Assessment of Climate Change Induced Trend, Magnitude, and Change Point Date in 24-Hourly AMS Rainfall Data for Port Harcourt Metropolis in Nigeria

ABSTRACT

The study determined the resultant effect of changing climate on rainfall 24-hourly annual maximum series (AMS) downscaled data which were found to be statistically insignificant in trend for the Port Harcourt metropolis. The rainfall time series data for this study were collected for 35 years (1971-2005) from the Nigeria Meteorological Agency (NIMET). The 24-hourly (AMS) rainfall data extracted were further downscaled into shorter duration rainfall using Indian Meteorological Department (IMD) method. The slope magnitude showed a mild increasing trend which varied from 0.0249 to 0.5250, and 0.0250 to 0.7625 with the rate of change at 24 hours duration evaluated as 0.0249 and 0.0250 mm/hr/year for the IMD and the Modified Chowdhury Indian Meteorological Department MCIMD time series data, respectively. Translating to a variable rate of 0.6 mm/year or 6.00 mm/decade. Relatively, the trend test for the 24-hourly monthly maximum series (MMS), also showed a p-value of 0.2289 which is greater than the alpha value at a 5% significant level with a slope value of 0.0006 to confirm the positive mild trend status of the 24-hourly AMS sample data. The change point date was given by the plot of the distribution-free cumulative (CUSUM) test to occur in 1988, while the sequential MK (SQMK) test gave another year of change point date as 1994 to further intensify the positive trend change in Port Harcourt metropolis. Therefore, proving in this study the existence of mild and positive changing climatic conditions.

Keywords

Rainfall data, annual time series, trend, trend variation, trend change point, statistical test.

1. INTRODUCTION

Anthropogenic and natural weather-induced causes have led to an increase in global warming and extra-value precipitation extremes globally and within the Niger Delta for over a century. The survival of critical infrastructures designed based on the stationary assumption of time-variant parameters is being called to question with the resultant severe climatic changes.

Rainfall serves as an indicator of climate change which could have increasing or decreasing characteristics. The rainfall measurements constitute a series of data that can be analyzed as a time series. Time-series analysis is an applied tool for the detection and quantitative description of trend, its variation in quantity and change point which is characteristic of a given set of observations in rainfall time series data. The generative process of the time series possesses both gradual and abrupt changes that are described as either a trend or a trend change point. Therefore, trend analysis deal with evaluating gradual future events from past measured data, while change point detection deal with determining the unexpected, structural, changes in the time series data properties like mean or variance (Mann, 1945; Zhang et al., 2006). We have different approaches in the literature used in computing both the trend variation rate and change point dates. A non-parametric test is applied to the data which should be independent, and tolerant of outliers. The non-parametric test for trend analysis in time series most commonly applied is the Mann-Kendall test (Mann, 1945; Kendall, 1975, Lehmann, 1975; Longobardi and Villani, 2010; Yanming et al., 2011) and the Sen Slope estimator is also used for evaluating the trend magnitude and the intercept (Sen, 1968).

Available techniques in the literature for the analysis of trend change points include the Wild binary segmentation, the Bayesian analysis of change points, the E-Agglomerative algorithm, and Iterative robust detection methods (Baranowski & Frylewicz, 2014; Fryzlewicz, 2013; Erdman & Emerson, 2007). However, for application in this study are the Distribution-free cumulative sum (CUSUM) and the Sequential Mann-Kendall (SQMN) tests (McGilchrist & Woodyer, 1975; Taubenheim, 1989; Sneyers, 1990).

Therefore, this study shall examine the effect of changing climate in the Port Harcourt metropolis, Nigeria using measured time series rainfall data recorded for 35 years between 1971-

2005) regarding the trend, the variation and magnitude including the trend change point dates. The 'python statsmodel library-pymannkendall' (Seabold and Perktold, 2010) and 'trendchange' (R Core Team, 2021; Patakamuri, 2022) were the two different open-source software packages adopted for the various analyses.

2. METHODOLOGY

2.1 Study Area

Port Harcourt metropolis is located between Latitude 4°45'N and Latitude 4°55'N, and Longitude 6°55'E and Longitude 7°05'E in Rivers State. This spans from Port Harcourt City through Obio/Akpor Local Government Area to part of Ikwerre and Etche Local Government Areas. Omagwa International Airport where the meteorological station of the Nigerian Meteorological Agency (NIMET) is located is in the Ikwerre Local Government area. Therefore, the four Local Government Areas situated in Rivers State constitute the affected catchment area (see Figure 1). Located at about 25 km from the Atlantic Ocean, It lies at an average altitude of about 12 m above mean sea level. Temperatures over the Port Harcourt metropolis are constantly high with a mean maximum of about 34°C and a mean minimum of about 21°C. The highest temperatures are recorded between the months of April and October. The area experiences heavy seasonal rainfall from March to October and a dry period that lasts from November to February with occasional rainfall (Gobo, 1988). The rains vary in duration and intensity and also decrease from the South to the North.

2.2 Data Collection

The rainfall time series data for this study were collected for 35 years (1971-2005) from the Nigeria Meteorological Agency (NIMET) meteorological gauge station. The rainfall amount collected was recorded in mm against corresponding durations recorded in minutes. The data were further sorted out by extraction of the maximum daily (24-hourly) rainfall amount for each month with the maximum for each year extracted to obtain the annual maximum series (AMS) data for the 35 years interval.

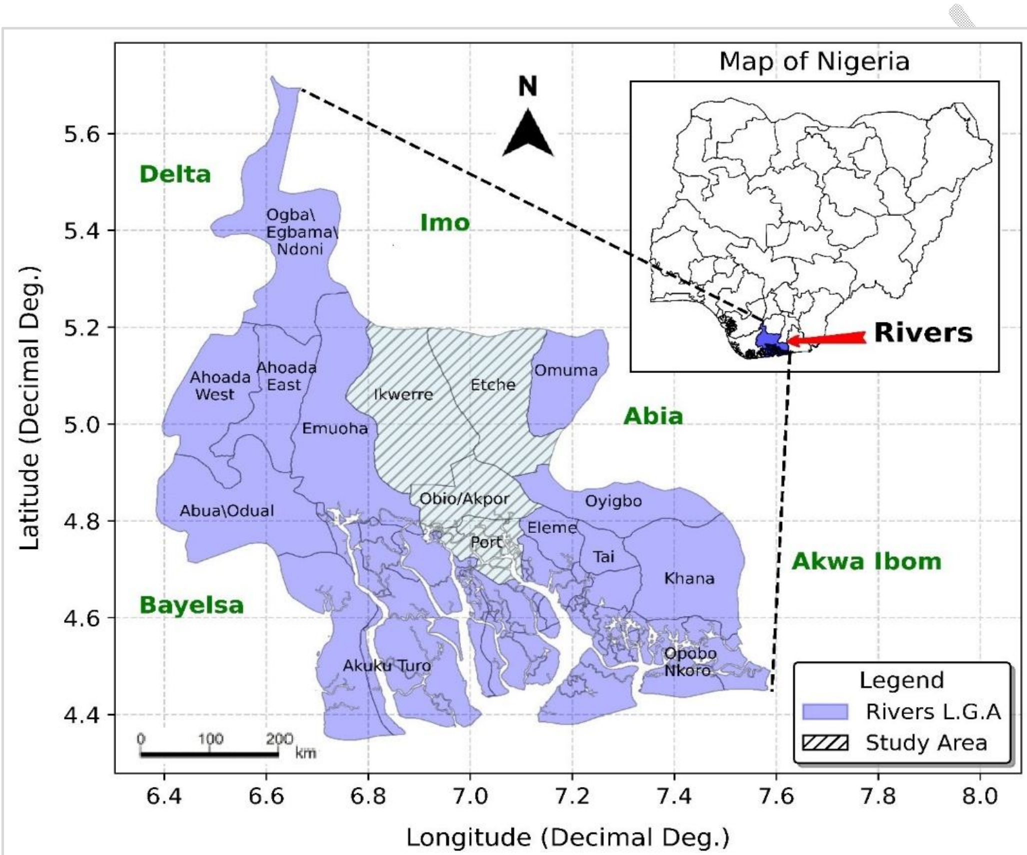

Figure 1. Map of Rivers State showing Port Harcourt metropolis

2.3 Downscaling 24 Hours into Shorter Durations Time Series Data

The 24-hourly annual maximum series (AMS) rainfall data extracted were further downscaled into shorter duration rainfall as documented in detail in Sam, et al. (2021) for the study, applying the proposed Indian Meteorological Department (IMD, Ramaseshan, 1996) and the Modified Chowdhury Indian Meteorological Department (MCIMD, Rashid et al., 2012).

2.4 Mann-Kendall Trend & Sen's Slope Test

Mann Kendall test (Mann 1945, Kendall 1975, Gilbert 1987) is a rank-based statistical test that helps to check if there is a monotonous increasing or decreasing trend existing in the time series data. Mann Kendall (MK) test is a non-parametric test in which the distribution of the data must not be normally distributed without serial correlation (autocorrelation). Trend Free Pre-Whitening (TFPW) was adopted in this study in order to remove serial correlation where it exists in the rainfall intensity as outlined in Sam, et al. (2022). But where the ACF is not significant MK test can be applied directly to the original data set. The python statsmodel library- pymannkendall (Seabold and Perktold, 2010) was used to compute both the ACF for lag 1 to ascertain if the data require TFPW. The magnitude of the trend and intercept was computed using the Sen Slope estimator. Microsoft xlstat 2016 and python pymannkendall library were used in the analysis of the Sen Slope and intercept.

2.5 Trend Change-Point Test

To carry out the trend change-point analysis, two non-parametric testing methods, the Distribution-free cumulative sum (CUSUM) test (McGilchrist and Woodyor, 1975) and the Sequential Mann-Kendall test (Taubenheim, 1989; Sneyers, 1990) was used. The free CUSUM test uses a cumulative sum chart, while the sequential Mann-Kendall (SQMK) test utilizes each sample point sequence sequentially treated in both prograde and retrograde procedures. Sam, et al. (2022a) also documented in detail the application of both non-parametric approaches. The software package used for the change-point analysis is "trendchange" which is an open-source library freely available via the CRAN repository and version 1.2 (R Core Team, 2021; Patakamuri, 2022).

3. Results and Discussion

3.1 Results

3.1.1 Rainfall data set from 24-hourly annual maximum time series

Three different sets of data were used for detecting the trend in the time series data. The first set of data were rainfall measurements obtained from downscaling 24-hourly rainfall data (see Table 1) using the IMD formula in models, while the second set of data were obtained using the MCIMD model. The third data set is the initial sorted 24-hourly monthly maximum series (MMS) for 35 years (1971-2005).

3.1.2 Mann-Kendall (MK) Trend Change Analysis

The MK test execution initially commenced with the computation of the autocorrelation function (ACF) which result indicated that the ACF was not significant at a 95% Confidence interval as in Figure 2. Thus, 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 2 with the value computed for IMD model data ranging from 0.9943 to 1.0242 and those for the MCIMD model ranging from 0.9943 to 1.0238. 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 0.2993 to 0.3201 for the durations, while the MCIMD model p-value also varied from 0.3059 to 0.3201. 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.

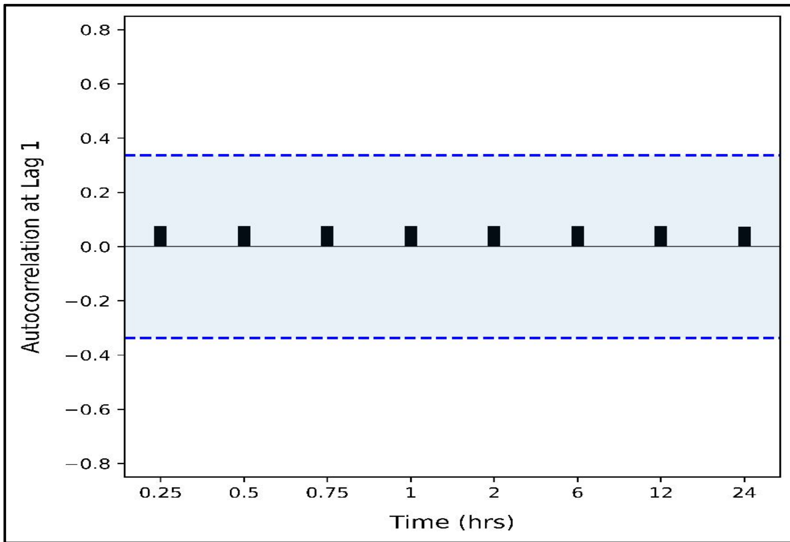

Figure 2: *Correlogram of ACF at lag-1 for various 24-hourly AMS downscaled durations using IMD model for Port Harcourt metropolis.*

Table 1: Downscaled rainfall intensity using IMD model for Port Harcourt metropolis

Year No	*0.25hr*	*0.5hr*	*0.75hr*	*1hr*	*2hr*	*6hr*	*12hr*	*24hr*
1	142.2$^{\pm}$	89.6	68.4	56.4	35.6	17.1	10.8	6.8
2	86.0	54.2	41.4	34.1	21.5	10.3	6.5	4.1
3	73.6	46.4	35.4	29.2	18.4	8.9	5.6	3.5
4	58.6	36.9	28.2	23.3	14.7	7.0	4.4	2.8
5	123.6	77.9	59.4	49.1	30.9	14.9	9.4	5.9
6	142.3	89.6	68.4	56.5	35.6	17.1	10.8	6.8
S7	68.8	43.3	33.1	27.3	17.2	8.3	5.2	3.3
8	94.5	59.5	45.4	37.5	23.6	11.4	7.2	4.5
9	66.5	41.9	32.0	26.4	16.6	8.0	5.0	3.2
10	100.7	63.5	48.4	40.0	25.2	12.1	7.6	4.8
11	124.3	78.3	59.8	49.3	31.1	14.9	9.4	5.9
12	81.9	51.6	39.4	32.5	20.5	9.8	6.2	3.9
13	86.6	54.5	41.6	34.4	21.6	10.4	6.6	4.1
14	61.2	38.5	29.4	24.3	15.3	7.3	4.6	2.9
15	65.3	41.2	31.4	25.9	16.3	7.9	4.9	3.1
16	75.2	47.4	36.2	29.8	18.8	9.0	5.7	3.6
17	91.1	57.4	43.8	36.2	22.8	11.0	6.9	4.3
18	81.8	51.5	39.3	32.4	20.4	9.8	6.2	3.9
19	104.3	65.7	50.1	41.4	26.1	12.5	7.9	5.0
20	103.2	65.0	49.6	40.9	25.8	12.4	7.8	4.9
21	90.4	57.0	43.5	35.9	22.6	10.9	6.8	4.3
22	81.2	51.1	39.0	32.2	20.3	9.8	6.1	3.9
23	104.3	65.7	50.1	41.4	26.1	12.5	7.9	5.0
24	116.9	73.6	56.2	46.4	29.2	14.1	8.9	5.6

25	112.2	70.7	53.9	44.5	28.0	13.5	8.5	5.4
26	110.7	69.7	53.2	43.9	27.7	13.3	8.4	5.3
27	67.1	42.3	32.3	26.6	16.8	8.1	5.1	3.2
28	115.2	72.6	55.4	45.7	28.8	13.8	8.7	5.5
29	116.1	73.1	55.8	46.1	29.0	14.0	8.8	5.5
30	70.3	44.3	33.8	27.9	17.6	8.5	5.3	3.4
31	81.4	51.3	39.1	32.3	20.4	9.8	6.2	3.9
32	84.1	53.0	40.4	33.4	21.0	10.1	6.4	4.0
33	161.9	102.0	77.8	64.2	40.5	19.5	12.3	7.7
34	151.5	95.4	72.8	60.1	37.9	18.2	11.5	7.2
35	72.8	45.8	35.0	28.9	18.2	8.7	5.5	3.5

±Dis-segregated Rainfall Intensities (mm/hr).

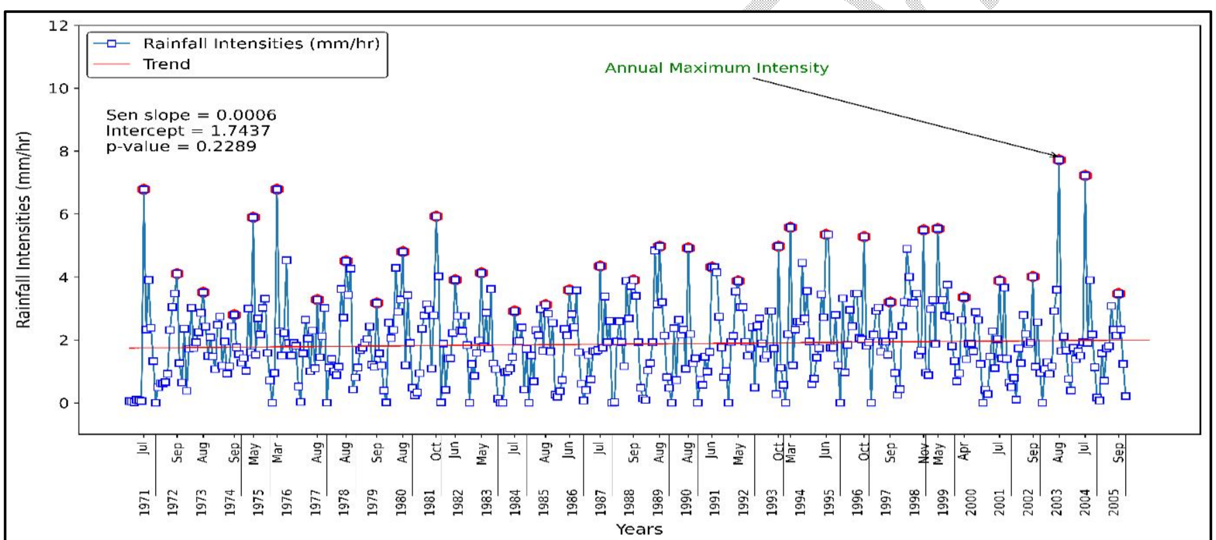

Figure 3: *24-hourly MMS rainfall intensities trend pattern for Port Harcourt metropolis (1971- 2005).*

3.1.3 Sen's Slope Trend Magnitude

The magnitude of the trend was evaluated using Sen's slope estimator, and presented in Table 2. The result of the slope shows decreasing positive values of 0.5250 (at 0.25 hour) to 0.0249 (at 24 hours) and 0.7625 (at 0.25 hour) to 0.0250 (at 24 hours) for IMD and MCIMD models, respectively. The intercept for the IMD method also decreased from 81.475 to 3.875 at 0.25 and 24 hours, respectively. The MCIMD data produced higher intercept values which similarly decreased from 142.138 to 4.175 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 0.0006 mm/hr/year and intercept of 1.7437. The p-value of 0.2289 obtained is far greater than the alpha value at 5% level significance.

3.1.4 Time Series Data Trends Change-Point Analysis

The trend graph plots of the 24-hourly AMS rainfall intensities for both long (24 hours) and short (0.25 hours) durations are presented in Figures 4 and 5, respectively.

Table 2: Result of Mann-Kendall (MK) Test and Sen Slope Estimates (SSE)

Time (hrs)	Statistic	IMD	MCIMD
		Value	Value
0.25	Z	1.008	1.008
	p-value	0.3133	0.3133
	Q_i	0.5250	0.7625
	Intercept	81.475	142.138
0.5	Z	0.9943	1.008
	p-value	0.3201	0.3133
	Q_i	0.3333	0.4583
	Intercept	51.333	82.3083
0.75	Z	0.9943	1.008
	p-value	0.3201	0.3133
	Q_i	0.25	0.3375
	Intercept	39.25	59.862
1	Z	1.008	0.9943
	p-value	0.3133	0.3201
	Q_i	0.2083	0.2708
	Intercept	32.36	47.896
2	Z	1.009	0.9943
	p-value	0.3132	0.3201
	Q_i	0.1333	0.1625
	Intercept	20.33	27.938
6	Z	1.0379	1.0232
	p-value	0.2993	0.3062
	Q_i	0.0625	0.0750
	Intercept	9.8375	11.925

12	Z	1.0232	0.9948
	p-value	0.3062	0.3198
	Q_i	0.040	0.0400
	Intercept	6.120	7.02
24	Z	1.0242	1.0238
	p-value	0.3057	0.3059
	Q_i	0.0249	0.0250
	Intercept	3.875	4.175

Level of significant $\propto = 0.05$, where Z = standardized Mann Kendall statistic, Q_i = Sen Slope (mm/hr/year), Critical Z-value = 1.96.

Table 3: Distribution free CUSUM result for Port Harcourt metropolis

Parameters	Values
Maximum CUMSUM value	5
Critical value at 90% CI	7.22
Critical value at 95% CI	8.05
Critical value at 99% CI	9.64
Date of Change	1988

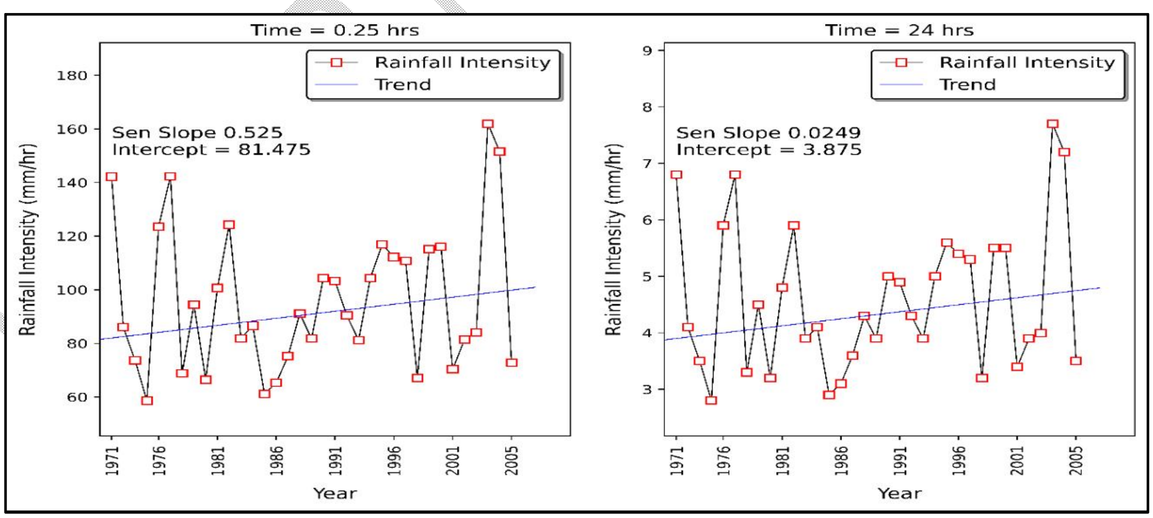

Figure 4: *24-hourly AMS rainfall intensities trend pattern for IMD model downscaled durations for Port Harcourt metropolis (1971-2005).*

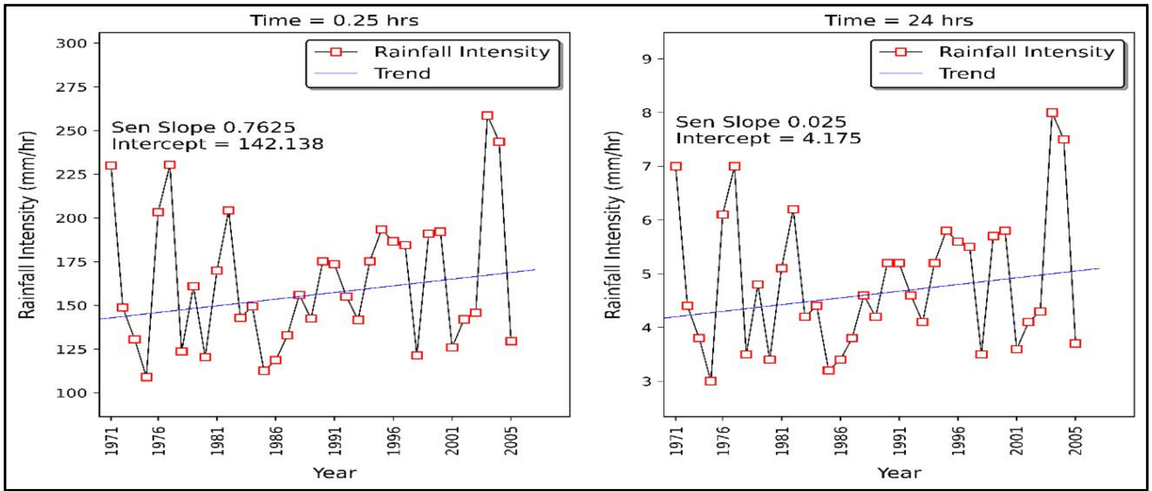

Figure 5: *24-hourly AMS rainfall intensities trend pattern for MCIMD model downscaled durations for Port Harcourt metropolis (1971-2005).*

Table 4: Trend change point for different downscaled duration rainfall intensities for various stations Port Harcourt metropolis

Rainfall Durations (mins)	CUSUM	SQMK
15	1988	1994
30	1988	1994
45	1988	1994
60	1988	1994
120	1988	1994
360	1988	1994
720	1988	1994
1440	1988	1994

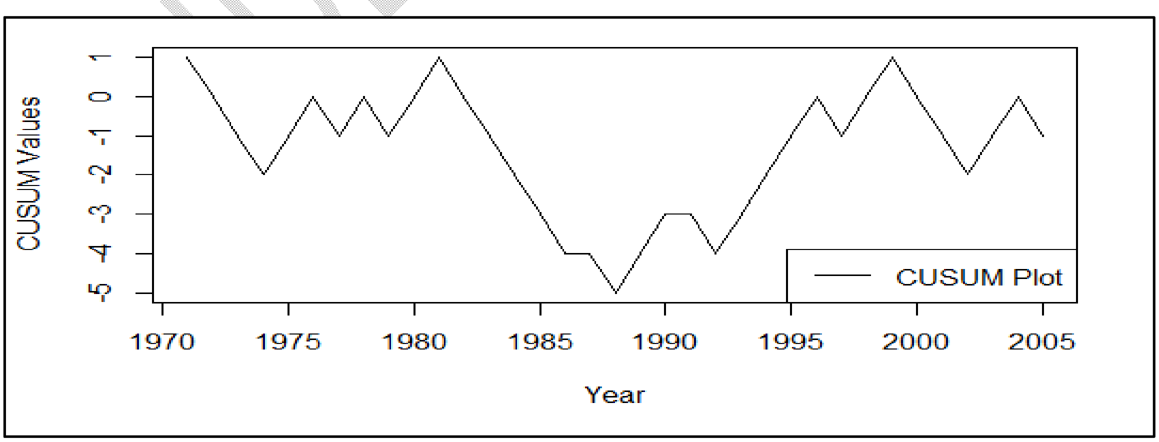

Figure 6: Distribution-free CUSUM plot for 24-hourly AMS rainfall intensity for Port Harcourt metropolis.

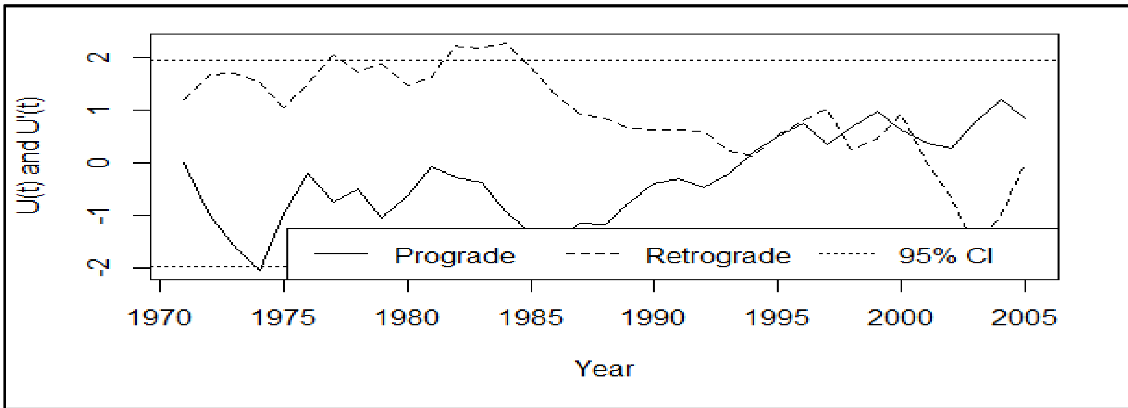

Figure 7: Sequential Mann-Kendall plot for 24-hourly AMS rainfall intensity for Port Harcourt metropolis

Also, analysis was carried out for the trend change-point for all downscaled durations with the results of the distribution-free CUSUM and the Sequential Mann-Kendall tests presented in Tables 3 & 4. Figures 6 and 7 show the distribution-free CUSUM plot and Sequential Mann-Kendall plot for 24-hourly AMS rainfall intensities, respectively, obtained via the "trendchange" software package (R Core Team, 2021; Patakamuri, 2022).

3.2 Discussion of Results

3.2.1 Trend Analysis of 24-Hourly AMS Rainfall

This investigation established the existence of hydrological trends and variation in 24-hourly AMS extracted data from 24-hourly Monthly Maximum Series (MMS) historical precipitation (rainfall) data (HPD). Three sets of meteorological time-series data were applied, the downscaled data using the Indian meteorological department (IMD), and the modified Chawdury IMD (MCIMD) downscaling model as shown in Table 1. The third is the initially extracted MMS-measured data.

3.2.2 Trend Change-Point Analysis of 24-Hourly AMS Rainfall

The change point analysis identified the probable date with a significant change occurring 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 4. Figures 6 and 7 have the distribution-free CUSUM and SQMK plots, respectively, for different durations of rainfall intensity. The distribution-free CUSUM plot showed a change date in 1988 at the maximum CUMSUM value of 5.00 less than the critical value of 8.05 obtained at 95% CI showed in Table 3. Coincidentally, the SQMK plot presented in Figure 7 produced a definite intersection between the pro-grade and retrograde in 1994 at 95% CI for the Port Harcourt metropolis, notwithstanding showing the time series had intersections at several places which should have meant the absence of a significant trend. Hence we adopt the change point date given by the plot of the distribution-free CUSUM test in the year 1988. However, 1994 can be viewed as another year of further intensification of a positive trend change as provided by the SQMK test result.

3.2.3 Autocorrelation and TFPW of 24-Hourly AMS Rainfall

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.

3.2.4 Trend and Variations in MK Test and Sen Slope Estimator Statistics

The Mann-Kendall test results are presented in Table 2. The statistic measured by the MK test for the trend is the p-value at a 5% level of significance and the standardized MK statistic is 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 0.2993 to 0.3201, and 0.3059 to 0.3201 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 0.9943 to 1.0242 for both IMD and MCIMD data series and was all less than the critical Z-value of 1.96. The verdict is that no significant trend exists in the time series data.

Considering the Sen's Slope test, it also showed that the magnitude of the slope varied from 0.0249 to 0.5250 and 0.0250 to 0.7625 for IMD and MCIMD time series data, respectively. The intercept varied from 3.875 to 81.475 and 4.175 to 142.138 for the IMD and MCIMD data series, respectively. The Port Harcourt metropolis 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 Uyo town. The Sen's Slope results were also in tandem 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 (Sam et al., 2022).

3.2.5 Variations in Magnitude and Trend of Evaluated Test Statistic

The results of the MK trend and Sen Slope analysis presented in Table 2 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 congruent with some earlier publications (Yue et al., 2002; Shadmani et al., 2012; Ahmad et al., 2015).

The slope magnitude showed a mild increasing trend variation statistically insignificant. The rate of change in the magnitude of rainfall intensity is evaluated using the SSE technique. From Table 2 the Q at 24 hours duration is evaluated as 0.0249 and 0.0250 mm/hr/year for the

IMD and the MCIMD data series, respectively, which translates to a variable rate of 0.6 mm/year or 6.00 mm/decade for both the IMD and MCIMD models, respectively.

The trend test for the 24-hourly MMS in Figure 3, the parent sample, also produced a p-value of 0.2289 which is greater than the alpha value at a 5% significant level. The slope value was given as 0.0006 to confirm the positive mild trend status which is like the 24-hourly AMS sample data.

The present study variation rate in rainfall intensity is consistent with most earlier research work for the coastal stations of the Gulf of Guinea for instance, Ayensu (2004) had 13mm/decade for Ghana, Nwaogazie and Ologhadien (2014) also had 55.2 mm/decade for gauge stations in the Niger Delta, and most recently Sam et al. (2022) had 21.288mm/decade for Uyo in the Niger Delta. The results were at variance with the opinion of Okafor et al. (2017), 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 (Ebele & Emodi, 2016; Elisha et al., 2017) and increases in the coastal region (Olaniyi et al., 2013; Nwaogazie & Ologhadien, 2014, Sam et al., 2022).

4. CONCLUSION

The aftermath of changing climate effect analyzed for Port Harcourt metropolis 24 – hourly AMS rainfall data were found to be statistically insignificant in trend. The p-values were more than the alpha value of 0.05 at a 5% level of significance. The computed p-value varied from 0.2993 to 0.3201, and 0.3059 to 0.3201 for IMD and MCIMD time series data, respectively. While the MK statistic also varied from 0.9943 to 1.0242 for both data series which were less than the critical Z-value of 1.96. The slope magnitude also showed a mild increasing trend variation. However, the trend magnitude varied from 0.0249 to 0.5250 and 0.0250 to 0.7625 with the rate of change in the magnitude of rainfall intensity at 24 hours duration evaluated as 0.0249 and 0.0250 mm/hr/year for the IMD and the MCIMD time series data, respectively, which translates to variation rate of 0.6 mm/year or 6.00 mm/decade. The trend test for the 24-hourly MMS, the parent sample, also produced a p-value of 0.2289 which is greater than the alpha value at a 5% significant level. The slope value produced was 0.0006 to confirm the positive mild trend status which is like the 24-hourly AMS sample data. The change point date was given by the plot of the distribution-free CUSUM test to occur in 1988, and the year 1994 was also viewed as another year of change point date that further intensified the positive trend change as provided by the SQMK analysis for Port Harcourt metropolis.

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