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Comparative Analysis of Climatic Change Trend and Change-Point Analysis for Long-Term Daily Rainfall Annual Maximum Time Series Data in Four Gauging Stations in Niger Delta

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Abstract

The aim of this study is to establish the prevailing conditions of changing climatic trends and change point dates in four selected meteorological stations of Uyo, Benin, Port Harcourt, and Warri in the Niger Delta region of Nigeria. Using daily or 24-hourly annual maximum series (AMS) data with the Indian Meteorological Department (IMD) and the modified Chowdury Indian Meteorological Department (MCIMD) models were adopted to downscale the time series data. Mann-Kendall (MK) trend and Sen's Slope Estimator (SSE) test showed a statistically significant trend for Uyo and Benin, while Port Harcourt and Warri showed mild trends. The Sen's Slope magnitude and variation rate were 21.6, 10.8, 6.00 and 4.4 mm/decade, respectively. The trend change-point analysis showed the initial rainfall change-point dates as 2002, 2005, 1988, and 2000 for Uyo, Benin, Port Harcourt, and Warri, respectively. These prove positive changing climatic conditions for rainfall in the study area. Erosion and flood control facilities analysis and design in the Niger Delta will require the application of Non-stationary IDF modelling.

Keywords

Rainfall Time Series Data, Climate Change, Trend Analysis, Variation Rate, Change Point Dates, Non-Parametric Statistical Test

1. Introduction

The adversity contributed by anthropogenic activities and the variability of rainfall contributes to climate change and play a significant role in the economy of most countries. In Nigeria, the adverse impact on the society and economy is felt in agriculture, food production, health, energy, water resources, societal relations and human settlements [1] [2]. Without any form of adaptation, the impact of climate change on all sectors of the economy could result in a loss of between 6% - 30% in the Nigerian GDP by the year 2050 [3]. The Niger Delta region, for instance, 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].

Trends in rainfall and temperature patterns constitute two indicative variables in the study of climate change which are also functions of the vegetation, soil type, topography, land use, and climate zone lithology [5] [6]. Data gathered for trends in rainfall patterns and temperature have been applied extensively as indicators of climate change by different authors in investigating studies regarding climate change [7] [8] [9] [10].

Rainfall measurement recorded for a long term constitutes time series data with two types of characteristic behaviour. When the time series data possess a gradual pattern—that is a trend, but when the pattern has an abrupt end that is a trend change point. Long-term measurements of data for parameters, such as rainfall or temperature, are required for evaluating trends and variability as indicators of climate change.

Researchers worldwide have used trends, magnitude and variation in rainfall time series data to investigate climate change existence for different meteorological parameters in different countries [11]-[18]. In the coastal Niger Delta region of Nigeria, meteorological records indicate an increasing rainfall trend, whereas in the inland Savanah, a decreasing trend is observed [19]-[24].

The Mann-Kendall (MK), Sen Slope Estimator (SSE), and the Trend change point date non-parametric statistical tools are most often preferable for trend, magnitude and variation analysis in time series data as demonstrated in [9] [24].

The aim of the study is to conduct a comparative analysis of the non-stationarity of rainfall as an indicator of changing climate in the Niger Delta in terms of trend, variation in magnitude, and change point date on 24-hourly annual maximum series (AMS) rainfall data from the four meteorological gauge stations. The Mann-Kendall, and Theil-Sen statistical approaches were adopted in the analysis, using two open-source software packages: "python statsmodel library-pymannkendall" [25] and "trend change" [26] [27].

2. Materials and Methods

2.1. Study Area

The study area is bounded by longitude 4˚15'N - 6˚30'N and latitudes 5˚32'E - 8˚22'E located at the Southern end of the Niger Delta River in Nigeria as shown in **Figure 1**. The figure shows the location map of the study area. Four locations

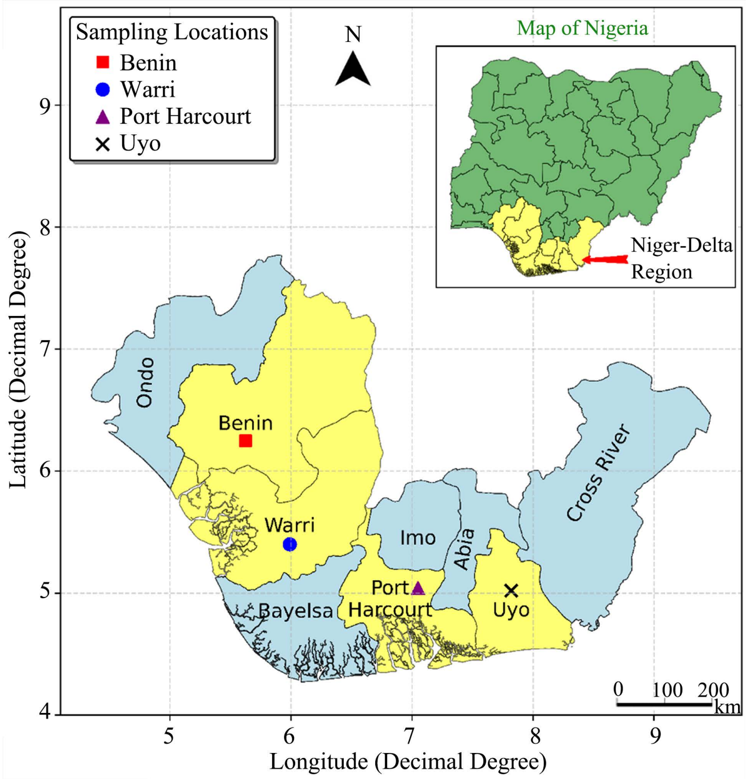


Figure 1. Map showing study stations in the Niger Delta.

were chosen for the study and are identified by GIS location, viz; Uyo: 5.0377˚N and 7.9128˚E, Benin City: 6.3350˚N and 5.6037˚E, Port Harcourt: 4.8156˚N and 7.0498˚E, and Warri: 5.5544˚N and 5.7932˚E.

The Atlantic Ocean borders the study area in the South, and the Northern boundary is close to the Savanah stretching to the Sahara desert. These two geographic features influence the rainfall pattern of the study area. The study area has a semi-hot and humid Equatorial climate with a heavy rainfall pattern, it experiences heavy seasonal rainfall from March to October and a dry period that is from November to February with occasional rainfall. The rain varies in duration and intensity and decreases from the South to the North [28].

2.2. Data Collection

Historical rainfall time series data recorded in mm with corresponding duration in minutes were collected for each of the four meteorological gauging stations from the Nigerian Meteorological Agency (NIMET). The data collected covered 30 years for Uyo, 36 years for Benin and Warri and 35 years for Port Harcourt. The historical data were initially sorted into 24-hourly Monthly Maximum Series (MMS), from which were obtained the 24-hourly Annual Maximum Series (AMS) used for the study. The daily (24-hourly) AMS data collated for each station were further desegregated into shorter durations of 0.25, 0.5, 0.75, 1, 2, 6, and 12 hours using the Indian Meteorological Department (IMD), and the Modified Chowdhury IMD (MCIMD) downscaling models as demonstrated in [29].

2.3. Statistical Test Methods

Three types of non-parametrical statistical approaches were employed in this study. The Mann-Kendall (MK) test was used to check for a monotonous trend in the time series data [30] [31] [32] [33] [34]. Next, the Sen's Slope Estimator (SSE) test was applied to determine the trend magnitude and variation of the time series data [35]. The third statistical approach was the Trend change-point test, which comprises two types of methods—the Distribution-free cumulative sum (CUSUM), and the Sequential Mann-Kendall (SQMK) tests. The cumulative sum chart is utilized in the distribution-free CUSUM test [36], whereas, for the SQMK, the sequence of each sample point is sequentially considered in terms of the pro-grade and retrograde distribution patterns [37] [38]. The test procedure is documented in [9] [24].

2.4. Software Packages Applied

Two different open-source software packages the "Statsmodel: Python statsmodel library-pymannkendall" [25] and "trendchange" [26] [27], were used. The Python statsmodel library-pymannkendall was also used to compute the nonparametric Mann–Kendall test and the autocorrelation functions for lag 1, Trend-Free Pre-Whitening to the time series data set, and the magnitude of the trend. The "trendchange" software, was used for trend change-point analysis. The packages were developed in the R language and are freely available via the Comprehensive R Archive Network (CRAN) repository and Github version control platform.

3. Results

3.1. Rainfall Data Set Used for the Statistical Analysis

Three sets of data were used for detecting the trend in the time series data, as presented in section 2.2. The data comprises the 24-hourly Monthly Maximum Series (MMS), the downscaled Indian Meteorological Method (IMD), and the Modified Chowdhury IMD (MCIMD) obtained from the 24-hourly Annual Maximum Series (AMS) collated from the MMS.

3.2. Mann-Kendall (MK) Trend Change Analysis

The computation of the autocorrelation function (ACF) at a 95% Confidence interval was carried out for the study stations. Here, the result showed no trend-free pre-whitening (TFPW) application was necessary for application to the original time-series data for three stations of Benin, Port Harcourt and Warri. The MK test was performed directly on the original time series data. However, in the case of Uyo, it was different and required TFPW before the MK test. The four gauge station results of the MK test are presented in **Table 1** for the MCIMD downscaled data. Shown in the table, are the results of the standardized MK statistic Z compared against the critical $|Z|$ value at 1.96, and the p-value at a 5% level of significance. Details of the IMD downscaled data results can be found in earlier publications [24] [39] [40] [41].

Table 1. Mann-Kendall test and Sen's slope estimates result for the four stations using the MCIMD downscaling model.

Time (hours)	Statistic	Uyo	Benin	PHC	Warri
		Values	Values	Values	Values
0.25	Z	3.2451	2.0978	1.008	1.4029
	p-value	0.0012	0.0359	0.3133	0.16063
	Q_i	2.6908	1.3893	0.7625	0.5426
	Intercept	136.1760	139.0875	142.138	169.655
0.5	Z	3.2451	2.0978	1.008	1.4030
	p-value	0.0012	0.0359	0.3133	0.16063
	Q_i	1.6022	0.8274	0.4583	0.3249
	Intercept	78.7928	80.5208	82.3083	98.665
0.75	Z	3.2451	2.0978	1.008	1.4305
	p-value	0.0012	0.0359	0.3133	0.1526
	Q_i	1.1830	0.6095	0.3375	0.2375
	Intercept	57.3189	58.6346	59.862	72.043
1	Z	3.2451	2.0844	0.9943	1.4167
	p-value	0.0012	0.0371	0.3201	0.1566
	Q_i	0.9540	0.4929	0.2708	0.1928
	Intercept	45.7703	46.825	47.896	57.626
2	Z	3.2451	2.0844	0.9943	1.4167
	p-value	0.0012	0.0371	0.3201	0.1566
	Q_i	0.5680	0.2935	0.1625	0.1152
	Intercept	26.6804	27.314	27.938	33.734
6	Z	3.2451	2.0986	1.0232	1.4586
	p-value	0.0012	0.0359	0.3062	0.1447
	Q_i	0.2497	0.1232	0.0750	0.0518
	Intercept	11.4112	11.7938	11.925	14.494
12	Z	3.2451	2.0986	0.9948	1.4597
	p-value	0.0012	0.0359	0.3198	0.1444
	Q_i	0.1487	0.0768	0.0400	0.0306
	Intercept	6.6991	6.8562	7.02	8.5145
24	Z	3.2451	2.0995	1.0238	1.4624
	p-value	0.0012	0.0359	0.3059	0.1436
	Q_i	0.0885	0.0474	0.0250	0.0175
	Intercept	3.9411	4.0197	4.175	5.0434

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

3.3. Variations in Magnitude and Trend of Evaluated Test Statistics

The Sen's Slope Estimator method was used for the evaluation of the magnitude of the trend as demonstrated in [24]. The computations are based on the indicated trend line, intercept and slope. The values of the intercept and slope obtained are also shown in **Table 1** for the various stations. **Figure 2** and **Figure 3** show the plotting of rainfall intensities (mm/hr) versus duration (years) which indicate a trend line, the intercept and slope values for a shorter duration at 0.25 hours and a 24-hour longer duration for MCIMD downscaling model for study stations.

3.4. Trend Change-Point Analysis of 24-Hourly AMS Rainfall Data

The plots of the 24-hourly AMS rainfall intensities for the four gauge stations of Uyo, Benin, Port Harcourt, and Warri were subjected to trend change point analysis. The analysis was carried out for all downscaled durations using the "trendchange" software package mentioned in section 2.4 for both the distribution-free cumulative (CUSUM) test and the Sequential Mann-Kendall (SQMK) test. The results are plotted in **Figures 4-7** for both the distribution-free CUSUM and the SQMK tests for 24-hourly AMS rainfall MCIMD downscaled data for the various stations. The trend change points for Uyo, Benin, Port Harcourt, and Warri for different downscaled durations are presented in **Table 2**. **Figures 4-7** pinpoint the date of trend change precisely.

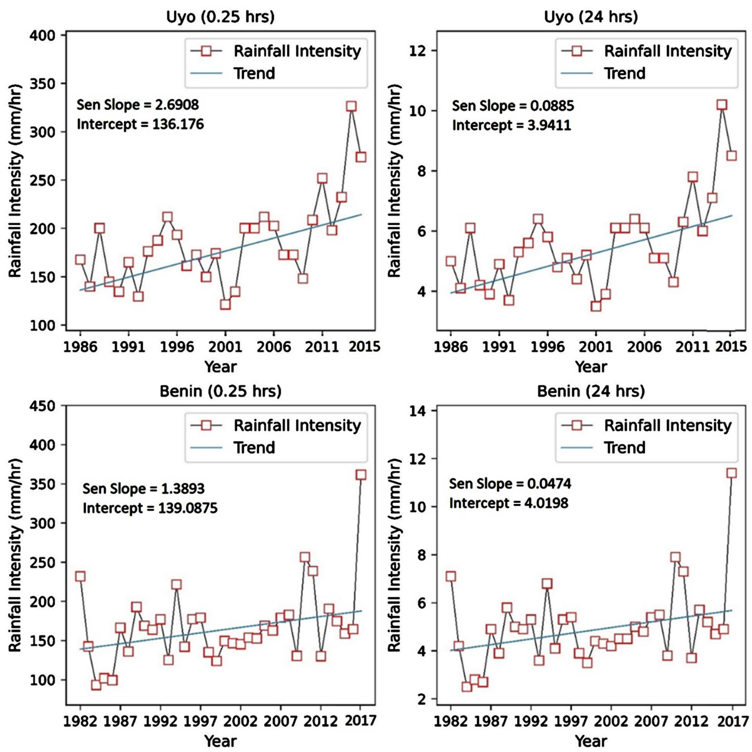


Figure 2. 24-hourly AMS rainfall trend using MCIMD model downscaled rainfall intensity for Uyo and Benin.

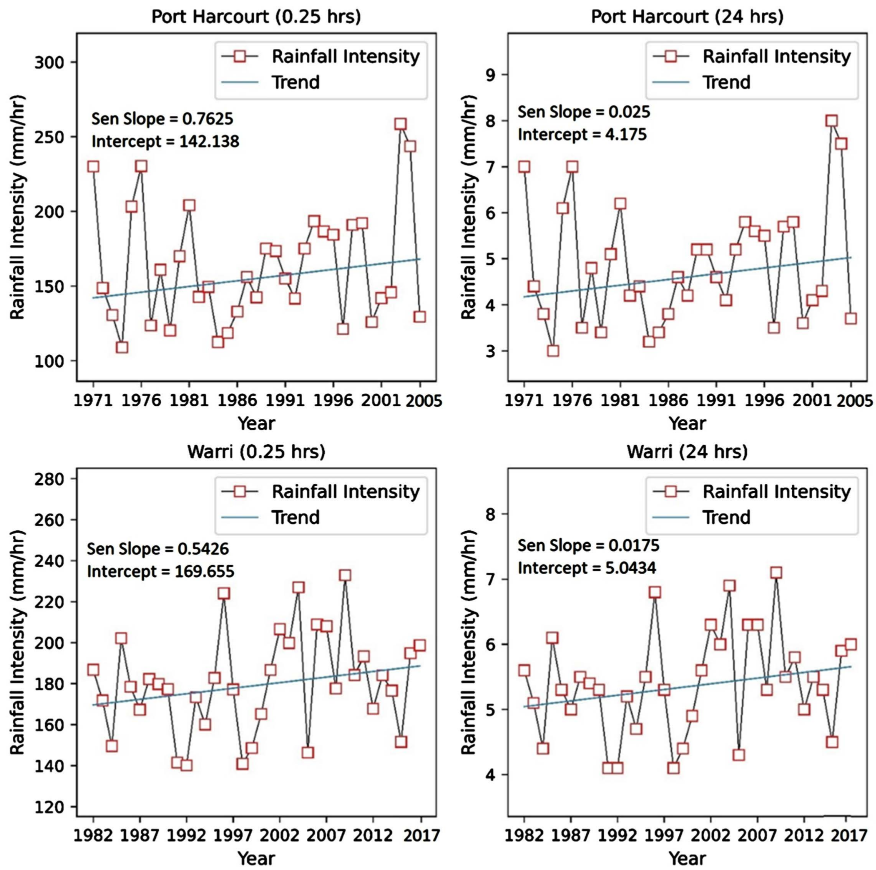


Figure 3. 24-hourly AMS rainfall trend using MCIMD model downscaled rainfall intensity for Port Harcourt and Warri.

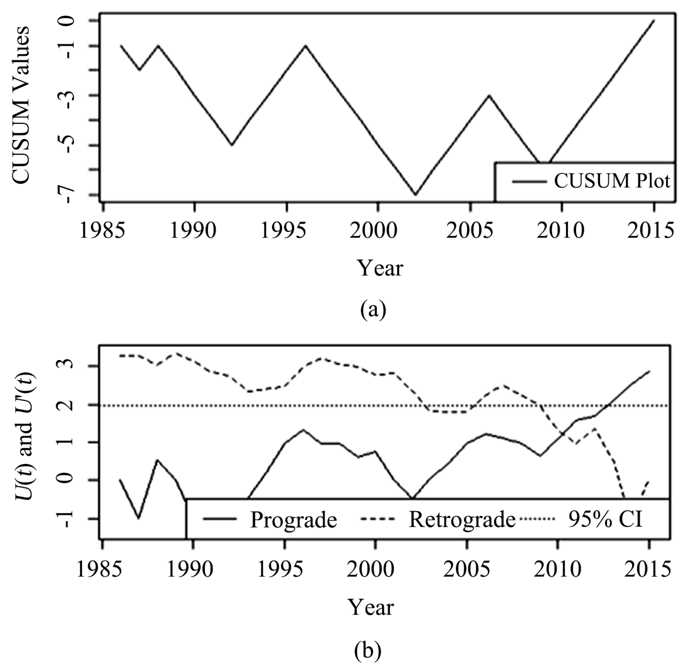
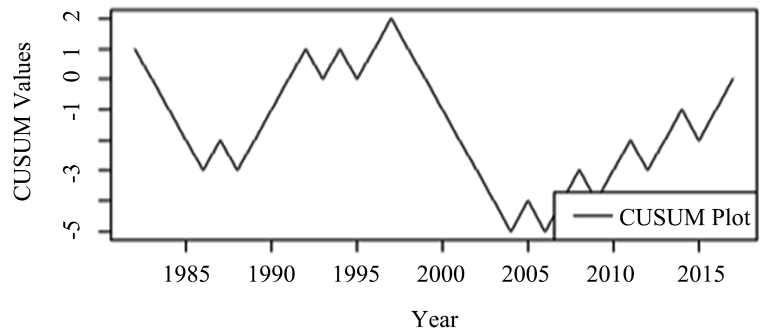
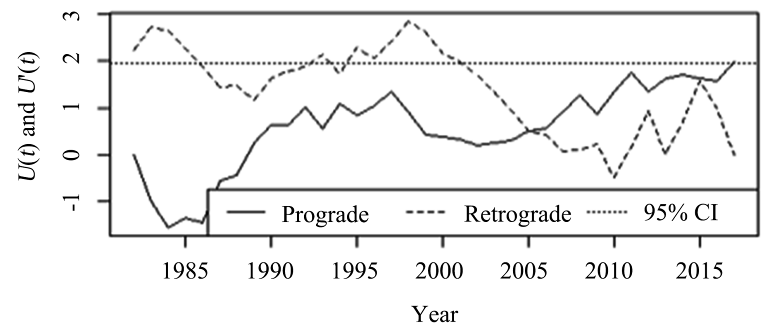


Figure 4. (a) Distribution-free CUSUM and (b) Sequential Mann-Kendall plot for 24-hourly AMS rainfall intensity for Uyo.

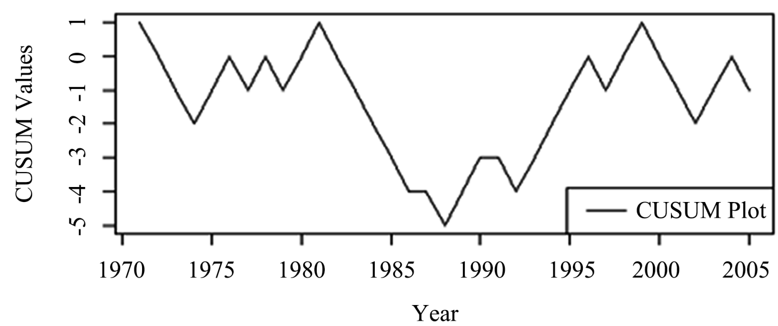


(a)

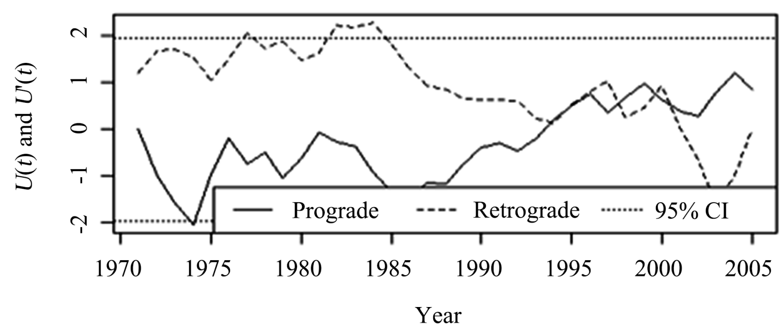


(b)

Figure 5. (a) Distribution-free CUSUM and (b) Sequential Mann-Kendall plot for 24-hourly AMS rainfall intensity for Benin.

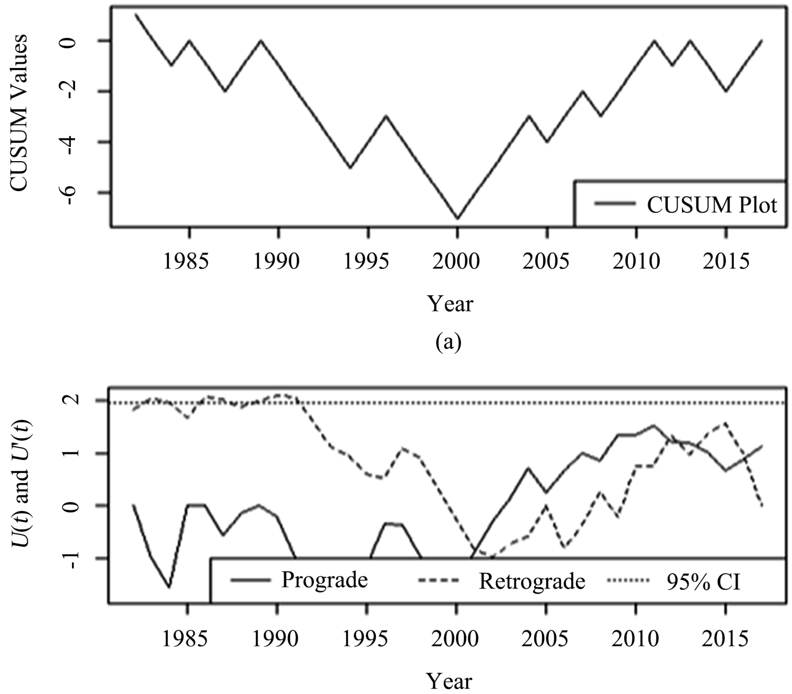


(a)



(b)

Figure 6. (a) Distribution-free CUSUM and (b) Sequential Mann-Kendall plot for 24-hourly AMS rainfall intensity for Port Harcourt.



(a)

(b)

Figure 7. (a) Distribution-free CUSUM and (b) Sequential Mann-Kendall plot for 24-hourly AMS rainfall intensity for Warri.

Table 2. Distribution free CUSUM Test values & summary of trend change point date using MCIMD data at 24 hours for the four stations.

Parameters	Uyo	Benin	Port Harcourt	Warri
Max CUMSUM value	7.00	5	5	7
Critical value at 90% CI	6.68	7.32	7.22	7.32
Critical value at 95% CI	7.45	8.16	8.05	8.16
Critical value at 99% CI	8.93		9.64	9.78
CUSUM Test Dates	2002	2004 &2006	1988	2000
SQMK Test Dates	2011	2005	1994	2002

4. Discussion

4.1. Establishing Non-Stationary Trend Pattern in the Rainfall Time Series Data

Modelling Non-stationary Intensity-Duration-Frequency (NS-IDF) models requires the establishment of rainfall trends and variation that may likely exist in time series data and is a necessary pre-condition for NS-IDF modelling.

The study focused on finding meteorological trends and variation in 24-hourly AMS data extracted from 24-hourly Monthly Maximum Series (MMS) collected from the various study stations via the use of the Mann-Kendall (MK) trend test and Sen Slope estimator (SSE) test. The results will enable an informed decision in selecting the type of intensity-duration-frequency modelling applicable for the time-series data for the study stations.

The curves of rainfall intensity against time were plotted for each shorter durations of 0.25, 0.5, 0.75, and 1 hour and those of longer durations of 2, 6, 12, and 24 hours as shown in **Figure 2** and **Figure 3** using the MCIMD model downscaling. Uniformly distributed patterns of rainfall intensities were observed for the four stations, with a few escalations of higher intensities records for Uyo in 2015, Benin in 2017, Port Harcourt in 2014, and Warri in 2011. The observed uniformity in the plotted rainfall distribution curves provides a reason for the stationarity assumption, where all statistical parameters of the sample data are considered constant with time. If trends exist to prove non-stationarity, the changing sample statistical parameters are considered, like the sample mean, shape, and location parameters, and evaluated as co-variate with time for IDF modelling. This justifies the essence of the variation and change point evaluation.

4.2. Trend Change-Point Analysis of Rainfall in the Time Series Data

The change point analysis identifies the most likely date when a significant change occurred in the time series. Analysis of trend change points was for all the 24-hourly AMS time series downscaled durations for the four stations. Results of the distribution-free cumulative sum (CUSUM) and sequential Mann-Kendall (SQMK) tests and change point dates are in **Table 2**. Plots of **Figures 4-7** provide distribution-free CUSUM and SQMK test results for the four stations. Interpreting the results relative to Uyo's gauging station, the free CUSUM plot date for the change point of rainfall trend took place in 2002 in **Figure 4(a)**. The maximum CUSUM value is 7.00, less than the 7.45 critical value at a confidence interval (CI) of 95% (see **Table 2**). Also, in **Figure 4(b)**, an increasing trend was observed in 2011 for the SQMK test, indicating another significant change point date for the station with the trend intensifying.

For Benin, the distribution-free CUSUM plot in **Figure 5(a)** showed two change point dates in 2004 and 2006 at the maximum CUSUM value of 5.00 less than the critical value of 8.16 at 95% CI presented in **Table 2**. Contrastingly, the SQMK plot in **Figure 5(b)** produced a definite intersection change point between the prograde and retrograde in 2005 at 95% CI as another date to serve as the most appropriate for the station. The positive trend continued its intensification through the year 2015.

For Port Harcourt, the SQMK plot in **Figure 6(b)** showed the time series had intersections at several points, most of which were not significant but in 1994. Hence we adopt the change point date given by the plot of the distribution-free CUSUM test in the year 1988 in **Figure 6(a)**. The value emerged at the maximum CUSUM of 5, less than the critical value of 8.05 at 95% CI presented in **Table 2**. However, 1994 is another year of the commencement of further intensification of a positive trend increase as provided by the SQMK test result.

The fourth station Warri, had the year 2000 as the date of a trend change from the distribution-free CUSUM plot shown in **Figure 7(a)**. The value is obtained from the maximum CUSUM value of 7, less than the critical value of 8.16 at 95% C.I. presented in **Table 2**. The trend maintained a significant and steady positive increase from 2010 to 2015. In contrast, the result of the SQMK plot in **Figure 7(b)** pointed at 2002 as the change point date being the most significant intersection observed from the test for the station. The trend further intensified from that date.

4.3. Autocorrelation and TFPW of the Rainfall Time Series Data

Autocorrelation analysis at a 95% Confidence interval for the four study stations, was performed on the data to confirm if there was a serial correlation in the time series data. The Correlogram plotted showed that the autocorrelation function (ACF) at lag 1 was statistically significant for all downscaled rainfall durations for Uyo. For instance, for Uyo to eliminate the Type-1 error observed, the rainfall intensity time-series data were subjected to Trend Free Pre-Whitening (TFPW) before the Mann-Kendall test to detect if there was any autocorrelation as documented in [24]. Thus, TFPW was carried out on each of the original time-series data before the MK test.

However, Benin, Port Harcourt, and Warri time-series data had ACF values at a 95% Confidence interval that were statistically insignificant. The results did not require any trend-free pre-whitening (TFPW) because the time series data had no significant serial autocorrelation. Thus, the MK test was applied directly to the time series data for the three stations.

4.4. Trend and Slope Variations Pattern in the Rainfall Time Series Data

The Mann-Kendall and Sen's Slope test results are presented for the four gauge stations in **Table 1**. The indices measured by the MK test for the trend are the p-value at the alpha value of 0.05 (5% level of significance) and the standardized MK statistic value compared to the critical Z-value at 1.96. Examining the various results of the MK and Sen's Slope test presented in **Table 1**, we have the following observations for each station.

The result for Uyo shows that the computed p-value varied from 0.0012 to 0.0015 for the IMD and MCIMD data series and was lower than the alpha value of 0.05 at a 5% significance level. The standardized MK statistic value varied from 3.1701 to 3.2451 for both the IMD and MCIMD time series and was also higher than the critical Z-value of 1.96. The result indicates a trend exists in the time series data. Also, the Sen's Slope value for Uyo varied from 0.0889 to 1.8562 and 0.0885 to 2.6908 magnitude for IMD and MCIMD data series, respectively, at values increasing from 24 hours to 0.25 hours. The intercept also increased from 24 hours to 0.25 hours in value for both time series.

For Benin, as indicated in **Table 1**, the computed p-value varied from 0.0312 to 0.0359 for both IMD and MCIMD time series data. The p-value was less than the alpha value of 0.05 at a 5% level of significance. The MK statistic varied from 2.0710 to 2.0995 for both IMD and MCIMD data series and were all greater than the critical Z-value of 1.96. The verdict is that a trend does exist in the time series data. Sen's Slope test also showed that the magnitude of the slope varied from 0.0420 to 0.9574 and 0.0470 to 1.3893 for IMD and MCIMD time series data, respectively. The intercept varied from 3.8647 to 79.3963 and 4.0197 to 139.0875 for the IMD and MCIMD data series, respectively. The data series for Benin indicates the same trend pattern and variation in the magnitudes of the slope and the intercept as those of Uyo station. That is an increase in value from a higher duration of 24 hours to a lower 0.25 hours duration. The result obtained for Benin differed from the opinion of Ologhadien's [42] report of insignificant trends in observed data.

Also, Port Harcourt had a p-value varying from 0.3057 to 0.3201 for both IMD and MCIMD time series data and was greater—than the alpha value of 0.05 at a 5% significance level as presented in **Table 1**. Similarly, the MK test statistic varied from 0.9943 to 1.0379 for both IMD and MCIMD time series data which were also less than the critical Z-value of 1.96. The result shows that there was no statistically significant trend in the time series data. Sen's Slope test result showed that the slope magnitude was very minimal and varied from 0.0249 to 0.5250 and 0.0250 to 0.7625 for the IMD and MCIMD data series, respectively. The intercept values also varied from 3.875 to 81.475 and 4.175 to 142.138 for the IMD and MCIMD time series data, respectively. It was observed that the slope magnitude was minimal and exhibited the same characteristics in variation as those of Uyo and Benin. The intercept also had similar behavior increasing in value from higher duration to lower duration.

In the case of Warri, the MK test and Sen's Slope test from **Table 1** are very similar to that of Port Harcourt. The p-value varied from 0.1408 to 0.16063 for IMD and MCIMD data series and was greater than the 0.05 level of significance of alpha. The MK test statistic varies from 1.4029 to 1.4729 for both IMD and MCIMD data series. The critical Z-value of 1.96 was also more than the calculated Z-values. We can infer that the trend is not statistically significant. The Sen's Slope test result also showed minimal values varying from 0.0189 to 0.3713 and 0.0175 to 0.5426 for the IMD and MCIMD data series, respectively. The intercept values with variations from 4.769 to 100.553, and 5.0434 to 169.655, for both IMD and MCIMD time series data, were observed, respectively. Like the case of Port Harcourt station, the Sen's Slope magnitude and the intercept increased in size from a higher duration of 24 hours to a lower duration of 0.25 hours. Rainfall trend results were similar in characteristics to those obtained in similar previous studies published for the Niger Delta area [19] [20] [21]. The p-values and slope magnitudes obtained for the 24-hourly monthly maximum series (MMS) were also in agreement; with those of the 24-hourly AMS data for the various stations presented in **Figure 2** and **Figure 3**. The implication is that the 24-hourly AMS data could adequately serve as representative time series data for trend establishment for NS-IDF for the predictions of rainfall intensity for any catchment area. Non-stationary IDF modelling, therefore, is appropriate in developing IDF curves for all rainfall durations for the Niger Delta region.

The Sen's Slope results also showed an interesting relationship. It proved that the magnitude of the trend tends to decrease as the duration of rainfall increases. This implies that shorter durations tend to exhibit a higher value than longer durations. The Sen's Slope result shown in **Table 1** indicates that the Non-stationary IDF modelling is the most appropriate IDF model for application for shorter durations. Consequently, having met the condition for non-sta-tionary modelling, the IDF curves using the stationary concept will produce unreliable and a shortfall in rainfall intensity predictions for shorter and longer durations [43].

4.5. Variations in Magnitude and Trend of Evaluated Test Statistic

The MK trend and Sen Slope analysis results presented in **Table 1** proved that both tests exhibited a high level of consistency and had statistically significant positive trend increase in the values of evaluated parameters for 24 hours higher duration to 0.25 hours lower durations. The observed performance in the consistency of both tests agrees with some earlier publications [44] [45] [46].

The slope magnitude showed a positive trend variation statistically significant for Uyo and Benin. The SSE is used to quantify the rate of change of rainfall intensity magnitude. For instance, the slope, Q, and the rate of variation observed for the four stations from **Table 1** for Uyo; the slope magnitude, Q, is 0.0885 mm/hr·year for the MCIMD data series at 24 hours duration. This value translates to 2.16 mm/hr·year or 21.6 mm/decade as the variation rate. Also, for Benin, the Q is given as 0.0474 mm/hr·year for the MCIMD data series and translates to a variation rate of 1.2 mm/year or 12 mm/decade. For Port Harcourt, the Q value obtained is 0.0250 mm/hr·year for the MCIMD data series, translating to 0.6 mm/year or 6.00 mm/decade variation rate. For Warri, the Q value obtained is also 0.0175 mm/hr·year for the MCIMD data series. This variation rate translates to 0.43 mm/hr·year or 4.3 mm/decade. The trend variation rate in extreme precipitation could be triggered by shifts in the global wind patterns, or due to changes in the Ocean surface temperature and the effect of human activity on the surface vegetation. Human activity generates greenhouse gas emissions and resultant land use changes. These factors could induce extreme precipitation events that could cause landslides and flooding.

These results are in accord with the publications of earlier authors such as Ayensu [16], who got 13 mm/decade for coastal stations in Ghana, and Nwaogazie and Ologhadien [21], who had 55.2 mm/decade for coastal gauging stations in the Niger Delta and most recently [24] [39] [40] [41] in Nigeria. However, the results did not agree with the opinion of Okafor *et al.* [47], whose work was on the Nigerian hinterland. They found a decreasing or negative trend in the rate of the variability of rainfall intensities and MK test statistics. The study outcome confirms the assertion of climatic change in trends and variability of rainfall increases in the Niger Delta region of Nigeria [20] [21] [22] [23].

5. Conclusions

The study showed the merit of applying the IMD and the MCIMD downscaling model in rainfall data as an indicator in modelling a changing climate. It also revealed the magnitude of the trend and variation rate of rainfall induced by climate change with the initial dates of change of rainfall pattern in the four study locations in the Niger Delta region. In effect, non-stationarity was established to exist in rainfall trends and variation in the 24-hourly AMS data for the four study stations confirming the presence of trend in the Niger Delta region.

The collected historical rainfall data for Uyo, Benin, Port Harcourt, and Warri sorted out into 24-hourly annual maximum series (AMS) served as a good representative sample for trend establishment for IDF modelling.

Statistically significant positive trends were established for Uyo and Benin, while Port Harcourt and Warri were mildly positive for the downscaled durations.

The magnitude of the trend and variation rate contributed by climate change at 24-hour duration was 21.6 mm/decade, 12 mm/decade, 6.0 mm/decade, and 4.3 mm/decade, with the initial rainfall change point dates as 2002, 2005, 1988, and 2000 for Uyo, Benin, Port-Harcourt, and Warri, respectively.

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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