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Comprehensive Analysis of Rainfall Variability in Urban Maiduguri, Nigeria: Implications for Climate Resilience and Sustainable Development

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climate variability, including its effects on precipitation and atmospheric conditions, is a critical aspect of Earth's dynamic climate system. The increasing frequency of extreme weather events worldwide necessitates a thorough understanding of climatic changes. To address the scarcity of localized climatic studies, this research focuses on Maiduguri, the capital of Borno State in northeastern Nigeria. This study aimed to assess the rainfall variability of urban Maiduguri, with the objectives of investigating rainfall patterns, examining trends, and evaluating variability. The study

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utilized 31 years of rainfall data from the Nigerian Meteorological Agency, spanning from 1992 to 2023. The data was statistically analyzed using the Coefficient of Variation, Rainfall Anomaly Index (RAI), Sen slope, and the Mann-Kendall trend test. The findings indicate that the minimum annual rainfall in Maiduguri is 292.7 mm, the maximum is 838.2 mm, and the mean annual rainfall is 519.34 mm. These values provide essential insights into the range and central tendency of Maiduguri's annual rainfall, contributing to a comprehensive understanding of the region's climatic conditions. Moreover, August stands out as the month with the highest mean value of 196.66 mm, 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. The calculated Sen's Slope of 172.000 highlights the peak rainfall during the core months of the rainy season. This indicates 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 suggests potential shifts in precipitation patterns. This research serves as a foundation for informed decision-making by local authorities, urban planners, and environmental stakeholders.

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 the Earth's dynamic climate system [1]. 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 [2,3,4]. Maiduguri, situated in northeastern Nigeria, is not exempt from the broader global trend of climate variability and the associated surge in extreme weather occurrences [3]. Extreme weather events, including floods, pose significant challenges to both natural ecosystems and human settlements [5,6,7,8]. The relationship between climate variability and these events has far-reaching implications, impacting various facets of urban life, infrastructure, and environmental sustainability [1,4]. Rainfall variability introduces uncertainties, posing challenges for effective climate adaptation [1]. 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 a 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. [9] explored spatial and temporal temperature trends in Nigeria from 1901 to 2000. Other studies include Bose et al. [10] on rainfall trend detection in Northern Nigeria, Mustapha et al. [11] analyzing rainfall variations in the northern part of Nigeria, and Sawa and Buhari [12] examining temperature variability in Zaria, Northern Nigeria. Abaje and Oladipo's [13] analysis of temperature and rainfall data (1971-2016) in Kaduna state, Bose et al. [14] temperature and rainfall trend analysis in the Semiarid Zone of Northeastern Nigeria over 40 years (1971 - 2010). Abaje [13] conducted a study on meteorological drought and recurrence intervals in the extreme northeastern region of Nigeria, analyzing changes (1979-2019). Edokpa et al. [15] focused on rainfall and temperature variations in a dry tropical environment, emphasizing Maiduguri and utilizing the Mann-Kendall test. Furthermore, Ibrahim and Mohammed [16] assessed temperature records from 1970-2012 for 11 northern states, identifying a positive increasing trend. Atuma et al. [17] analyzed 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 provide 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 [18]. The specific objectives are to evaluate Maiduguri's exposure to extreme weather events associated with rainfall and analyse and detect trends in historical rainfall data. 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 centre of Borno State, spans an extensive land area of 137,356 square kilometres, situated between latitudes 11° 46´ 18"N and 11° 53´ 21"N, and longitudes 13° 02´23" E and 13° 14´ 19"E. According to data from the National Population Commission, the projected population of Maiduguri reached 822,000 in 2022, with significant growth observed in urbanized areas, establishing it as a pivotal city in northeastern Nigeria. Rapid urbanization has consequently led to the city's expansion into additional land areas. The climate of Maiduguri is characterized by a prolonged dry season and a brief wet season. From October to April, the region experiences a dry spell, while rainfall typically occurs from late May to early July, peaking in August and continuing until September. According to data from the Nigerian Meteorological Agency [3], the standard rainy season duration in the area ranges between 110 to 120 days, with fewer than 90 days considered abnormal. The soil composition of urban Maiduguri predominantly consists of brown and reddish-brown hydromorphic alluvial soil, prevalent throughout the Borno region. This soil type is characteristic of the region's arid to semi-arid climate. Additionally, the vegetation in Maiduguri mirrors the features of the Sahel savanna, comprising shrubby vegetation interspersed with tall trees and woodland [19].

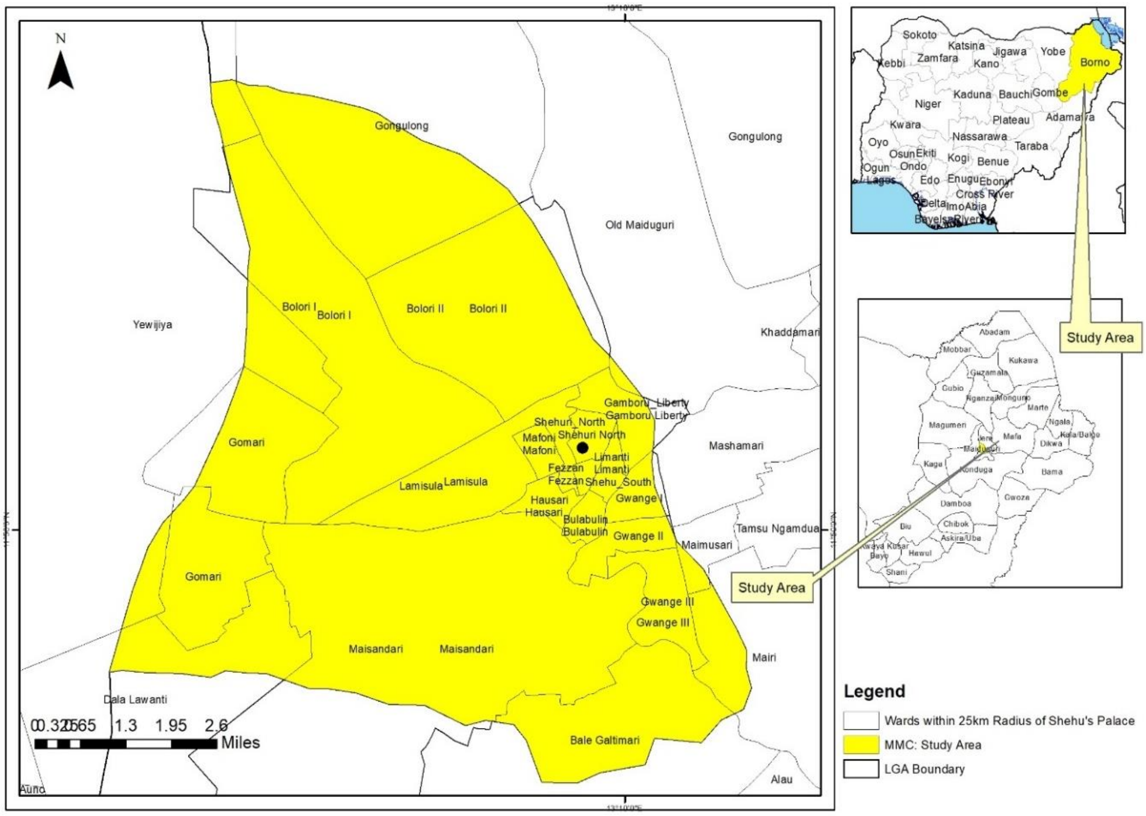

Fig. 1. Maiduguri Urban

Source: Author’s Analysis (2024) Modified from BOGIS

Table 1. Meteorological station 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 [3]

2.2 Data

Data for Maiduguri from 1992 to 2023 were recorded from the 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.

2.3 Data Analysis

2.3.1 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:

$$\text{CV (\%)} = \frac{\sigma}{\mu} \text{ x } 100 \qquad (1)$$

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 [20].

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 [21]. 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. The equation is as follows:

$$\text{RAI} = \frac{R_{observed} - R_{reference}}{\sigma} \qquad (2)$$

Where:

$R_{observed}$ is the observed rainfall value for a specific period (e.g., month, season).

$R_{reference}$ is the reference rainfall value, typically the long-term average or median rainfall for the corresponding period.

σ is the standard deviation of historical rainfall data for the same period.

By applying this equation, hydrologists and meteorologists can quantify the degree to which observed rainfall deviates from the expected climatological conditions, providing valuable insights into the severity and spatial extent of anomalous weather patterns. This information is vital for informing drought monitoring, water resource management, and disaster preparedness efforts, ultimately aiding in the development of effective mitigation and adaptation strategies to address the impacts of climate variability and change.

2.3.2 Trend analysis

The methodology employed the Mann-Kendall test and Sen's slope methods for trend detection.

2.4 Mann-Kendall Test

For trend detection in Maiduguri's rainfall, we employed the Mann–Kendall (MK) non-parametric test [22,23] a widely accepted method in hydro-meteorological variables trend detection [24,25,26,27]. 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 and 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.

The Mann-Kendall (MK) test is used to detect trends in time series data, such as rainfall variability. The test statistic, denoted as S, is calculated as:

$$S = \sum_{i-1}^{n-1} \cdot \sum_{i-1}^{n-1} \operatorname{sgn}(xj - xi) \qquad (3)$$

Where xj and xi are the annual values in years j and I, j>I, respectively, and

$$\text{sgn (xj- xi)} = \begin{cases} 1\ if\ xj - xi > 0 \\ 0\ if\ xj - xi = 0 \\ -1\ if\ xj - xi < 0 \end{cases} \qquad (4)$$

A positive value of S indicates an upward trend (increasing rainfall), while a negative value indicates a downward trend (decreasing rainfall). It is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend. the variance associated with S is calculated from [22,28].

$$\text{Var (S) Var (S)} = \frac{\mathrm{n(n-1)(2n+5)} - \sum_{k=1}^{n} tk(tk-1(2tk+5).}{18} \qquad (5)$$

Where m is the number of tied groups and tk is the number of data points in group k. in cases where the sample size n>10, the statistics Z(S) is calculated from

$$Z = \frac{S-1}{\sqrt{var(s)}}\ \ \mathrm{if\, S > 0, Z = 0i\, f\, S = 0} \qquad (6)$$

$$Z = \frac{S-1}{\sqrt{var(s)}}\ \ \mathrm{if\, S < 0, Z = 0i\, f\, S = 0} \qquad (7)$$

The trend is said to be decreasing if Z is negative and the absolute value is greater than the level of significance while it, increases if Z is positive and greater than the level of significance. If the absolute value of Z is less than the level of significance, there is no trend. In this study, the desired value of alpha is 0.05, which indicates the level of confidence [29]. The trend is considered decreasing if Z is negative and greater than the level of significance, increasing if Z is positive and greater than the level of significance, and no trend if the absolute value of Z is less than the level of significance.

2.5 The Sen's Slope Estimator

Sen's slope is a robust and nonparametric estimate of the slope of a time series. The magnitude of the trend in a time series is estimated by a slope estimator, denoted by β [30]. β provides a reliable estimate of the trend and is the median of all possible combinations of pairs for the entire data set. A positive value of β indicates an "upward trend" (increasing values with time), while a negative value of β indicates a "downward trend" [31,32]. In the calculation of Sen's slope, all sets of slopes (dk) are computed using each pair of Xi d Xj, as per Eq. (8). The Sen Slope (β1) is then calculated as the median of all slopes, dk, using Eq. (9) [33]. Each set of slopes, dk, is calculated by

$$dk = \frac{xj-xi}{j-i} \qquad (8)$$

The sen slope (β1) is calculated by

$$\beta 1 = \text{median (dk) = median} = \left(\frac{xj-xi}{j-i}\right) \qquad (9)$$

Where i and j are indices for values of the variable X, for all 1 _ i < j _ n.

A positive value of β indicates an upward trend (increasing rainfall), while a negative value indicates a downward trend.

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 62.09mm, 153.39mm, and 196.66mm, respectively, indicating the peak of the rainy season. These values are crucial for agricultural planning, signalling 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 the maximum is 838.2 mm emphasising 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 [34].

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, signalling fluctuating precipitation conditions during this month. In May consistent negative RAI values were 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 [35,36].

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. In 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 provide 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.

3.3 Rainfall Trend Analysis for Maiduguri from 1992 to2023

The rainfall trends in Maiduguri from 1992 to 2023 have revealed significant implications for the region's climatic dynamics. By employing the Mann-Kendall trend test, the results indicate a z-statistic of 2.773 and a p-value of 0.005554, which together suggest the existence of a genuine trend within the monthly rainfall dataset, rather than randomness. Sen's Slope (S) and Kendall's Tau (tau) are key statistical parameters derived from the Mann-Kendall test, with Sen's Slope having a calculated value of 172.000 and Kendall's Tau standing at 0.3468. These metrics provide insight into the magnitude and direction of the discerned trend, as well as its strength and directionality. Additionally, the variance of Sen's Slope (varS), estimated at 3802.67, highlights the degree of fluctuation inherent in the trend's estimation. The Coefficient of Variation and the statistically significant outcomes of the Mann-Kendall test collectively suggest a dynamic landscape characterized by both variability and discernible trends in Maiduguri's monthly rainfall throughout the investigated period. Notably, the positive value of Sen's Slope implies a potential upward trajectory in rainfall patterns, which carries significant implications for the region's hydrological and ecological systems. The observed trend in Maiduguri's rainfall patterns has important implications for various sectors and stakeholders. The statistically significant findings indicate a departure from historical norms, necessitating a reevaluation of existing water resource management strategies. Moreover, the potential upward trend in rainfall may impact local ecosystems, affecting agricultural productivity, biodiversity, and overall environmental resilience.

The analysis emphasizes the need for adaptive measures to tackle the consequences of severe weather events, such as floods or droughts, which may become more prevalent due to climate change. Policymakers, urban planners, and community leaders must consider these insights in long-term planning initiatives to strengthen the region's resilience against future climate-related uncertainties.

3.4 Monthly Trend Analysis between 1992 to 2023

The monthly rainfall trends in Maiduguri from 1992 to 2023, employing the Mann-Kendall test across various months, provide valuable information on the fluctuation of precipitation patterns over time.

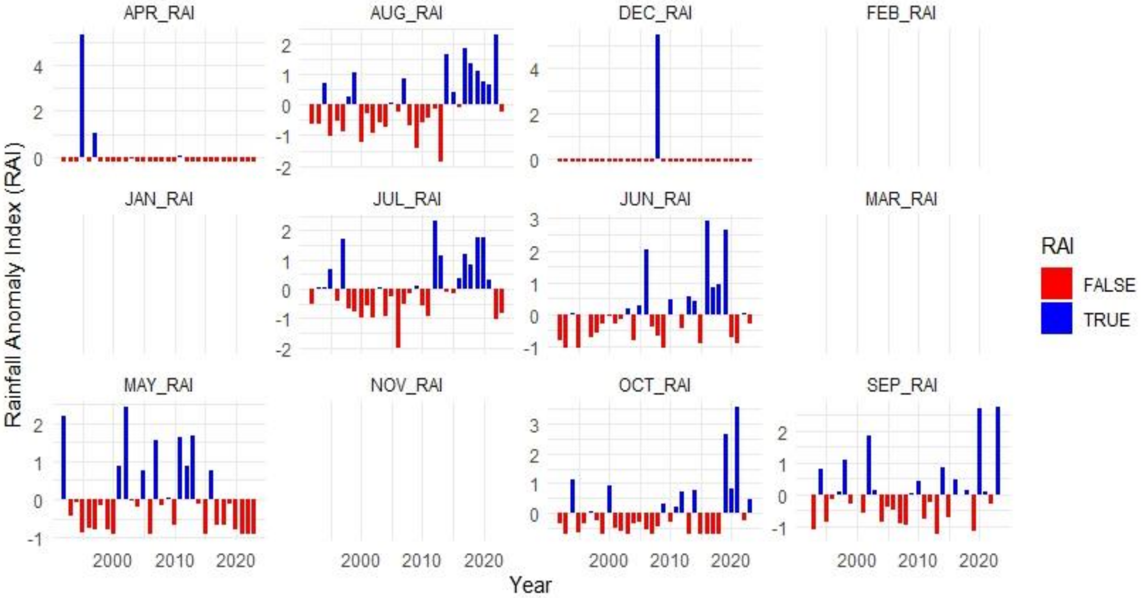

Fig. 2. Monthly Rainfall Anomaly Index (RAI) of Maiduguri from 1992 to 2023

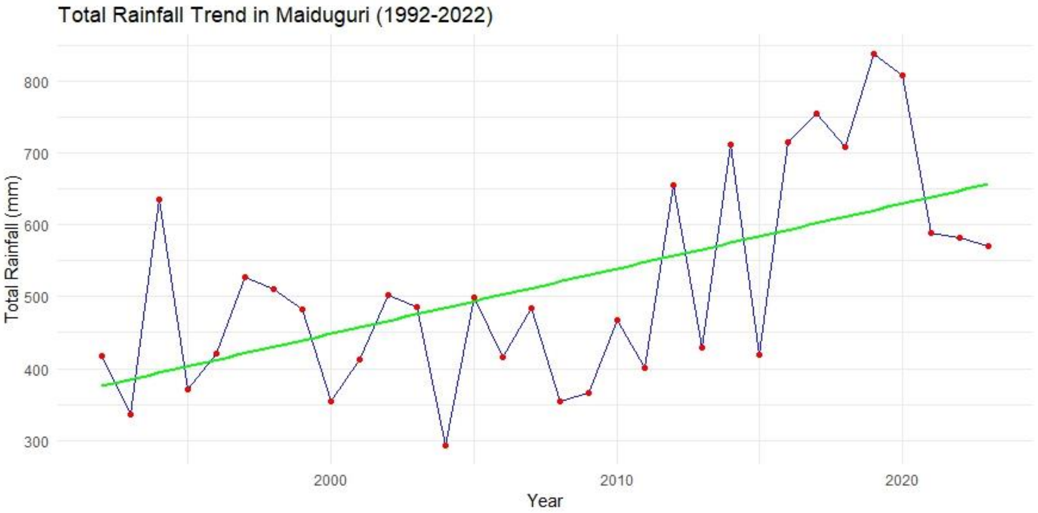

Fig. 3. Trend of Annual Rainfall Variability in Maiduguri from 1992 to 2023

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)

The lack of significant trends in monthly total rainfall during April and May, as indicated by p-values of 0.07086 and 0.2049, respectively, suggests a degree of stability in precipitation behaviour during these months throughout the analyzed period. This stability is beneficial for planning and resource management, allowing for more informed decision-making processes. Conversely, June displays a notable upward trend in monthly total rainfall, as indicated by a p-value of 0.04608. This observation suggests a discernible shift towards increased precipitation during June, which may signal changes in regional hydrological regimes. Such changes necessitate careful consideration in water resource management strategies, agricultural practices, and infrastructural planning to accommodate potential alterations in rainfall intensity and distribution. Similar to April and May, both July and September do not exhibit significant trends in monthly total rainfall, with p-values of 0.2118 and 0.5271, respectively. This sustained stability in rainfall patterns during these months provides a reliable foundation for long-term planning initiatives and resource allocation strategies.

The month of August, unlike other months, demonstrates a substantial upward trend in monthly total rainfall, as indicated by a p-value of 0.0074. This trend raises crucial concerns about the intensification of rainfall events in August, which can pose challenges to existing drainage systems and increase the likelihood of flooding incidents. To address these concerns, it is essential to implement a comprehensive approach that includes urban planning interventions, flood risk management strategies, and community engagement initiatives aimed at enhancing the resilience of communities to extreme precipitation events. In contrast, the month of October does not exhibit a significant trend in monthly total rainfall, as evidenced by a p-value of 0.3328. This finding reinforces the stable precipitation patterns observed during this month, which can support effective planning and decision-making processes. Overall, while some months exhibit consistent precipitation patterns, the significant upward trends observed in June and August necessitate proactive measures to account for potential changes in rainfall dynamics. By incorporating these findings into policy frameworks and adaptive management strategies, policymakers, researchers, and stakeholders can collaborate to enhance climate resilience and promote sustainable development trajectories in Maiduguri and beyond.

The complexities and far-reaching consequences of the observed trends in monthly rainfall patterns in Maiduguri from 1992 to 2023 are multifarious. These trends have significant implications for diverse sectors and stakeholders. On the one hand, the detection of stable precipitation patterns in specific months, such as April, May, July, September, and October, provides a solid foundation for the development of dependable planning and resource management strategies. This stability offers assurance to agricultural practitioners, water resource managers, and urban planners, enabling them to make well-informed decisions based on predictable climatic patterns. However, the noticeable upward trends in June and August indicate potential shifts in precipitation dynamics, necessitating proactive measures to adapt to increased rainfall intensities. These changes present challenges for water management infrastructure, agricultural practices, and urban planning efforts, requiring innovative solutions to mitigate flood risks and ensure sustainable development. Furthermore, these trends have broader implications, highlighting the interconnectedness of regional climate systems and emphasizing the importance of coordinated action to address climate change impacts on a larger scale. In conclusion, leveraging these insights to inform adaptive strategies and policy interventions is crucial to enhance resilience and promote sustainable development in the face of evolving climatic conditions.

4. CONCLUSION

The comprehensive examination of Maiduguri's monthly rainfall patterns from 1992 to 2023 reveals a complex landscape of climatic variability and discernible trends. Certain months exhibit stability, while notable trends in June and August highlight the necessity for proactive monitoring and adaptation strategies to mitigate potential consequences arising from changing precipitation dynamics in the region. These findings have considerable implications for key sectors such as agriculture, water resource management, and urban planning, necessitating well-informed decision-making processes to bolster resilience and sustainability in the face of evolving climatic conditions. The presence of a positive Sen's Slope value and a moderate Coefficient of Variation underscores the intricate interplay between variability and trend detection within Maiduguri's monthly rainfall patterns. Such insights are essential for devising and implementing adaptive measures tailored to address the dynamic climate context. By incorporating these findings into policy frameworks and strategic planning initiatives, stakeholders can promote a proactive approach towards climate resilience, ensuring the continued viability of critical sectors reliant on consistent precipitation patterns. The findings presented in this study serve as a call to action for concerted efforts towards enhancing adaptive capacity and fostering sustainable development trajectories in Maiduguri. By leveraging the insights gleaned from this analysis, policymakers, researchers, and stakeholders can collaboratively confront the challenges posed by climate change, safeguarding the well-being of communities and ecosystems alike in pursuit of a more resilient future.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Intergovernmental Panel on Climate Change. Sixth Assessment Report; 2021.
2. Abaje IB, Oladipo EO. Recent changes in the temperature and rainfall conditions over Kaduna State, Nigeria. Ghana J. Geogr. 2019;11(2):127-157.
3. NiMet (Nigerian Meteorological Agency). Climate variability and trends in Maiduguri; 2020.
4. Ati OF, Aremu K, Olatunde AF, Abaje IB, Oladipo EO. Meteorological drought and temperature in the Sudan-Sahelian region of Nigeria under increasing global warming. In: Stuart Harris (Ed) The Nature, Causes, Effects and Mitigation of Climate Change on the Environment, Chapter 12, Intech Open Book Series, London; 2022.
5. United Nations Office for Disaster Risk Reduction. Global Assessment Report on Disaster Risk Reduction; 2019.
6. Akande A, Costa AC, Mateu J, Henriques R. Geospatial analysis of extreme weather events in Nigeria (1985–2015) using self-organizing maps. Advances in Meteorology;2017.
   Available:https://doi.org/10.1155/2017/8576150
7. Yu W, Liu H, Wang J. Analysis of climate change trend in the Guangzhou area in recent 65 years. Int. J. Hosp. Inf. Technol; 2016: 9(12):67e76.
8. Islam MT, Nursey-Bray M. Adaptation to climate change in agriculture in Bangladesh: The role of formal institutions. J. Environ. Manag. 2017;200:347e358.
9. Oguntunde PG, Abiodun BJ, Lischeid G. Spatial and temporal temperature trends in Nigeria, 1901–2000. Meteorology and Atmospheric Physics. 2012;118(1-2):95–105.
   Available: https://doi.org/10.1007/s00703-012-0199-3
10. Bose MM, Abdullah AM, Kasim I, Harun R, Mande KH, Abdullahi AC. Rainfall trend detection in Northern Nigeria over the period of 1970-2012. Journal of Environment and Earth Science. 2015; 5(2):94.
11. Mustapha Baba-Aji Mamman, Ahmad A. Bello, Ahmad A. Usman. Analysis of rainfall variation over northern parts of Nigeria. Environmental and Earth Sciences Research Journal. 2018; 5(3): 74-78.
    Available : http://iieta.org/Journals/EESRJ
12. Sawa B, Buhari B. Temperature variability and outbreak of meningitis and measles in Zaria, Northern Nigeria. Research Journal of Applied Sciences, Engineering and Technology. 2011;3: 399-402.
13. Abaje IB. Geo-Statistical analysis of meteorological drought and recurrence intervals in the context of climate change over extreme Northeastern Region of Nigeria. Tanzania Journal of Science. 2023;49(1):152-166.
    Available:https://dx.doi.org/10.4314/tjs.v49i1.14
14. Bose MM. Climate change incidence analysis: Evidence from the semiarid zone of North Eastern Nigeria. IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSRJESTFT). 2018;12 (3):55-62.
15. Edokpa DO, Ede PN, Diagi BE, Ajiere SI. Rainfall and temperature variations in a dry tropical environment of Nigeria. Journal of Atmospheric Science Research. 2023;6(2): 50–57.
    Available:https://doi.org/10.30564/jasr.v6i2.5527
16. Ibrahim K, Mahmud Mohammed B. Rising temperature: Evidence of global warming in Northern Nigeria. Journal of Environment and Earth Science. 2015;5(22):50.
17. ATUMA, Ifeanyi Morrison, et al. Analysis of rainfall distributions and

variations in Nigeria. Hmlyn J Agr, 2023; 4(4):72-80.

18. Kundu A, Chatterjee S, Dutta D, SA. Meteorological trend analysis in Western Rajasthan, India using geographical information system and statistical techniques. Journal of Environment and Earth Science. 2015;5(5).
19. Waziri M. Spatial pattern of Maiduguri city: Researcher's guide. S Adamu Joji Publishers Kano, Nigeria, 2009;4-8.
20. Asfaw A, Simane B, Hassen A, Bantider A. Variability and time series trend analysis of rainfall and temperature in Northcentral Ethiopia: A case study in Woleka sub-basin. Weather and Climate Extremes. 2018;19:29-41.
21. Tilahun K. Analysis of rainfall climate and evapotranspiration in arid and semi-arid regions of Ethiopia using data over the last half a century. Journal of Arid Environments. 2006;64(3):474–487. Available:https://doi.org/10.1016/j.jaridenv.2005.06.013
22. Mann HB. Nonparametric tests against trend. Econometrica. 1945;13:245–259.
23. Kendall MG. Rank correlation methods, 2nd ed. Hafner Press; 1962.
24. Rajeevan M, Bhate J, Jaswal AK. Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. Geophys. Res. Lett. 2018;35(18708):1–6.
25. Karmeshu N. Trend detection in annual temperature & precipitation using the mann kendall test – A case study to assess climate change on select states in the Northeastern United States. (master's thesis, University of Pennsylvania); 2012.
26. Telemu K. Trend analysis of monthly rainfall data in Central Zone. J. Math. Stat. 2013;9(1):1–11.
27. Talaee PH, Kouchakzadeh M, Shifteh SBS. Homogeneity analysis of precipitation series in Iran. Theor. Appl. Climatol. 2014; 118:297–305.
28. Kendall MG. Rank correlation measures. London, UK: Charles Griffin; 1975.
29. Birhan G. Impacts of climate change on crop yields in South Gonder zone, Ethiopia. World Journal of Agricultural Research. 2017;5(2):102-110.
30. Hirsch RM, Slack JR, Smith RA. Techniques of trend analysis for monthly water quality data. Water Resources Research. 1982;18(1):107-121.
31. Xu ZX, Li JY, Liu CM. Long-term trend analysis for major climate variables in the yellow river basin. Hydrological Processes. 2007; 21:1935-1948.
32. Karpouzos DK, Kavalieratou S, Babajimopoulos C. Trend analysis of precipitation data in Pieira Region (Greece). European Water. 2010;30:31-40.
33. Pohlert T. Non-parametric trend tests and change-point detection: The R project for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2018.
34. Kasim I, Mahmud Mohammed B. Rising temperature: Evidence of global warming in Northern Nigeria. Journal of Environment and Earth Science. 2015;5 (22):50.
35. Nigerian Meteorological Agency (NiMet). State of the climate in Nigeria. Nigerian Meteorological Agency, Abuja. 2021;92.
36. Karmeshu N. Trend detection in annual temperature & precipitation using the mann kendall test – A case study to assess climate change in select states in the Northeastern United States. master's thesis, University of Pennsylvania, Philadelphia, PA, USA; 2012.

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