Establishing Climate change on Rainfall Trend, Variation and Change Point Pattern in Umuahia, Nigeria.

Abstract

This study investigates the prevailing conditions of changing climatic trends and change point dates in Umuahia, Nigeria, using daily annual maximum series (AMS) rainfall data spanning 31 years. The Indian Meteorological Department (IMD) was employed to downscale the time series data into durations ranging from 5 minutes to 24 hours. Mann-Kendall (MK) trend and Sen's Slope Estimator (SSE) tests revealed a statistically significant increasing trend across all durations. The Sen's Slope magnitude ranged from 0.1373 mm/year for 5-minute duration to 0.9045 mm/year for 24-hour duration, corresponding to a variation rate of 9.05 mm/decade for the 24-hour duration. Trend change-point analysis, utilizing Distribution-free CUSUM and Sequential Mann-Kendall tests, identified 2002 as the initial rainfall change-point date. These results provide robust evidence of positive changing climatic conditions for rainfall in Umuahia, indicating that non-stationary Intensity-Duration-Frequency (IDF) modelling may be more appropriate for flood risk management and urban planning in this area.

Keywords: Climate Change, Rainfall trend, Changepoint pattern, Sen's Slope Estimator (SSE) test, Distribution-free CUSUM test,Non-Stationary analyses, Owerri.

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1. INTRODUCTION

Climate change presents significant challenges to global environmental systems, with particular impacts on rainfall patterns. These precipitation changes have far-reaching consequences for agriculture, water resources management, urban planning, and ecosystem stability. In Nigeria, where rain-fed agriculture plays a crucial role in the economy, changes in rainfall patterns can have substantial economic and social ramifications (Amadi& Udo, 2015). The Niger Delta region of Nigeria, encompassing Umuahia, has been identified as highly susceptible to climate change impacts due to its geographical characteristics and anthropogenic activities (Matemilola, 2019). Understanding the trends and variations in rainfall patterns in this region is crucial for developing effective adaptation and mitigation strategies.

Long-term rainfall data measurements are essential for evaluating trends and variability as indicators of climate change. Global research has utilized trends, magnitude, and variation in rainfall time series data to investigate climate change manifestations across various meteorological parameters (Bărbulescu, 2023; Huang et al., 2019; Margaritidis, 2021). These studies have provided valuable insights into the changing nature of precipitation patterns and their potential sectoral impacts. Previous research has highlighted changing rainfall patterns across different regions of Nigeria. Nwaogazie&Ologhadien (2014) reported increasing rainfall trends in the Gulf of Guinea region, while Ebele &Emodi (2016) discussed the broader impacts of climate change on the Nigerian economy. However, there remains a need for localized studies providing detailed insights into specific areas within the country.

This study aims to conduct a comprehensive analysis of rainfall non-stationarity as an indicator of changing climate in Umuahia. The research focuses on analyzing trends in 24-hourly annual maximum series (AMS) rainfall data and its downscaled shorter durations, quantifying the variation in magnitude of these trends, and identifying change point dates signifying significant shifts in rainfall patterns. To achieve these objectives, the study employs robust statistical approaches including the Mann-Kendall test, Sen's Slope Estimator, and trend change-point analysis methods. These non-parametric techniques are widely recognized for their effectiveness in detecting trends and changes in hydrological time series data. The findings of this study have significant implications for urban planning, water resource management, and climate change adaptation strategies in Umuahia and potentially other cities in the Niger Delta region. By providing a detailed understanding of the changing rainfall patterns, this research contributes to the broader body of knowledge on climate change impacts in Nigeria and offers valuable insights for policymakers and stakeholders involved in climate resilience efforts.

2. MATERIALS AND METHODS

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2.1 Study Area

Umuahia, the capital city of Abia State, is situated in southeastern Nigeria within the Niger Delta region, at 5.5544°N latitude and 5.7932°E longitude (Figure 1). The city experiences a tropical climate characterized by a rainy season from April to October and a dry season from November to March. Umuahia's climate is influenced by its proximity to the Atlantic Ocean and its location within the Guinea Forest-Savanna mosaic ecoregion. The area typically receives significant annual rainfall, making it susceptible to flooding events and other rainfall-related challenges. Rapid urbanization in recent years has further heightened the city's vulnerability to climate change impacts, particularly concerning changing rainfall patterns.

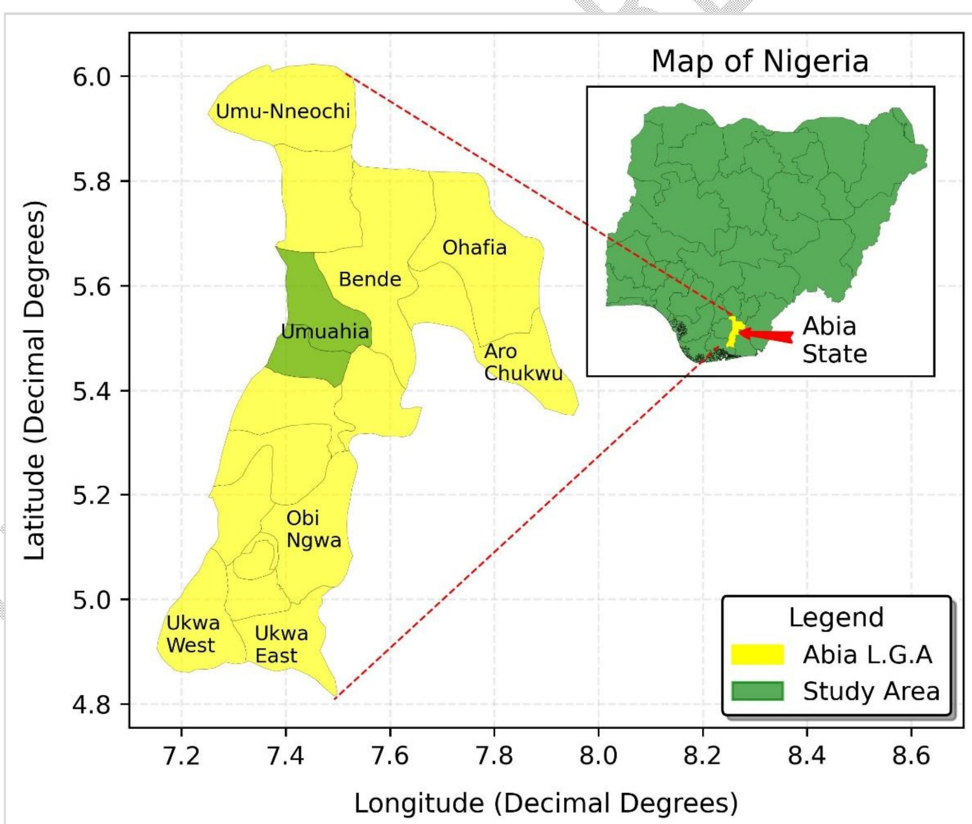

Figure 1: Map of Study Area

2.2 Data Collection

Historical rainfall time series data covering a period of 31 years (1992-2022) were obtained from the Nigerian Meteorological Agency (NIMET) for Umuahia. The data comprised daily rainfall measurements, which were initially sorted into 24-hourly Monthly Maximum Series (MMS). From this, the 24-hourly Annual Maximum Series (AMS) was extracted for analysis. To enable a more comprehensive analysis of rainfall patterns across different durations, the 24-hourly AMS data were further desegregated into shorter durations by downscaling models using the Indian Meteorological Department (IMD) model. The downscaled durations included 5, 10, 20, 30, 60, 120, 360, 720, and 1440 minutes (24 hours).

2.3 Statistical Test Methods

Three non-parametrical statistical approaches were employed in this study: the Mann-Kendall (MK) test to check for monotonous trends in the time series data; the Sen's Slope Estimator (SSE) test to determine the magnitude and variation of the trend; and the trend change-point test, comprising the Distribution-free cumulative sum (CUSUM) test and the Sequential Mann-Kendall (SQMK) test. Prior to applying these tests, the data were checked for serial correlation using autocorrelation function (ACF) analysis. In cases where significant serial correlation was detected, trend-free pre-whitening (TFPW) was applied to eliminate its influence on the trend analysis results.

2.4 Software Packages Applied

The analysis was conducted using two open-source software packages: "Python statsmodel library-pymannkendall" for computing the non-parametric Mann-Kendall test, autocorrelation functions, and trend magnitude; and "trendchange" for trend change-point analysis, including both the Distribution-free CUSUM and Sequential Mann-Kendall tests.

3. RESULTS

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3.1 Trend of rainfall precipitation in Umuahia

The analysis of rainfall precipitation patterns in Umuahia over various durations from 5 minutes to 1440 minutes (24 hours) reveals consistent trends and notable fluctuations across the study period as shown in Figure 2. All the rainfall input data were subjected to autocorrelation function (ACF) test to establish if there is any serial correlation at Lag 1. Figure 3 shows that there is no evidence of auto correlation at Lag 1; invariably, the remaining statistical analyses such as MK-trend analysis was carried out. Across all duration intervals, the overall pattern of precipitation exhibits remarkable consistency, suggesting that the temporal distribution of rainfall events in Umuahia follows a similar trend regardless of the timeframe examined. A pronounced spike in rainfall precipitation was observed around the years 2010 and 2015, representing the highest recorded precipitation levels for Umuahia across all durations. This peak indicates a period of particularly intense rainfall, which may have significant implications for urban drainage systems and flood management strategies. A notable feature of the precipitation pattern is the presence of a significant trough around 2002, where rainfall levels dropped markedly across all durations. This pronounced dip in precipitation could be indicative of a drought period or a significant shift in regional climate patterns. The result from Figure 2 suggest a slight trend towards increased rainfall variability in recent years, particularly from 2010 onwards. This increased variability is evident in the more pronounced fluctuations between high and low precipitation levels compared to the earlier part of the study period. Such a trend could have important implications for water resource management and urban planning in Umuahia, potentially necessitating more adaptive and resilient infrastructure designs. It is worth noting that while the overall patterns are consistent across durations, the magnitude of precipitation increases with longer durations, as expected.

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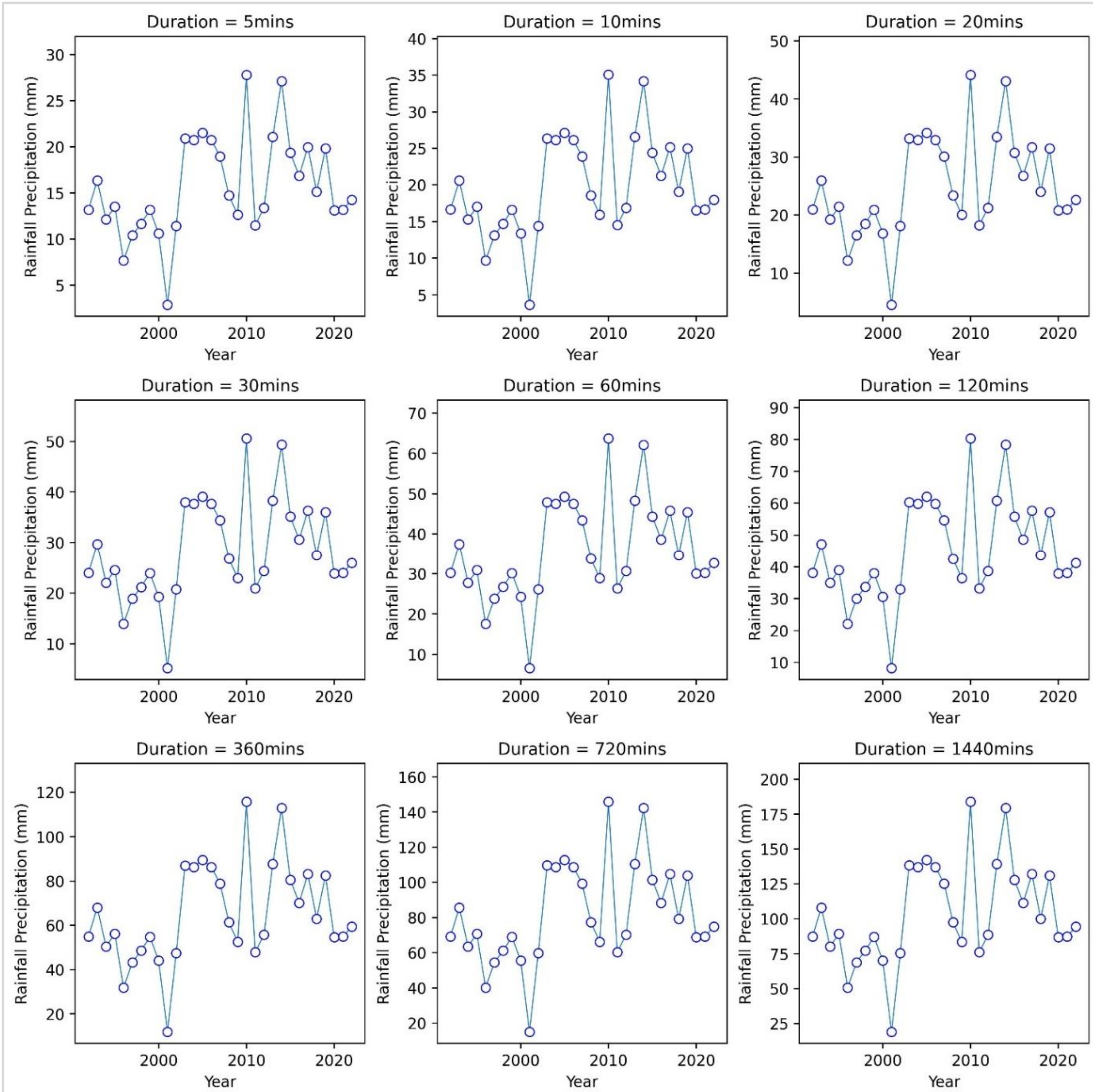

Figure 2: Rainfall distribution for the duration 5 – 1440 mins for 1992 – 2022 for Umuahia city

3.2 Mann-Kendall (MK) Trend Analysis

The Mann-Kendall test results for Umuahia revealed a consistent and statistically significant increasing trend across all time intervals, from 5 minutes to 24 hours (Table 1). The standardized MK statistic (Z) was consistently 1.1418 across all durations, with uniform p-values of 0.2535. While the p-values were above the conventional 0.05 significance level, they were below 0.10, indicating a moderately significant trend. These results suggest a consistent upward trend in rainfall intensity across all durations in Umuahia over the study period.The Sen's Slope Estimator (SSE) results provided quantitative measures of the trend magnitudes. For the 5-minute duration, Q = 0.1373 mm/hr/year, increasing to Q = 0.9045 mm/hr/year for the 24-hour duration. This 24-hour duration slope translates to a variation rate of 9.05 mm/decade, indicating a substantial increase in rainfall intensity over time, particularly for longer duration events. The intercept values also showed an increasing trend from longer to shorter durations, ranging from 80.7318 for 24-hour duration to 12.2209 for 5-minute duration.

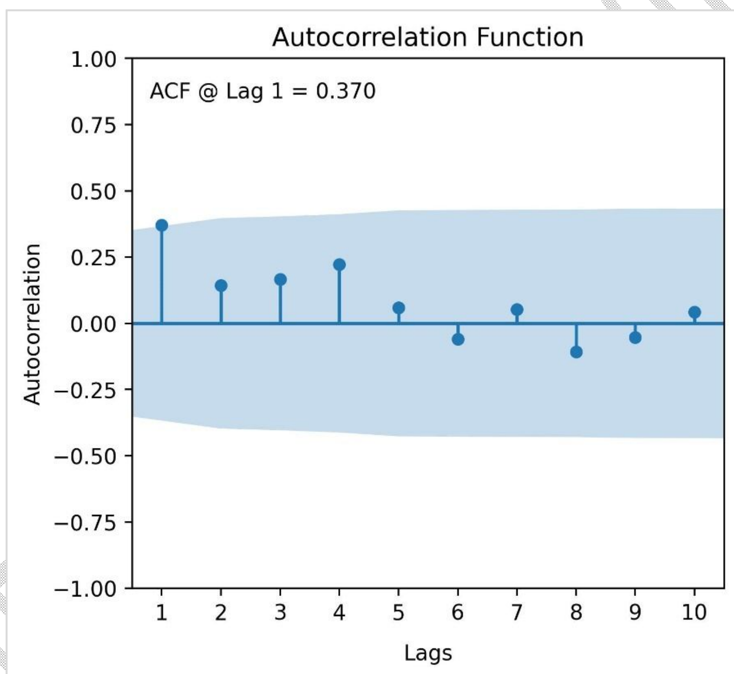

Figure 3: Rainfall correlogram of ACF for Umuahia

Table 1: Mann-Kendall test and Sen's Slope estimates result for Umuahia.

Time	Z-Value	p-value	Qi	Intercept	Status
5mins	1.1418	0.006	0.1373	12.2209	increasing
10mins	1.1418	0.006	0.1727	15.3991	increasing
20mins	1.1418	0.006	0.2173	19.4109	increasing
30mins	1.1418	0.006	0.2486	22.2205	increasing
60mins	1.1418	0.006	0.3136	27.9855	increasing
120mins	1.1418	0.006	0.3955	35.2582	increasing
360mins	1.1418	0.006	0.5695	50.8668	increasing

720mins	1.1418	0.006	0.7177	64.0841	increasing
1440mins	1.1418	0.006	0.9045	80.7318	increasing

3.3 Trend Change-Point Analysis

The trend change-point analysis revealed important shifts in Umuahia's rainfall patterns (Figure 4). The CUSUM test identified 2002 as the change point year, with a maximum CUSUM value of 9, surpassing the critical values at all confidence levels (90%, 95%, and 99%) (Table 2). The SQMK test identified 2003 as the change point, showing a clear intersection between the progressive and retrograde series (Figure 5). These results suggest that a significant shift in rainfall patterns occurred in Umuahia around 2002-2003, marking the beginning of a period of increased rainfall intensity.

Table 2: CUSUM and Sequential Mann Kendall Change Point

Change Point test	Maximum CUSUM Value	CI @ 90	CI @ 95	CI @ 99	Change Point Year	Remark
CUSUM	9	6.7927	7.5722	9.0755	2002	Significant change point
Sequential Mann Kendall	-	-	-	-	2003	Significant change point

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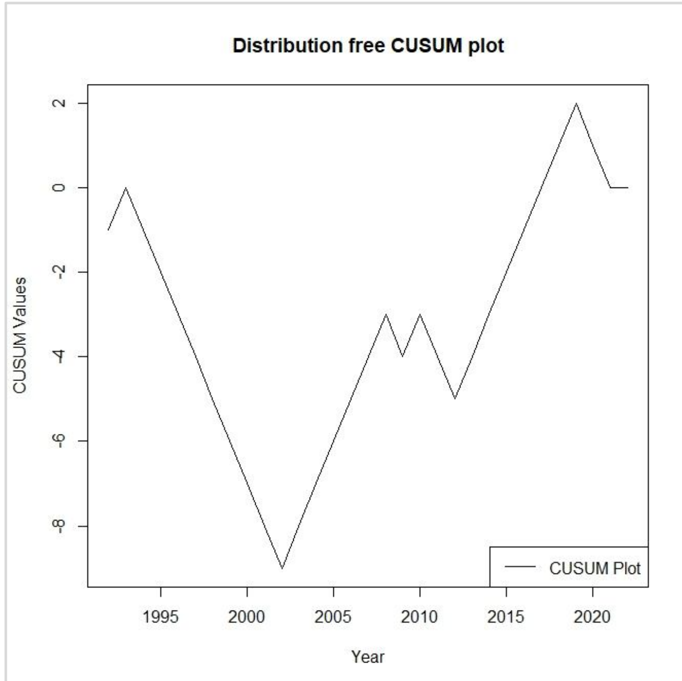

Figure 4: Distribution-free CUSUM plot for 24-hourly AMS rainfall intensity for Umuahia

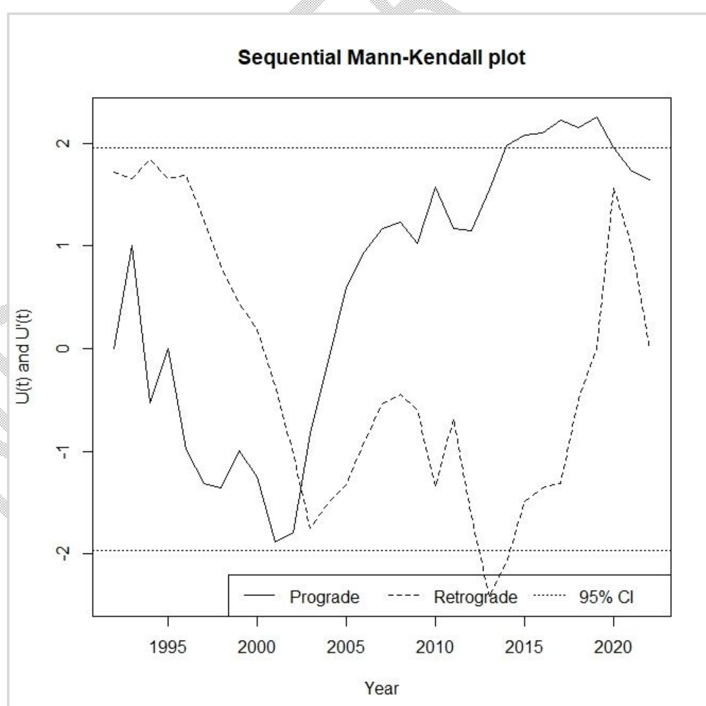

Figure 5: Sequential Mann-Kendall plot for 24-hourly AMS rainfall intensity for Umuahia

4. DISCUSSION

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The results of this study provide strong evidence for a non-stationary trend in the rainfall data for Umuahia. The consistent positive trend across all durations, from 5 minutes to 24 hours, suggests a significant and widespread change in the rainfall patterns over the study period. This non-stationarity has important implications for hydrological modeling and water resources management in the region. Traditional stationarity-based approaches to flood frequency analysis and infrastructure design may no longer be adequate to capture the changing nature of rainfall patterns in Umuahia.

The observed trends align with broader regional studies in the Niger Delta, such as those by Nwaogazie and Ologhadien (2014), who reported increasing trends in rainfall in the Gulf of Guinea region. However, the current study provides more localized and detailed insights specific to Umuahia, allowing for more targeted adaptation strategies. The result is similar to the study carried out by Sam et al. (2023a) for Uyo city in Niger Delta in which two change points were identified at 2005 & 2011, respectively.

The identification of 2002-2003 as the change point years is a crucial finding of this study. This period marks a significant shift in the rainfall regime of Umuahia, after which the increasing trend becomes more pronounced. Several factors could contribute to this change point, including global climate change, local land-use changes due to rapid urbanization, and regional climate oscillations. The identification of this change point provides valuable information for climate change adaptation planning in Umuahia, suggesting that rainfall data and related infrastructure designs from before 2002 may not be representative of current and future rainfall patterns.

The consistent positive trend and the increasing slope magnitude from longer to shorter durations indicate that rainfall intensity is increasing across all temporal scales, with particularly pronounced changes in shorter duration events. This pattern has several important

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implications, including increased flood risk, potential for soil erosion, and challenges for water resource management.

The variation rate of 9.05 mm/decade for the 24-hour duration rainfall is substantial and aligns with findings from other studies in the Niger Delta region (Sam et al. (2023b), (2023c)). This rate of increase in rainfall could lead to more frequent and intense flooding events if not accounted for in urban planning and infrastructure design. It underscores the need for adaptive management strategies and the potential reassessment of existing flood control measures in Umuahia.

5. CONCLUSION

This study establishes the existence of a statistically significant increasing trend in rainfall for Umuahia across multiple durations, with a clear change point around 2002-2003. The key findings include a consistent positive trend in rainfall intensity across all analyzed durations, a substantial variation rate of 9.05 mm/decade for 24-hour duration rainfall, and the identification of 2002-2003 as a significant change point in rainfall patterns.

These findings have several important implications, including the need for non-stationary approaches in rainfall modeling and infrastructure design, updating of design standards, adaptive urban planning, and regional climate change adaptation. The study highlights the urgency of reassessing existing infrastructure and flood management systems designed using pre-2002 data to account for the observed changes in rainfall patterns.

Future research should focus on the implications of these trends for urban planning, flood management, and water resource strategies; developing non-stationary Intensity-Duration-Frequency (IDF) curves for Umuahia; investigating the drivers behind the observed changes; and assessing the socio-economic impacts of changing rainfall patterns in Umuahia to develop targeted adaptation strategies.

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This study provides robust evidence of changing rainfall patterns in Umuahia, underscoring the urgent need for adaptive management strategies and climate-resilient urban planning in the face of ongoing climate change.

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