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Trend and Spatial Distribution of Rainfall: A Case Study of Edo State, Southern Nigeria from 1983 – 2023

Chika Floyd Amaechi*, Michael Jimmy Emejulu, Akus Kingsley Okoduwa, Miracle Obeto

Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, PMB 1154, Benin City, Nigeria.

***Corresponding author E-mail:** chika.amaechi@uniben.edu

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Abstract

Understanding rainfall patterns and geographical distribution is critical for sustainable water resource management, agriculture, and disaster preparedness. This study analyzed rainfall trends and patterns in Edo State, Nigeria, from 1983 - 2023 using data from the Climate Hazards Group Infrared Precipitation with Station Data (CHIRPS). Rainfall records were analyzed using the non-parametric Mann-Kendall (MK) test and Sen's slope estimator. Results show that the mean annual rainfall ranged from 1425 mm in the year 1983 to 1892 mm in the year 2023, with the highest average recorded in the year 1995 at 2242 mm. Spatial maps revealed consistently lower rainfall in northeastern LGAs like Akoko-Edo, Esan Central, and Esan North-East, while southwestern LGAs such as Egor, Ikpoba-Okha, and Oredo experienced higher rainfall. Despite the observed variability, no statistically significant trend ($p > 0.05$) was detected over the 41-year period. These findings highlight the region's dynamic rainfall patterns, providing valuable insights for climate adaptation strategies and informed decision-making in water resource management.

1.0. Introduction

A crucial component of Earth's climate system is rainfall, a complex and dynamic phenomenon that shapes our physical surroundings, affects ecosystems, and influences human activity in various parts of the world [1]. The distribution and variability of rainfall are determined by the intricate interaction of atmospheric processes, geographic characteristics, and climatic systems [2-3]. Rainfall directly impacts several societally important industries, including agriculture [4], water management, infrastructure development, and disaster preparedness.

Extreme rainfall has been identified as a major contributor to floods in numerous studies [5-7]. The shifting patterns and rainfall variability are among the most evident signs of climate change [8]. Changes in temperature and atmospheric circulation patterns can affect the location, intensity, and frequency of rainfall events [9], leading to wide-ranging effects on ecosystems, altering water availability, and threatening social well-being and food security [10].

Extreme rainfall events can have various effects on agriculture, affecting everything from crop yields to soil health [11]. Waterlogging and nutrient leaching caused by prolonged heavy rain can compromise crop yields and soil structure [9]. Additionally, heavy rainfall can result in soil erosion, nutrient runoff, and decreased soil fertility, potentially affecting the long-term sustainability of agriculture [9].

Extreme rainfall events can also increase the spread of infections and pose health risks by overwhelming sewage systems and contaminating water supplies [12]. Flooding induced by heavy rains can compromise sanitary systems in urban areas, elevating the risk of disease outbreaks [13].

The shift in rainfall patterns and their variability is one of the most obvious signs of climate change [8]. The climate system's inherent variability in rainfall patterns is impacted by elements including oceanic currents, variations in atmospheric circulation, and solar radiation [14]. Precipitation volumes and intensities can fluctuate as a result of these shifts over inter-annual, decadal, and even longer timeframes.

Nigeria, a country with vast landscapes and diverse ecosystems, has complex rainfall patterns that shape its socioeconomic and environmental dynamics. These rainfall patterns vary due to the intricate interactions between regional climatic parameters, global climate phenomena, and topographical features [15]. In Nigeria, there is significant regional variance in rainfall amounts. The coastal districts receive abundant rainfall, often exceeding 2,000 mm annually, influenced by maritime air masses. In contrast, the northern regions experience relatively less rainfall, frequently leading to water scarcity and drought-related issues [16].

The effects of Nigeria's rainfall patterns are extensive, impacting various societal and economic sectors. Seasonal rainfall is crucial for crop production in Nigeria's agricultural sector, a key component of the country's economy. Variations in rainfall, especially in rural regions, can lead to crop failure, food shortages, and economic instability [17]. In urban centers, particularly in the southern regions, heavy and intense rainfall events pose the problem of flooding. Inadequate drainage systems and urban planning exacerbate flood risks, resulting in infrastructure damage and health issues [18].

The threat of global climate change further complicates Nigeria's rainfall patterns. Changes in atmospheric circulation patterns, increasing temperatures, and modifications in oceanic conditions can affect the timing, intensity, and distribution of rainfall events. According to [16], these changes impact water availability, agricultural production, and disaster management plans. As Nigeria strives for sustainable development and climate resilience, a thorough understanding of rainfall trends and spatial patterns across all states is essential. Accurate and current rainfall data, combined with advanced geospatial techniques, enable informed decision-making, adaptive strategies, and the formulation of effective policies.

Due to its unique combination of geography, socioeconomic importance, and climate sensitivity, Edo State in southern Nigeria presents an intriguing case for this study. The region's diverse topography, which includes forests, savannahs, and river ecosystems, offers a unique opportunity to investigate how shifting rainfall patterns affect various environments. Given its history and rapid urbanization, it is essential to fully understand how rainfall patterns have affected and will continue to shape its development. The complex relationships between urbanization, land use change, and climate dynamics require a comprehensive examination of these interconnections and their potential to influence changes in rainfall [19-20].

This research aims to uncover trends and spatial distribution of rainfall in Edo State, Southern Nigeria. The findings of this research could benefit a wide range of stakeholders, including policymakers, environmental managers, agricultural professionals, and community leaders.

2.0 Materials and Methods

2.1. Study Area

Edo State (Figure 1) is situated in the south-south geopolitical zone of Nigeria [21]. This inland state is made up of 18 Local Government Areas (LGAs) [22]: Akoko-Edo, Egor, Esan Central, Esan North-East, Esan South-East, Esan West, Etsako Central, Etsako East, Etsako West, Igueben, Ikpoba-Okha, Oredo, Orhionmwon, Ovia North-East, Ovia South-West, Owan East, Owan West, and Uhunmwonde. Edo State shares its northern and eastern borders with Kogi State, its southern boundary with Delta State, and is bounded to the west by Ondo State.

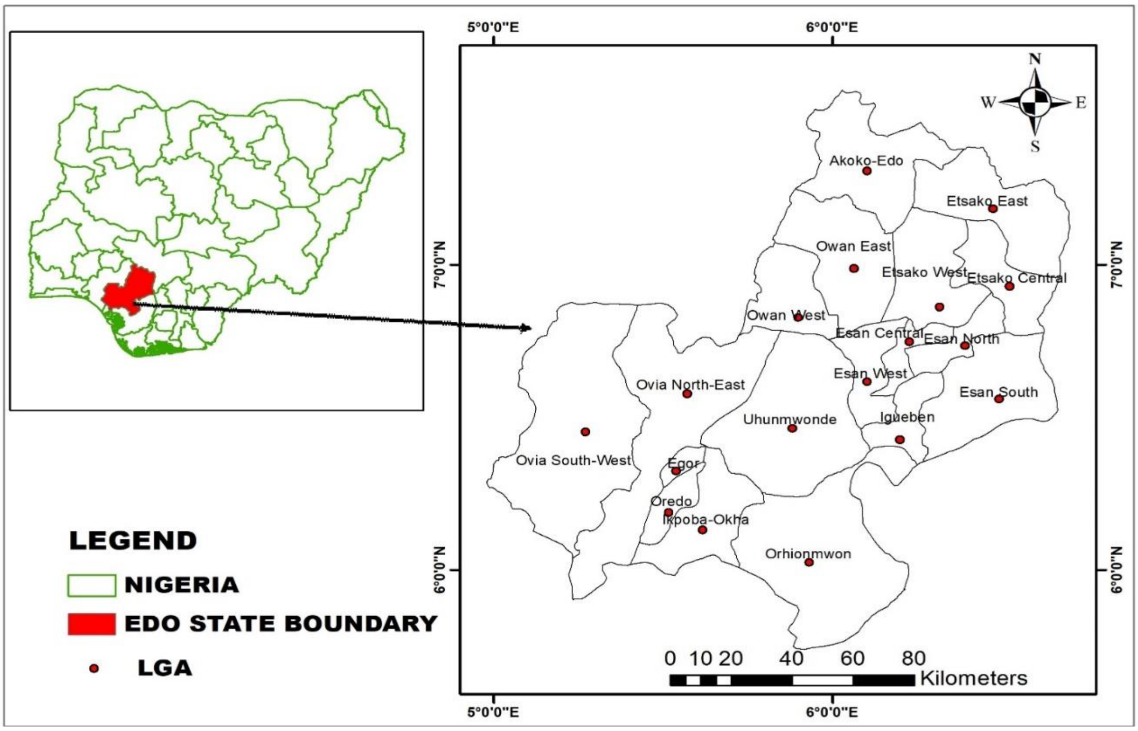

Figure 1. Map of Edo State

The altitude across Edo State varies, ranging from about 150m above sea level in the southern regions to an impressive 550m above sea level in the north [23]. The prevailing landscape is enveloped by a lush tropical rainforest, which extends over a substantial portion of the state's expanse of around 17,802 square kilometers [23].

The state is surrounded by the tropical rainforest and Guinea savanna zones, factors that shape its distinct rainfall characteristics [24]. The annual rainfall cycle in Edo State is composed of two distinct seasons; the wet and dry seasons. The rainy season usually lasts from April to October, with the most rainfall happening between June and September. The dry season, on the other hand, normally lasts from November to March. During this time, rainfall reduces dramatically, and the weather becomes drier and more consistent. Temperatures are generally higher during the dry season compared to the wet season [25-26]. Throughout the rainy season, Edo State witnesses varying levels of rainfall. The highest rainfall is usually registered in June and September, often exceeding 100 mm per day [16].

2.2. Data Type/Source

The data utilized in this research is derived from the Climate Hazards Group Infrared Precipitation with Station data (CHIRPS), a composite dataset amalgamating information sourced from ground-based stations and satellite imagery to furnish accurate, comprehensive, and accessible global insights into precipitation trends and quantities [27-29]. The absence of a robust network of meteorological stations covering the study area necessitated the use of the CHIRPS dataset. CHIRPS is a quasi-global (50°S-50°N) rainfall dataset with a high resolution (0.05°), offering daily, pentadal, and monthly precipitation data from 1981 to the near present [30-31].
Several validation studies have recently assessed CHIRPS's performance. [32] found that CHIRPS performs better in regions with high precipitation compared to arid and semi-arid areas. Wu et al.

(2019) demonstrated the dataset's utility in estimating monthly rainfall. [33] concluded that CHIRPS is effective on both monthly and annual scales, providing a reliable geographical distribution of mean monthly and annual precipitation. [34] observed that CHIRPS's mean monthly precipitation data closely matched that from rainfall stations. For this study, the latest version of CHIRPS (CHIRPS v.2) was utilized. Rainfall records for Edo State, covering a forty-one year timeframe from 1983 to 2023, were gathered at decadal intervals, Utilizing QGIS 3.8, raster data were obtained and confined to the study area (Edo State), followed by the compilation of minimum, maximum, mean, and standard deviation values for each decade. Figure 2 shows the research methodology flowchart.

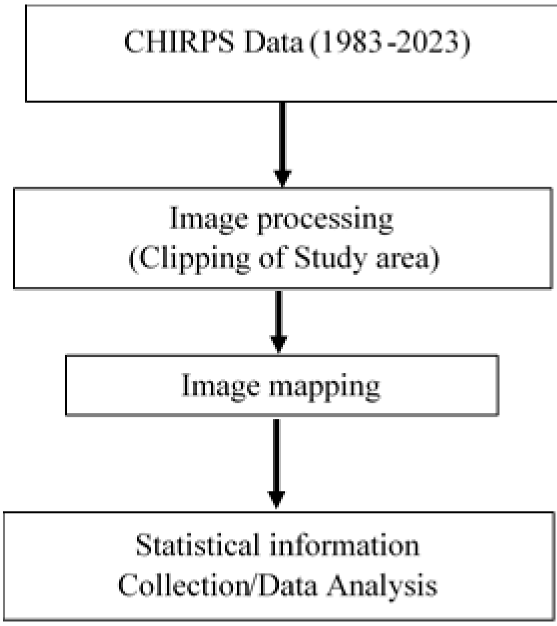

Figure 2. Methodology framework of study

2.3. Mann–Kendall Trend Test

Trend analysis is a crucial method for examining time series data, providing insights into changes over time [35]. To estimate the yearly rainfall trend, a non-parametric Mann-Kendall (MK) test was applied using the pyMannKendall library in Python 3.12, a high-level, general-purpose programming language. The MK test evaluates the presence of monotonic trends in a dataset without requiring the data to follow any specific distribution [35-38]. The test relies on two hypotheses: the null hypothesis (H_0), which assumes no significant trend in the time series, and the alternative hypothesis (H_a), which posits a significant trend [39]. Additionally, Sen's slope estimator was used to quantify the magnitude of detected trends. The MK test assumes that data points in the time series are independent and free from serial correlation. When serial correlation is present, it can lead to inflated Type I errors (false positives) [40]. The Mann–Kendall trend test evaluates trends by ranking observations rather than using their exact values, making it independent of the data's underlying distribution. This feature ensures that the test remains robust against outliers, unlike parametric trend tests that typically assume a normal distribution and are more susceptible to extreme values [41].

3.0. Results and Discussion

3.1. Mean Levels of Rainfall in Edo State

Table 1 provides a detailed account of the annual mean rainfall in Edo State from 1983 - 2023, measured in millimeters (mm). The data highlight variations across the years, reflecting fluctuating rainfall patterns. The earliest recorded year, 1983, had a rainfall of 1425 mm, the lowest in the dataset. Rainfall values varied notably during the 1980s, with increases observed in years like 1987 (1920 mm) and 1989 (1899 mm). A similar trend of variability persisted into the 1990s, where 1995 recorded the highest value in the dataset at 2242 mm, followed by slightly lower values such as 1950 mm in 1996 and 1922 mm in 1997. The 2000s maintained this variability, with years like 1999 (2182 mm) and 2009 (2098 mm) showing high values, while 2001 had a lower value of 1450 mm. In the subsequent decade, rainfall values remained inconsistent, with 2013 recording a lower rainfall of 1528 mm compared to 2018, which had a high value of 2035 mm. The most recent data from 2023 show a rainfall of 1892 mm, indicating a rebound from lower values in years such as 2020 (1525 mm) and 2013. These fluctuations underscore the region's dynamic nature of rainfall patterns over the 41 years. These findings of this research align with prior research on rainfall patterns in Edo State [24, 42-43]. Figure 3 depicts the trend in rainfall from 1983-2023.

Table 1: Annual mean values for rainfall from 1983 – 2023

Year	Rainfall (mm)	Year	Rainfall (mm)	Year	Rainfall (mm)
1983	1425	1997	1922	2011	1895
1984	1757	1998	1739	2012	1871
1985	1782	1999	2182	2013	1528
1986	1572	2000	1715	2014	1712
1987	1920	2001	1450	2015	1542
1988	1843	2002	1891	2016	1712
1989	1899	2003	1709	2017	1582
1990	1864	2004	1739	2018	2035
1991	2114	2005	1621	2019	2003
1992	1771	2006	1938	2020	1525
1993	1678	2007	1976	2021	1907
1994	2023	2008	1900	2022	1766
1995	2242	2009	2098	2023	1892
1996	1950	2010	1792	-	-

The MK test and Sen's slope estimator were used to estimate the rainfall trend, and the test results are summarized in Table 2. A negative Kendall's tau value of -0.04 indicates a decreasing trend over time, and a negative Sen's slope of -0.62 suggests a downward trend. The obtained p-value (0.74) surpasses the significance level (alpha=0.05), hence the null hypothesis Ho should be accepted, and the alternative hypothesis Ha should be rejected. These findings show that the decreasing trend in rainfall from 1983 to 2023 was not statistically significant (p-value > 0.05). This finding aligns with the work of [44], who found no significant increasing or decreasing trend in the South-South region of Nigeria, to which this study area belongs. Similarly, [45] reported no significant trend in rainfall in Edo State.

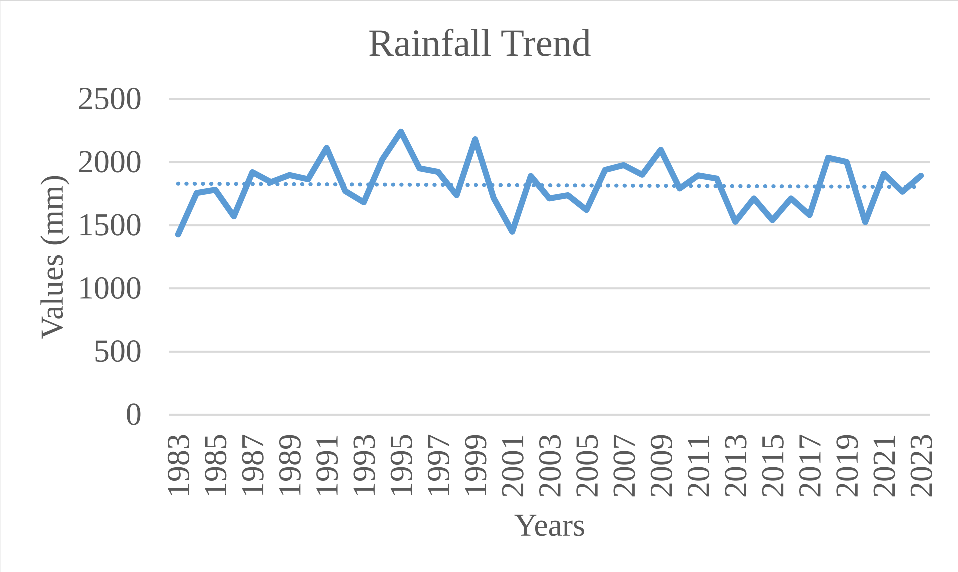

Figure 3: Trend of annual mean rainfall

Table 2: Mann-Kendall Trend and Sen's Slope Test

Tau	-0.04
slope	-0.62
p-value	0.74
Trend/ Interpretation	No trend/accept HO

Figure 4 depicts the regional distribution of rainfall for five years—1983, 1993, 2003, 2013, and 2023. The analysis of the maps indicates an inconsistent rainfall distribution. The lowest rainfall amount was recorded in Akoko-Edo, Esan Central, Esan North-East, Esan South-East, Esan West, Etsako Central, Etsako East, Etsako West, Owan East, and Owan West. In contrast, most rainfall occurs in Egor, Igueben, Ikpoba-Okha, Oredo, Orhionmwon, Ovia North-East, Ovia South-West, and Uhunmwonde. Comparing the spatial maps of 1983, 1993, 2003, and 2013 with 2023, a decrease in rainfall distribution is evident in Uhunmwonde, Orhionmwon, and Ovia South-West.

Oredo, Ikpoba-Okha, Ovia North East, and Egor local government areas (LGAs) constitute the capital of Edo State [46]. These areas have been reported to be susceptible to flooding [47]. This susceptibility can be attributed to heavy rainfall experienced in these areas and poorly constructed drainage systems [48]. According to [49], GIS-based induced flood risk mapping in Uhunmwonde revealed that approximately 40.4% of the LGA was classified as a high flood risk zone, 35.3% as a moderate flood risk zone, and roughly 24.3% as a low flood risk zone. Benin City is vulnerable to flooding due to a combination of factors, including high rainfall, unsustainable land use and land cover changes, and its flat, high-water table location near the Atlantic Ocean [18].

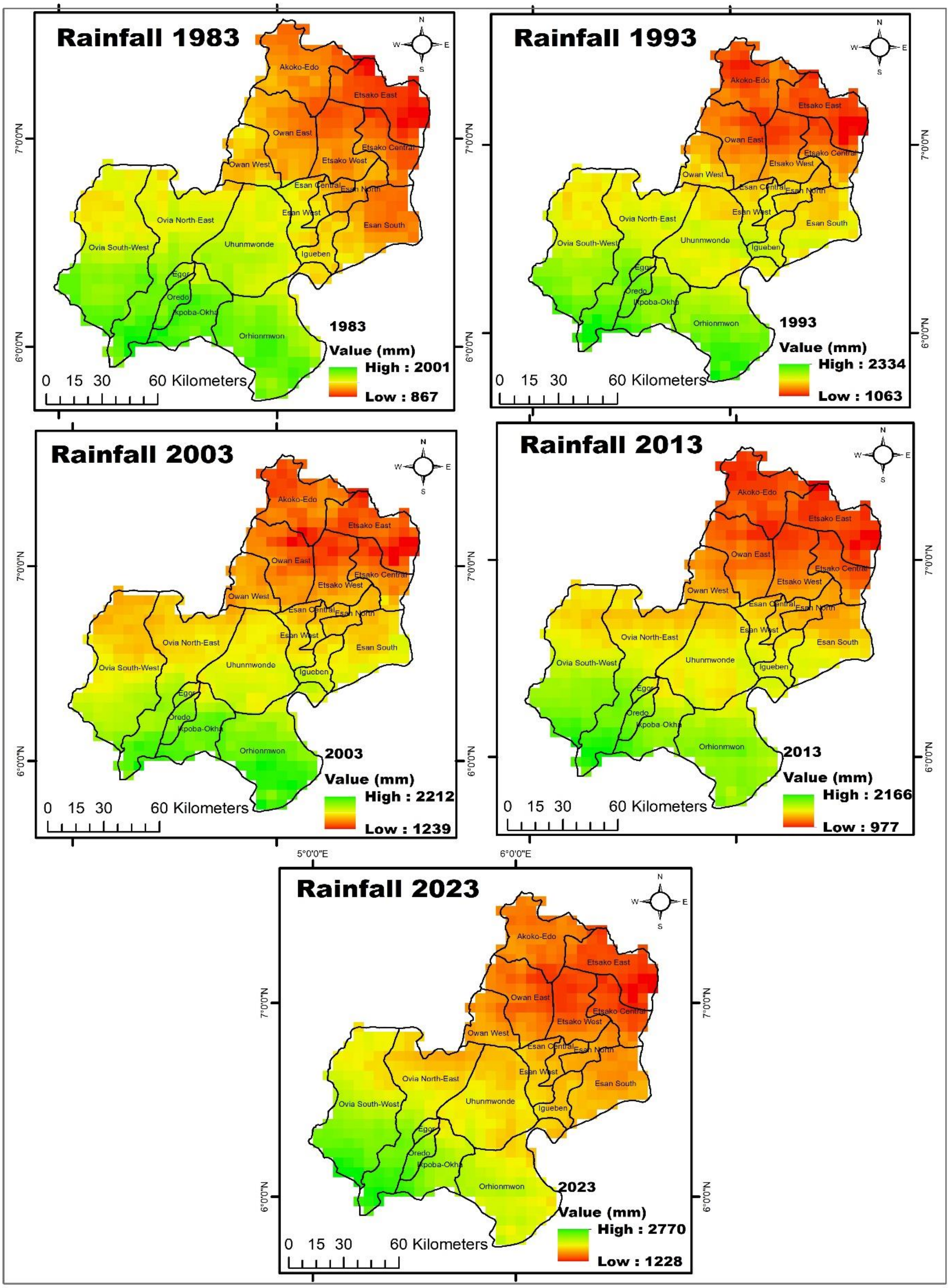

Figure 4: Map showing spatial distribution of annual Rainfall

Agriculture in Edo State is highly dependent on seasonal rainfall for crop cultivation and yield [43]. The observed variations in annual rainfall can significantly impact crop planning, potentially affecting food security, the livelihoods of local farmers, and general human comfort and health [24]. The variability in rainfall patterns can lead to excessive rainfall events, contributing to the risk of flooding [50]. Flooding can result in property damage, displacement of communities, and a strain on infrastructure and resources. Therefore, Edo State must develop flood risk management plans and infrastructure improvements to mitigate the impacts of excessive rainfall. The findings of this study can be a useful resource for policymakers and water resource managers in the region.

4.0 Conclusion and Recommendation

This study examined the rainfall trends and spatial distribution in Edo State from 1983 - 2023. Despite observing a negative trend in mean annual rainfall over the study period, the findings from the Mann–Kendall test and Sen's slope estimator revealed that this trend was not statistically significant ($p > 0.05$). Spatially, the study highlighted varying rainfall patterns, with lower amounts consistently recorded in the northeastern regions of Edo State (e.g., Akoko-Edo and Esan LGAs) and higher values in southwestern areas (e.g., Egor and Ikpoba-Okha). Notably, a decrease in rainfall distribution was observed in Uhunmwonde, Orhionmwon, and Ovia South-West LGAs over the past decades.

Implications and Recommendations

1. **Flood Management**: Regions with high rainfall, particularly southwestern LGAs prone to flooding (e.g., Benin City), require robust flood risk mitigation strategies. This includes the construction of efficient drainage systems and regular maintenance to accommodate peak rainfall events.

2. **Agricultural Planning**: The observed variability in rainfall patterns necessitates adaptive agricultural practices. Policymakers and farmers should prioritize climate-resilient crops and irrigation systems to mitigate the adverse effects of rainfall fluctuations on food security.

3. **Urban Development**: Urbanization and land-use changes in high-rainfall areas like Ikpoba-Okha and Egor must incorporate sustainable planning to prevent flood-related hazards. Integration of GIS-based flood risk mapping can guide development and infrastructure placement.

To enhance climate resilience, Edo State should invest in continuous climate data monitoring, public education on disaster preparedness, and cross-sectoral collaborations to implement adaptive strategies. These measures will safeguard livelihoods and foster sustainable development in the face of ongoing climatic changes.

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