     |
| Sen's slope          | −0.919       | −0.309     | −0.490     | −0.757     |

### 3.6 Meteorological drought in Kaduna State

This study calculated the occurrence and intensity of meteorological drought in Kaduna State based on four selected stations. The thresholds for the SPI are presented in Table 3. The results are shown in Fig. 4 and Table 8.

Figure 4 and Table 8 show that Birnin Gwari experienced 18 months of intense drought between 1973 and 1987. The highest drought intensity was  $-2.671$  in August 1984. The mean intensity for the entire period is  $-2.370$ . For Kaduna town, droughts occurred in a total of 18 months, with the highest and mean intensities of  $-3.111$  and  $-2.377$ , respectively. The drought events were spread between 1973 and 1986. Kafanchan town experienced 25 months of drought, with the most catastrophic drought occurring in August 1973, with an intensity of  $-2.643$ , while the mean drought intensity was  $-2.220$ . The drought events in Kafanchan occurred between 1961 and 1986. Finally, Zaria town experienced the longest period of drought, covering 30 months. The most devastating drought occurred in August 1984, with an intensity of  $-3.069$ , while the mean intensity for the entire period was  $-2.318$ . The drought events were intermittent between 1973 and 1994.

## 4 Discussion

### 4.1 Rainfall variability

A coefficient of variation of 0.119 is considered low variability [60, 61]. Thus, across the four locations selected in this study, rainfall exhibited low variability (Table 5). This result is similar to that of [73], who revealed that rainfall in Kamuku National Park exhibited moderate variability. On the other hand, [14] also revealed low rainfall variability in Kaduna between 1980 and 2020, but [74] revealed a decreasing trend of rainfall in Kafanchan. High rainfall variability is associated with risks in crop production [75]. Thus, all four stations under study experienced low risk because the rainfall variability was generally low.

For the PCI, the findings revealed different concentrations of rainfall, which were mainly high and very high in the four locations examined. This implies that few months receive a large proportion of the total annual precipitation. This can result in several problems, such as the risk of flooding, soil erosion, damage to infrastructure and landslides during wet periods [76]. During dry periods, there is a tendency for water shortages and a lack of balance in the ecosystem [77].

### 4.2 Trend of rainfall in Kaduna

For the trend of rainfall, this study disagreed with the findings of [78], who revealed that rainfall in Zaria is significantly increasing, but agreed with [79], who revealed that there is no significant trend in rainfall distribution in Zaria. The trend of precipitation at the four locations reported in this study is consistent with that reported in previous studies. Isa et al. [32] and Animashaun et al. [40] reported a decreasing trend in rainfall in the Kaduna River Basin and Niger Central

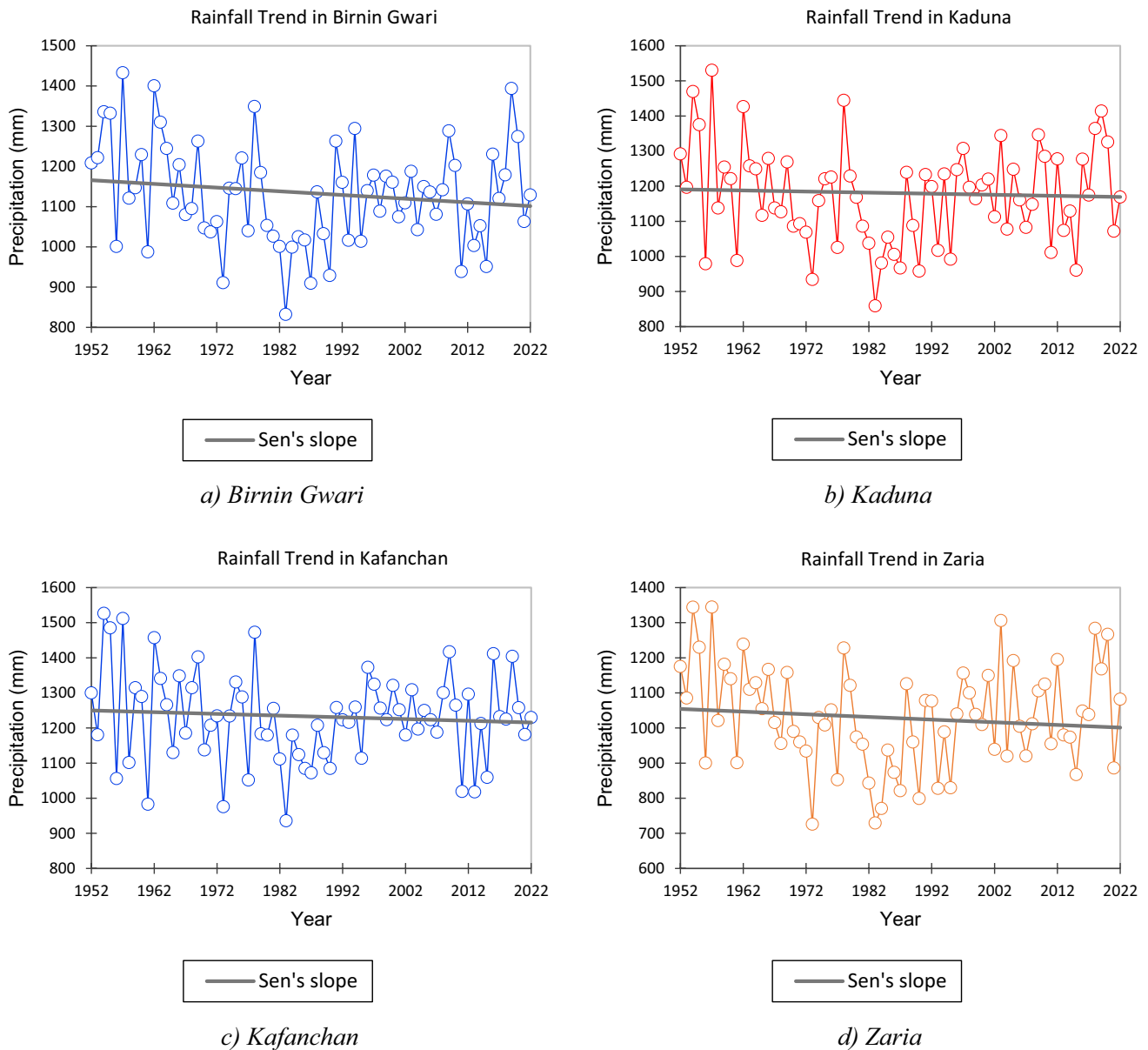


Fig. 3 MK test for **a** Birnin Gwari, **b** Kaduna, **c** Kafanchan and **d** Zaria

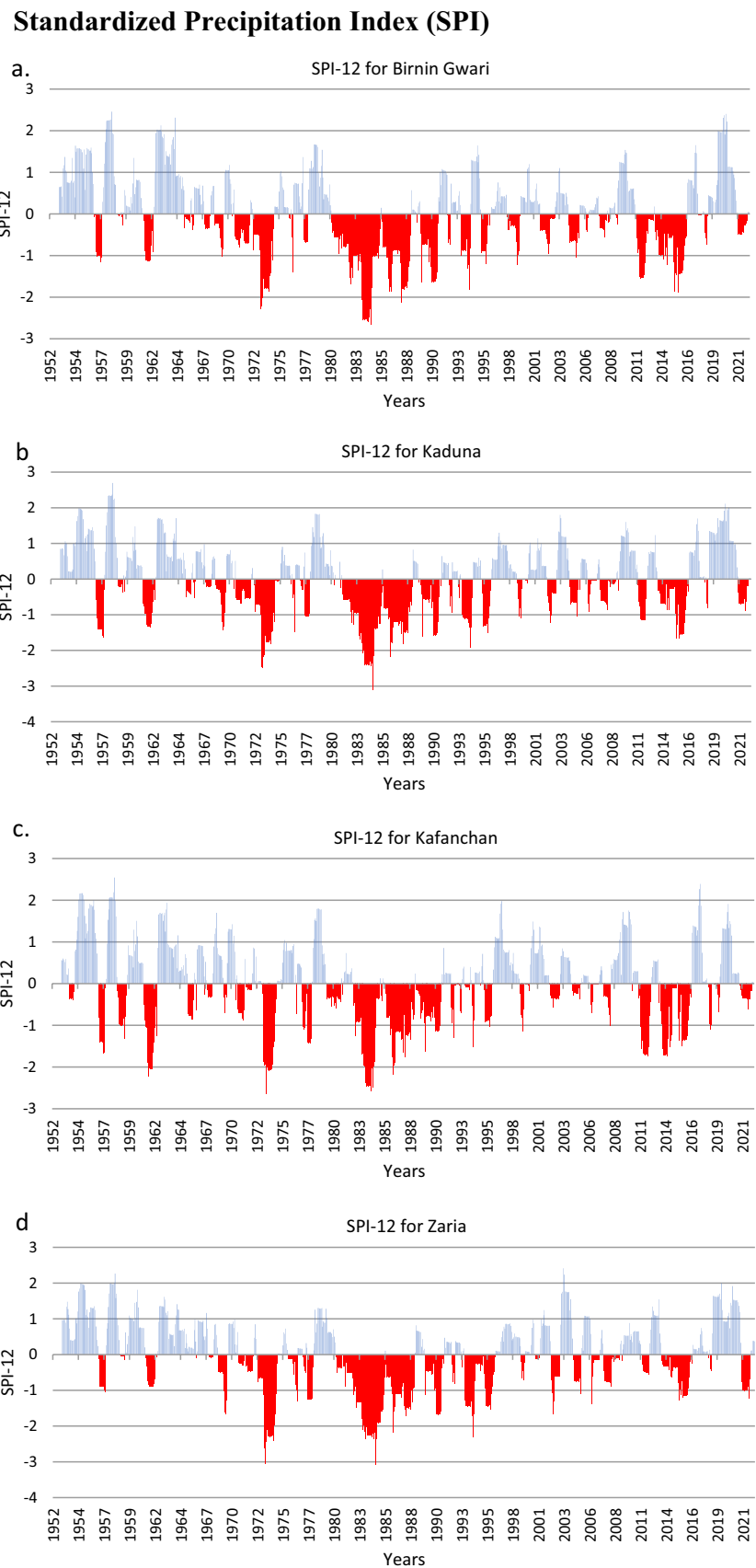
Hydrological Area. A decrease in rainfall will impact agricultural activities considering that agriculture in the study area is mainly rainfed. This will further stress the already tense situation of food security. A decrease in rainfall also has implications for surface and groundwater recharge [80].

### 4.3 Meteorological drought

In all four locations, the droughts were more pronounced in 1973/74 and 1983/84. These periods are the driest conditions on record in the savanna regions of Nigeria [81]. According to [82] and [83], northern Nigeria experienced one of its worst drought events in 1983. Within this period, [84] revealed that drought in southwestern Nigeria exhibited a cyclical pattern. In other parts of the world, extreme drought events have occurred in Africa [85, 86], Central and Southeast Asia [87–89], North America [90, 91], South America [92–94], and parts of Europe [95, 96].

Rainfall drought is closely related to famine experienced in northern Nigeria [97]. Additionally, the results revealed that the 1950s and 1960s were extremely wet, with the exception of a few years in all the locations. However, these wet periods were followed by two decades of decreasing rainfall, leading to the most catastrophic drought events in the

**Fig. 4** SPI values for **a** Birnin Gwari, **b** Kaduna, **c** Kafanchan and **d** Zaria



**Table 8** Historic drought events identified by the SPI-12 in Kaduna State, Nigeria

| Drought index                 | Birnin Gwari        | Kaduna              | Kafanchan                  | Zaria                      |
|-------------------------------|---------------------|---------------------|----------------------------|----------------------------|
| Starting dates                | 05/73, 08/83, 09/87 | 05/73, 08/83, 06/86 | 09/61, 08/73, 09/83, 06/86 | 05/73, 05/83, 06/86, 07/94 |
| Ending dates                  | 08/73, 08/84, 10/87 | 08/73, 09/84, 07/86 | 02/62, 03/74, 06/84, 07/86 | 04/74, 09/84, 07/86, 08/94 |
| Mean intensity, $M$           | -2.370              | -2.377              | -2.220                     | -2.318                     |
| Maximum intensity, $M_{\max}$ | -2.671              | -3.111              | -2.643                     | -3.069                     |
| Duration, $D$ (months)        | 18                  | 18                  | 25                         | 30                         |

records [98]. In particular, the years 1973/73 and 1984/84 were the driest within the study period [99, 100]. Finally, this study revealed that with respect to drought from 1995 to 2022, the four stations experienced very dry years, with SPI values below  $-1.99$ . This further confirmed the findings of [82] that there was no meteorological drought in Kaduna State for more than 15 years.

## 5 Conclusion

This study assessed rainfall trends and characterized droughts in four locations (Birnin Gwari, Kaduna, Kafanchan and Zaria). The study revealed that the highest CV was 14.0% in Zaria, and the lowest was 10.5% in Kafanchan. Overall, rainfall in Kaduna has low to moderate variability. Additionally, the study revealed a decreasing rainfall trend across the four locations, with Birnin Gwari having the highest magnitude and Kaduna town having the lowest magnitude. The study also revealed periods of extremely dry years in the 1970s and 1980s, which followed years of extreme rainfall in the 1950s and 1960s. The PCI values revealed different concentrations of rainfall, which were mainly high and very high. The trend analysis revealed that rainfall experienced a downwards trend at all four locations within the period under study. Finally, it can be concluded that all four study locations experienced severe droughts in the 1970s and 1980s, with Zaria experiencing the longest period of droughts, 30 months. This affected food security in the study area, especially in the 1970s. This study recommends that the government and relevant stakeholders educate farmers on the effects of rainfall variability, especially in relation to agriculture. Additionally, an adequate understanding of the relationship between climate variability and the spread of infectious diseases is needed.

**Author contributions** MLA: conceptualization, methodology, validation, formal analysis, data curation. AIW: writing—original draft preparation, writing—review and editing. MAS: visualization and editing. AFA: review and supervision. All authors have read and agreed to the published version of the manuscript.

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**Data availability** Datasets used in this research can be found at (<https://crudata.uea.ac.uk/cru/data/hrg/index.htm#current>) a gridded monthly rainfall data provided by the Climate Research Unit (CRU), University of East Anglia (UEA) [54].

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Institutional review board statement** Not applicable.

**Competing interests** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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