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Understanding Climate Variability and Rainfall Distribution Patterns in Osogbo, Southwestern Nigeria

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ABSTRACT
Understanding rainfall variability and distribution is critical for climate adaptation, agricultural planning, and water resource management, particularly in tropical regions like Nigeria. This study analyses the temporal variability and distribution of rainfall in Osogbo, Southwestern Nigeria, over a 34-year period (1990–2023) using the Rainfall Variability Index (RVI) and the Precipitation Concentration Index (PCI). RVI was employed to quantify interannual rainfall anomalies and classify drought intensities, while PCI assessed the seasonal distribution of rainfall across annual, dry, and wet periods. Results from the RVI revealed a near-balanced pattern of rainfall anomalies, with 53% of the years showing below-average rainfall and 47% above average. Drought classification showed that 76% of the years experienced no drought, while 24% ranged from moderate to extreme drought conditions. Dry season analysis indicated higher variability, with a predominance of irregular and strongly irregular rainfall distribution (PCI > 16) in 85% of the years, suggesting unseasonal or erratic rainfall events. In contrast, the wet season exhibited more stable and uniform rainfall patterns, with 74% of the years showing PCI values below 10, indicating favourable conditions for rain-fed agriculture. The findings underscore increasing rainfall unpredictability, particularly during the dry season, and highlight the growing need for climate-resilient agricultural practices, improved seasonal forecasting, and integrated water management strategies. This study contributes to the understanding of local-scale climate behaviour and supports evidence-based decision-making in the face of climate variability and change.

Keywords:
Rainfall Variability,
Precipitation Concentration Index (PCI),
Rainfall Variability Index (RVI),
Climate Change.

INTRODUCTION

Rainfall is a critical climatic element in the hydrological cycle, especially in tropical regions where agriculture, water resources, and ecological systems are highly sensitive to variations in precipitation. In Nigeria, as in many West African countries, rainfall is not only seasonal but also highly variable in time and space. This variability has far-reaching implications for food security, water supply, and disaster risk management (Adefolalu, 1986; Odekunle et al., 2008). Recent decades have witnessed increasing concern over changing rainfall patterns, marked by irregular distribution, altered onset and cessation dates, and increasing incidence of both droughts and intense rainfall events likely associated with global climate change and regional climatic oscillations (Nicholson, 2013; IPCC, 2021). Recent studies by Njoku and Onugwu (2023) have also highlighted changing rainfall distribution patterns in other regions of Nigeria, reinforcing the need for localized analyses of rainfall variability.

Two important indices for assessing temporal rainfall variability and distribution are the Rainfall Variability Index (RVI) and the Precipitation Concentration Index (PCI). The RVI measures how much annual or seasonal rainfall deviates from the long-term mean, expressed in terms of standard deviation. It is a useful tool in climatological and hydrological studies for identifying dry and wet years and quantifying their intensity (Hare, 1983; Atedhor et al., 2019). The RVI enables researchers to classify years into different drought categories, ranging from near-normal to moderate, severe, or extreme drought, providing a deeper understanding into the frequency and severity of rainfall anomalies.

In contrast, the Precipitation Concentration Index (PCI), developed by Oliver (1980), is designed to assess the temporal distribution of rainfall over months or seasons. It is particularly effective in identifying whether rainfall is evenly distributed throughout the year or concentrated in a few months. PCI values below 10 indicate uniform rainfall, values between 11 and 15 suggest moderate concentration, and values above 20 denote strong irregularity. High PCI values imply the likelihood of intense precipitation over a short duration, which may lead to flooding, soil erosion, and runoff losses (Ezenwaji et al., 2020). Conversely, low PCI values indicate favourable rainfall distribution that supports rainfed agriculture and reduces drought risk.

Understanding both RVI and PCI is crucial in a changing climate, especially in regions like Nigeria where rain-fed agriculture dominates and resilience to climatic shocks is limited. Several studies have investigated rainfall variability and trends in Nigeria (e.g., NIMET, 2011; Ojo et al., 2020), but comprehensive analyses using both RVI and PCI at local scales remain limited. Furthermore, the seasonal disaggregation of these indices—into dry and wet seasons—offers more nuanced insights into the timing and intensity of rainfall extremes, which is critical for agricultural planning, water management, and climate adaptation strategies (Oladipo, 1993).

This study focuses on analyzing rainfall patterns in Osogbo, southwestern Nigeria, over a 34-year period (1990–2023) using both the Rainfall Variability Index (RVI) and the Precipitation Concentration Index (PCI), specifically evaluating the interannual variability in total, dry, and wet season rainfall using RVI, the temporal concentration and distribution of rainfall across different seasons using PCI, and the frequency and intensity of droughts and rainfall concentration anomalies.

By applying these indices, this research aims to provide empirical evidence of changing rainfall dynamics in Osogbo, contributing to the broader discourse on climate variability and its implications for sustainable development, disaster risk reduction, and climate-resilient agriculture in Nigeria.

MATERIALS AND METHODS

Study Area

Osogbo, the capital of Osun State in southwestern Nigeria, is situated between latitudes 7.75°N–7.80°N and longitudes 4.56°E–4.60°E (Figure 1), within the tropical rainforest savanna ecosystems. Since its designation as the state capital in 1991, Osogbo has experienced considerable urban expansion and development. The area has an estimated population of about 300,000 people (NPC, 2006) and spans approximately 723.67 square kilometers. The city's topography is characterized by gently undulating terrain, with elevations ranging from 300 to 450 meters above sea level. Osogbo lies within the Osun River Basin, where tributaries and seasonal streams facilitate runoff and influence local floodplain dynamics (Alimi et al., 2022).

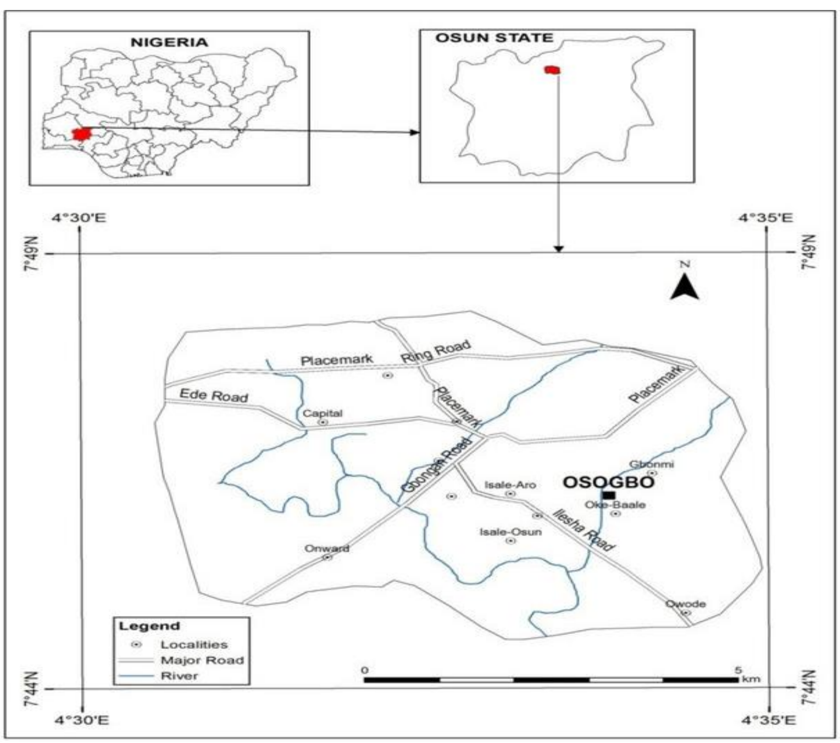

Figure 1: Map of Osogbo, Osun State, Nigeria. (Source: Ibitoye and Okende 2016)

Osogbo's climate is classified as tropical wet-and-dry (Aw) under the Köppen-Geiger system. Rainfall and temperature patterns are primarily shaped by two dominant air masses: the moist southwesterly winds from the Atlantic Ocean and the dry northeasterly harmattan winds from the Sahara Desert (Olaniran & Sumner, 1989). This interaction produces a bimodal rainfall regime, March–July (first rainy season), August (short dry spell), September–mid-November (second rainy season), and mid-November–February (dry season).

Annual rainfall typically ranges from 1,200 mm to 1,500 mm, with peaks in June and September. August is often marked by a short dry period known locally as the "August Break" (Ayoade, 1983; Odekunle, 2004). Mean monthly temperatures range from 24°C to 32°C, with annual means between 27°C and 29°C. Humidity is highest during the rainy season, contributing to heat discomfort (NIMET, 2011).

Data

This study utilized monthly rainfall data obtained from the Nigerian Meteorological Agency (NIMET), the official body responsible for weather and climate observation in Nigeria. The dataset covers a continuous period of 34 years, spanning from 1990 to 2023, and includes measurements of total monthly rainfall in millimetres (mm). The data specifically pertains to Osogbo, the capital of Osun State, located in the southern region of Nigeria. The dataset is complete, with no missing values throughout the 34-year period. This consistency ensures a robust basis for long-term trend analysis and seasonal rainfall variability studies.

Data Analysis

This study employed two key indices, the Precipitation Concentration Index (PCI) and the Rainfall Variability Index (RVI), to analyze the temporal distribution and variability of rainfall in Osogbo over the period 1990–2023.

The Precipitation Concentration Index (PCI) is a widely recognized metric used to evaluate the temporal distribution of rainfall at both seasonal and annual scales. Originally introduced by Oliver (1980) and subsequently refined by De Luis et al. (2011), the PCI provides insight into how precipitation is concentrated across time. In this study, PCI values were computed using monthly rainfall data, as outlined in Equations 1 to 3. According to Oliver's classification, PCI values below 10 indicate a uniform rainfall distribution, between 11 and 15 suggest moderate concentration, between 16 and 20 reflect irregular distribution, and above 20 denote strong irregularity, implying that rainfall is concentrated in a few months of the year.

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

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

$$PCI_{wet} = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{7} P_i\right)^2} \times 58 \quad (3)$$

where Pi represents monthly precipitation of any of the month i.

In addition to PCI, the study utilized the Rainfall Variability Index (RVI) to assess the frequency and severity of drought conditions. The RVI distinguishes between wet and dry periods by computing standardized rainfall anomalies from the historical rainfall time series, following the approach described in Equations 4 to 6. As defined by Agnew and Chappell (1999), the RVI values are interpreted using the following thresholds, Extreme drought ($\delta < -1.65$), Severe drought ($-1.65 < \delta \leq -1.28$), Moderate drought ($-1.28 < \delta \leq -0.84$), and No drought ($\delta > -0.84$).

$$\partial_{annual} = \frac{(P_{annual} - \mu)}{\sigma} \quad (4)$$

$$\partial_{dry} = \frac{(P_{dry} - \mu)}{\sigma} \quad (5)$$

$$\partial_{wet} = \frac{(P_{wet} - \mu)}{\sigma} \quad (6)$$

where δ_{annual}, δ_{dry}, and δ_{wet} represent the annual RVI , dry season RVI, and wet season RVI respectively. Likewise, P_{annual}, P_{dry}, and P_{wet} represent annual rainfall, wet season rainfall , dry season rainfall respectively. μ and σ denote mean and standard deviation in the annual rainfall, dry season, and wet season.

RESULTS AND DISCUSSION

The analysis of annual rainfall data for Osogbo between 1990 and 2023 reveals significant interannual variability. Some years recorded moderate totals, while others experienced either excessive or deficient precipitation. Such variability aligns with the known behavior of the West African Monsoon, which is inherently influenced by synoptic-scale systems and ocean-atmosphere interactions (Nicholson, 2013; Omotosho et al., 2000).

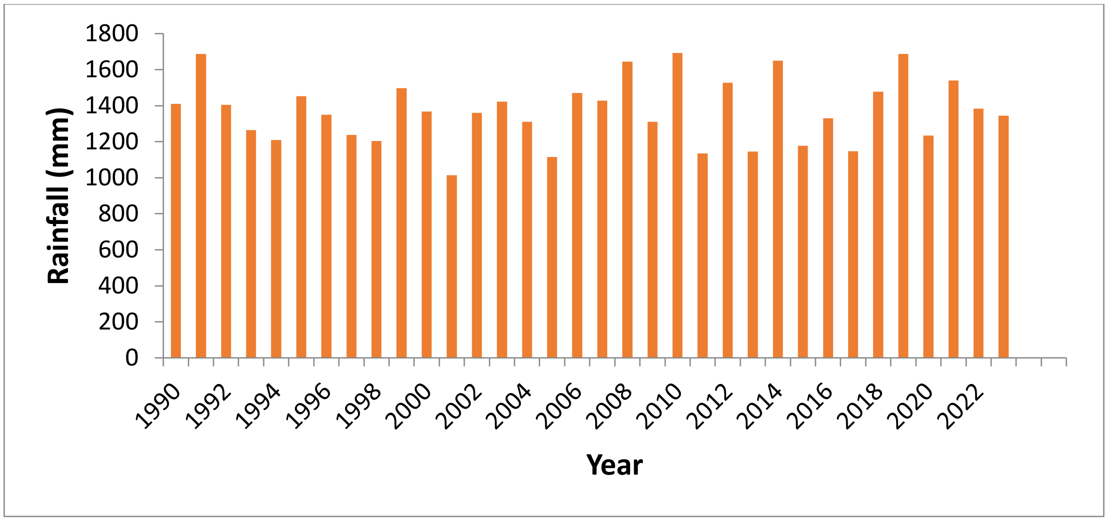

Figure 2: Annual rainfall amount for the period (1990-2023)

The wettest years, such as 2019, 2023, and 2018, each exceeded 1,700 mm, whereas drier years like 1990, 1991, and 2007 fell well below the long-term mean as shown in Figure 2. This variability may reflect not only natural fluctuations but also climate change signals, as extreme events—both wet and dry—are becoming more frequent in many parts of West Africa (IPCC, 2021).

A well-defined unimodal rainfall pattern is evident in Osogbo. Rainfall begins to rise in March, peaks between May and October, and tapers off by November. The core rainy months as observed in Figure 3 are June (185.4 mm), September (224.7 mm), and October (216.3 mm) accounting for the bulk of annual rainfall, which is consistent with the region's tropical wet-and-dry climate (Aw) (Peel et al., 2007). The marked seasonality is driven by the north-south oscillation of the Intertropical Convergence Zone (ITCZ), which governs moisture transport into the region (Nicholson, 2009). The dry months especially January (6.4 mm) and December (8.2 mm) highlight the impact of the harmattan season, during which dry northeasterly winds from the Sahara dominate the region's climate (Adejuwon, 2006).

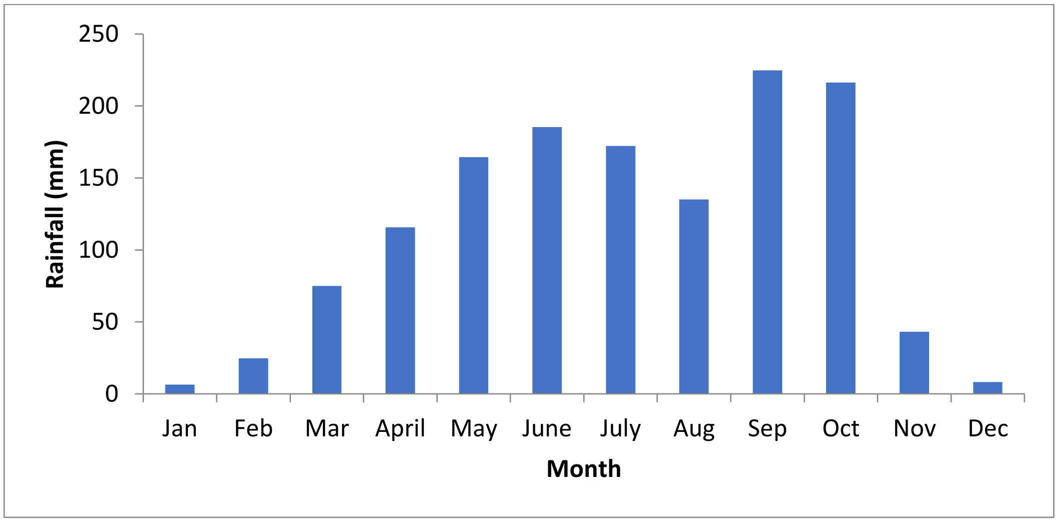

Figure 3: Mean monthly amount of rainfall for the period (1990–2023)

Precipitation Concentration Index (PCI)

The Precipitation Concentration Index (PCI) serves as a useful metric for evaluating the temporal distribution of rainfall over time. Proposed by Oliver (1980), the PCI categorizes rainfall distribution into three main classes: uniform distribution (PCI < 10), moderate concentration (PCI = 11–15), and strong irregularity (PCI > 20). Values between 16–20 suggest irregular distribution. This analysis was applied to annual, dry season, and wet season rainfall data for Osogbo from 1990 to 2023.

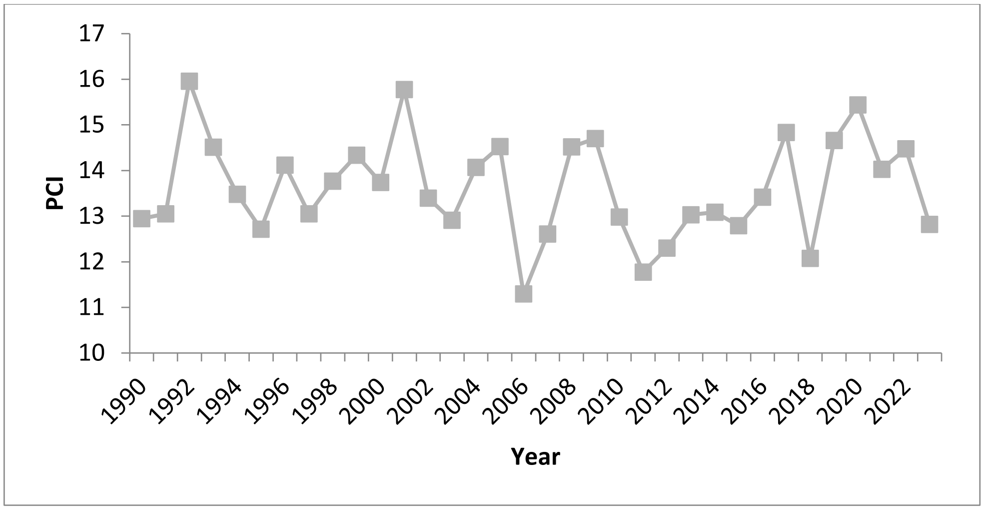

Figure 4: Annual Precipitation Concentration Index for the period (1990–2023)

The mean dry season PCI over the study period was calculated to be 19, categorizing the dry season as irregular in rainfall distribution on average, with 44% of the 34 years analyzed recording PCI values greater than 21 (strong irregularity), 15% falling within the moderate range (11–15), and 41% exhibiting irregular distribution with PCI values between 16 and 20.

In contrast, wet season PCI values (Figure 4) reveal a more stable and uniform rainfall distribution. PCI values ranged from 8.54 in 2007 to 11.16 in 2020, with most years falling between 9 and 10. Only a few years 2020 (11.16), 1993 (10.85), and 2005 (10.32) exceeded a PCI of 10, indicating minor concentration tendencies. Analysis over the 34-year period showed that 74% of the years exhibited uniform precipitation distribution (PCI < 10), and 26% fell within the moderate concentration range (PCI = 11–15). The mean PCI value for the wet season was 10, further confirming the generally uniform distribution of rainfall during this period.

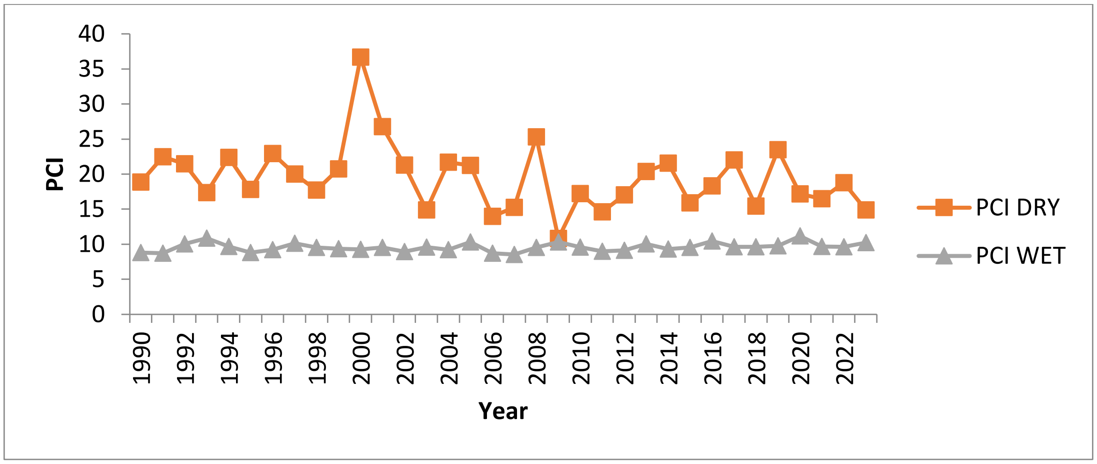

Figure 5: Precipitation Concentration Index during the wet and dry season for the period (1990–2023)

The PCI analysis clearly illustrates the seasonal dynamics of rainfall distribution in Osogbo as shown in Figure 5. The dry season, shows a markedly higher degree of rainfall concentration, with several years experiencing extreme irregularity (PCI > 20). This irregularity increases the risk of soil erosion, water wastage, and crop vulnerability, particularly in systems reliant on residual soil moisture. It underscores the need for investments in rainwater harvesting, water storage, and early warning systems. In contrast, the wet season exhibits remarkable rainfall uniformity, a positive indicator for rainfed farming systems and recharge of water bodies. Importantly, the analysis reveals no significant long-term trend in PCI values, implying that rainfall concentration patterns in Osogbo are primarily influenced by interannual variability rather than a progressive climatic shift. These results are consistent with findings from similar climatic zones in West Africa (Akinsanola & Zhou, 2019; Njoku et al., 2023).

Rainfall Variability Index Analysis

The Rainfall Variability Index (RVI) was employed to assess the temporal variability in rainfall over the study period (1990–2023), considering total annual rainfall, as well as seasonal variations during the dry and wet seasons. The RVI, calculated as a standardized anomaly of annual rainfall values from the long-term mean, provides insight into interannual fluctuations in precipitation, and is widely used in climatological studies (Hare, 1983; Atedhor et al., 2019).

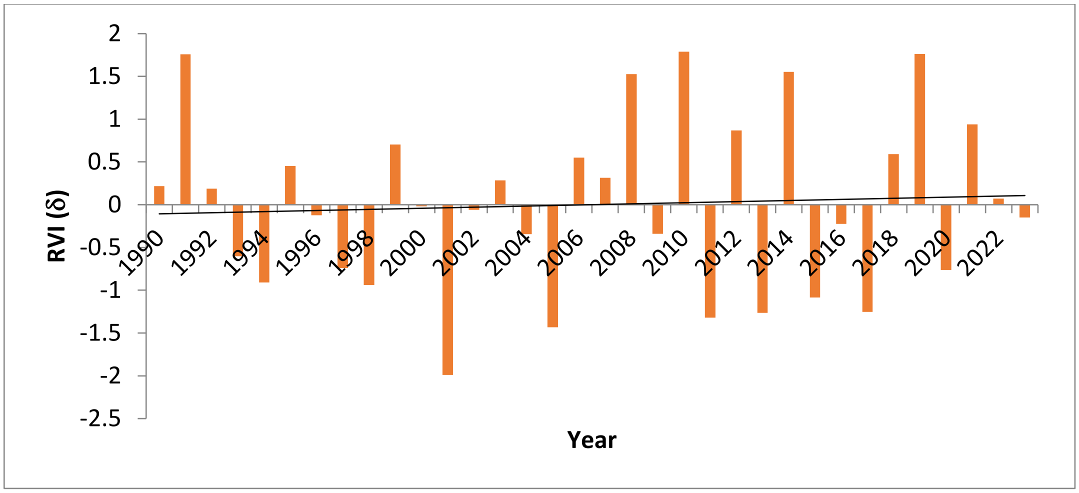

Figure 6: Annual Rainfall Variability Index for the period (1990–2023)

Further analysis of the RVI for total annual rainfall (Figure 6) reveals substantial interannual variability across the 1990–2023 periods. The annual values ranged from a minimum of -1.99 in 2001 to a maximum of +1.79 in 2010, with no year exceeding the ±2.0 threshold that typically denotes extreme wet or dry conditions. Nevertheless, several years exhibited moderately wet anomalies, including 1991 (1.76), 2008 (1.53), 2010 (1.79), 2014 (1.55), and 2019 (1.76). In contrast, moderately dry years were recorded in 2001, 2005, 2011, 2013, 2015, and 2017, indicating episodic drought occurrences.

The dominance of near-normal years interspersed with these wet and dry anomalies underscores the high interannual rainfall variability experienced in the station. Notably, the clustering of wet years during the 2010s may be indicative of broader climatic influences such as the El Niño–Southern Oscillation (ENSO), Atlantic Multidecadal Oscillation, or shifts in West African monsoon dynamics (Nicholson, 2013; Animashaun et al., 2020). Such climatic oscillations are known to modulate rainfall patterns in tropical West Africa, influencing the frequency and intensity of droughts and wet spells. Overall, the RVI analysis for total annual rainfall reveals that while extreme conditions are relatively rare, the region is exposed to significant interannual fluctuations, necessitating adaptive strategies in water resource planning and agricultural practices.

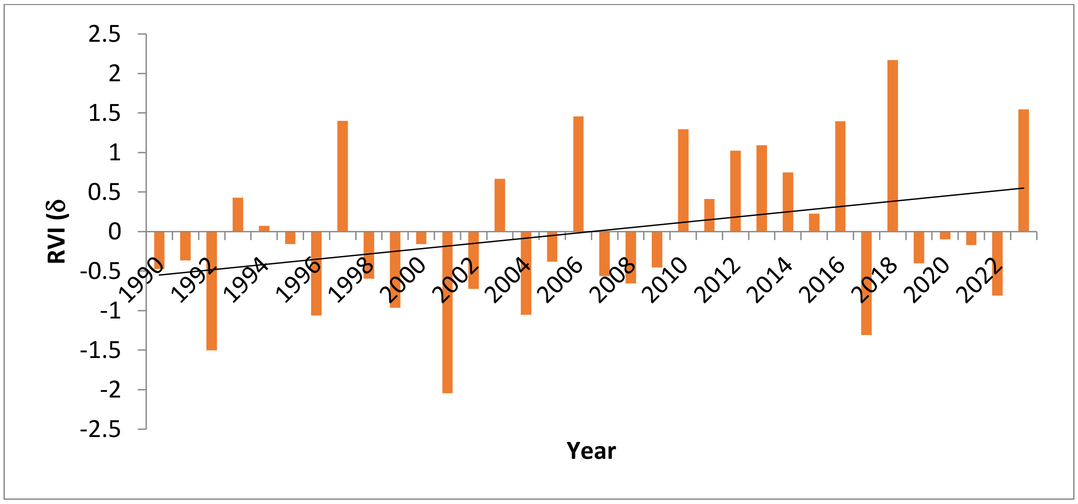

Figure 7: Rainfall Variability Index during the dry season for the period (1990–2023)

The Rainfall Variability Index for the dry season presented in Figure 7, reveals a 59% tendency toward negative anomalies and 41% toward positive anomalies over the study period. An analysis of drought severity based on RVI classification indicates that 82% of the years experienced no drought, while 9% recorded moderate drought, 6% severe drought, and 3% extreme drought conditions.

Although dry seasons typically contribute less to the annual rainfall total, the dry season data reveal notable deviations from the mean. Specifically, the years 2006 (1.46), 2016 (1.40), 2018 (2.17), and 2023 (1.55) were characterized by unusually wet conditions during what is conventionally a dry period. Such anomalies suggest the occurrence of off-season rains, which may signal disruptions in the onset and cessation of the West African monsoon.

In contrast, significantly dry seasons were recorded in 1992, 1996, 2001, 2004, and 2017, marking periods of suppressed dry season rainfall. The presence of both anomalously wet and dry years within the dry season highlights an increasing variability and unpredictability, potentially driven by shifting climatic patterns and localized convective influences. The increasing complexity of rainfall behavior during the dry season is consistent with broader observations of regional climate variability (Ayanlade, 2019).

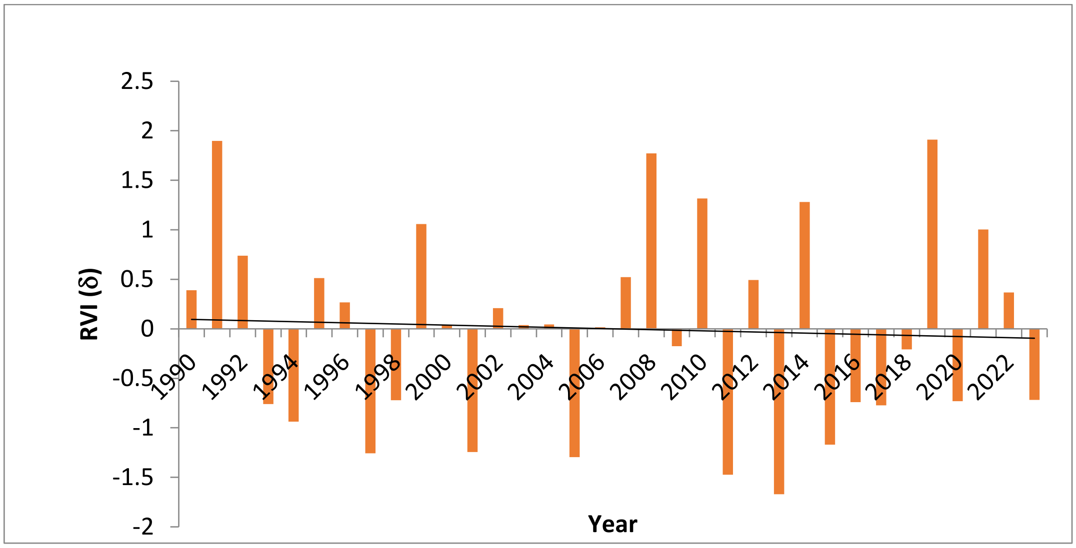

Figure 8: Rainfall Variability Index during the wet season for the period (1990–2023)

As shown in Figure 8, the RVI for the wet season indicates that 56% of the years exhibited positive anomalies, while 44% showed negative anomalies during the study period. The classification of climate regimes based on RVI thresholds revealed that 79% of the years experienced no drought, 12% were moderately dry, 6% severely dry, and 3% extremely dry.

Wet season rainfall variability was more pronounced than in the dry season, with wet season RVI values ranging from -1.67 in 2013 to +1.91 in 2019. Years such as 1991 (1.90), 2008 (1.77), 2010 (1.32), and 2019 (1.91) were identified as notably wet, while 2011, 2013, and 2015 were characterized by significant dryness.

The wet season plays a dominant role in shaping the total annual rainfall pattern in the study area. Consequently, fluctuations during this season have a direct influence on the annual hydrological balance and agricultural productivity. The frequency and intensity of wet and dry anomalies in recent decades suggest a trend toward greater interannual volatility, raising concerns for rainfed farming systems, flood control infrastructure, and disaster risk reduction strategies. These sharp interannual shifts may reflect the growing influence of climate change, including the changing behavior of key atmospheric drivers such as the Intertropical Convergence Zone (ITCZ), ENSO, and Saharan Heat Low dynamics (IPCC, 2021, Grist et al., 2002).

CONCLUSION

This study examined rainfall variability and distribution in Osogbo, Southwestern Nigeria, over a 34-year period (1990–2023) using the Rainfall Variability Index (RVI) and Precipitation Concentration Index (PCI), providing valuable insights into the temporal behaviour of rainfall on both annual and seasonal scales and highlighting patterns of climatic fluctuations with implications for key socio-economic sectors. The RVI analysis showed significant inter-annual variability, with a slight predominance of below-average rainfall years (53%) over above-average ones (47%), and although most years fell within the near-normal range, about 24% of the period experienced varying degrees of drought, including moderate, severe, and extreme events. The clustering of wet anomalies in the 2010s and the occurrence of dry years in the early 2000s underscore the influence of larger climate oscillations such as ENSO and shifts in the West African monsoon. Seasonal disaggregation of RVI further revealed greater unpredictability during the dry season, with some years recording unusually wet conditions likely due to anomalous rainfall events outside the typical rainy period. The PCI analysis confirmed these trends, indicating that while annual rainfall distribution was moderately concentrated, dry season rainfall was highly irregular in most years, whereas the wet season displayed predominantly uniform rainfall patterns favourable for agriculture and groundwater recharge. These findings underscore practical implications for agriculture, water resource planning, and climate risk management, as increasing dry season irregularity and occasional extreme rainfall events point to a changing climate regime that demands proactive adaptation strategies. Policymakers and stakeholders should prioritize the development of early warning systems, climate-smart agriculture, and improved rainfall forecasting to reduce vulnerability to climatic extremes, while the integration of long-term rainfall variability data into local planning frameworks can support more resilient livelihoods and sustainable development in the face of ongoing climate variability and change.

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