




Chapter 7

Analysis of Rainfall Trend and Variability in Lagos, Southwestern Nigeria



Christian A. Njoku , **Vincent N. Ojeh** , **Edward Naabil** ,
Michael C. Ekwe, **Maaku M. Joshua**, **Elizabeth Elijah**,
and **Micheal W. Malgwi**

Abstract The rainy season in the littoral city of Lagos has offered a lingering problem to water resource managers and the region's socioeconomic activities over the years. In a changing climate, it is critical to understand how seasonal wet regimes vary in order to predict floods and manage water resources. The aim of this research is to assess rainfall changes using the trend and variability of two independent meteorological stations located inside Lagos' coastal city. Monthly cumulative rainfall data was acquired and examined on monthly, seasonal, and annual scales for a 30-year period (1984–2013). Modified Mann–Kendall (MM-K) and Sen's slope estimator (Q) were used to estimate rainfall trends and statistical significance tests, while the Precipitation Concentration Index (PCI) and Rainfall Variability Index (RVI) were used to quantify rainfall variability (RVI). Rainfall increased from January to May and November to December, but declined from July to August at both stations. In June, August, and October, however, both stations showed a distinct mix of upward and downward trends: dry season rainfall increased across stations, whereas wet season and yearly rainfall increased in the Ikeja station and fell in the Lagos Roof station, respectively. For Ikeja and Lagos Roof stations, PCI wet and dry seasons range from 9 to 20 and 9 to 42, respectively, while annual PCI ranges from 11 to 28 for both

C. A. Njoku
Nigerian Meteorological Agency, Abuja, Nigeria

V. N. Ojeh (✉) · M. M. Joshua · E. Elijah
Department of Geography, Taraba State University, Jalingo, Nigeria
e-mail: vinceojehnetwork@gmail.com

E. Naabil
Department of Agricultural Engineering, Bolgatanga Technical University, Bolgatanga, Ghana
e-mail: naabil.edward@bolgatu.edu.gh

M. C. Ekwe
National Space Research and Development Agency, Lugbe, Nigeria

M. W. Malgwi
Department of Geography, Nigerian Army University, Bui, Borno State, Nigeria

stations. In the wet and dry seasons, the Lagos Roof station had higher positive RVI tendencies than the Ikeja station depicting a high variability of rainfall within Lagos.

Keywords Rainfall variability · Rainfall trend · Modified Mann–Kendall · Sen's slope · Seasonal variation · Climate change

Introduction

Climatic variables such as rainfall, temperature, and streamflow are often studied for the purpose of ascertaining the tendency for environmental change over time (Oguntunde et al. 2011a). Water resource planning and management are made easier through the analysis of long-term records of rainfall. However, the increasing rate of population and economic growth suggests that there will be an increasing demand for water resources (Oguntunde et al. 2011a). The climate projections for Nigeria have also indicated a continued rise in rainfall with severe impacts on human, agriculture, and water resources (e.g., Daramola et al. 2017; Abiodun et al. 2012). Therefore, it is imperative to continually study rainfall trends and variability, especially in a changing climate (e.g., Odjugo 2010; De Luis et al. 2011; Bello 1998).

Several studies on rainfall characteristics have been conducted at different scales in Nigeria (Oguntunde et al. 2011a; Ifabiyi and Ojoye 2013; Akinsanola and Ogunjobi 2014; Ogungbenro and Morakinyo 2014; Salami et al. 2016; Daramola et al. 2017). For instance, Oguntunde et al. (2011a) observed that spatial distribution of rainfall was highly dependent on latitude while no clear longitudinal relationship was seen. Rainfall trend over the Sahelian region of Nigeria also revealed that the drought episodes of 1972/73 and 1980 were a consequence of downward trend of rainfall amount in the 1970s and 1980s, while the upward trend in rainfall amount between 1990 and 2009 resulted in flooding over northern Nigeria within that period (Ifabiyi and Ojoye 2013). According to Ogungbenro and Morakinyo (2014), a significant transition of rainfall regimes from dry to wet, indicating an upward shift of rainfall distribution, were found in the climate zones of Nigeria. Similar findings have also been reported using observational (Akinsanola and Ogunjobi 2014) and model (Daramola et al. 2017) data across Nigeria. At the local scale, Oguntunde et al. (2011b) indicated a non-significant increasing trend in rainfall over Ibadan, Nigeria. At the basin scale, Animashaun et al. (2020) found varying results in rainfall changes, with some sub-basins showing negative rainfall trends, and the reverse is true for other sub-basins within the same climate zones. These confirm the previous findings of Oloruntade et al. (2017) over the Niger South basin. While the previous studies have provided useful information about rainfall changes and distribution across different parts of Nigeria and at different scales, the differing results of rainfall variability between stations within the same climatic zones or hydrological response units suggest a strong local influence on rainfall-induced mechanisms (Odonuga and

Oyebande 2007; Animashaun et al. 2020). The regional-scale assessment of rainfall may potentially lead to mischaracterizations of local rainfall distribution, with implications on agriculture and water resource management.

Therefore, the aim of the present study is to assess the trend and variability of rainfall in the coastal city of Lagos, southwestern Nigeria. The focus is on two independent weather stations, Ikeja and Lagos Roof, with different geographical characteristics namely Lagos mainland and Lagos Island, respectively. The difference in the geographical characteristics of the stations will help evaluate the argument about the potential local influence on rainfall variability (Animashaun et al. 2020). The findings will therefore enhance reliable seasonal rainfall predictions, flood forecasting, and early warning systems in the littoral mega city.

Materials and Methods

Study Area

The coastal mega city of Lagos in southwestern Nigeria is predominantly a commercial city and the hub of economic activities in the southern part of Nigeria, yet prone to consistent flooding activities. It lies between longitude $2^{\circ}42' - 3^{\circ}42'$ E and latitude $6^{\circ}23' - 6^{\circ}41'$ N (Fig. 7.1). It is one of the most populated cities in the entire globe, harboring over 24.6 millions people (<https://lagosstate.gov.ng/about-lagos/>). The area is characterized by a tropical climate (Köppen-Geiger climate classification is Aw) with average annual rainfall estimated to be 1693 mm while the average temperature is 27°C ; the highest rainfall is observed in June while least rainfall occurs in December. The city experiences two distinct seasons, wet (April–October) and dry (November–March) (<https://en.climate-data.org/africa/nigeria/lagos/lagos-552>). The wet season is bimodal, with a little dry season in July/August (Omotosho 1988). Ikeja weather station lies on 39.4 m above the sea level and is sited inside an international airport located in the mainland area, while Lagos Roof weather station is on 14 m above the sea level located on the shoreline of the island area of Lagos, the stations are less than 20 km apart (Table 7.1). Hydrologically, the Owo River is one important surface water source in Lagos particularly in the western section of the city (Adegun, et al. 2015). It is the source of direct water intake for water supply by Lagos State Water Corporation to Amuwo-Odofin, Ojo and parts of Badagry Local Government Areas. Additionally, the area is drained by the lower Ogun River, which discharges into the Lagos Lagoon through a meandering system with several bifurcations due to erosional activities, sedimentation, and human activities. The sub-surface geology of Lagos indicates a complex lithology of alternating sequence of sand and clay deposits (Longe et al. 1987).

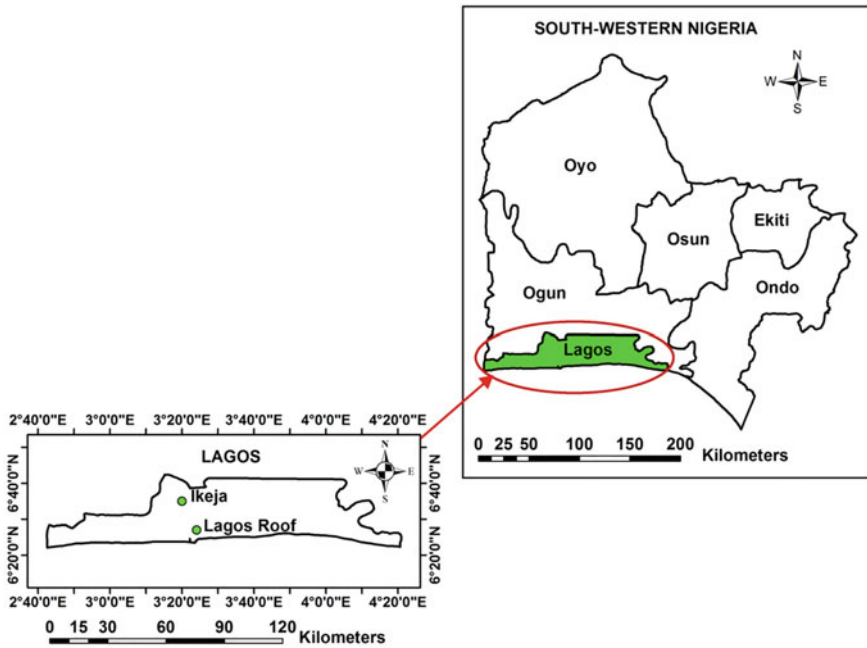


Fig. 7.1 Map of study area showing the selected weather stations

Table 7.1 Descriptions of stations location

Station name	Latitude (°N)	Longitude (°E)	Altitude (m)	Period of Data
Ikeja	06.35	03.20	39.4	1984–2013
Lagos Roof	06.27	03.24	14	1984–2013

Rainfall Data

Monthly accumulated rainfall measured by data spanning 1984–2013 (30 years) were utilized in this study. The data for the selected weather stations were daily rain gauge-observed rainfall amount aggregated to total monthly rainfall, and the data set was obtained from the data section of the Nigerian Meteorological Agency. The rainfall data covered all the months of the year and the choice of the period is as a result of the consistency in the data.

Trend Analysis

The statistical significance and the magnitude of the trend analysis in the time series data used in this study were determined using the modified Mann–Kendall (MMK) (Hamed and Rao 1998) and Sen’s slope estimator (Sen 1968). Non-parametric methods such as Mann–Kendall (MK) (Mann 1945; Kendall 1975) and modified Mann–Kendall (MMK) have been used by researchers around the world to ascertain the trend in hydro-meteorological parameters (You and Wang 2004; Krishan et al. 2015; Hamed 2009), MK and MMK assume the null hypothesis (H_0) of no trend, and this is tested against the alternative hypothesis (H_A) of either a decreasing or increasing trend in the data series. Data are checked for randomness using the autocorrelation function; this is achieved by computing autocorrelation for the data set at different time lags. To check for significant autocorrelation in the data series for this study, the autocorrelation syntax `acf()` in R programming language was adopted, where significant autocorrelation coefficient existed in the series; the Bias-Corrected Pre-Whitening (BCPW) proposed by Hamed (2009) was performed before trend testing (Hamed 2008a, b; Hamed 2009). An important advantage of the MMK is that the effect of statistically significant autocorrelation coefficient is minimized or not expected in the resulting trend (Krishan et al. 2015; Abdul Aziz and Burn 2006; You and Wang 2004). Mann–Kendall statistics (S) is calculated as follows (Eq. 7.1):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k), \quad (7.1)$$

where n is the length of data series, $k = 1, 2, 3, \dots, n-1$, $j = k+1, k+2, k+3, \dots, n$, x_j and x_k are values of sequential data, and x_j is a reference point of each of the data point to be compared with the rest of the data points x_k as shown in Eq. 7.2

$$\text{sgn}(x_j - x_k) = \begin{bmatrix} 1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{bmatrix}, \quad (7.2)$$

When length of data series is equal to 18, the statistics S is approximately Gaussian with mean $E(S)$ and variance $\text{Var}(S)$ as follows (Eqs. 7.3 and 7.4):

$$E(S) = 0, \quad (7.3)$$

$$\text{Var}(S) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{h=1}^g t_h(t_h-1)(2t_h+5) \right], \quad (7.4)$$

where n denotes the number of data points, stands for a number of tied groups (tied groups are set of data samples with the same value), while the represents a number of ties of extent h . Mann–Kendall Statistics (S) is then computed in a standardized statistics form (Z) as given below (Eq. 7.5):

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases}, \quad (7.5)$$

Modified Mann–Kendall (MMK) Trend Test

When data is not random and influenced by autocorrelation, the modified Mann–Kendall tests may be used for trend detection studies (Krishan et al. 2015). Hamed and Rao (1998) have proposed a variance correction approach to address the issue of serial correlation in trend analysis. Data are initially detrended and the effective sample size is calculated using the ranks of significant serial correlation coefficients which are then used to correct the inflated (or deflated) variance of the test statistic (Blain 2013; Patakamuri and O’Brien 2020).

In this method, the effect of all significant autocorrelation coefficients is removed from the data set as proposed by Hamed and Rao (1998). For this purpose, a modified variance of S , designated as $\text{Var}(S)^*$, was adopted as follows (Eq. 7.6):

$$\text{Var}(S)^* = V(S) \frac{n}{n^*} \quad (7.6)$$

where $n^* =$ effective sample size. The n/n^* ratio was computed directly from the equation proposed by Hamed and Rao (1998) as follows (Eq. 7.7):

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-1)(n-i-1)(n-i-2)r_i \quad (7.7)$$

where $n =$ actual number of observations and $r =$ lag - i significant autocorrelation coefficient of rank i of time series. Once $\text{Var}(S)^*$ was computed from Eq. (7.7), then it was substituted for $\text{Var}(S)$ in Eq. (7.6). At 90, 95, and 99% confidence levels, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_A) of a trend is accepted if Z is greater than 1.645, 1.96, and 2.33, respectively, a positive or negative value of Z indicates an upward or downward trend, respectively, in hydro-meteorological variables.

Sen's Slope Estimator

Sen's slope estimator, which is also non-parametric, is used to estimate the true slope overtime of an existing linear trend in hydro-meteorological variables. This is necessary because these variables do not follow a particular pattern in their fluctuation or deviation from the normal distribution over time (Sen 1968). Some of the studies which applied this estimator include Aditya et al (2021), who used it for rainfall trend analysis in West Kalimantan; Aswad et al. (2020), for time series rainfall of 70 years in Iraq; Agbo and Ekpo, (2021) for trend analysis of the variations of ambient temperature in Calabar, Southern Nigeria; and Ghalhari et al. (2022), in trend analysis of Humidex as a heat discomfort index in Iran. With the assumption that the trend is linear, Sen's slope can be computed as follows (Eq. 7.8):

$$f(t) = Qt + B \quad (7.8)$$

where Q is the slope and B is a constant. To obtain the slope estimate Q in Eq. 7.8, the slopes of all the data value pairs are calculated as (Eq. 7.9):

$$Q_i = \frac{x_j - x_k}{j - k} \quad (7.9)$$

where x_j and x_k denote the data measurements at time j , k is subsequent time after time k ($j > k$). If there are values of x_j in the data time series, we get as many as $N = n(n-1)/2$ slope estimates Q_i . The Sen's estimator of the slope is the median of these N values of Q_i . The N values of Q_i are ranked from the smallest to the largest, and the Sen's estimator is the median of all slopes, Sen's estimator is computed as $Q_{\text{med}} = T(N+1)/2$ if N is odd, and it is considered as $Q_{\text{med}} = [T(N/2) + T(N/2 + 1)]/2$ if N is even. In the end, Q_{med} is calculated by a two-sided test at $100(1 - \alpha)\%$ confidence interval, and then a true slope can be obtained by the non-parametric test. A positive value of Q_i indicates an increasing or upward trend, while a negative value denotes a decreasing or downward trend in the time series.

Rainfall Variability

The city of Lagos is the hub of economic activities in southwestern Nigeria, and it is very prone to flooding; hence, the study of the variability of rainfall will help decision-makers come up with policies for water resources management as well as reduce loss of lives and economic goods, so many indices exist for the study of rainfall variability: Standard Precipitation Index (SPI), Coefficient of Variance (CV), Precipitation Concentration Index (PCI), Rainfall Variability Index (RVI), in the present study, PCI (e.g., Adegun and Balogun 2015; Ezenwaji et al. 2017), and RVI (e.g., Ogunrinde et al. 2019; Wagaye and Antensay 2020) were applied in studying rainfall variability at seasonal and annual time scales.

Precipitation Concentration Index (PCI)

Precipitation Concentration Index (PCI) is a powerful temporal rainfall distribution indicator that can be used for seasonal and annual time scales, according to Zhang et al. (2019). PCI proposed by Oliver (1980) and further developed by De Luis et al. (2011) was calculated at seasonal and annual time scales as indicated by Eqs. (7.10–7.12). PCI values below 10 represent low precipitation distribution (uniform monthly precipitation distribution during the season/year), values from 11 to 15 signify moderate precipitation distribution, and values ranging 16 and 20 denote irregular precipitation distribution, while high precipitation concentration (strong irregularity of precipitation) is denoted by values above 20 (Zamani et al. 2018; Ezenwaji et al. 2017; Oliver 1980) (Eqs. 7.10, 7.11 and 7.12).

$$PCI_{\text{wet}} = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} \times 58 \quad (7.10)$$

$$PCI_{\text{dry}} = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^5 P_i\right)^2} \times 42 \quad (7.11)$$

$$PCI_{\text{annual}} = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} \times 100 \quad (7.12)$$

where P_i represents monthly precipitation of any given month i .

Rainfall Variability Index (RVI)

Rainfall Variability Index is used for the assessment of the frequency and severity of drought by separating wet and dry seasons/years from available rainfall time series, RVI is computed as standardized rainfall anomaly using Eqs. (7.13–7.15), and the result is classified into different climatic regimes such as extreme drought ($\delta < -1.65$), severe drought ($-1.28 > \delta > -1.65$), moderate drought ($-0.84 > \delta > -1.28$), and no drought ($\delta > -0.84$) according to Agnew and Chapel (1999) (Eqs. 7.13, 7.14 and 7.15).

$$\delta_w = \frac{(P_w - \mu)}{\sigma} \quad (7.13)$$

$$\delta_d = \frac{(P_d - \mu)}{\sigma} \quad (7.14)$$

$$\delta_i = \frac{(P_i - \mu)}{\sigma} \quad (7.15)$$

where δ_w , δ_d , and δ_i indicate the wet season, dry season, and annual RVI; P_w , P_d , and P_i represent the wet season, dry season, and annual rainfall; and σ and μ denote standard deviation and mean in the wet season, dry season, and annual rainfall.

Results and Discussion

Rainfall Climatology: Monthly, Seasonal, and Annual

The monthly mean of rainfall amount in Lagos (Fig. 7.2) for the period (1984–2013) shows that rainfall in Lagos is bimodal with the first peak in June for Ikeja (284.26 mm) and Lagos-Roof (383.76 mm) stations while the second peak is in September (188.42 mm) and October (213.59 mm) for Ikeja and Lagos-Roof stations, respectively; minimum mean monthly rainfall was recorded in January (16.61 mm) for Ikeja station and in December (16.41 mm) for Lagos Roof station. The maximum cumulative monthly rainfall observed were 619.5 mm (June 1997) and 753.5 mm (May 2003) in Ikeja and Lagos-Roof stations.

The seasonal accumulated amount of rainfall depicted by Fig. 7.3 shows that Ikeja station in the wet season recorded values ranging from 871.2 mm (1986) to 1766.4 mm (1997), whereas Lagos roof station recorded values ranging from 775.7 mm (2008) to 2301 mm (1996). Dry season rainfall observed in Ikeja station ranges from 77.9 mm (2000) to 588 mm (2013), while Lagos Roof station observed values ranging from 28 mm (1989) to 352.9 mm (2004).

The annual rainfall amount depicted by Fig. 7.4 shows that Ikeja station recorded values ranging from 1045 mm to 2019.9 mm, while Lagos Roof recorded values ranging from 939.2 mm to 2535.9 mm. The descriptive statistics of the annual rainfall in the two weather stations is presented in Table 7.2. The monthly, seasonal, and annual trends of rainfall for the period of study (1984–2013) is presented in Table 7.3.

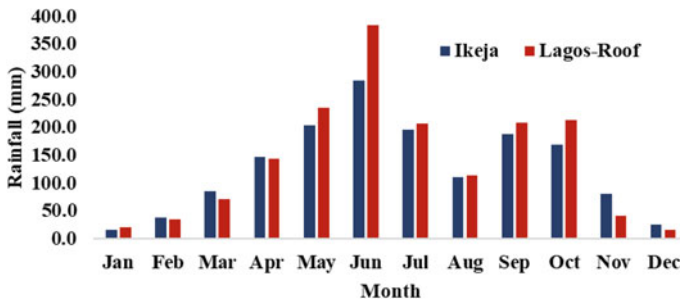


Fig. 7.2 Mean monthly amount of rainfall for the period (1984–2013)

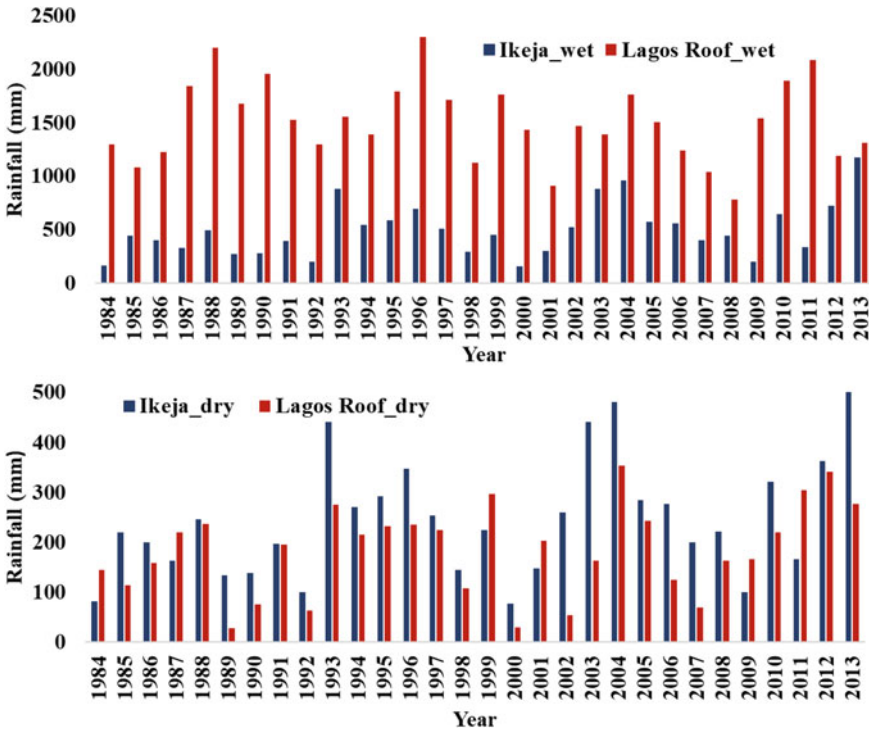


Fig. 7.3 Seasonal amount of rainfall for the period (1984–2013)

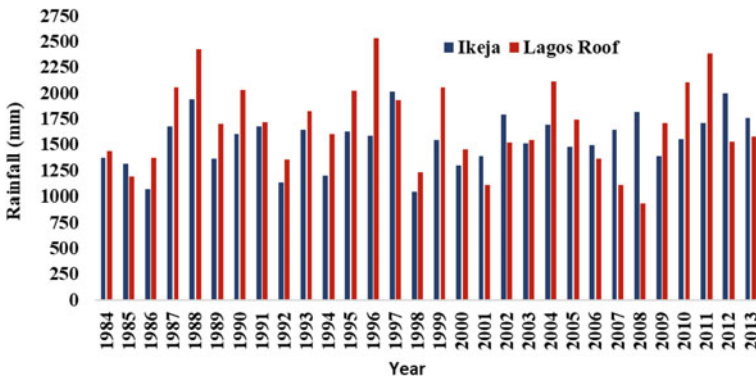


Fig. 7.4 Annual rainfall amount for the period (1984–2013)

Table 7.2 Descriptive statistics of weather stations for annual rainfall (1984–2013)

Station	Min	Max	Mean	First Quartile	Median	Third Quartile	SD	C.V	SE
Ikeja	1045	2019.90	1546.8	1378.7	1572.55	1689.60	254.40	0.16	46.4
Lagos Roof	939.2	2535.90	1689.9	1393.2	1652.45	2029.0	414.45	0.25	75.7

Min = Minimum; Max = Maximum; SD = Standard Deviation; C.V = Coefficient of Variance; S.E = Standard Error

Table 7.3 Monthly, seasonal, and annual trend for the period (1984–2013)

Ikeja					Lagos-Roof			
Period	MM-K test (Z)	Sen's slope (Q)	Trend	Sig	MM-K test (Z)	Sen's slope (Q)	Trend	Sig
Jan	2.24	0.13	↑	**	0.25	0.10	↑	
Feb	1.50	0.68	↑		0.82	0.54	↑	
Mar	0.30	0.25	↑		0.74	0.80	↑	
Apr	0.32	0.32	↑		0.64	1.30	↑	
May	0.92	1.68	↑		0.71	1.28	↑	
June	2.17	6.31	↑	**	-0.21	-0.88	↓	
July	-0.64	-1.79	↓		-0.24	-0.86	↓	
Aug	0.07	0.17	↑		-0.78	-1.26	↓	
Sep	0.50	0.8	↑		-1.85	3.42	↓	*
Oct	1.03	1.37	↑		-1.21	-2.26	↓	
Nov	1.62	2.06	↑		0.80	0.54	↑	
Dec	0.70	0.06	↑		0.67	0.03	↑	
Wet season	0.67	3.48	↑		-0.71	-7.8	↓	
Dry season	2.10	4.89	↑	**	1.64	3.4	↑	*
Annual	1.81	10.1	↑	*	-0.21	-2.01	↓	

↑ = upward; ↓ = downward; Sig. = Significance; * = at 90%; ** = at 95%

Rainfall Trends

See Table 7.3.

Monthly Rainfall Trend

Ikeja and Lagos Roof weather stations exhibit a positive trend from January to May and November to December, and both stations also observe a decreasing trend in July. However, a contrasting trend for both stations is observed from June and August to October, while rainfall trend is positive in Ikeja from June and August to October;

Lagos Roof depicts a negative rainfall trend in the same period. Ikeja observed a 95% confidence level of positive trend in January and June, respectively, Lagos Roof showed a 90% confidence level of negative trend in September. The magnitude of the positive trend for Ikeja and Lagos-Roof ranges from 0.13 mm/year to 6.31 mm/year and 0.10/year to 1.30 mm/year, respectively. July is the only month Ikeja station observed a negative trend, and it was in the magnitude of -1.79 mm/year; the rate of decrease in monthly rainfall observed in Lagos Roof ranges from -0.88 mm/year to -3.42 mm/year.

Seasonal Rainfall Trend

Dry season rainfall is observed to be at increased rates of 4.89 mm/year and 3.40 mm/year for Ikeja and Lagos Roof stations, respectively; Ikeja station shows significance at 95% confidence level, while Lagos Roof station depicts 90% confidence level significance. Wet season recorded contrasting observations for both stations. Ikeja station shows an upward trend at a rate of 3.48 mm/year, while Lagos Roof station depicted a downward trend in the magnitude of -7.8 mm/year; wet season trend for both stations was not significant.

Annual Rainfall Trend

Ikeja station observed an increase in annual rainfall at a magnitude of 10.1 mm/year, while Lagos Roof recorded a decrease in annual rainfall at a rate of -2.01 mm/year. The upward trend in Ikeja shows significance at 90% confidence level, but no significance was observed in the downward trend in Lagos Roof station.

Rainfall Variability

Precipitation Concentration Index (PCI)

Seasonal PCI for Ikeja and Lagos Roof stations depicted in Fig. 7.5 shows that there is higher uniformity in wet season rainfall than dry season rainfall. Wet season PCI for both stations ranges between 9 and 20, and Ikeja station recorded 9 and 13 as lowest and highest PCI values, respectively, while Lagos Roof recorded 9 and 20 as its lowest and highest PCI values in wet season, respectively; 37 and 63% of the wet season in the period under review witnessed low and moderate PCI categories in Ikeja station, respectively, while 13, 80, and 7% of the wet season in Lagos Roof observed low, moderate, and irregular PCI categories, respectively. Dry season PCI for both stations ranges from 9 to 42, and Ikeja recorded 10 and 41 as the minimum and maximum values, while Lagos Roof observed 9 and 42 as the minimum and maximum values, respectively; 3, 47, 33, and 17% of the study duration recorded

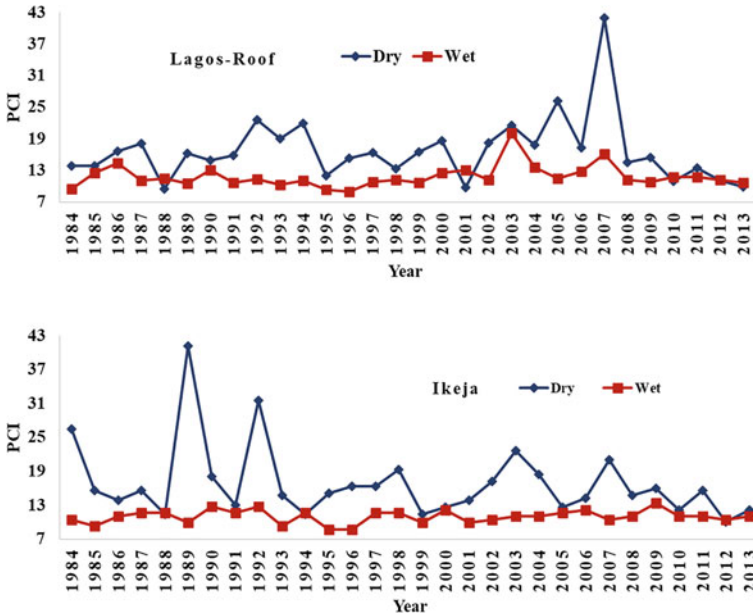


Fig. 7.5 Seasonal Precipitation Concentration Index for the period (1984–2013)

PCI categories of low, moderate, irregular, and strong irregularity of precipitation in Ikeja, while 10, 37, 36, and 17% of the period observed PCI categories of low, moderate, irregular, and strong irregularity of precipitation in Lagos Roof station.

Annual PCI for Ikeja and Lagos Roof stations (Fig. 7.6) ranges from 11 to 28. Ikeja station observed the lowest and highest annual PCI values of 11 and 20 in 1993 and 2009, while Lagos Roof station recorded its lowest and highest annual PCI values of 13 and 28 in 1996 and 2003, respectively. Ikeja station recorded moderate and irregular precipitation in 63 and 37% of the period examined, while Lagos Roof station observed moderate, irregular, and strong irregularity of precipitation in 37, 50, and 13% of the study duration (Fig. 7.7).

Rainfall Variability Index (RVI)

Seasonal RVI: Rainfall wet season standardized anomaly (Fig. 7.8) shows that Ikeja station recorded 57% negative to 43% positive anomaly tendency, while Lagos Roof station recorded 50% negative to 50% positive tendency. Categories of climate regimes for Ikeja were 80% no drought, 10% moderate drought, 3% severe drought, and 7% extreme drought, while 77% no drought, 13% moderate drought, 7% severe drought, and 3% extreme drought for the study period were recorded in Lagos Roof station. Dry season standardized anomaly (Fig. 7.9) indicates that Ikeja station recorded 53% negative to 47% positive tendency, while Lagos Roof station recorded

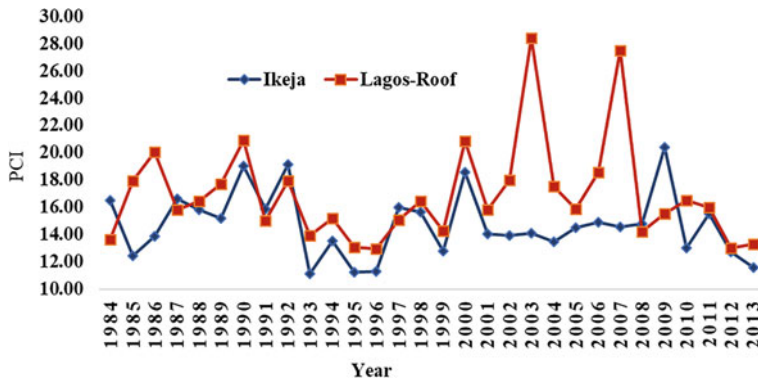


Fig. 7.6 Annual Precipitation Concentration Index for the period (1984–2013)

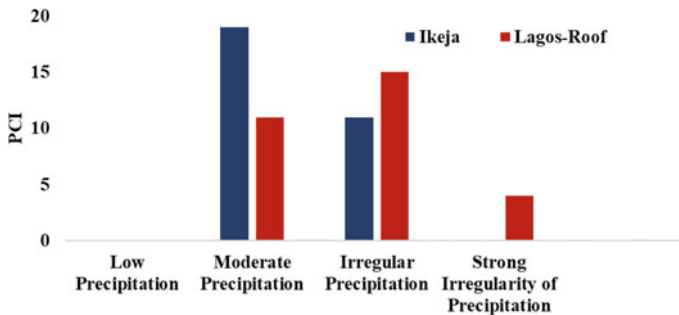


Fig. 7.7 Frequency occurrence of PCI categories for the period (1984–2013)

47% negative to 53% positive tendency. Classes of climate regimes for Ikeja were 73% no drought, 20% moderate drought, and 7% severe drought, while Lagos Roof station recorded 77% no drought, 7% moderate drought, 13% severe drought, and 3% extreme drought periods.

The annual standardized anomaly depicted by Fig. 7.10 shows a 43% negative to 57% positive tendency for Ikeja station and a 50% negative to 50% positive tendency for Lagos Roof station. Climate regimes were 80, 7, 7, and 6% of no drought, moderate drought, severe drought, and extreme drought years in Ikeja station, while 73, 17, 7, and 3% of no drought, moderate drought, severe drought, and extreme drought years in Lagos Roof station, respectively. About 37, 33, and 30% of the study period show uniformity in positive anomaly (1987, 1988, 1990, 1991, 1993, 1995, 1996, 1997, 2004, 2010 and 2011), consistency in negative anomaly (1984, 1985, 1986, 1992, 1994, 1998, 2000, 2001, 2003 and 2006), and contrasting anomaly (1989, 1999, 2002, 2005, 2007, 2008, 2009, 2012 and 2013) annually, respectively,

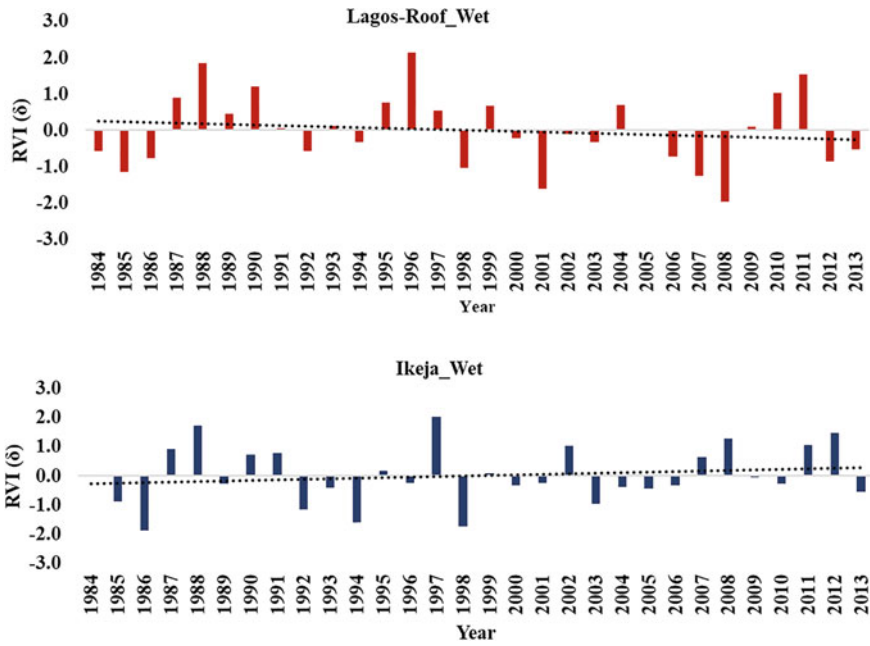


Fig. 7.8 Wet season Rainfall Variability Index (RVI) for the period (1984–2013)

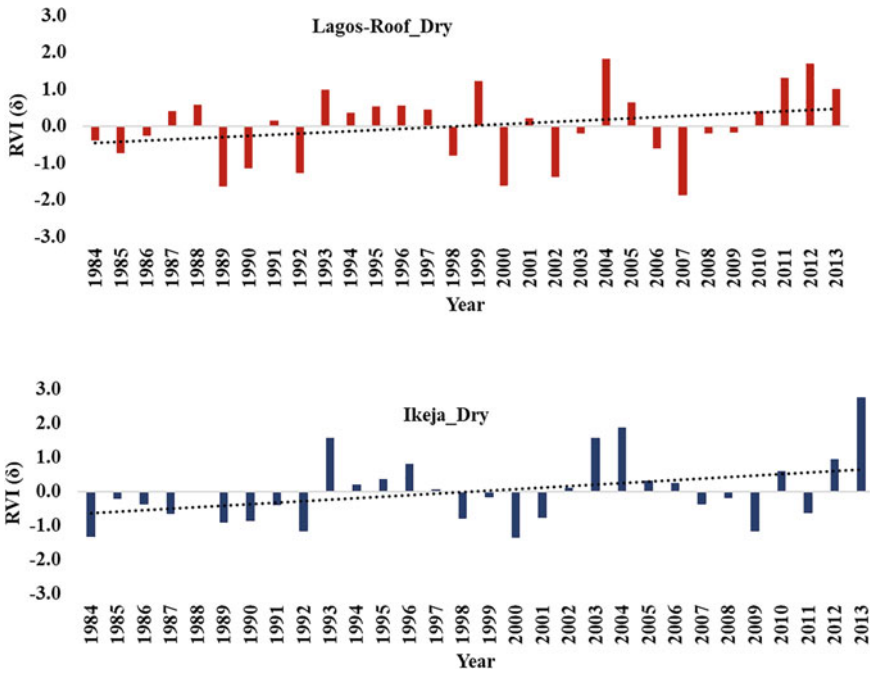


Fig. 7.9 Dry season Rainfall Variability Index (RVI) for the period (1984–2013)

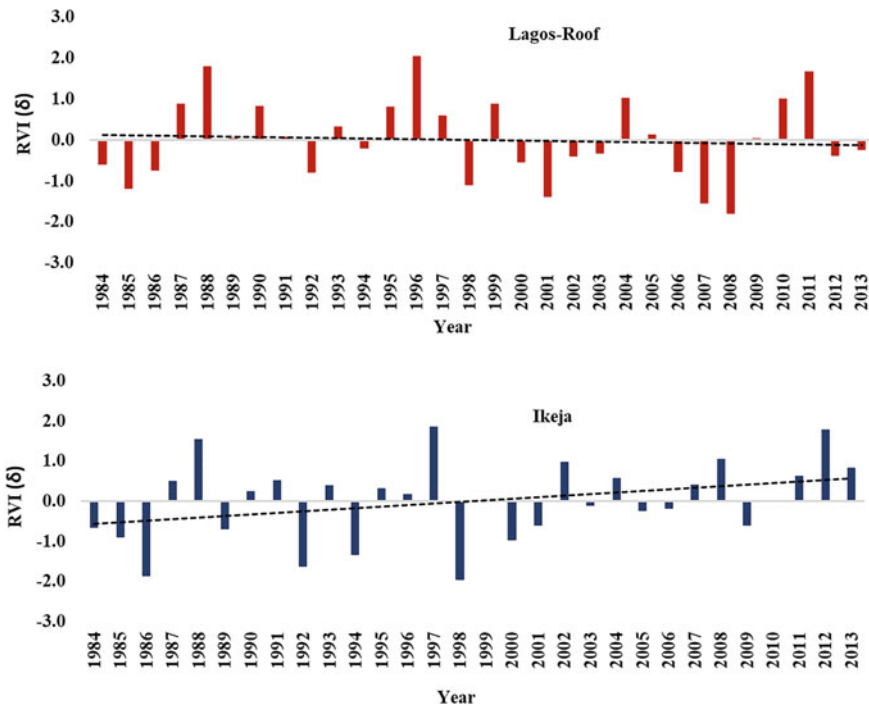


Fig. 7.10 Annual Rainfall Variability Index (RVI) for the period (1984–2013)

between the two stations studied. Extreme drought was recorded in Ikeja (1986, 1998) and Lagos Roof (2008), while severe drought occurred in 1992 and 1994 in Ikeja station, and 2001 and 2007 in Lagos Roof station.

Conclusion

The study was conducted on rainfall trend and variability in Lagos, a littoral mega city in Southeastern Nigeria with a view of evaluating the potential local influence of geographical characteristics on rainfall variability. Two independent weather stations at Ikeja and Lagos Roof with distinct geographical characteristics were used and analysis was done through the modified Mann–Kendall (MM-K) and Sen’s slope estimator (Q). Trend analysis of rainfall undertaken by this study has shown that monthly rainfall from January to May, November, and December is on the increase in both stations while a downward trend was observed in both stations only in the month of July, even as the months of June, August, and September show contrasting upward and a downward trend in both stations.

Seasonally, both stations observed an upward trend in dry season rainfall, which signals the strength of other forcing functions apart from the African Easterly Jet (AEJ) that may be responsible for rainfall during the wet season (Omotosho and Abiodun 2007), and contrary trend in the wet season. On the annual scale, rainfall is increasing in Ikeja station, which is in agreement with the findings of Akinsanola and Ogunjobi (2015) and decreasing in Lagos Roof station for the period under investigation; this disparity between closely sited stations could be attributed to the influence of local climate forcing and climate change effect especially in a densely populated city like Lagos that has witnessed very rapid urbanization in the past few decades. This is congruent with Trenberth (2008) and Ogou et al. (2021) who observed that there is a direct influence of global warming on changes in precipitation and heavy rains and that the patterns of where it rains also have been observed to change, with dry areas becoming drier throughout the subtropics and wet areas becoming wetter, especially in mid to high latitudes. In India, Nair et al. (2018) observed that there are different remote and local climate forcings to seasonal and regional inhomogeneity in rainfall in India among which are the Eastern and Central Pacific El Niño Southern Oscillation, equatorial zonal winds, Atlantic zonal mode and surface temperatures of the Arabian Sea and Bay of Bengal, as well as the sea surface temperature of the North Atlantic and extratropical oceans. Simulations by Vera et al. (2019) also confirm that anthropogenic forcing is a necessary condition to explain the positive trends detected in the co-variability between tropical SST and regional U200 anomalies in rainfall variability in the South American Altiplano.

Rainfall variability study conducted herein indicated high levels of variability within Lagos across different time scales in conformity with the findings of Sojobi et al. (2016). Urbanization has been observed to increase extreme rainfall events over or downwind of cities (Jia et al. 2019). PCI is more uniform in the wet season than in the dry season, which is in agreement with the findings of Ezenwaji et al. (2017) in Awka, which is a tropical city in Nigeria with the same climate features (Omotosho and Abiodun 2007). Wet season PCI for both stations varies from 9 to 20 while dry season PCI for both stations varies from 9 to 42; low and moderate rainfall dominated wet season, while strong and irregular rainfall dominated the dry season. Annually, PCI in Ikeja station is dominated by 63% moderate rainfall in contrast to 37% moderate rainfall recorded in Lagos Roof station. RVI study shows that Lagos Roof station recorded a higher positive tendency than Ikeja station in both wet and dry seasons as well as high percentages of no drought characteristics in both seasons (77 and 80% for the wet season while 77 and 73% for the dry season for Lagos Roof and Ikeja stations, respectively). Annual RVI shows that Ikeja station has 57% positive tendency compared to 50% positive tendency recorded in Lagos Roof station, some level of consistency was recorded between both stations in the first and second decade. However, contrasting anomaly between the stations was more visible in the last decade of the study, which could be likened to the effect of a changing climate.

Limitations, Perspectives for Future Research, and Recommendations

As can be seen from the study, finding out what is happening to rainfall trends in mega cities is vital due to urbanization and the impact of climate change and variability which has become rampant in recent years. This is not only important for accuracy and precision in rainfall prediction but also in water resource planning and environmental management for a sustainable society and environment. These efforts provide a potential data source to address variability on heavy rainfall, in terms of their intensities and frequencies, within and across different climate regions.

Lagos is an economic city that is occasionally prone to heavy flooding annually; therefore, there is a need for policymakers to conceptualize a framework for mitigation and adaptation. The result of this study also calls for more research using hourly, daily, and weekly data with a longer time frame as this study is limited to monthly data series of 30 years (1984–2013).

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