RAINFALL VARIABILITY AND TREND ANALYSIS IN URBAN MAIDUGURI, BORNO STATE

ABSTRACT

Climate variability, encompassing impacts on precipitation and atmospheric conditions is a fundamental aspect of earth's dynamic climate system. The escalating frequency of extreme weather events globally necessitates a comprehensive understanding of climatic shifts. Addressing the shortage of localized climatic studies, this research focuses on Maiduguri, capital of Borno State in northeastern Nigeria. Previous research predominantly concentrated on broader national or regional analyses within Nigeria resulting in a significant gap in understanding Maiduguri's climatic dynamicsin recent times. Consequently, this study aimed to assess the rainfall variability of urban Maiduguri with the objectives to explore rainfall patterns, examine trends, and evaluate variability. 31 years (1992 to 2023) rainfall data from Nigerian Meteorological Agency was used for the study. The data was statisticallyanalyzed using the Coefficient of Variation, Rainfall Anomaly Index (RAI), Sen slope, and the Mann-Kendall trend test. The finding revealed that the minimum annual rainfall is 292.7 mm, the maximum is 838.2 mm, and the mean total annual rainfall of Maiduguri is 519.34 mm. These values provide crucial insights into the range and central tendency of Maiduguri's annual rainfall contributing to a holistic understanding of the region's climatic conditions. Furthermore,August stand out with substantial mean value of196.66mm, indicating the peak of the rainy season. The Total Annual Rainfall Trend in Maiduguri shows a significant positive Sen's Slope value obtained from the Mann-Kendall test (z-statistic = 2.773, p-value = 0.005) suggesting an increasing trend in monthly rainfall, with a calculated Sen's Slope of 172.000 emphasizing the peak rainfall during the core months of the rainy season.This means a moderate level of rainfall variability (CV = 28.3%), accompanied by notable fluctuations in the Rainfall Anomaly Index (RAI) during critical months. The Mann-Kendall trend test indicates a statistically significant upward, suggesting potential shifts in precipitation patterns.This comprehensive assessment of Maiduguri's rainfall patterns, especially during the peak months of June, July, and August, contributes to a more nuanced understanding of the region's climatic dynamics. The research serves as a foundation for informed decision-making by local authorities, urban planners, and environmental stakeholders. Proactive strategies for climate adaptation, disaster preparedness, and sustainable development can be developed based on insights gained from this in-depth assessment. The findings not only bridge existing knowledge gaps but also offer critical information to enhance resilience in the face of changing climate conditions in Maiduguri.

Keywords: Climate, Rainfall, Variability, Rainfall Anomaly Index, Urbanization,

1. INTRODUCTION

Rainfall variability, a crucial component of climate dynamics, significantly influences the environmental conditions of regions across the globe. The recognition of climate variability, marked by fluctuations in temperature, precipitation, and atmospheric conditions, is fundamental to understanding earth's dynamic climate system (International Panel on Climate Change, 2021). Over the past decades, a global increase in the frequency and intensity of extreme weather events has been observed, emphasizing the importance of comprehending climatic shifts (Environmental Protection Agency, 2020). Changes in the climatological average of fundamental indicators serve as clear indications of climate change (Abaje and Oladipo, 2019; NiMet, 2021; Ati *et al.*, 2022).Maiduguri, situated in northeastern Nigeria, is not exempt from the broader global trend of climate variability and the associated surge in extreme weather occurrences (NiMet, 2020). Extreme weather events, including floods, pose significant challenges to both natural ecosystems and human settlements (UNDRR, 2019; Akande *et al.,* 2017; Yu *et al.,* 2016; Islam and Nursey-Bray, 2017). The relationship between climate variability and these events has far-reaching implications, impacting various facets of urban life, infrastructure, and environmental sustainability (IPCC, 2021; Ati *et al.,* 2022). Rainfall variability introduces uncertainties, posing challenges for effective climate adaptation (IPCC, 2021). Once considered sporadic, these events now exhibit patterns that warrant closer scrutiny, necessitating a focused investigation into their historical trends and potential future trajectories. The impacts of these changes, particularly on rainfall patterns, demand thorough investigation to comprehend the extent of exposure to extreme weather conditions.

Despite the observable impact of extreme weather events in Maiduguri, there exists a notable scarcity of studies on climatic conditions in this region. The available literature primarily concentrates on broader national or regional analyses within Nigeria, with limited attention given to the climatic dynamics of Maiduguri. Oguntunde *et al*., (2012) explored spatial and temporal temperature trends in Nigeria from 1901 to 2000. Other studies include Bose *et al*., (2019) on rainfall trend detection in Northern Nigeria, Mustapha *et al*., (2020) analyzing rainfall variations in the northern part of Nigeria, and Sawa and Buhari (2011) examining temperature variability in Zaria, Northern Nigeria.Abaje and Oladipo's (2019) analysis of temperature and rainfall data (1971-2016) in Kaduna state, Bose *et al*., (2018) temperature and rainfall trend analysis in the Semiarid Zone of Northeastern Nigeria over 40 years (1971 - 2010). Abaje (2023) conducted a study on meteorological drought and recurrence intervals in the extreme northeastern region of

Nigeria, analyzing changes (1979-2019). Edokpa *et al*., (2023) focused on rainfall and temperature variations in a dry tropical environment, emphasizing Maiduguri and utilizing the Mann-Kendall test. Furthermore, Ibrahim and Mohammed (2015) assessed temperature records from 1970-2012 for 11 northern states, identifying a positive increasing trend. Atuma *et al*., (2023) conducted an analysis of rainfall distributions and variations, contributing to the broader understanding of climate variability in the region. These studies collectively inform our understanding of climatic changes and provides a foundation for the present research focused on rainfall, temperature, and wind speed variability assessment in Maiduguri. Consequently, this research aims to fill this critical gap by providing an in-depth assessment of rainfall in urban Maiduguri from 1992 to 2023.

This research aimed to fill this critical gap by providing an in-depth assessment of rainfall patterns in Maiduguri from 1992 to 2023. The long-term trends of rainfall are crucial for assessing their impact on the environment (Kundu *et al.*, 2015). The specific objectives are to evaluate Maiduguri's exposure to extreme weather events associated with rainfall, analyzing and detecting trends in historical rainfall data. The study also investigated the relationship between rainfall patterns and occurrences of flooding. The findings will be useful to inform local authorities, urban planners, and environmental stakeholders in developing proactive strategies for climate adaptation, disaster preparedness, and sustainable development in Maiduguri.

2. MATERIALS AND METHODS

2.1 Study Area

Maiduguri, the administrative center of Borno State, covers an expansive land area of 137,356 square kilometers and is situated between latitudes 11° 46´ 18"N and 11° 53´ 21"N, as well as longitudes 13° 02´23"E and 13° 14´ 19"E. The region has witnessed a consistent rise in population, escalating from 570,331 in 2006 to 822,000 in 2022(National Population Commission, 2006). This growth is particularly notable in the urbanized Maiduguri, recognized as a key city in the northeast region of Nigeria. The swift population surge and urbanization have led to the city's expansion into additional land areas.

The climate of Maiduguri is characterized with a prolonged dry season and short duration of wet season. The dry season extends from October to April whereas the short rainfall season onset mostly in late May to early July attaining it peak maxima in August spanning through September for cessation. Thus, the normal period of rainy season in the study area is usually between 110days-120days with less than 90 days considered as abnormal (NiMet,2020).The soil composition in the urban environment of Maiduguri aligns with the brown and reddish-brown hydromorphic alluvial soil prevalent in the entire Borno region. In tandem with the soil and climate characteristics, the vegetation mirrors Sahel savanna, featuring shrubby vegetation interspersed with tall trees woodland (Waziri 2009).

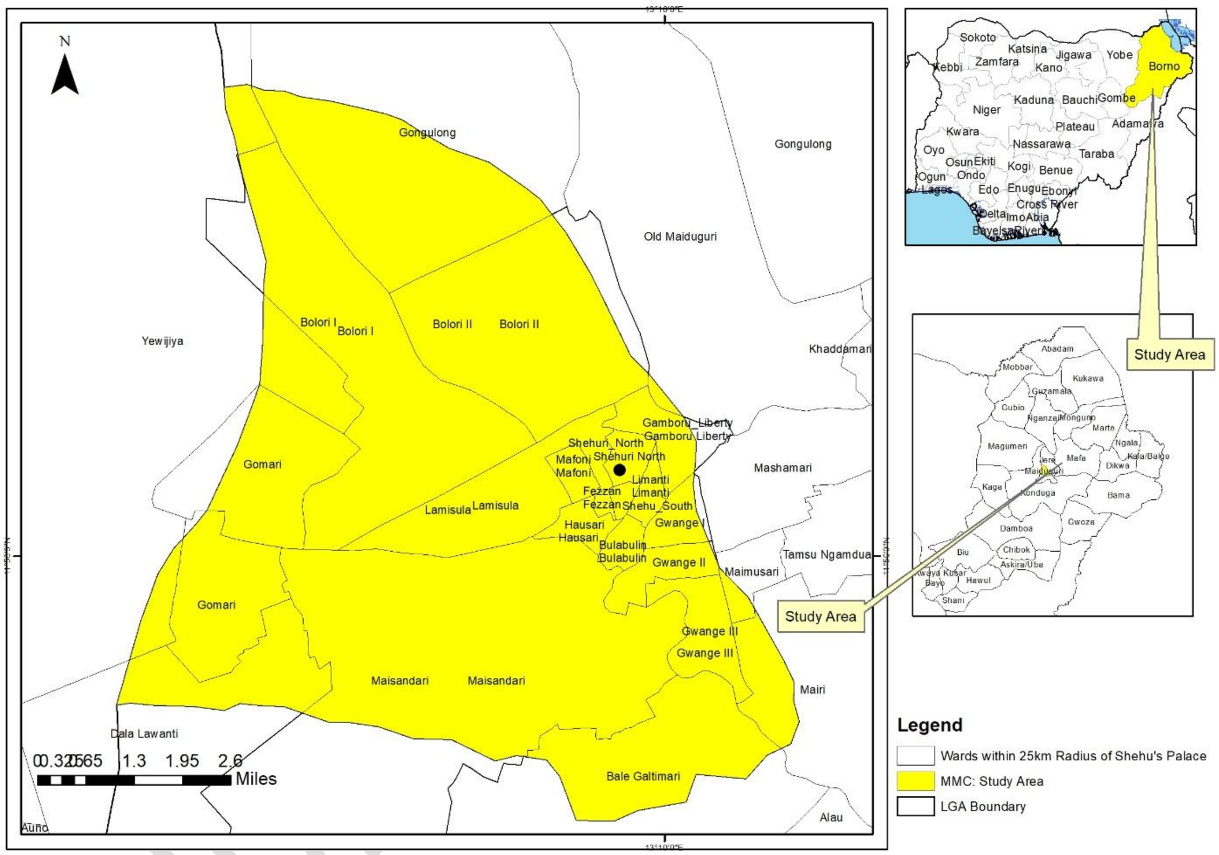

Figure. 1: Maiduguri Urban
Source: Author's Analysis (2024) Modified from BOGIS

2.2 Data

Data for Maiduguri from 1992 to 2023 were sourced from Tropical Application of Meteorology Using Satellite Data (TAMSAT) and validated using the Nigerian Meteorological Agency (NiMet) ground-based station data. The dataset includes monthly and yearly records of rainfall.

Table. 1: MeteorologicalStation and Period of Data

Station	Station Number	Latitude	Longitude	Altitude	Climatic Variable	Period	No. of Years
Maiduguri		11^{o}.51'N	13^{0}.05'E	334.0m	Rainfall (mm)	1992-2023	31

Source: NiMet (2024)

2.2 Data Analysis

2.2.1 Variability Analysis

The coefficient of variation (CV) serves as a relative indicator of variability, depicting the standard deviation's magnitude concerning its mean. In this study, the coefficient of variation was employed to assess the variability of annual occurrences. The formula for CV:

$$CV\ (\%) = \frac{\sigma}{\mu}\ x\ 100 \qquad \text{……..}(a)$$

Where σ represents the standard deviation and μ denotes the mean precipitation during the recording period, was utilized for this purpose. The degree of rainfall variability was categorized based on the resulting CV values: CV < 20% signifies low variability, CV = 20% to 30% indicates a moderate level of variability, and CV > 30% suggests a high degree of variability.The rainfall anomaly index (RAI) serves as a singular hydro-climatic metric for assessing both wet and dry conditions associated with climatic changes. In this context, the yearly fluctuations in rainfall were assessed through the application of the rainfall anomaly index (RAI), as introduced by Tilahun (2006). The calculation of RAI involves a specific methodology, particularly for positive anomalies, and is employed to gauge the impact of climatic variations on hydrological conditions.

2.2.2 Trend Analysis

The methodology employs the Mann-Kendall test and Sen's slope method for trend detection.For trend detection in Maiduguri's rainfall, temperature, and wind speed data, we employed the Mann–Kendall (MK) non-parametric test (Mann 1945; Kendall 1962) a widely accepted method in hydrometeorological variables trend detection (Rajeevan *et al.,* 2008; Karmeshu 2012; Telemu 2013; Talaee *et al.*, 2014). The Mann-Kendall test is applied to assess monotonic trends in the time series of annual values for rainfall. This non-parametric test involves comparing each data point with subsequent data points, calculating the Mann-Kendall statistic (S) to determine the trend. Increments and decrements in S result from the relationship between consecutive data points. The significance of the trend is statistically quantified using the normalized test statistic Z. Rejection of the null hypothesis at specific significance levels (95%) indicates the presence of a significant trend. This test provides a robust method for detecting trends in climatic variables.Interannual variability will be assessed by discriminating surplus and deficit years using the standardized variable index (I) developed by McKee *et al.,* (1993) and found in various articles (Lawin *et al.*, 2010; Soro *et al.,* 2014).

The index (I) is calculated as:

$$I(i) = \frac{(X_i - \bar{X}_m)}{\sigma} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (b)$$

Where Xi, $\bar{X}$, and σ represent the value for the year i, the average, and the standard deviation of the time series, respectively. A year is considered normal if its index falls between 0.5 and +0.5, surplus if greater than +0.5, and deficit if below 0.5. Despite criticisms, this interval effectively discriminates deficit from surplus years and facilitates the analysis of interannual variability.Sen's slope method will be employed to calculate slopes for sets of ordinal time points, with the median of these slopes representing the total slope. Assuming a linear trend, the method calculates slopes between all data pairs to estimate the overall slope. This method provides a linear trend assessment and is valuable for understanding the direction and magnitude of trends in rainfall.

3. RESULTS AND DISCUSSION

3.1 Exploratory Analysis

The rainfall analysis for Maiduguri reveals significant insights when considering the mean, standard deviation, and cumulative rainfall for each month. June, July, and August stand out with substantial mean values of 62.09, 153.39, and 196.66, respectively, indicating the peak of the rainy season. These values are crucial for agricultural planning, signaling optimal periods for crop cultivation and water resource management. Examining standard deviation, the peak variability occurs in June, July, and August, with values of 53.43, 69.67, and 75.30, respectively. This high variability underscores the unpredictability of rainfall during the peak rainy season, posing challenges for farmers in planning and executing agricultural activities effectively. The cumulative rainfall further emphasizes the importance of August, which records the highest total of 4755.20. This aligns with expectations for August being the peak of the rainy season, crucial for replenishing water reservoirs. However, the excess rainfall in this month also raises concerns about potential flooding, necessitating robust infrastructure and flood management strategies.The range highlights the variability, with August exhibiting the widest range of 311.10. The minimum total annual rainfall is 292.7mm and maximum is 838.2 mm emphasize the diversity of rainfall patterns, ranging from 12.50 to 366.20. The sum of the rainfall values over the entire period is 16099.60, providing a comprehensive perspective on the overall precipitation Maiduguri experiences. Therefore, these findings emphasize the need for adaptive agricultural practices that can navigate the variability in rainfall. Additionally, urban planning and infrastructure development should factor in the potential challenges posed by high rainfall, especially during peak months.

Table. 2: Exploratory Analysis of rainfall in Maiduguri from 1992 to 2023

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mean	0.00	0.00	0.00	0.64	13.45	62.09	153.39	196.66	81.14	11.96	0.00	0.02	519.34
Standard Error	0.00	0.00	0.00	0.49	2.66	9.60	12.51	13.52	10.22	2.95	0.00	0.02	26.46
SD	0.00	0.00	0.00	2.74	14.79	53.43	69.67	75.30	56.88	16.45	0.00	0.11	147.35
Range	0.00	0.00	0.00	15.00	52.90	212.20	300.40	311.10	225.20	69.50	0.00	0.60	545.50
Minimum	0.00	0.00	0.00	0.00	0.00	4.00	12.50	55.10	10.00	0.00	0.00	0.00	292.70
Maximum	0.00	0.00	0.00	15.00	52.90	216.20	312.90	366.20	235.20	69.50	0.00	0.60	838.20
Sum	0.00	0.00	0.00	19.70	416.90	1924.80	4755.20	6096.40	2515.20	370.80	0.00	0.60	16099.60
C.L(95%)	0.00	0.00	0.00	1.01	5.42	19.60	25.55	27.62	20.86	6.03	0.00	0.04	54.05

Source: Author’s Analysis from NiMet Data (2024)

3.2 Rainfall Variability (1992-2023)

The analysis of the rainfall data from 1992 to 2022 for Maiduguri reveals important insights into the variability and trends associated with the total rainfall. The Coefficient of Variation, a measure of relative variability, is calculated at 28.3%, indicating a moderate level of variability in the total rainfall data. This percentage reflects the extent to which the standard deviation deviates from the mean, signifying a noteworthy but not extreme variability in the dataset.

The Rainfall Anomaly Index (RAI) analysis conducted on Maiduguri's precipitation patterns for 1992 to 2023, provides insights into the city's climatic conditions. The RAI in April exhibits a considerable degree of variability. For instance, the year 1995 stands out with significantly positive values, indicating above-average rainfall. Conversely, other years demonstrate negative values, signaling fluctuating precipitation conditions during this month. In May consistent negative RAI values was observed across most years, suggesting a prevailing trend of below-average rainfall. The persistent negativity in May raises concerns for water resource availability and agricultural activities, emphasizing the potential impact on local ecosystems. While June's rainfall variability values show a spectrum of erraticism, encompassing both positive and negative ranges. This diversity underscores the unpredictable nature of rainfall during June, with certain years experiencing above-average precipitation, while others face below-average conditions.

Similarly, July and August demonstrate mixed RAI values, indicating a diverse pattern of rainfall during these pivotal summer months. The fluctuating RAI values in these months underscore the need for a nuanced understanding of seasonal variability for effective climate risk management.September's RAI continues the trend of variability, featuring both positive and negative values. This variability highlights the unpredictable nature of rainfall conditions during September, necessitating adaptive measures for sectors reliant on consistent precipitation.October tends to lean towards negative RAI values, suggesting a proclivity for below-average rainfall during this month. This insight is crucial for water resource planning and agricultural scheduling, considering the potential implications of reduced rainfall.The analysis with December, akin to April, the RAI exhibits considerable variability. Some years showcase positive values, indicative of above-average rainfall, while others register negative values, pointing to below-average conditions. This variability underscores the need for adaptive strategies to cope with the unpredictability of December's precipitation.Maiduguri's monthly RAI values from April to

December provides a comprehensive understanding of the city's climatic dynamics. These insights are indispensable for devising informed strategies in agriculture, water resource management, and overall climate resilience.

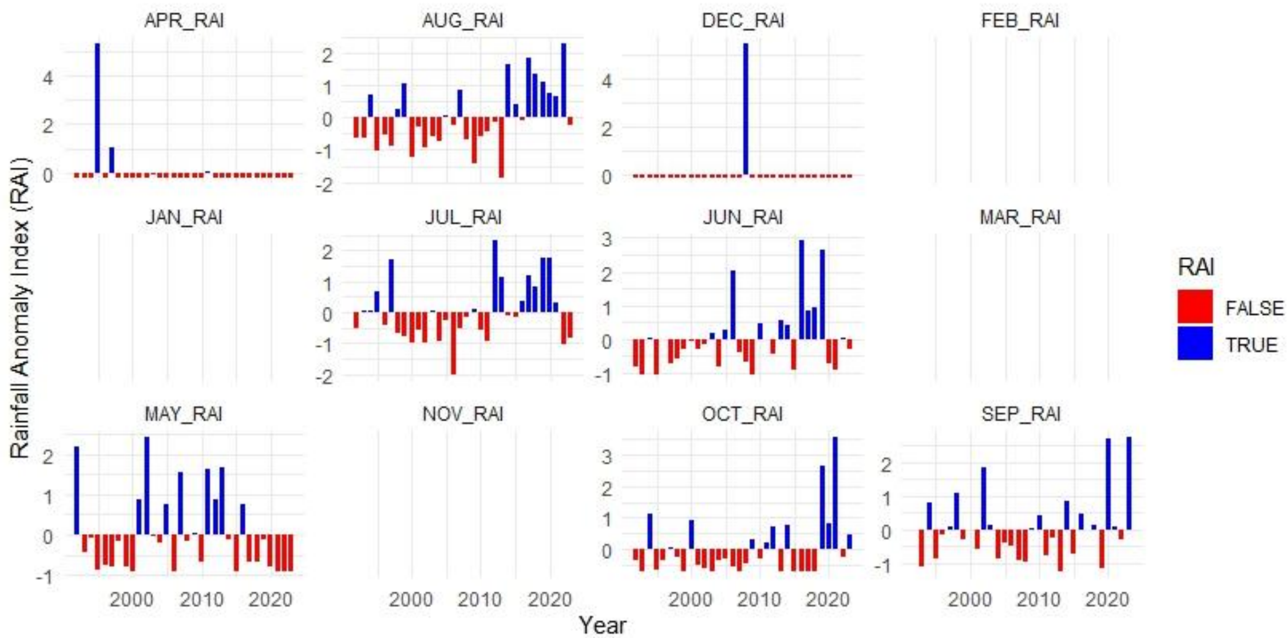

Fig. 2: Monthly Rainfall Anomaly Index (RAI) of Maiduguri from 1992 to 2023

3.3 Rainfall Trend Analysis for Maiduguri (1992-2023)

The Mann-Kendall trend test showed a z-statistic of 2.773 with a corresponding p-value of 0.005554. This p-value is less than alpha level of 0.05, providing evidence to reject the null hypothesis. The alternative hypothesis suggests that there is a true trend (S is not equal to 0) in the monthly rainfall data.The sample estimates from the Mann-Kendall test further contribute to proper understanding of the trend. Sen's Slope (S), estimated at 172.000, indicates the magnitude and direction of the trend. The variance of Sen's Slope (varS) is calculated to be 3802.67, representing the variability in the estimated slope. Additionally, Kendall's Tau (tau) is estimated at 0.3468, providing a measure of the strength and direction of the monotonic trend in the data.The moderate Coefficient of Variation, coupled with the statistically significant Mann-Kendall test results, suggests that Maiduguri's monthly rainfall exhibits variability and a discernible trend from 1992 to 2023. The positive Sen's Slope value implies a potential increasing trend.

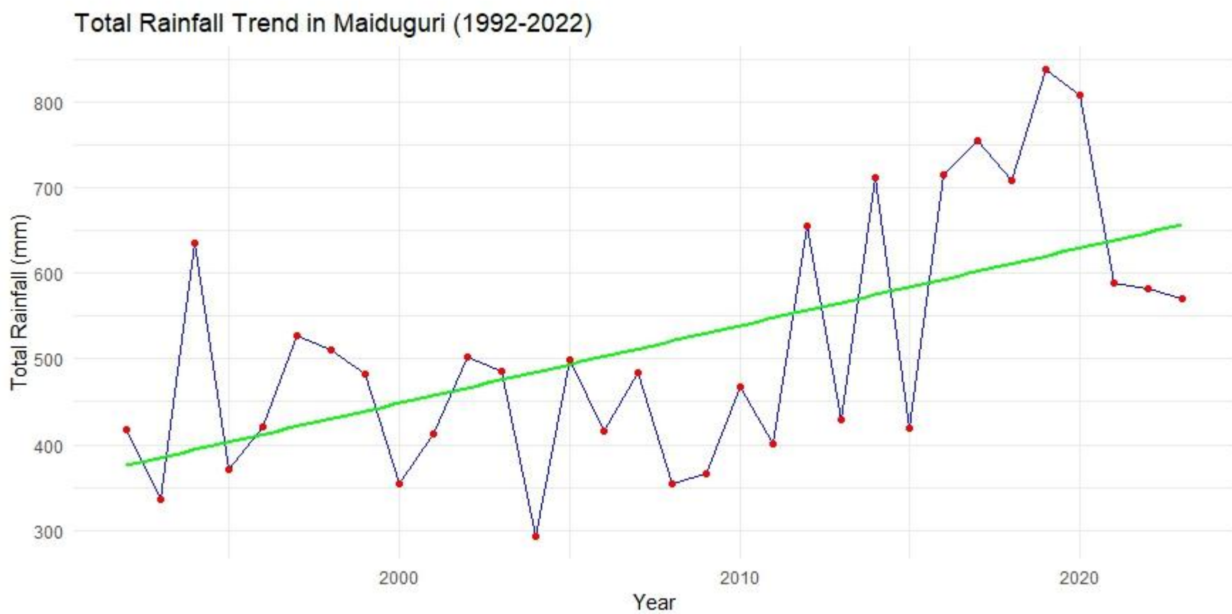

Fig.3: Trend of Annual Rainfall Variability in Maiduguri from 1992 to 2023

3.4 Monthly Trend Analysis 1992 to 2023

The Mann-Kendall trend test was conducted on monthly total rainfall data from 1992 to 2022 for Maiduguri across various months. The results indicated that for the month of April, there is no significant evidence of a trend in the monthly total rainfall, as the p-value (0.07086) exceeds the conventional significance level of 0.05. Similarly, May does not exhibit a significant trend, with a p-value of 0.2049. However, June shows a noteworthy upward trend, supported by a p-value of 0.04608. In contrast, July and September do not display significant trends, with p-values of 0.2118 and 0.5271, respectively. Notably, August demonstrates a significant upward trend in monthly total rainfall, supported by a p-value of 0.0074. Lastly, October does not show a significant trend, with a p-value of 0.3328. The non-significant trends observed in April, May, July, September, and October imply a relative stability in the monthly total rainfall for these months over the analyzed period. This stability can be reassuring for planning and resource management, as it suggests a consistent and predictable rainfall pattern during these months.

On the other hand, the significant upward trends identified in June and August carry important implications. The observed increase in monthly total rainfall during these months may signal a potential shift in precipitation patterns, indicating a higher likelihood of more intense or prolonged rainfall events. This has implications for local water management, agriculture, and infrastructure planning. Authorities and stakeholders may need to consider these trends in their decision-making processes to enhance resilience and adaptability to changing climate conditions.In particular, the significant upward trend in August raises concerns about the potential for increased rainfall during this month. This could impact drainage systems, leading to an elevated risk of flooding. Therefore, urban planning and flood preparedness measures may need to be revisited and reinforced to mitigate the potential consequences of intensified rainfall during August.

4. CONCLUSION

The findings exhibit stable rainfall patterns, identified trends in June and August underscore the importance of ongoing monitoring and adaptation strategies to address the potential impact of changing precipitation patterns in Maiduguri. These findings are crucial for informed decision-making in sectors such as agriculture, water resource management, and urban planning to enhance resilience and sustainability in the face of evolving climatic conditions. The positive Sen's Slope value, coupled with the moderate Coefficient of Variation, indicates both variability and a discernible trend in Maiduguri's monthly rainfall from 1992 to 2023. These findings have critical implications for sectors reliant on consistent precipitation, urging the implementation of adaptive measures to address the changing climate conditions in Maiduguri.

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