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ANALYSIS OF RAINFALL VARIABILITY IN OSOGBO, OSUN STATE USING REMOTE SENSED DATA FROM 1993 TO 2023

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Abstract https://doi.org/10.65760/sjgs.v4.i1.2

This study investigated rainfall variability in Osogbo, Nigeria, over a 31-year period (1993-2023) using CHIRPS remote sensing data. The research analyzed patterns and fluctuations in annual, seasonal, and monthly rainfall across 20 locations within the study area. Utilizing geospatial tools and statistical techniques, the study revealed notable differences in rainfall distribution both over time and between locations. Results showed that 2019 recorded the highest annual rainfall, while 2021 experienced the lowest, highlighting significant inter-annual variability. Seasonal rainfall patterns remained relatively stable, though certain years exhibited marked deviations. Monthly analysis identified September as the most variable month in terms of rainfall, while December had the lowest values of rainfall. Spatial analysis further showed that the following areas: GRA, Oke Oniti, and Osun River received higher amount of rainfall, compared to Boripe and Conference Hall experienced lower values. These findings underscore the complex and dynamic nature of Osogbo's rainfall regime.

Keywords: *Rainfall, Variability, Remote Sensing, Climate Change and Season.*

1.1 Introduction

Rainfall is a major determinant of agricultural production in any agro-ecological zone anywhere in the world. Its seasonal and annual characteristics such as the onset and intra-seasonal rainfall distribution that promote good crop yields are, however, characterized by marked fluctuations. The climate science community is in agreement that several hydroclimatic parameters are changing as a result of global warming caused by an increase in greenhouse gases (IPCC, 2021; Trenberth et al., 2014). Based on a recent study, the average temperature of the Earth has increased by about 0.6°C, over the twentieth century (Tabari & Hosseinzadeh, 2011). Climate change has led to enhanced evaporation and more frequent extreme precipitation events, while rainfall continues to be a critical variable controlling monsoon dynamics across the globe. Previous studies suggest that the quantity of rainfall at weekly, monthly, and annual time scales varies widely (Valli, Sree, & Krishna, 2013). The variability in rainfall is expected to be exacerbated by climate change leading to intensification of water fluxes, with more evaporation and more precipitation (Some'e, Ezani, & Tabari, 2013). Similarly, precipitation amount has been unequally distributed around the globe, and several areas are expected to see significant reductions or major changes in the timing of wet and dry seasons. It

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has also been asserted that unbalanced distribution of rainfall may evoke periods of rainfall excess and periods of drought, which may make plant and crop growth difficult (Rosenzweig et al., 2025).

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

Remote sensing technology has emerged as a powerful tool for monitoring and analyzing rainfall patterns over large areas. By utilizing satellite-based data, it is possible to obtain accurate and timely information on rainfall distribution, intensity, and variability (Singh et al., 2015).

In Nigeria, rainfall variability has been linked to climate change, land use changes, and urbanization (Oguntunde et al., 2022). There is a paucity of knowledge on the area of seasonal rainfall in Osogbo and this research aims at improving on the existing body of knowledge.

2.0 Materials and Methods

2.1 Study Area

Osogbo, the capital of Osun, is located between Latitude 7°46′N and 7°76′N and Longitude 4°34′E and 4°55′E of Greenwich Meridian (Figure 1). The study has an average land mass area of about 47 km^2. It lies within the tropical rainforest zone, with an average annual rainfall of 1,200 - 1,500 mm. The geology consists of Basement Complex which outcrop considerable parts of the area. Rocks of the basement complex in Osogbo are schist and synite which are associated with quartzite ridges. The landscape of Osogbo is situated on a raised land, which is well over 500 m above the sea level and is drained by River Osun and its tributaries. The climate is humid tropical type and characterized by wet and dry seasons. The wet season begins toward the end of March and ends in October while the dry season begins with the onset of tropical continental air mass commonly referred to as Harmattan. This wind is usually predominant between the months of November and February (Olaniran 2000). Osogbo falls into the southern savanna zone. This zone is a transition between the high forest in the southern part of the country and the north with woodland properties. Agricultural activities such as fish farming, poultry, market gardening, poultry, and cultivation of vegetables, yam and maize are predominant in Osogbo.

Osogbo, experiences a tropical wet and dry climate, classified as 'Aw' under the Köppen-Geiger climate classification system. The city maintains consistently warm temperatures throughout the year, with average daily temperatures ranging from 24°C (77°F) to 32°C (88°F). The climate is characterized by distinct wet and dry seasons, with the eainy season typically lasting from March to October, peaking between May and September. During this period, Osogbo receives an average annual rainfall of 1200 to 1500mm, which supports robust vegetation growth and sustains the agricultural activities that dominate the region. (Wikipedia (2022).

In terms of vegetation, Osogbo is situated within the lowland rainforest derived savanna ecological zone. Historically, the region was covered by dense tropical rainforest, but human activities such as agriculture, urbanization, and logging have altered the natural vegetation into a derived savanna, where scattered trees exit alongside grasses and shrubs (Areola, 1983). Remnants of the natural forest can still be found in Osun-Osogbo Sacred Grove, which supports a variety of native plant and animal species essential to biodiversity conservation in southern Nigeria (Adekola & Ogunsesan, 2016).

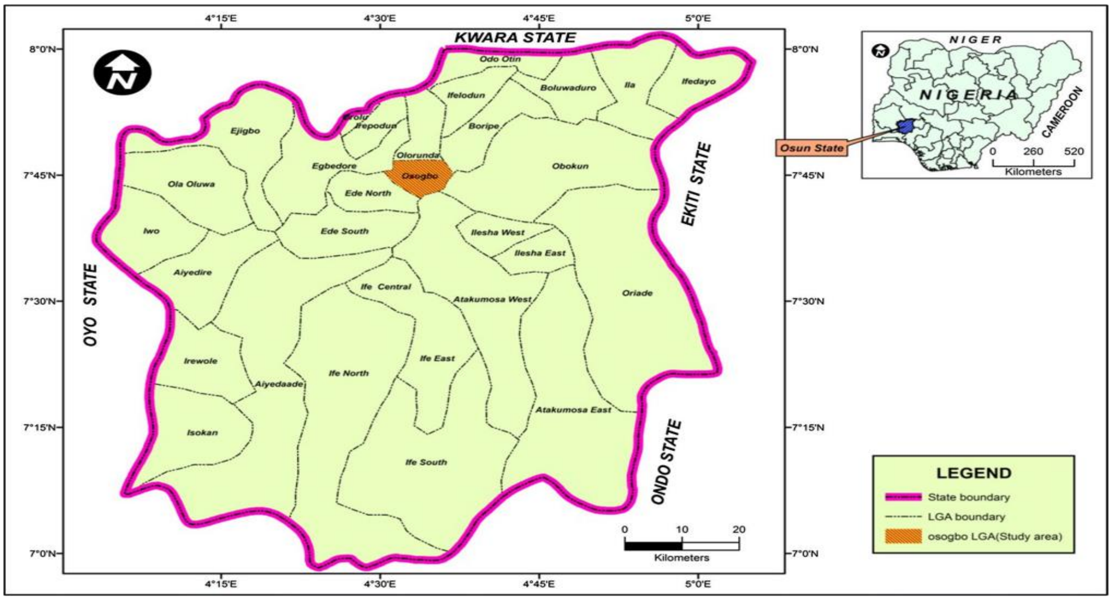

Figure 1: Schematic of Osogbo in Osun State, Nigeria

2.2 Data Collection

The data used in this study were remotely sensed rainfall data from the CHIRPS (Climate Hazards Group InfraRed Precipitation with Station Data) dataset, covering 1988-2023 of daily rainfall data for Osogbo. The total rainfall for these selected months was summed, and comparisons were made between study locations. The Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a quasi-global rainfall data set. As its title suggests it combines data from real-time observing meteorological stations with infra-red data to estimate precipitation. The data set runs from 1981 to the near present.

CHIRPS incorporates a high spatial resolution of 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring. Since 1999, United State Geological Survey (USGS) and Climate Hazards Group (CHG) scientists, supported by funding from the United States Agency for International Development (USAID), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA), have developed techniques for producing rainfall maps, especially where surface data is sparse. The creation of CHIRPS has supported drought monitoring efforts by the USAID Famine Early Warning Systems Network.

There are two main data sets. The first is quasi-global and covers the whole world from Latitude 50°N to 50°S. The second covers Africa and parts of the Middle-East. It covers the area from Latitude 40°N to 40°S and Longitude 20°W to 55°E. The global data set has data on a 0.05° grid at monthly, pentad and daily time's steps. This is equivalent to 31 km^2. The 'Africa' data set also includes data at a 0.10° grid at a 6-hour time step.

3.0 Results and Discussion

This section presents and interprets the findings of the study in relation to the objectives to analyze the spatial distribution of rainfall; identify temporal trends; and examine the factors influencing rainfall variability in Osogbo from 1993 - 2023.

3.1 Spatial Distribution of Rainfall

The results of the spatial distribution were given in form of diagrams in Figures 2 and 3. The spatial analysis, based on remote sensing data and QGIS mapping, revealed clear geographical patterns in rainfall distribution across the 20 locations in Osogbo. The contour maps illustrated that rainfall is not evenly distributed across the city, with certain areas such as GRA, Oke Oniti, and Powerline consistently receiving higher amounts of rainfall, while stations like Boripe, Dims Hotel, and Obanisola experienced relatively lower precipitation. These variations were clearly visualized through the spacing of contour lines, indicating zones of rapid rainfall change and areas with more uniform distribution.

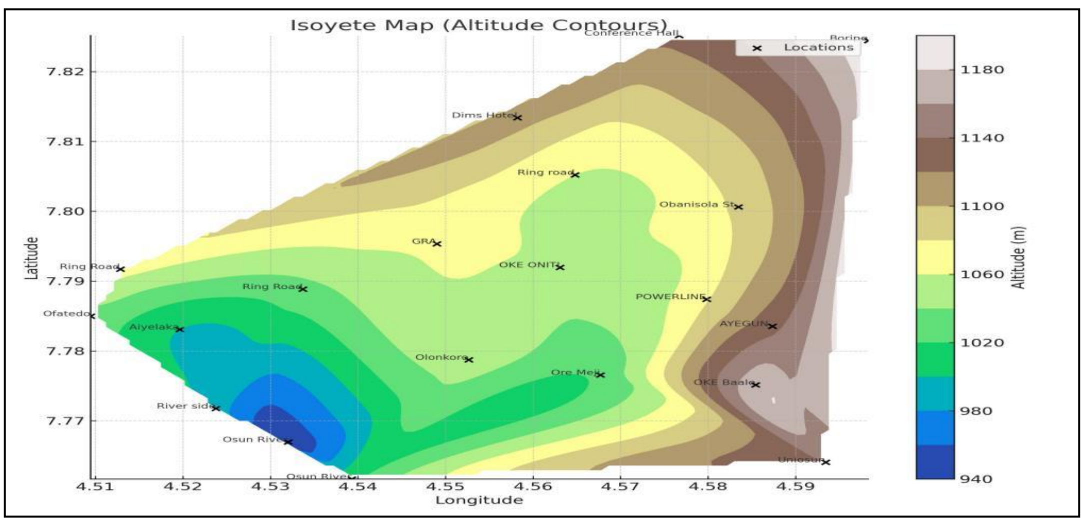

Figure 2: Rainfall is Distributed Across Different Locations

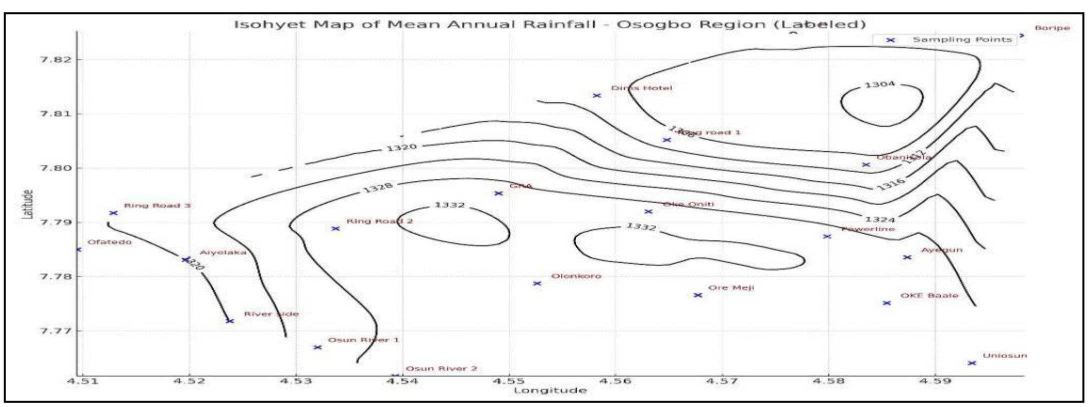

Figure 3: Mean Annual Isohyetal Contours in Osogbo

Also, Figure 4 illustrates the total yearly rainfall distribution across 20 synoptic stations in Osogbo over the past 31 years (1993 - 2023). The total annual rainfall for each location was calculated and plotted yearly. Both statistical analysis and visual inspection of the plot indicate variations in annual rainfall across the study locations. The year 2021 recorded the lowest annual rainfall, with Boripe, Conference Hall, Obanisola, Dims Hotel, and Ring Road receiving 941mm each. Other locations such as GRA, Oke Oniti, Powerline, Ayegun, Oke Baale, Ore Meji, Olonkoro, and Osun River recorded slightly higher amounts, ranging from 925mm to 949mm. Conversely, the highest rainfall was recorded in 2019, with Boripe, Conference Hall, Obanisola, Dims Hotel, and Ring Road receiving 1724mm each. Locations like GRA, Oke Oniti, Powerline, Ayegun, Oke Baale, Ore Meji, Olonkoro, Osun River, and Uniosun recorded between 1737mm and 1744mm. Although annual rainfall differences were minimal in some years, i.e., 1995, 2003, 2004, 2007, 2008, 2010, 2018, and 2019, variations were still observed.

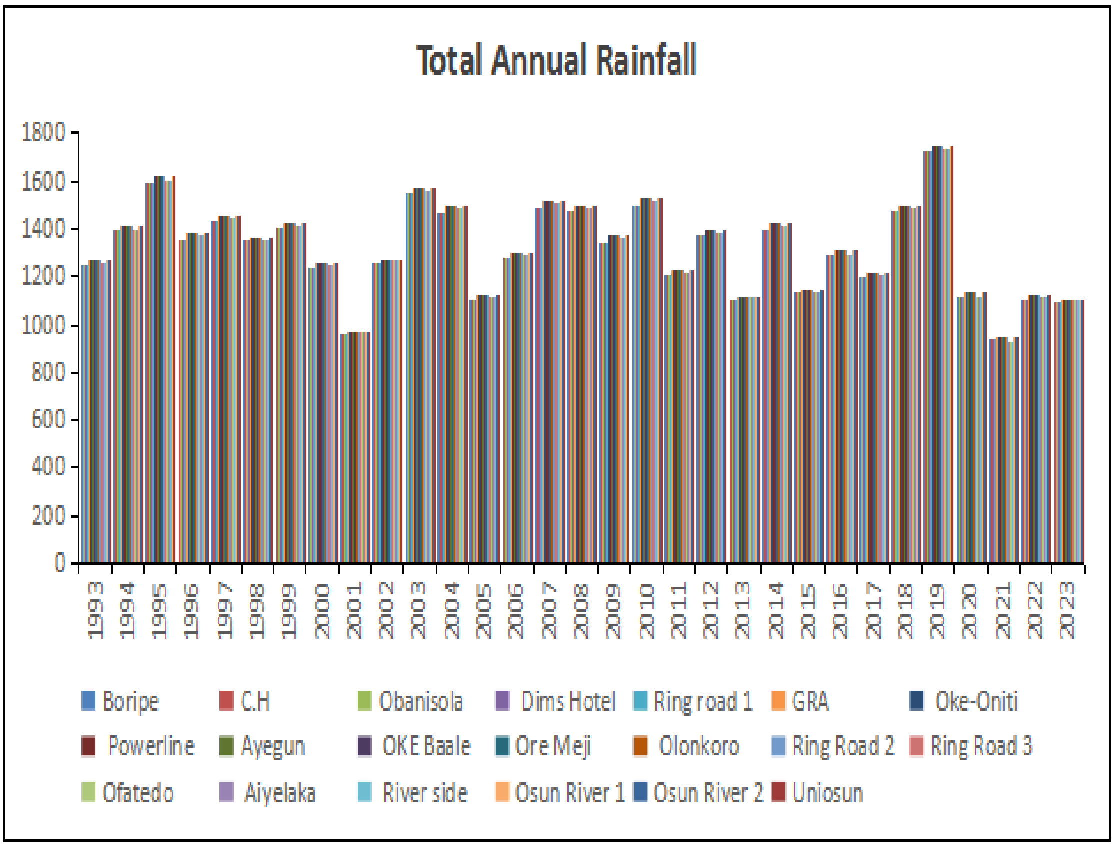

Figure 4: Total Annual Rainfall Variation from (1993 - 2023)

Furthermore, Figure 5 indicates clear spatial variability in rainfall distribution across the study area. The result showed that GRA, Oke Oniti, P owerline, Ayegun, Oke Baale, Ore Meji, Olonkoro, Osun River, Uniosun, and Ring Road 2, recorded the highest rainfall, followed by Ofatedo Aiyelaka, Ring Road 3 and Riverside, while Boripe, Obanisola, Dims Hotel, Ring Road 1 and Conference Hall had the lowest rainfall over the years. This spatial contrast likely reflects differences in topography, proximity to river channels, and local land-use characteristics, which influence moisture convergence and convective rainfall processes over time.

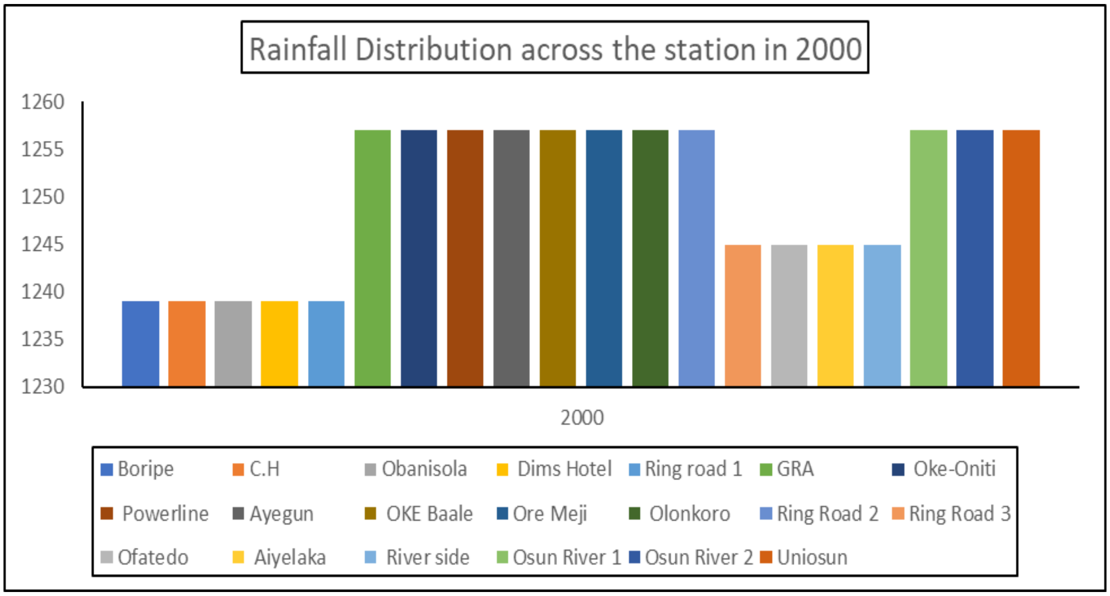

Figure 5: Rainfall Distribution Across the 20 Stations in 2000

3.2 Rainfall Trends from 1993 to 2023

The presented in Figure 6 represent a Dekadal comparison of rainfall trends across the 20 locations in Osogbo over the three decades from (1993 to 2022) with 2023 representing the most recent year. The chart compared the average annual rainfall grouped from 1993-2002, 2003-2012, 2013-2022, and 2023 respectively.

The comparison revealed the highest rainfall was recorded in 2003-2012 across the most locations, showed the peak of rainfall over three decades. Rainfall level began to decline steadily from 2013 to 2022, with 2023 showed a clear drop in rainfall compared to all the previous decades, indicating that recent rainfall has reduced significantly.

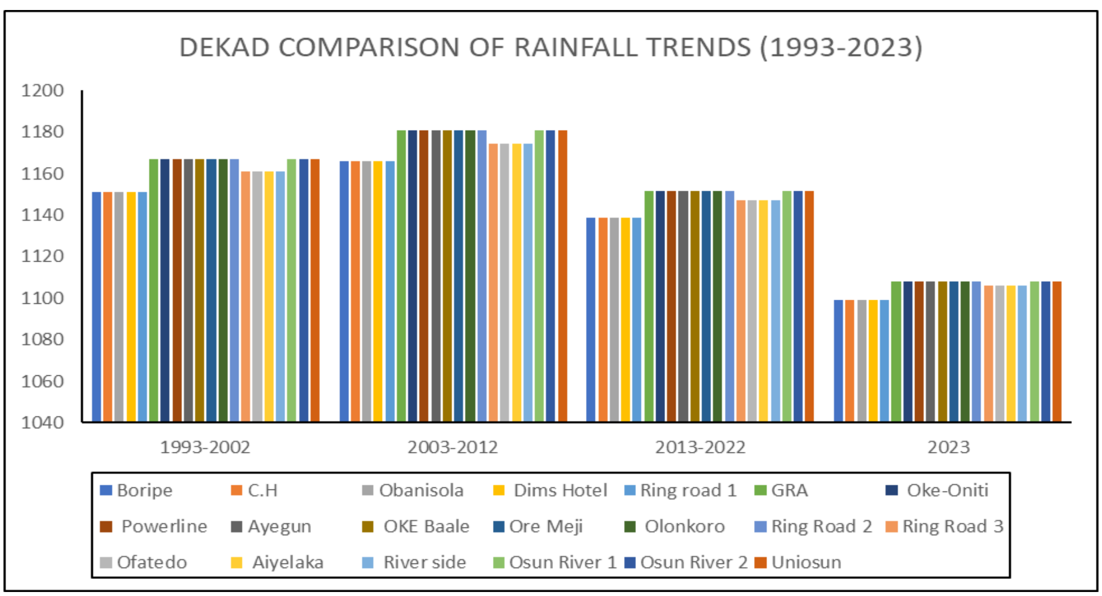

Figure 6: Dekadal Comparison of Rainfall Trends (1993 - 2023)

Figure 7 presents the annual seasonal rainfall recorded in the study area. The rainy season was defined as spanning from March to November to account for years when it started earlier or extended later.

The annual rainfall data (Figure 7) showed minimal differences across the study locations for most years. However, notable deviations occurred in 1995, 1997, 1999, 2003, 2004, 2007, 2008, 2010, 2014, and 2018, when total annual rainfall was substantially higher or lower compared to the long-term average across the sites.

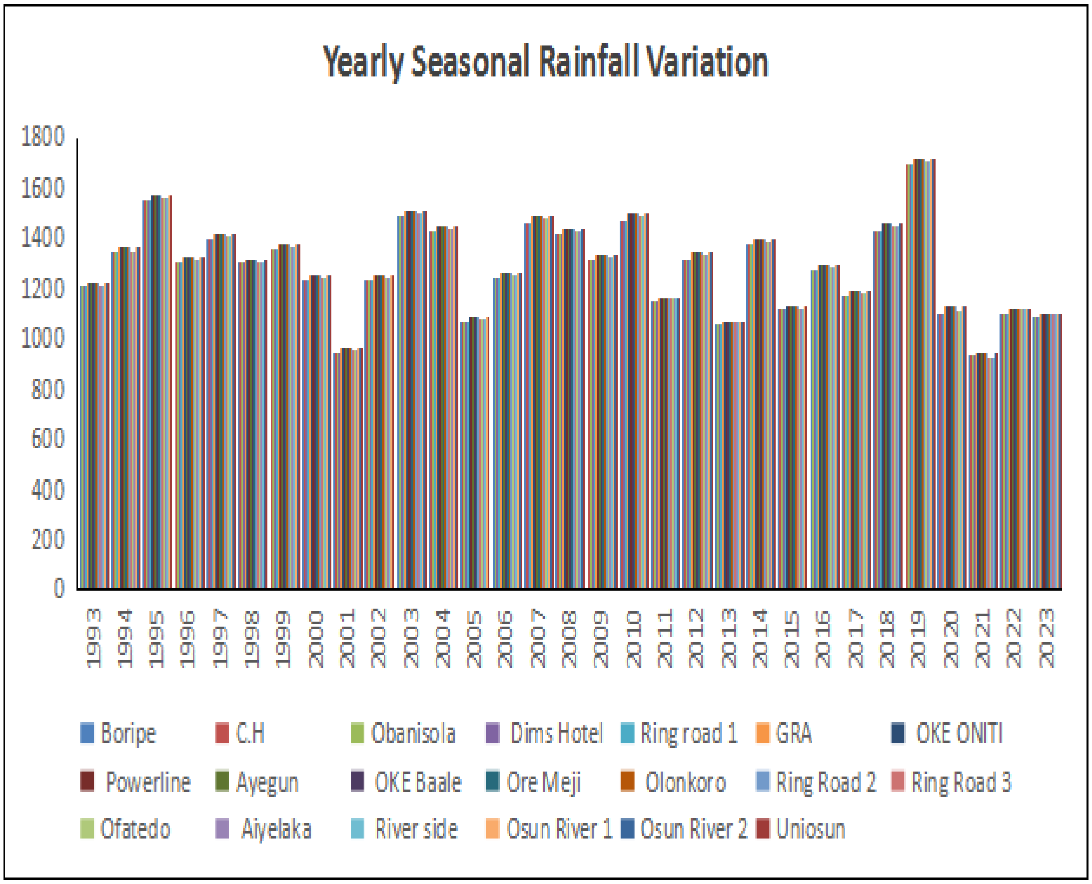

Figure 7: Annual Rainfall Variation from 1993 -2023

As shown in Figure 8, total monthly data were selected for each year and listed then the average was calculated per month over the study period. The average for each month was calculated and plotted, it was observed September (250.9mm) and October (213.4mm) had the highest rainfall difference in the study area while January (8.5mm), and December (6.5mm) had the least rainfall difference. Therefore, the month noticed to have had the highest average rainfall variation was September while the observed month with the lowest was December. The rainfall pattern showed a bimodal distribution, with peaks typically in September and October. Overall, Figures 6, 7 and 8 showed that rainfall in Osogbo exhibited noticeable inter-annual variability, with no consistent upward or downward trend.

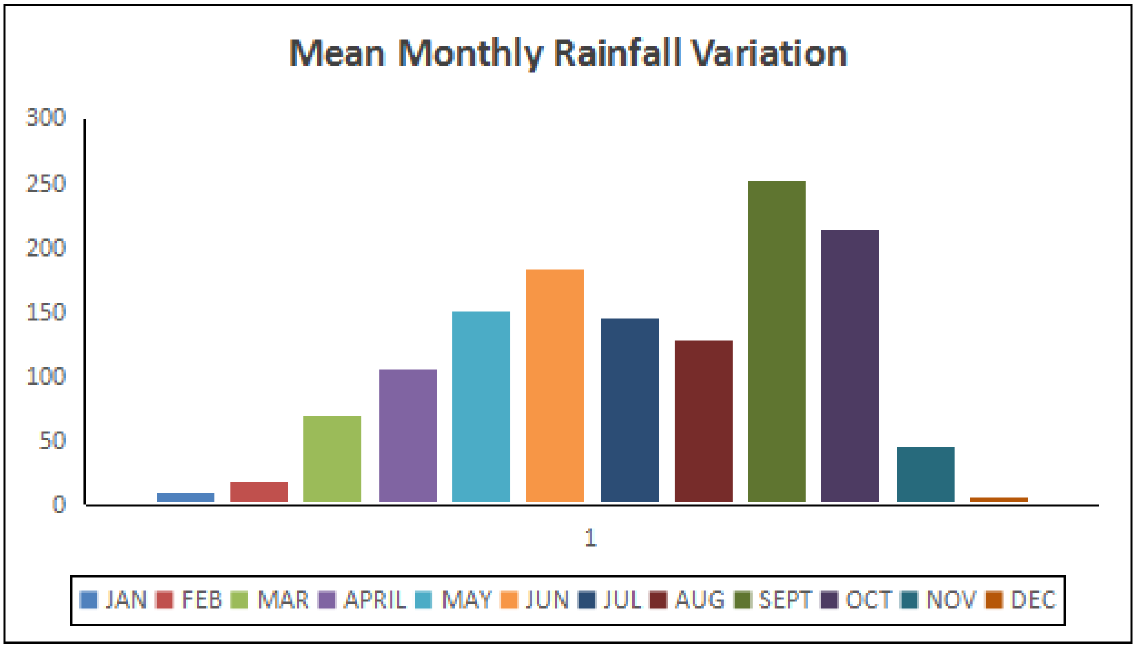

Figure 8: Mean Monthly Rainfall Variation

3.3 Factors Influencing Rainfall Variability

In the past 32 years (1993-2024), significant El Niño events were observed in 1997-1998, 2002-2003, 2009-2010, 2015-2016, and 2023-2024. The following details summarize the effects of these El Niño events on annual rainfall in Osogbo:

i. **El Niño 1997-1998**

Impact Year:1998

The El Niño event began in 1997 and extended into early 1998. The total annual rainfall in 1998 was 1354 mm, slightly above the mean annual rainfall of 1330 mm, indicating that this event did not significantly affect rainfall in Osogbo.

ii. **El Niño 2002-2003**

Impact Year: 2003

Despite the occurrence of the El Niño event between 2002 and 2003, rainfall in 2003 was approximately 1550 mm, higher than the mean of 1330 mm, suggesting no reduction in rainfall during this period.

iii. **El Niño 2009-2010**

Impact Year: 2010

Similarly, the 2009-2010 El Niño episode did not reduce rainfall in Osogbo, with total annual rainfall in 2010 reaching approximately 1500 mm, significantly above the mean.

iv. El Niño 2015-2016

Impact Year: 2016

The 2015-2016 El Niño event corresponded with a slight decrease in rainfall. Total annual rainfall in 2016 was approximately 1290 mm, below the mean of 1330 mm, indicating a possible El Niño-related reduction.

v. El Niño 2023-2024

Impact Year: 2024

The 2023-2024 El Niño event began in mid-2023. Rainfall in 2023 fell below the average, and data for 2024 are not yet available, so the full impact on Osogbo cannot currently be assessed.

Table 1: El Niño Events and Corresponding Annual Rainfall in Osogbo

El Niño Event	Impact Year	Total Annual Rainfall (mm)	Mean Annual Rainfall (mm)	Observed Effect
1997 - 1998	1998	1354	1330	No significant reduction
2002 - 2003	2003	1550	1330	No reduction
2009 - 2010	2010	1500	1330	No reduction
2015 - 2016	2016	1290	1330	Slight reduction, possible El Niño effect
2023 - 2024	2024	Data not yet available	1330	Impact inconclusive

Source: El Niño event years based on National Oceanic and Atmospheric Administration (NOAA) ENSO database; annual rainfall data calculated from observations in Osogbo

4.0 Conclusion and Recommendations

This study analyzed the spatial distribution, temporal trends, and underlying factors influencing rainfall variability in Osogbo over a 31-year period (1993–2023) using remote sensed data. The findings provided a comprehensive understanding of rainfall behavior in the region and its implications for environmental planning and resource management.

The spatial analysis, based on remote sensing data and GIS mapping, revealed clear geographical patterns in rainfall distribution across the 20 synoptic stations in Osogbo. The contour maps illustrated that rainfall is not evenly distributed across the city, with certain areas such as GRA, Oke Oniti, and Powerline consistently receiving higher amounts of rainfall, while stations like Boripe, Dims Hotel, and Obanisola experienced relatively lower precipitation. These variations were clearly visualized through the spacing of contour lines, indicating zones of rapid rainfall change and areas with more uniform distribution.

In examining temporal trends, the study revealed significant inter-annual variability in rainfall. The dekadal comparison showed that the period from 2003 to 2012 recorded the highest average annual rainfall across most locations, suggesting a wetter decade. However, a steady decline in rainfall was observed from 2013 to 2022, with 2023 recording the lowest rainfall in the entire study period. This trend was also evident in the seasonal rainfall analysis (March to November), where certain years like 1995, 2003, 2007, and 2018 exhibited higher seasonal totals compared to other years. Additionally, the mean monthly rainfall variation displayed a bimodal pattern, with peaks typically occurring in September and October, and the least rainfall in December and January. This seasonal rhythm aligns with the broader West African monsoon system.

Regarding the third objective, the study explored the influence of El Niño events on rainfall variability. Although some El Niño years such as 2016 corresponded with lower-than-average rainfall in Osogbo, not all events showed a clear impact. For example, the 1997-1998, 2002-2003, and 2009-2010 episodes did not lead to noticeable rainfall deficits. This suggests that while El Niño may influence rainfall patterns, its impact in Osogbo appears to be inconsistent and potentially moderated by local climatic or geographical factors. Notably, the most recent El Niño event (2023-2024) coincided with a drop in rainfall in 2023, though the full extent of its influence remains uncertain due to the absence of complete 2024 data.

In conclusion, rainfall in Osogbo is characterized by marked spatial differences and significant temporal variability. While long-term trends do not indicate a consistent increase or decrease in total rainfall, there are clear periods of higher and lower precipitation. Understanding these patterns is vital for improving agricultural planning, water resource management, and climate adaptation strategies in the region. Future studies could further investigate the combined effects of other climatic phenomena such as the Atlantic Niño or local land-use changes on rainfall dynamics in Osogbo.

Based on the findings of this study, the following recommendations are proposed:

i. The inconsistent influence of El Niño on local rainfall underscores the importance of localized weather prediction models. Investment should be made in expanding and upgrading weather monitoring stations across Osogbo. This will enhance the accuracy of rainfall forecasting and early warning systems, helping communities prepare for extreme weather events or prolonged dry periods.

ii. Areas with high rainfall accumulation, such as GRA, Oke Oniti, and Powerline, require proper drainage systems to prevent urban flooding. Urban planners and engineers should use the spatial distribution data in this study to guide the design and improvement of drainage networks, particularly in flood-prone areas.

iii. Given the observed spatial and temporal variability in rainfall, particularly the declining trend in recent years, there is a need for local authorities and water resource agencies to adopt adaptive water management strategies. Rainwater harvesting systems should be promoted in areas with high rainfall, while efficient water storage and distribution infrastructures should be developed to support areas receiving less rainfall.

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