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Assessing Rainfall Trends and Change Points in Owerri, Nigeria: Implications of Climate Change

Chimeme M. Ekwueme [a], Ify L. Nwaogazie [a*] and Chiedozie Ikebude [a]

[a] *Department of Civil and Environmental Engineering, University of Port Harcourt, Rivers State, Nigeria.*

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

This study aims to analyze long-term rainfall trends and change points in Owerri, Nigeria, to understand climate change impacts on local precipitation patterns. The study utilized daily annual maximum series (AMS) rainfall data spanning 31 years (1992-2022). The Indian Meteorological Department (IMD) model was employed to downscale the time series data into durations ranging from 5 minutes to 24 hours. The choice of IMD is based on availability in literature. Mann-Kendall (MK) trend and Sen's Slope Estimator (SSE) tests revealed a statistically insignificant decreasing trend across all durations. The Sen's Slope magnitude ranged from -0.0679 mm/year for 5-minute duration to -0.4474 mm/year for 24-hour duration, corresponding to a variation rate of -4.474 mm/decade for the 24-hour duration. While the trends in rainfall patterns are decreasing, they lack statistical significance, the. Also, trend change-point analysis, utilizing Distribution-free CUSUM and

**Corresponding author: Email: ifynwaogazie@yahoo.com;*

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Sequential Mann-Kendall tests, identified 2013 and 2017 as potential change points in the rainfall pattern. These findings underscore the importance of continued monitoring to inform urban planning and water resource management in a climate-sensitive region.

Keywords: Water resource management; monitoring; rainfall trends; Mann Kendall.

1. INTRODUCTION

Man engaging in certain anthropogenic activities in a quest to improve man's quality of life on earth has resulted in some negative consequences, especially on the climate. Rainfall and temperature which are two of the most critical climate variables have been the most impacted because of these activities [1]. Rainfall has been extensively considered as an initial point toward the apprehension of climate change progressions, establishing one of the important constituents of the hydrological cycle [2]. Analysing rainfall trends and detecting the point where significant change commenced is important for the future development and sustainable management of water resources of a given region. In Nigeria, the impacts of climate change through changes in rainfall amount and variability have been felt through droughts of (1968 and 1973/74) and floods of (1998, 1999, 2001, and 2005), [3]. The Niger Delta region of Nigeria, encompassing Uyo and Benin City has been identified as highly vulnerable to climate change impact due to rainfall brought about by temperature differences, relative humidity, sea level rise, flooding, and intensive oil exploration and industrial activities [4].

Several studies have examined rainfall trends in Nigeria and the Niger Delta region. The studies reported both increasing and decreasing trends based on the region of the country. Oguntunde et al. [5] observed that about 90% of the entire nation showed decreasing trends in rainfall observing rainfall records from 1901 to 2000. They observed that significant change points occurred between 1969 and 1971. Ogunrinde et al. [6] found increasing rainfall trends in nine out of the eighteen stations they analyzed using rainfall records from 1981 to 2015. They reported Nigeria experienced more annual rainfall totals albeit with high variability within the rainy months. Oloruntade et al. [7] reported mostly insignificant trends in rainfall over the Niger South Basin. A more recent study by [8,9] reported a significant increasing trend in rainfall in Benin and Uyo. Sam et al. [10] reported that Warri and Port Harcourt showed a positive trend in the rainfall, but it was not significant. Understanding the impact of climate change in Nigeria is crucial, as the country's limited coping capacity makes it particularly vulnerable to adverse climate events [11]. This study aims to analyse the trend and change point of rainfall in Owerri. The research focuses on analysing 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.

2. MATERIALS AND METHODS

2.1 Study Area

Owerri, the capital city of Imo State, is situated in southeastern Nigeria within the Niger Delta region, at 5.4837°N latitude and 7.0352°E longitude (Fig. 1). Two major seasons are evident in Owerri metropolis such as, rainy period between March & October and a dry period between ranges from November to February. The Atlantic Ocean tends to influence the climate of the city, given its proximity to Guinea Forest-Savanna mosaic ecoregion. The city occasionally experiences seasonal flooding, which is attributed to the influence of climate change. The metropolis is a holiday resort environment particularly during the dry season period of the year. The inhabitants are mostly civil servants, traders, small & medium enterprises. Owerri is the capital of Imo state and so it houses international airport, 5 institutions of higher learning: State University, Federal University, College of Education, College of Technology and Polytechnic, respectively. Rapid urbanization in recent years has further heightened the city's vulnerability to climate change impacts, particularly concerning changing rainfall patterns.

2.2 Data Collection

Establishing trends in rainfall requires long historical data. A 31-year rainfall record starting from 1992 to 2022 was obtained from the Nigerian Meteorological Agency (NIMET) for Owerri. The data obtained was the 24-hour monthly rainfall record for Owerri city. Smaller rainfall duration records were obtained by downscaling the 24-hour rainfall record utilizing

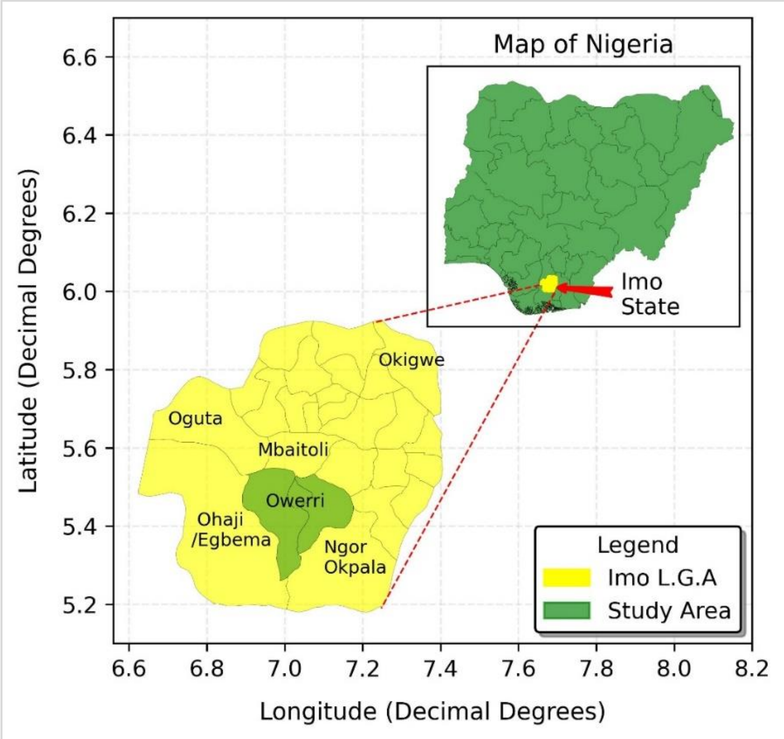

Fig. 1. Map of Study Area

Indian Meteorological Department (IMD) model which is given by Equation (1) [12]. The shorter duration record obtained included 5, 10, 20, 30, 60, 120, 360, and 720 minutes.

$$R_t = R_{24}\left(\frac{t}{24}\right)^{1/3} \quad (1)$$

Where R_t = Downscaled rainfall or precipitation, R_{24} = daily rainfall precipitation (mm), t = time.

2.3 Statistical Test Methods

To identify trend in the rainfall record Mann Kendall was utilised while Sen slope was used to quantity the magnitude of the trends. Two change points statistical test were utilized for change point detection in the rainfall data. Distribution-free cumulative sum (CUSUM) test and the Sequential Mann-Kendall (SQMK) test were the two statistical tests used for change point analysis.

2.3.1 Mann kendall test

Most trend analysis studies utilized either Linear regression or Mann Kendall for trend detection. Since most rainfall data exhibit some sort of skewness, Mann Kendall which is a non-parametric test is normally utilized to detect trends in rainfall data. The Mann-Kendall (MK) test check for monotonous trends in the time series data. The test is suitable for rainfall data that are not normally distributed. The Mann-Kendall test establishes the null hypothesis H_O as there is no trend in the population from which the data are drawn while the alternative hypothesis H_1 is that there is an increasing or decreasing monotonous trend. Prior to applying these Mann Kendall tests, the rainfall data were checked for serial correlation using autocorrelation function (ACF) analysis. The existence of serial correlation especially at lag 1 requires that correction of the time series data be made before applying Mann Kendall test to the data. Failure to apply correction to the time series result in committing a Type I error which result in establishing a trend in the absence of no trend [13]. Yue et al. [14] developed a correction for time series with serial correlation known as “Trend Free Pre-whitening (TFPW)”. Applying this correction is required before analysing the rainfall data for trend. Yue et al. [14] gave details on how to manually apply TFPW to time series data but where the ACF is not significant MK test can be applied directly to the original data set. Mann Kendall test is performed using Equations (2) – (4):

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sig\left(x_j - x_i\right) \quad (2)$$

$$sig(x_j - x_i) = \begin{cases} +1 & if\ (x_j - x_i) > 0 \\ 0 & if\ (x_j - x_i) = 0 \\ -1 & if\ (x_j - x_i) < 0 \end{cases} \quad (3)$$

$$V(S) = \frac{1}{18}\left[n\,(n-1)(2n+5) - \sum_{p=1}^{q} t_q(t_q - 1)(2t_q + 5)\right] \quad (4)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}}, & If\ S > 0 \\ \frac{S+1}{\sqrt{V(S)}}, & If\ S < 0 \end{cases} \quad (5)$$

Where: t_q = number of ties for p^{th} values; q = number of tied value; and Z = Standardized Mann Kendall statistic. A trend is detected in the time series data if the absolute standardized Mann Kendall statistic $|Z|$ is greater than the critical z-score $Z_{1-\alpha/2}$ or if the p-value is less than the level of 5% significance. "Python statsmodel library-pymannkendall" was use for performing Mann Kendall and autocorrelation analysis.

2.3.2 Theil Sen's slope

The Sen's Slope Estimator (SSE) test is to determine the magnitude and variation of the trend. The Sen' slope is estimated using the formula in Equation (6), [15,16].

$$\beta = \text{Median}\left(\frac{x_i - x_j}{t_i - t_j}\right) \quad (6)$$

Where x_i and x_j are rainfall data values at time t_i and t_j (i > j) respectively.

2.3.3 Change point analysis

Trend changes and their onset are crucial in meteorological and time-series studies. For trend change-point analysis, two non-parametric tests were used: the cumulative sum (CUSUM) test [17,18,19] and the sequential Mann-Kendall (SQMK) test [20,21]. The CUSUM test employs a cumulative sum chart, while the SQMK test treats each sample sequentially in both forward and backward directions. The absolute maximum CUSUM value is the point where the change point occurs. For SQMK, the point of intersection of the prograde series and the retrograde series indicates the trend change point, whereby, in the absence of a trend, the series intersects at several locations. CUSUM and SQMK were conducted using the open-source "trendchange" package, available via the CRAN repository [22,23].

3. RESULTS

3.1 Precipitation Description in Owerri from 1992 to 2022

Analysis of rainfall precipitation patterns in Owerri from 1992 to 2022 reveals complex temporal trends across multiple duration scales ranging from 5 minutes to 24 hours as shown in Fig. 2. The data reveal significant interannual variability, with pronounced peaks and troughs in rainfall amounts. A major precipitation maximum occurred in 2005 across all durations, representing the highest recorded rainfall levels for Owerri during the study period. This extreme event has important implications for urban drainage infrastructure and flood management strategies. Secondary rainfall maxima were observed in 2008 and 2010, further highlighting the variability in precipitation intensity over time. Conversely, a significant precipitation minimum occurred in 1998, with markedly reduced rainfall across all durations. This trough may indicate drought conditions or shifts in regional climate patterns. The rapid recovery of precipitation levels in subsequent years demonstrates the dynamic nature of the local climate system. The rainfall trend from the peak rainfall in 2005 showed a decreasing rainfall amount up till 2022.

3.2 Mann-Kendall (MK) Trend Analysis

To avoid violation of Mann Kendall's assumption of no serial correlation in the rainfall data set, autocorrelation was applied to the data set and the correlogram is presented in Fig. 3. The result from the correlogram especially autocorrelation at lag 1, showed that there was no significant autocorrelation as the ACF at lag 1. This was observed in Fig. 3 as the ACF value was within the confidence interval boundary. The non-serial correlation provided evidence that Mann Kendall can be applied directly to the data without the need for removal of the serial correlation in the data set.

The analysis of Owerri's rainfall data using the Mann-Kendall (MK) test presented in Table 1 revealed a consistent downward trend across all temporal scales, ranging from 5-minute to 24-hour intervals. However, this declining pattern did not meet the threshold for statistical significance. Quantitative assessment of the trend magnitudes using the Sen's Slope Estimator (SSE) corroborated the MK test findings, yielding negative values for all durations. The magnitude of the trend varied with duration, from -0.0679 mm/hr/year for 5-minute intervals to -0.4474 mm/hr/year for 24-hour periods. The uniformity of negative slopes across all durations further supports the observation of a mild decreasing trend in Owerri's precipitation patterns.

3.3 Trend Change-Point Analysis

Table 2 presents the result of the trend Change Point analysis. The trend change-point analysis revealed potential shifts in Owerri's rainfall patterns. For the CUSUM result which is presented in Fig. 4, an absolute maximum CUSUM value of 5 was obtained in the year 2013 which signifies the year of change in the trend of the rainfall. The change point identified using CUSUM was not significant at 90%, 95%, and 99% confidence intervals suggesting that while a change may have occurred, it was not statistically significant at conventional levels. The Sequential Mann-Kendall (SQMK) test identified 2017 as another potential change point, showing a subtle intersection between the progressive and retrograde series as shown in Fig. 5. The multiple crossing in the SQMK figure indicates that while a trend change point was identified, the trend change point was not significant. These results suggest that while there may have been shifts in rainfall patterns around 2013 and 2017, these changes were not dramatic enough to be considered statistically significant turning points in the overall trend.

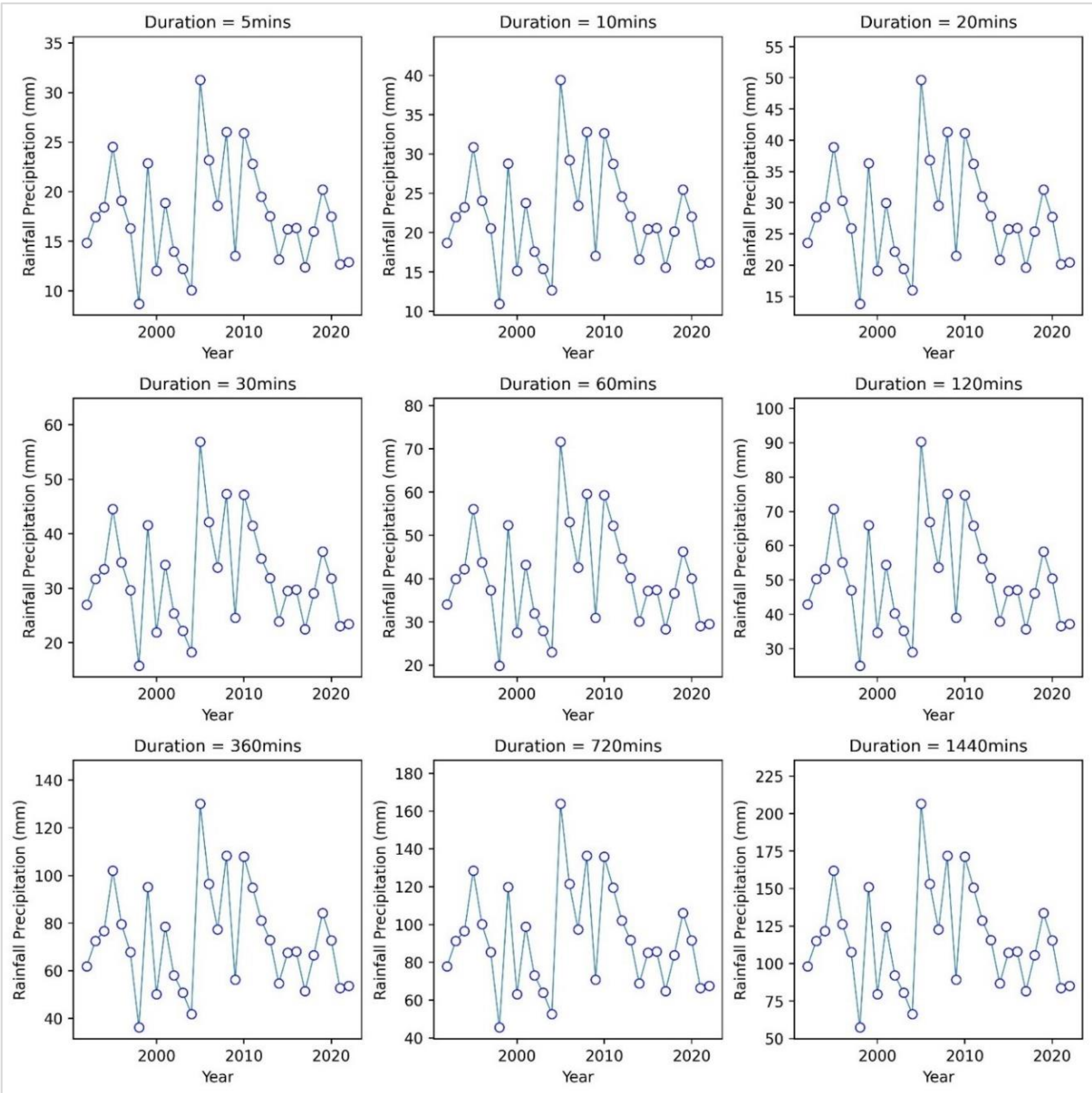

Fig. 2. Plot of rainfall precipitation for the duration of rainfall record for the study for Owerri

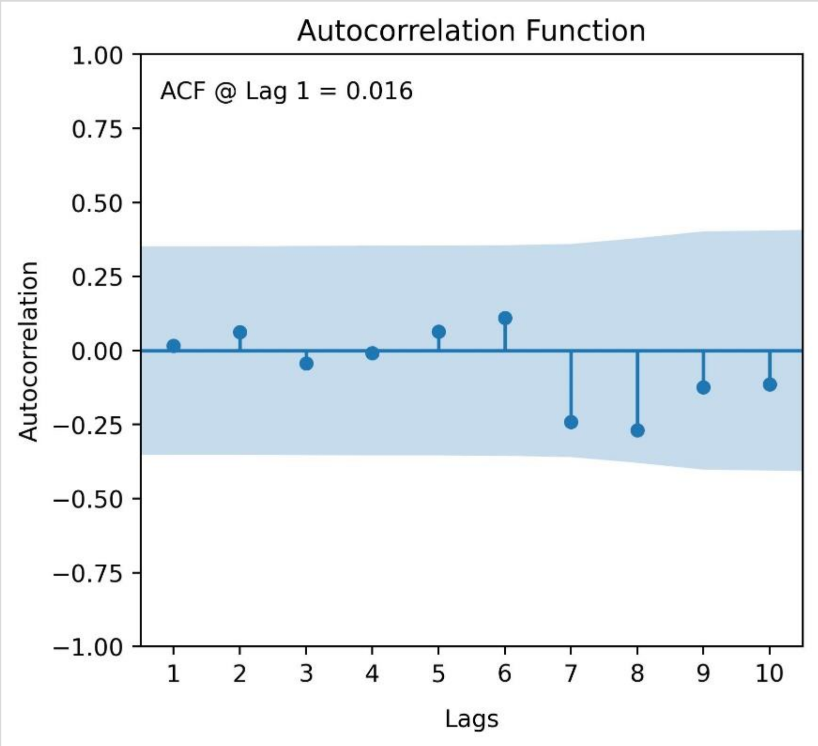

Fig. 3. Rainfall or precipitation correlogram of ACF for Owerri

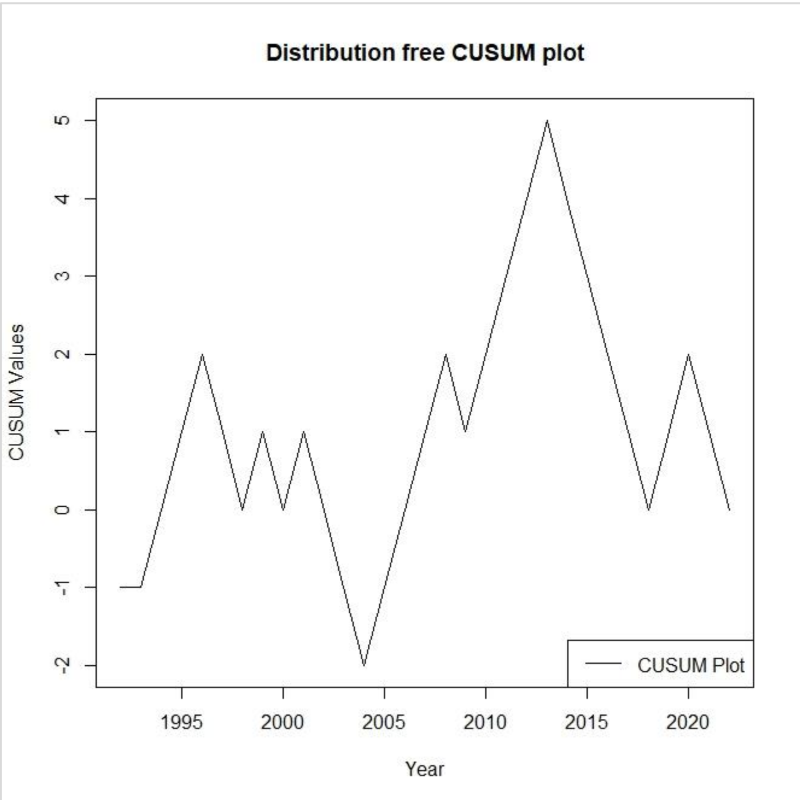

Fig. 4. Distribution-free CUSUM plot for 24-hourly AMS rainfall intensity for Owerri

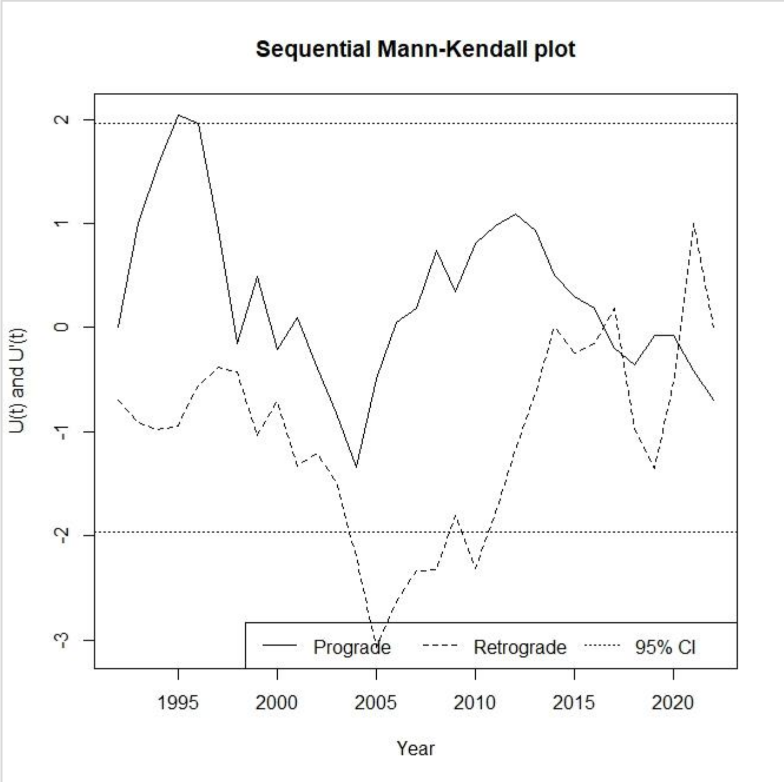

Fig. 5. Sequential Mann-Kendall plot for 24-hourly AMS rainfall intensity for Owerri

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

Time	Z-Value	p-value	Qi	Intercept	Trend	Status
5mins	-0.6799	0.4966	-0.0679	18.4484	Decreasing trend	Not Significant
10mins	-0.6799	0.4966	-0.0853	23.2389	Decreasing trend	Not Significant
20mins	-0.6799	0.4966	-0.1075	29.2825	Decreasing trend	Not Significant
30mins	-0.6799	0.4966	-0.1232	33.5174	Decreasing trend	Not Significant
60mins	-0.6799	0.4966	-0.1547	42.2211	Decreasing trend	Not Significant
120mins	-0.6799	0.4966	-0.1953	53.1989	Decreasing trend	Not Significant
360mins	-0.6799	0.4966	-0.2816	76.7337	Decreasing trend	Not Significant
720mins	-0.6799	0.4966	-0.3553	96.6789	Decreasing trend	Not Significant
1440mins	-0.6799	0.4966	-0.4474	121.8105	Decreasing trend	Not Significant

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	5	6.7927	7.5722	9.0755	2013	No significant change point
Sequential Mann Kendall					2017	No significant change point

4. DISCUSSION

The results of this study provide insights into the subtle changes occurring in the rainfall patterns of Owerri, Nigeria. The consistent but statistically insignificant decreasing trend observed across all durations suggests that while there may be a tendency towards reduced rainfall, this change is not yet pronounced enough to be considered statistically significant. Akamuga et al., [24] found that there was little or no statistically significant trend in the rainfall in Owerri from 1998 to 2020.

The lack of statistical significance in our findings echoes the work of [7], who found mostly insignificant trends in rainfall over the Niger South Basin. However, the finding in the current study contrasts with results obtained from trends analysis from other studies conducted within the South-South region of Nigeria. Studies within the South-South region of Nigeria have reported significantly increasing rainfall [25,19]. The variation in the rainfall trend direction highlights the importance of localized climate analyses and the potential for microclimatic variations within broader regional patterns. However, in Nigeria there is poor political will to address climate change [26].

The identification of 2013 and 2017 as potential change points, although not statistically significant, warrants further investigation. These years may mark subtle shifts in Owerri's rainfall regime, possibly influenced by broader regional climate patterns or local environmental changes such as urbanization or land use modifications. The fact that these change points are relatively recent could indicate an emerging trend that may become more pronounced in future years, aligning with [6] observation of increased annual rainfall totals in the early 21st century. Similar studies on change points have carried out with respect to temperature and relative humidity [27]. Equally important is a study trend detection in weather parameters using Mann Kendall [28].

The variation rate of -4.474 mm/decade for the 24-hour duration rainfall, while modest, suggests a gradual shift towards drier conditions. This trend, if continued or intensified, could have long-term implications for agriculture, water supply, and ecosystem health in the Owerri area. However, the lack of statistical significance emphasizes the need for cautious interpretation and continued data collection to confirm whether this represents a genuine long-term change or natural variability within the climate system.

5. CONCLUSION

This study provides valuable insights into the rainfall trends and patterns in Owerri, Nigeria, contributing to our understanding of climate change impacts in the Niger Delta region. While the analysis reveals a slight decreasing trend in rainfall across all durations, the changes are not statistically significant, indicating subtle rather than dramatic shifts in precipitation patterns. The identification of potential change points in 2013 and 2017 suggests recent shifts in the rainfall regime that merit further investigation. These findings emphasize the importance of continued and enhanced monitoring of rainfall patterns in Owerri. While the observed changes are not yet statistically significant, proactive adaptation strategies should be considered to enhance resilience against potential future changes in precipitation patterns. This may include reassessing urban drainage systems, water storage capacities, and agricultural practices to account for the possibility of reduced rainfall in the future.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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