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Detecting Climate Change Trend, Size, and Change Point Date on Annual Maximum Time Series Rainfall Data for Warri, Nigeria

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Abstract

The study focused on the detection of indicators of climate change in 24-hourly annual maximum series (AMS) rainfall data collected for 36 years (1982-2017) for Warri Township, using different statistical methods yielded a statistically insignificant positive mild trend. The IMD and MCIMD downscaled model's time series data respectively produced MK statistics varying from 1.403 to 1.4729, and 1.403 to 1.463 which were less than the critical Z-value of 1.96. Also, the slope magnitude obtained showed a mild increasing trend in variation from 0.0189 to 0.3713, and 0.0175 to 0.5426, with the rate of change in rainfall intensity at 24 hours duration as 0.4536 and 0.42 mm/hr.year (4.536 and 4.2 mm/decade) for the IMD and the MCIMD time series data, respectively. The trend change point date occurred in the year 2000 from the distribution-free CUSUM test with the trend maintaining a significant and steady increase from 2010 to 2015. Thus, this study established the existence of a trend, which is an indication of a changing climate, and satisfied the condition for rainfall Non-stationary intensity-duration-frequency (NS-IDF) modeling required for infrastructural design for combating flooding events.

Keywords

Climate Change, Annual Maximum Series, Statistical Test, Rainfall Trend and Size, Change Point Date

1. Introduction

Climate change is a reality that has become a challenge to the world. The resultant effect has become a fast, widespread and daunting task to mitigate as reported by the 2021 UN's Intergovernmental Panel on Climate Change (IPCC), with anthropogenic activities contributing so much to the worsening global climate change [1]. This global phenomenon is overwhelmingly impacting different parts of the Earth, thereby causing undue damage that calls for an urgent action plan to reverse the trend [2]. Two indicative variables in the study of climate change are trends in temperature and rainfall patterns which are functions of the land use, vegetation, topography, and soil type and lithology of the climate zone [3] [4] [5]. However, studies by different investigators have revealed that precipitation pattern is significantly affected by global warming in various regions of the Earth. Solar radiation produces heat waves to the Earth, which causes phenomena like relative humidity, sea level rise, flooding, and rainfall due to temperature differences. Therefore, climate data gathered from temperature and trends in rainfall patterns have been utilized as indicators of climate change by different scholars in investigating climate change studies [6] [7] [8] [9] [10].

Climate change is, therefore, measured via the increasing or decreasing phenomena inherent in rainfall. Rainfall measurements constitute a series of data recorded as rainfall amount with the corresponding duration of when it took place analyzed as time series data. The characteristics of observations in a given set of time series possess either a gradual process in a pattern referred to as a trend or may possess abrupt changes termed as a trend change point. The focus of climate change studies has been on long-term rainfall and temperature variability considered, as the most important climate change indicators. Thus, several researchers worldwide have investigated trends, magnitude and variation in rainfall time series as pointers of climate change presence in different meteorological parameters in many countries [11]-[18]. In Nigeria, meteorological records indicate an increasing rainfall trend in the coastal region and a decreasing rainfall inland [19]-[24].

There are different approaches to calculating the trend and change point of rainfall patterns. According to Zhang, *et al.* [25], the determination of unexpected and structural changes in the time series data properties like mean or variance is by the change point detection method, while trend analysis was by using gradual future events from past measured data. The non-parametric test is one of the most preferred methods in the trend analysis of time series data, such as the Mann-Kendall test [26] [27] [28] [29] [30] and the Sen's Slope estimator for the trend magnitude and its intercept [31], while the trend change point date is by applying the Distribution-free cumulative sum (CUSUM) and the Sequential Mann-Kendall (SQMN) tests [32] [33] [34]. Other methods in the literature for trend change points analysis include the Wild binary segmentation, the Iterative robust detection methods, the Bayesian analysis of change points, and the E- Agglomerative algorithm [35] [36] [37].

This study aims to detect the indicators of climate change existing in terms of trend, variation in magnitude, and change point date on 24-hourly annual maximum series (AMS) data for Warri recorded for 36 years (1982-2017). Statistical methods adopted were the Mann-Kendall (MK) trend test, Sen's slope estimator (SSE) to obtain the trend magnitude, and the trend change point by the use of the distribution-free cumulative sum test (CUSUM) and the sequential

Mann-Kendall test (SQMK). Two open-source software packages applied are: "python statsmodel library-pymannkendall" [38] and "trend change" [39] [40]. Thus, the essence of the analysis will enable the achievement of the purpose of this research which is to determine the existence of climate change in the study area.

2. Methodology

2.1. Study Area

The study station is geographically located between latitudes 5˚00'N - 5˚45'N and longitudes 5˚30'E - 60˚00'E, in the Delta State of Nigeria, as shown in **Figure 1** [41]. The elevation of the area is 15.97 meters above sea level. Warri Township has a tropical monsoon climate with a mean annual temperature of 32.8˚C and an annual rainfall amount of 2770 mm. It has a high temperature ranging between 28˚C and 32˚C. The area is predominantly surrounded by rainforest regions tending to swampland in some places.

2.2. Data Collection

The rainfall data were measured and collected for 36 years (1982-2017) for Warri Township from the gauging station of the Nigeria Meteorological Agency (NIMET). The recorded rainfall amount data collected was in mm against the duration in minutes. The record was sorted out by extraction of the 24-hourly maximum monthly series (MMS) rainfall amount against the corresponding duration for each month of the year. Furthermore, for each year, the maximum records were extracted to collate the 24-hourly annual maximum series (AMS) for the rest of the 36 years interval. Downscaling into the shorter duration of the

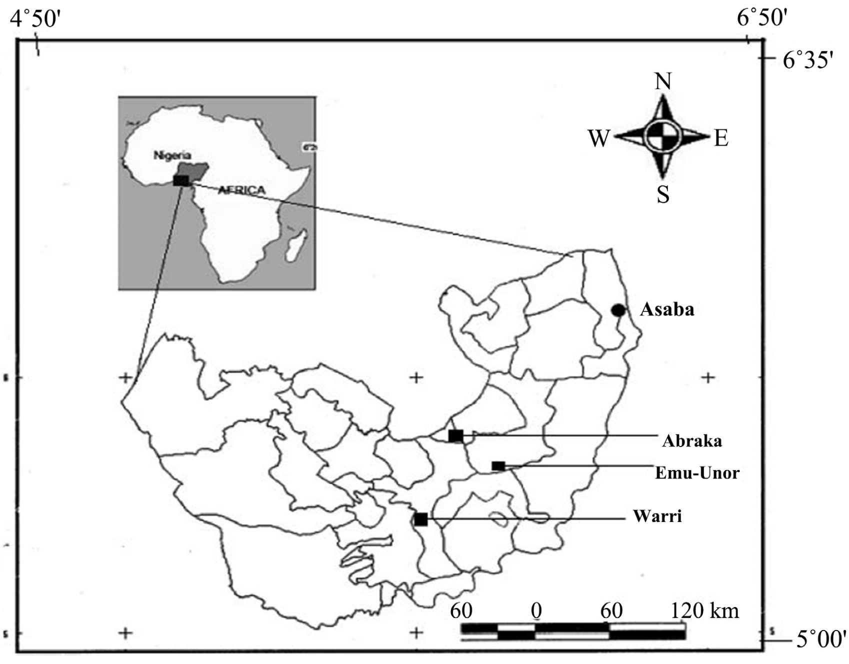

Figure 1. Map of delta state showing the study area—Warri.

24-hourly annual maximum series (AMS) rainfall data were carried out as detailed in [42] for the 36 years 24-hourly maximum annual data series dis-segregated using the Indian Meteorological Department (IMD) model as proposed by Rameseshan [43] and the Modified Chowdhury Indian Meteorological Department (MCIMD) [44].

2.3. Evaluation of Mann-Kendall Trend and Sen's Slope Magnitude

The Mann-Kendall (MK) test [45] is a rank-based, non-parametric statistical test that helps to check for monotonous trend movement in time series data. The test does not require the data set distribution to be auto-correlated that is, not serially correlated. To achieve a relatively error-free MK test result the conditions required are well-treated [46] [47] [48] [49]. Trend Free Pre-Whitening (TFPW) can be used in the removal of serial correlation in the rainfall intensity. The procedure used in performing the Mann-Kendall test is treated in [24], to find if a monotonous negative or positive trend exists in the time series data. The MK test is applied directly to the original data set where the ACF is not significant. The application of the Python statsmodel library-pymannkendall [38] was introduced to calculate the auto-correlation (ACF) at lag 1 and the TFPW to the time series data set before the MK test was carried out. The trend magnitude and variations analysis was also conducted using the Sen's Slope estimator technique with Microsoft Excel stat 2016 in the Python pymannkendall library.

2.4. Determination of Trend Change-Point Date in a Time Series Data

The identification of trends and the change point in precipitation parameters and time-series data studies are of significant value. The determination of the trend change-point was executed with two non-parametric testing methods namely the Distribution-free cumulative parameters (CUSUM) test [32] and the Sequential Mann-Kendall test [33] [34]. The distribution-free CUSUM test adopts a cumulative sum chart, and the sequential Mann-Kendall (SQMK) test applies each sample point sequence sequentially handled in both prograde and retrograde procedures. The application of both non-parametric approaches is demonstrated in [9]. The package applied for the change-point analysis was the "trend change" package. The software is an open-source library free package available via the CRAN repository in version 1.2 [39] [40].

3. Results

3.1. Detecting Trend Change in the Time Series Data

Three different sets of data were gotten for detecting trends in the time series data. The 24-hourly monthly maximum series (MMS), the 24-hourly rainfall data using the IMD model and the 24-hourly rainfall data using the MCIMD model were presented in section 2.2. The MK test execution initially was with the computation of the autocorrelation function (ACF), which indicated that the

ACF was not significant at a 95% Confidence interval as in Figure 2. This means, no trend-free pre-whitening (TFPW) was applied to the original time-series data. The MK test was performed directly on the original time series data. The results of the MK test are presented in Table 1 with the value computed for IMD model data ranging from 1.4030 to 1.4729 and those for the MCIMD model ranging from 1.4030 to 1.4624. All the MK computed values were less than the Critical Z-value of 1.96. Similarly, the p-value for the IMD model varied from 0.1408 to 0.1606 for the durations, while the MCIMD model p-value also varied from 0.1436 to 0.1606. These *p*-values obtained were all also more than alpha, $\propto = 0.05$ level of significance. These results show that the trend was positive and insignificant.

3.2. Detecting the Slope Trend Size and Variation in the Time Series Data

The magnitude of the trend was evaluated using Sen's slope estimator, and also presented in Table 1. The result of the slope shows decreasing positive values of 0.3713 (at 0.25 hour) to 0.0189 (at 24 hours) and 0.5426 (at 0.25 hour) to 0.0175 (at 24 hours) for IMD and MCIMD models, respectively. The intercept for the IMD method also decreased from 100.553 to 4.769 at 0.25 and 24 hours, respectively. The MCIMD data produced higher intercept values which similarly decreased from 169.655 to 5.043 at 0.25 to 24 hours, respectively. From the Figure 3 graph, the result obtained for the 24-hourly MMS data confirmed the slope or trend variation magnitude value as 0.000089 mm/hr/year and intercept of 2.0848. The p-value of 0.9760 obtained is far greater than the alpha value at 5% level significance.

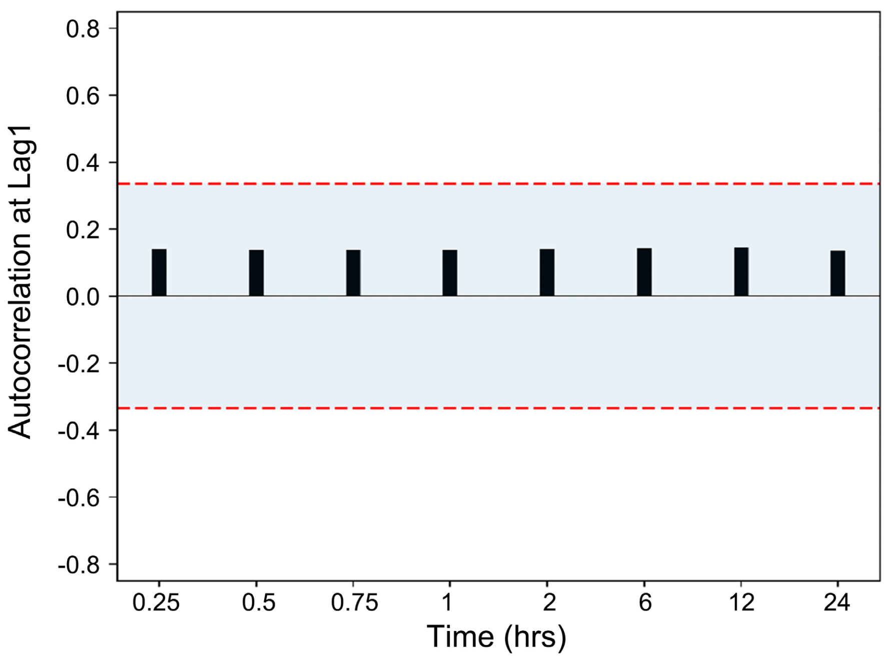

Figure 2. Correlogram of ACF at Lag-1 for various 24-Hourly AMS MCIMD Method Downscaled Durations for Warri.

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

Time (hrs)	Statistic	IMD	MCIMD
		Value	Value
0.25	Z	1.4167	1.4029
	p-value	0.1566	0.16063
	Q_i	0.3713	0.5426
	Intercept	100.553	169.655
0.5	Z	1.4305	1.4030
	p-value	0.1526	0.16063
	Q_i	0.2329	0.3249
	Intercept	63.325	98.665
0.75	Z	1.4305	1.4305
	p-value	0.1526	0.1526
	Q_i	0.1760	0.2375
	Intercept	48.371	72.043
1	Z	1.4030	1.4167
	p-value	0.16063	0.1566
	Q_i	0.1500	0.1928
	Intercept	39.825	57.626
2	Z	1.4442	1.4167
	p-value	0.1487	0.1566
	Q_i	0.0948	0.1152
	Intercept	25.091	33.734
6	Z	1.4729	1.4586
	p-value	0.1408	0.1447
	Q_i	0.0467	0.0518
	Intercept	12.033	14.494
12	Z	1.4325	1.4597
	p-value	0.1520	0.1444
	Q_i	0.0278	0.0306
	Intercept	7.614	8.5145
24	Z	1.4598	1.4624
	p-value	0.1443	0.1436
	Q_i	0.0189	0.0175
	Intercept	4.769	5.0434

Level of significant $\propto = 0.05$, where Z = standardized Mann Kendall statistic, Q_i = Sen Slope, Critical Z-value = 1.96.

3.3. Detecting Change-Point Date in Trend of the Time Series Data

The result for the trend graph plots of the 24-hourly AMS rainfall intensities for the station for both long (24 hours) and short (0.25 hours) durations are presented in **Figure 4** and **Figure 5**, for the IMD and MCIMD methods, respectively. Also carried out was trend change-point analysis for all downscaled durations and the results of the distribution-free CUSUM and the Sequential Mann-Kendall

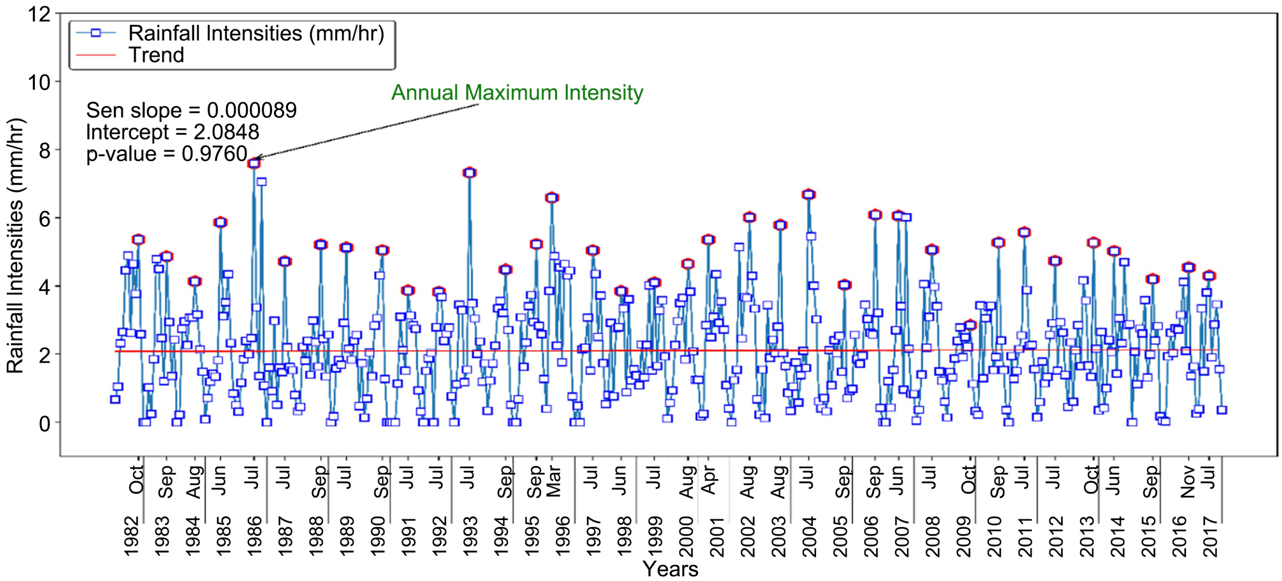

Figure 3. 24-Hourly MMS rainfall intensities vs time with trend line for Warri (1982-2017).

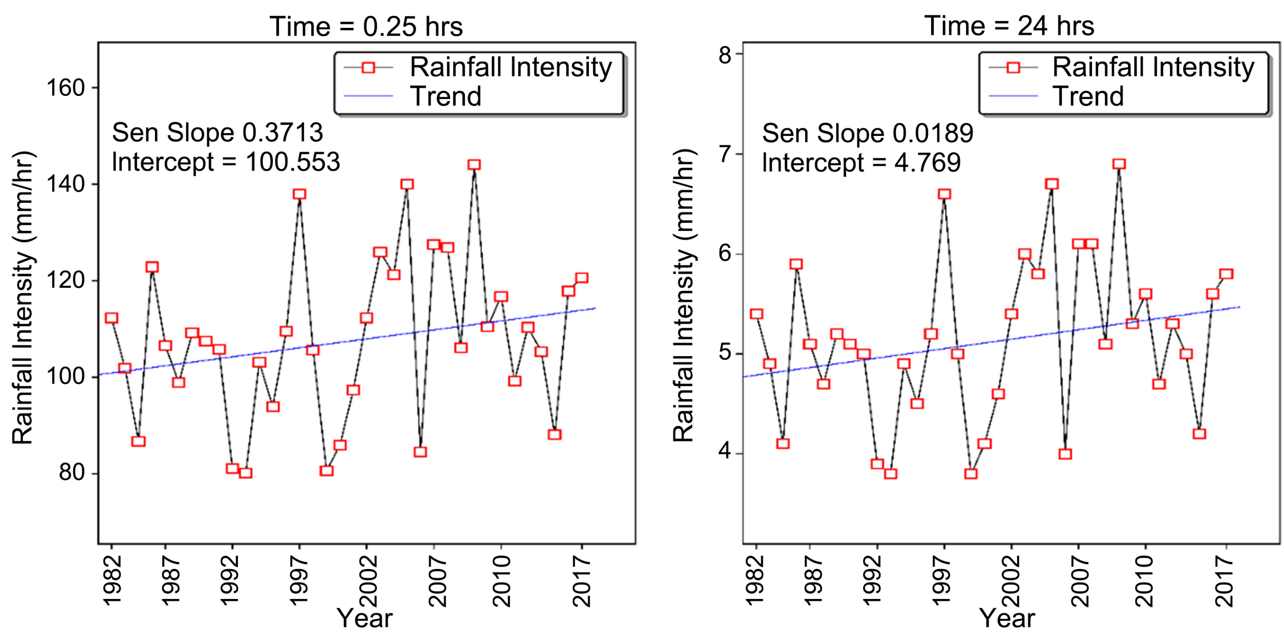

Figure 4. 24-Hourly AMS rainfall intensities versus time showing trend line for IMD method downscaled durations for Warri.

tests are presented in Table 2 and Table 3. Figure 6 and Figure 7 show distribution-free CUSUM plot and Sequential Mann-Kendall plot for 24-hourly AMS rainfall intensities, respectively, which were obtained via the "trend change" software package [39] [40].

4. Discussion

4.1. Analysis of Trend Pattern and the Variation

This investigation established the existence of meteorological trends and variation in 24-hourly AMS extracted data from the 24-hourly Monthly Maximum

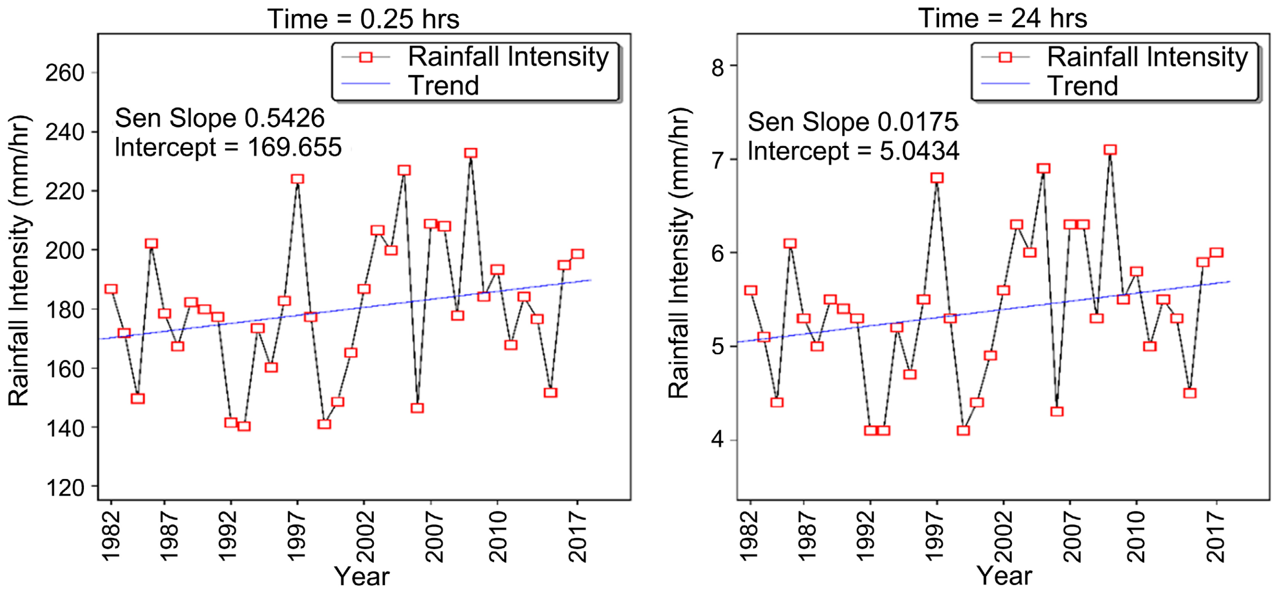

Figure 5. 24-Hourly AMS rainfall intensities versus time showing trend line for MCIMD method downscaled duration for Warri.

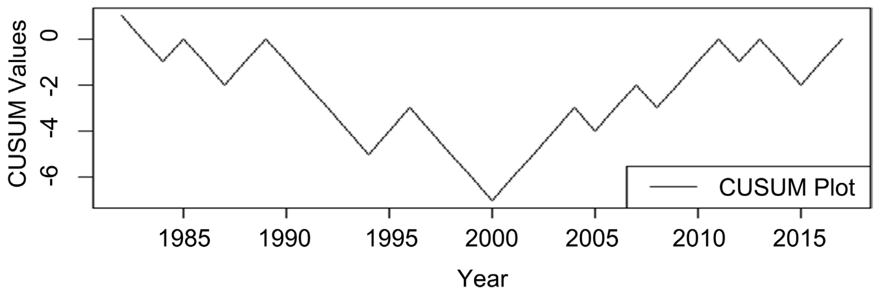

Figure 6. Distribution-free CUSUM plot for 24-hourly AMS rainfall intensity for Warri.

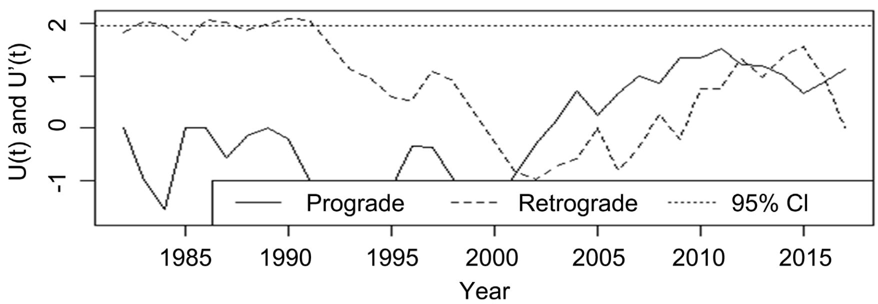

Figure 7. Sequential Mann-Kendall plot for 24-hourly AMS rainfall intensity for Warri.

Table 2. Distribution free CUSUM result for Warri.

Parameters	Values
Maximum CUMSUM value	7
Critical value at 90% CI	7.32
Critical value at 95% CI	8.16
Critical value at 99% CI	9.78
Date of Change	2000

Table 3. Trend change point for different downscaled duration rainfall intensities for Warri.

Rainfall Durations (mins)	CUSUM	SQMK
15	2000	2002
30	2000	2002
45	2000	2002
60	2000	2002
120	2000	2002
360	2000	2002
720	2000	2002
1440	2000	2002

Series (MMS) historical precipitation (rainfall) data (HPD). Three sets of meteorological time-series data were applied. The IMD model data and the MCIMD model data was downscaled from the 24-hourly AMS extracted data from the initially extracted MMS recorded rainfall intensities.

The Correlogram diagram presented in Figure 2 showed that the autocorrelation function (ACF) at lag 1 was statistically insignificant for all downscaled rainfall durations. The ACF values for the time-series data at a 95% Confidence interval were insignificant. This result does not require any trend-free pre-whitening (TFPW) because the time series data had no significant serial autocorrelation. The MK test was applied directly to the time series data.

The Mann-Kendall test results are presented in Table 1. The statistics measured for the trend is the p-value at a 5% level of significance and the standardized MK statistic similarly compared to the critical Z-value at 1.96. Thus, the results of the MK, p and the slope Q showed that; the computed p-value varied from 0.1408 to 0.1606, and 0.1436 to 0.1606 for IMD and MCIMD time series data, respectively. The p-values were more than the alpha value of 0.05 at a 5% level of significance. The MK statistic varied between the range of 1.403 to 1.473, and 1.403 to 1.436 for the IMD and MCIMD data series, respectively, and were all less than the critical Z-value of 1.96. The verdict is that no significant trend exists in the time series data.

4.2. Analysis of the Slope Size and the Variation

Considering the Sen's Slope test, it also showed that the magnitude of the slope varied from 0.0189 to 0.3713 and 0.0175 to 0.5426 for IMD and MCIMD time series data, respectively. The intercept varied from 4.769 to 100.553 and 5.043 to 169.655 for the IMD and MCIMD data series, respectively. The Warri township data series indicated the same trend pattern and variation in the values of its magnitude of the slope and the intercept as those of sister stations in the region such as Port Harcourt metropolis. The Sen's Slope results were also at par with the magnitude of the trend which decreased as the duration of rainfall increased which means that shorter durations tend to exhibit a higher value than longer durations [49].

The Sen's Slope results also proved that the magnitude of the trend decreases as the duration of rainfall increases that is to say that shorter durations tend to exhibit higher values than longer durations as also obtained in other gauge stations of Uyo [24] and Port Harcourt [49] within the Niger Delta in Nigeria.

4.3. Analysis of Variation in Rainfall Trend and the Magnitude

The results of the MK trend and Sen Slope analysis presented in **Table 1** also indicated that both tests were consistent. The results of the trend and slope showed a statistically insignificant positive trend increase in value for 24 hours higher duration to 0.25 hours lower durations. The observed performance in the consistency of both tests was well matched with some earlier publications [50] [51] [52].

The slope magnitude showed a statistically insignificant mild increasing trend variation. The rate of change in the magnitude of rainfall intensity is evaluated using the SSE technique. From **Table 1** the Q at 24 hours duration is evaluated as 0.0189 and 0.0175 mm/hr/year for the IMD and the MCIMD data series, respectively, which translates to a variable rate of 0.454 mm/year or 4.54 mm/decade, and 0.42 mm/year or 4.2 mm/decade for the IMD and MCIMD models, respectively.

The trend test for the 24-hourly MMS in **Figure 3**, also produced a p-value of 0.976 which is greater than the alpha value at a 5% significant level. The slope value was given as 0.000089 to confirm the positive mild trend status which is similar to the 24-hourly AMS sample data.

The variation rate in rainfall intensity of the meteorological gauge station is much the same with most earlier research work for the coastal areas of the Gulf of Guinea for instance, [16] had 13 mm/decade for Ghana, [21] also had 55.2 mm/decade for gauge stations in the Niger Delta, and most recently [24] [49] had 21.288 mm/decade for Uyo and 6.00 mm/decade for Port Harcourt in the Niger Delta. The results were at variance with the opinion of [53], whose work was on the Nigerian hinterland and found a negative trend in the rate of the variability of rainfall and the MK test statistic. These are evidence of climatic change variability in Nigeria whose trend shows rainfall decreases in the continental interiors [22] [23] and increases in the coastal region [20] [21] [24] [49].

4.4. Confirming Trend Change-Point Date of the Time Series Data

Change point analysis identifies the time for occurrence of significant change in the time series. Analysis of trend change points was for all the 24-hourly AMS time series downscaled durations. Results of the distribution-free cumulative sum (CUSUM) and sequential Mann-Kendall (SQMK) tests are presented in **Table 3**. **Figure 6** and **Figure 7** provide the distribution-free CUSUM and SQMK plots, respectively, for different durations of the 24-hourly AMS rainfall intensity. Table 3 shows Warri Township station indicating the year 2000 and 2002 as the date of a trend change points. However, from the distribution-free CUSUM plot shown in Figure 6, the maximum CUSUM value at 7 is approximately the same with the critical value of 7.32 at 90% C.I. strongly suggesting the year 2000 as the ideal change point as obtained in Table 2. The trend maintained a significant and steady positive increase from 2010 to 2015. In contrast, the result of the SQMK plot shown in Figure 7 pointed at 2002 as change point date, never the less, it stands rejected because of several intersections in different locations, showing the absence of a significant trend.

5. Conclusions

The study centered on the detection of the indicators of climate change existence in 24-hourly time series rainfall data collected for the Warri Township within the study period of 36 years (1982-2017). Rainfall intensity plotted against duration yielded a mild positive trend that was found statistically insignificant. The p-values obtained were more than the alpha value of 0.05 at a 5% level of significance for each downscaled duration. The computed p-value was found to vary from 0.1408 to 0.1606 and 0.1436 to 0.1606 for IMD and MCIMD time series data, respectively. Similarly, the MK statistic obtained also indicated variation from 1.403 to 1.4729 and 1.403 to 1.463 for the IMD and MCIMD time series data respectively, which were less than the critical Z-value of 1.96. The 24-hourly MMS initial rainfall data also produced a p-value of 0.9760 and slope magnitude of 0.000089 to show and confirm the positive mild trend status as the 24-hourly AMS sample data.

The slope magnitude also showed a mild increasing trend in variation from 0.0189 to 0.3713 and 0.0175 to 0.5426, with the rate of change in rainfall intensity at 24 hours duration as 0.4536 and 0.42 mm/hr.year (or, 4.536 and 4.2 mm/decade) for the IMD and the MCIMD time series data respectively. The trend change point date was found to occur in the year 2000 from the plot of the distribution-free CUSUM test, while the trend intensified by maintaining a significant and steady increase from 2010 to 2015.

Conclusively, the study detected the existence of a trend in the time series rainfall data, evidence of a changing climate and a necessary condition required for rainfall Non-stationary intensity-duration-frequency (NS-IDF) modeling. Therefore, the NS-IDF model is recommended for safe and accurate hydrologic infrastructural design to adequately combat flooding events and their menace in the study area.

Disclaimer

The products used for this research are commonly and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by the personal efforts of the authors.

Conflicts of Interest

The authors have declared that no competing interests exist.

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