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# Investigating precipitation pattern and variability in the Niger Delta: a statistical analysis of trends and change points (1972–2022)

**Mbachu Ikechukwu**

CIM Environmental Consults, Plot 590 Jahi, 900108, Abuja, Nigeria
Correspondence e-mail: talk2iyke@yahoo.com
https://orcid.org/0000-0001-7574-7596

**Abstract.** There has been significant variation in precipitation in different parts of the world, and increasingly this has been attributed to climate change. Despite reliance on rain-fed agriculture, detailed analysis of regional precipitation trends within specific sub-national areas, such as the Niger Delta, remains scant. This study examines annual rainfall trends over 51 years (1972–2022) across seven stations in the Niger Delta using different statistical methods. Descriptive statistics show different patterns among stations, some showing upward trends, others declines. Mean annual rainfall ranges from 1,969.05 mm in Akure to 2385.04 mm in Port Harcourt, showing significant regional variability. Linear regression and LOWESS analysis show mixed trends; Mann–Kendall and Spearman's Rho tests showed significant increase in Owerri, while Sen's slope analysis confirms varying trends across the region. Pettitt test results confirms Owerri's significant increase in precipitation. This study contributes to a greater understanding of precipitation trends in the Niger Delta.

**Key words:**
Precipitation,
Niger Delta,
Trend Analysis,
Mann–Kendall,
Spearman's Rho,
Pettitt test

## Introduction

Precipitation is an important component of the hydrologic cycle (Wagesho et al. 2013; Feng et al. 2016) and there is a increasing evidence that shows that different parts of the world have been experiencing increasingly unpredictable and intense precipitation (Groisman et al. 2012; Higgins and Kousky 2013) and this has been largely attributed to climate change (Liu et al. 2005; Wang and Zhang 2011; Taotao et al. 2016). Such changes in rainfall quantity and frequency will most likely alter the pattern of stream flows, water demands (especially agricultural), spatial and temporal distribution of runoff, etc. (Bari et al. 2016). Hence, understanding the spatial and temporal precipitation pattern is paramount. Precipitation is crucial for agricultural production, particularly in the context of developing countries, as precipitation largly dictates the types of crops grown in different regions throughout the world (Priyan 2015; Gajbhiye et al. 2016).

There is growing and sustained concern in the scientific community over whether there are significant changes in precipitation amount and intensity in different parts of the globe currently. This is reflected by the huge number of studies carried out over the last three decades dealing with the assessment of significance of trends in a variety of natural time series like temperature, evaporation, precipitation, and so on. For instance, Sippel et al. (2017) observed increasing trends in daily rainfall extremes and annual totals globally, aligning with Allan's (2011) findings of dry regions becoming drier and wet regions wetter. Dobler et al. (2024) noted decreasing daily precipitation area between 50°S and 50°N, accompanied by increased drought frequencies and rainfall intensity. On the regional level, Kuttippurath et al. (2021) observed decreases in precipitation in northeast India. Further, Sudarsan and Lasitha (2023) focusing on Kerala, India, revealed increasing overall rainfall trends but with significant variations across months and seasons, while Al-Dughairi (2023) demonstrated complex and varying rainfall patterns in north-eastern Saudi Arabia, with some areas experiencing rainfall declines and others showing more stable precipitation regimes. Another study by Tore et al. (2022) reveals a complex pattern of extreme rainfall in West Africa, the study concluded that rainfall distribution varies significantly between the wetter Gulf of Guinea coast and the drier Sahel region. The research indicated that climate change is altering these patterns, leading to both increased frequency of heavy rainfall events and prolonged dry spells in West Africa.

Despite the widespread agreement among scientists on the reality of climate change, there remains a significant gap in the understanding of the precise rate, characteristics, and variability of regional climatic phenomena, particularly regarding precipitation in many developing countries like Nigeria. Hence, it is crucial to conduct accurate assessments of recent precipitation trends at the regional or sub-national level. This is necessary because large-scale analyses often overlook important details concerning variations in hydro-climatic trends within small basins.

In Nigeria, to date, much of the research on precipitation has focused on regional and national-scale assessments with different conclusions (Chineke et al. 2010; Oguntunde et al. 2014). Anyadike (1992) examined the variations of rainy season rainfall over the different regions of Nigeria and the country as a whole over a 72-year period (1916–87). The result of the study revealed a tendency towards decreasing seasonal rainfall totals in nearly all the regions; however, only those of the Northern region and the country as a whole were significant. Odjugo (2005) studied rainfall patterns between 1970 and 2002 in 28 stations in Northern and Southern Nigeria and the result showed that there was a general decrease in the amount of rainfall in most of the stations apart from those in the coastal area in the south, which showed an increasing trend in rainfall. Furthermore, OlaOluwa et al. (2015) analyzed monthly rainfall data from 37 meteorological stations across the six geo-political zones of Nigeria between 1981 and 2013, and they found significant time trend coefficients that were positive, indicating that monthly rainfall has increased during the sampled periods nationwide.

In the context of the Niger delta, there have been few comparative studies of rainfall trend in the Niger Delta basin, as most studies have focused on analyzing climatic trend on a national scale, yet, fluctuations in the amount and distribution of precipitation do not just have potentially serious implications for the hydrological regimes of regional basins such as the Niger delta, but a huge influence on agricultural production and livelihoods as well.

The Niger Delta's rainfall regime is complex, influenced by factors like the Intertropical Convergence Zone (ITCZ), Sea Surface Temperatures (SSTs), coastal topography, land-use changes, and the El Niño Southern Oscillation (ENSO). These factors interact with the broader monsoon system, leading to the region's variable rainfall. Additionally, the Niger River's hydrological regime and agricultural practices in the delta are impacted by factors outside the delta, such as rainfall patterns in the upper Niger basin and hydrotechnical regulations like dam operations and irrigation practices. These regulations can significantly alter the volume and timing of water flow reaching the delta, leading to extremes like floods or water scarcity. These extremes disrupt ecosystems, affect livelihoods dependent on fishing, and damage infrastructure.

With 70% of its population involved in rain-fed subsistence agriculture in Nigeria, agricultural production is highly susceptible to rainfall variability because of its effects on available soil moisture and, by extension, crop productivity (Oguntunde et al. 2011). The reliance on rain-fed agriculture is even more acute in rural areas, where smallholder farmers reportedly accounted for over 90% of agricultural output. Given such heavy dependence on rainfall, it should be no surprise that drastic changes in precipitation pattern will pose significant challenge to livelihood in the area, so it is essential to analyze whether and how these variations occur.

In this study, using a number of statistical techniques, characteristics of rainfall series in the Niger delta basin are analyzed to find out whether there have been any significant changes in the rainfall trends. The study focuses on the following objectives.

- To detect the annual precipitation trend time using linear regression, Mann–Kendall tests, and the Theil-Sen slope
- Spatiotemporal variability of rainfall trend in the Niger delta
- Identification of abrupt changes in annual precipitation totals

## Materials and methods

### Study area

The Niger-Delta region is situated in the Southern part of Nigeria (Fig. 1) and its areal extent is over 29,100 km$^2$ (Ogunkoya and Eji 2003). The region falls between longitude 5.05°E and 7.35°E and latitude 4.15°N and 6.01°N. Between February and November, the climate of the Niger Delta region falls under the influence of the tropical maritime air mass, which originates from the south-west. From December to January, the region is mostly dominated by the dry tropical continental air mass, which comes from the north-east. This seasonal shift in air masses is characteristic of the monsoon circulation experienced in the region. The onset of rainfall is usually around March/April, attaining its highest between July and September, and ceases in November/December. The temperature of the region is mostly uniform. The temperature range for most cities along the coastal fringe is 27°C to about 28°C for cities in the interior part of the region. Relative humidity reduces slightly in the northern part where the mean is about 80% to 85% in the southern part of the region (Adejuwon 2012). Lately, devastating floods of high magnitudes have been experienced in the area, which many have attributed to climate and drastic unplanned changes in land use.

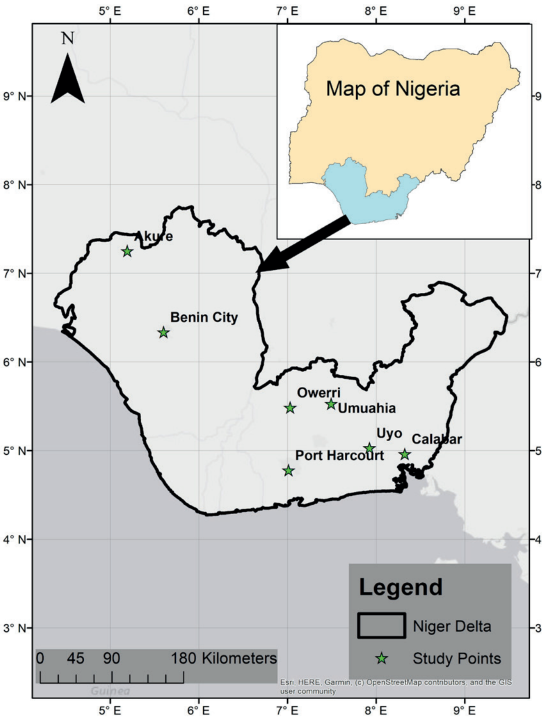

Fig. 1. Map of Niger Delta showing the study stations

### Data and methods

The study considers annual precipitation data from 51 years (1972–2022) at seven stations (Table 1) in the Niger Delta collected from the Nigerian Meteorological Agency. The stations used in the study were selected based on two primary criteria: the length of available record period and the relative completeness of the data. "Relative completeness" refers to the extent to which each station's record approached a full, uninterrupted 51-year dataset. The seven stations were chosen as they had the most comprehensive and continuous records available. Some years of data were missing for certain stations, but these gaps were minimal compared to other potential sites. Trend and variations in precipitation over time in the Niger Delta River basin are investigated and analyzed using different methods and tests such as linear trend analysis, Mann–Kendall and Spearman's Rho tests, Sen's slope, and the Pettitt test.

Table 1. List of selected stations and coordinates

| Station | Latitude | Longitude | Elevation (meters) |
|---|---|---|---|
| Akure | 7.2571° N | 5.2058° E | 350 |
| Benin city | 6.3350° N | 5.6037° E | 88 |
| Calabar | 4.9757° N | 8.3417° E | 32 |
| Owerri | 5.4891° N | 7.0176° E | 75 |
| Port Harcourt | 4.8156° N | 7.0498° E | 20 |
| Umuahia | 5.5250° N | 7.4922° E | 148 |
| Uyo | 5.0377° N | 7.9128° E | 70 |

## Descriptive statistics

Descriptive statistics, including maximum, mean, median, mode, standard deviation, skewness and kurtosis, were calculated for each station using Microsoft Excel (Version 16.0, Microsoft Corporation 2021) and XLSTAT software (Version 2023.1.1, Addinsoft, https://www.xlstat.com/). These measures provide a summary of the central tendency, variability and distributional shape of the precipitation data. The map of mean annual and maximum annual precipitation of the seven cities were interpolated using the inverse distance weighting (IDW) technique in TeREsA software (Version 1.1, CREALP 2016). The power-law distance exponent used in the IDW method was 2, which is a commonly used value that balances the influence of nearby and distant points, and is often considered suitable for environmental data interpolation.

## Linear trend analysis

Linear regression is very useful in climatic studies because it helps researchers find important trends in their data in simple fashion. Regression analysis is commonly used to assess linear trends by establishing internal relationships between time and the variable under scrutiny. To ensure accurate application, variables must exhibit normal distribution and possess spatial and temporal independence. Numerous researchers, including (Aamir and Hassan 2018; Alejandro and Suárez 2019; Khyber et al. 2021) have utilized the parametric statistical method in analyzing precipitation trend.

In analyzing trends within rainfall data time series, a simple linear regression model with the coefficient of determination (r2) was employed. The statistical formula for this regression model is as follows:

$$Y=aX+b \tag{1}$$

Where $X$ represents time; $a$ denotes the slope coefficient; and $b$ signifies the least square estimate of the intercept.

The slope coefficient indicates changes over time units. A positive value suggests an increasing trend, while a negative value indicates a decreasing trend within the model. Yanogo and Yaméogo (2013) extensively described the steps involved in running the linear model.

Locally weighted scatterplot smoothing (LOWESS) was employed to fit a smooth line to the time series data over time. The LOWESS method safeguards against deviant points in the time series and allows for the clearer observation of the data trend (Cleveland 1979). LOWESS predicts the mean through a non-parametric, robust local regression of the time series data utilizing a weight function. Smoothness of the fit increases as the fraction of the data used to calculate the mean at each abscissa value increases. Several authors have applied LOWESS smoothing to analyzing rainfall trends (Javari 2016; Adeyeri et al. 2017; Harishnaika et al. 2022).

## Trend detection

There are various types of tests employed for detecting trends in meteorological time series, which can be classified broadly into parametric and non-parametric (Gocic and Trajkovic 2013). A test is said to be parametric if the change evaluated by the test can be specified in terms of one or more parameters. In parametric testing, it is necessary to make assumptions underlying distribution for the data (often the normal distribution) and to assume that data observations are independent of one another. Conversely, in non-parametric and distribution-free methods, fewer assumptions about the data need to be made (Kundzewicz and Robson 2004). Parametric tests are more powerful but require that data be independent and normally distributed, which is rarely true for hydrological time series data as many hydrologic variables tend to exhibit a marked right skewness due to the influence of natural phenomena (Viessman and Lewis 2003). Hence, in most hydrometeorology research, non-parametric tests are preferred, as they do not require data series to be normally distributed.

In this study, the Mann–Kendall statistical test (Mann 1945; Kendall 1975) and additionally the Spearman's Rho test were utilized to detect precipitation trends in the Niger Delta. Numerous studies on hydrological series have shown the usefulness and capacity of the Mann–Kendall test for detecting trends in hydrological studies (de Lima et al. 2010; Scian and Pierini 2013; Wu et al.

2014; Mondal et al. 2015; Ávila et al. 2016). The test was chosen because it makes no assumption about the distribution of the data, and because the Mann–Kendall test is based on sign differences rather than values, it is amenable to the effect of extreme values and outliers, and performs well even with missing values (Helsel et al. 2020).

The test checks whether there is any trend in the series against the null hypothesis of no trend. The null hypothesis H0 of the trend test suggests that there is no trend and that the data are random and independent; the alternate hypotheses H1 suggest that a trend is present in the time series. The Mann–Kendall test statistic is computed as follows:

Mann–Kendall test is done in a series *xi*, where *i*=1,2, …, *n*−1 and *xj* where *j*=1,2, …, *n*. Each data point *xi* is taken as a reference point that compared with the data point *xj*. The Mann–Kendall test used the following equations:

$$\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(xj - xi) \qquad (2)$$

Where *N* is the number of data points, *xi* and *xj* are the data values in the time series *i* and *j(j>i)*, respectively, and *sgn(xj–xi)* is the sign function as:

$$Sgn(\theta) = \begin{cases} +1\ if\ xj - xi > 0 \\ 0 >if\ xj - xi = 0 \\ -1 > xj - xi < 0 \end{cases} \qquad (3)$$

The variance is computed as:

$$Var\ (S) = \frac{n(n-1)(2n+5) - \sum_{i}^{P} = 1ti(ti-1)(2ti+5)}{18} \qquad (4)$$

Where *n* is the number of data points, *p* is the number of tied groups, the summary sign *Σ* indicates the summation over all tied groups, and ti is the number of data values in the $p^{th}$ group. If there are not the tied groups, this summary process can be ignored (Kisi and Ay 2014). In cases of sample size n>10, the standard normal test statistic *Zs* is computed using Eq. (5).

$$Zs = \begin{cases} \frac{S-1}{\sqrt{Var(S),}}\ if\ S > 0 \\ 0\ if\ S = if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} if\ S < 0 \end{cases} \qquad (5)$$

Positive values of $Z_S$ indicate increasing trends while negative $Z_S$ values show decreasing trends. Testing trends is done at the specific α significance level. When |*ZS*|>[Z1-a/2], the null hypothesis is rejected and a significant trend exists in the time series. Z1-α/2 is derived from the standard normal distribution table. In this study, significance levels α= 0.01 and α= 0.05 were used. At the 5% significance level, the null hypothesis of no trend is rejected if |ZS|>1.96 (Mersin et al. 2022).

### Spearman's Rho Test

Spearman's Rho Test is another rank-based non-parametric method used for trend analysis and was also utilized in this study. The Rho test has been applied extensively by several authors to show the trend of precipitation (Zhao et al. 2015). In this test, which assumes that time series data are independent and identically distributed, the null hypothesis ($H_0$) indicates that there is no trend over time, while the alternate hypothesis ($H_1$) is that a trend exists and that data increase or decrease with *i*. The test statistics Zsp and standardized statistics Rsp are defined as:

$$Rsp = 1 - \frac{6\sum_{i=1}^{n}(Di - i)^2}{n(n^2 - 1)} \qquad (6)$$

$$Zsp = Rsp\sqrt{\frac{n-2}{1 - Rsp^2}} \qquad (7)$$

In these equations, *Di* is the rank of $i^{th}$ observation, *I* is the chronological order number, *n* is the total length of the time series data, and *Zsp* is Student's *z*-distribution with (*n*−2) degree of freedom. The positive values of *Zsp* shows an increasing trend in the time series, while negative values represent decreasing trends. The critical value of *t* at a 0.05 significance level of Student's *t*-distribution table is defined as *t*(*n*−2,1−α/2) [12]. If |*Zsp*| > *t*(*n*−2,1−α/2), ($H_0$) is rejected and a significant trend exists in the time series (Zhang et al. 2015; Perera et al. 2020).

### Sen Slope

In addition to identifying whether the trend exists, the magnitude of the trend was also estimated by a slope estimator (β), which was modified by Hirsch et al. (1982) from that proposed by Sen (1968). The Sen slope technique has been used in a plethora of studies in determining the slope of trends in climate variable time series (Adnan et al. 2015; Abdulkareem and Sulaiman 2016; Chattopadhyay and Edwards 2016). Sen's non-parametric method was utilized to compute the magnitude of trends in the time series data.

$$Ti = \frac{xj - xk}{j - k} \qquad (8)$$

In this equation, $xj$ and $xk$ represent data values at time $j$ and $k$, respectively. Consider:

$$Qi = \begin{cases} \frac{T(N+1)}{2} \; if\ N\ is\ odd \\ \frac{1}{2}\left(\frac{N}{2} + \frac{T(N+2)}{2}\right) if\ N\ is\ even \end{cases} \qquad (9)$$

A positive $Qi$ value shows an increasing trend; a negative $Qi$ value shows a decreasing trend over time. Tabari et al. (2011), Ahmad et al. (2015), Frimpong et al. (2022) and Alam and Majumder (2022) and many others have extensively described and discussed the steps involved in the computation of the Sen method.

### Change Point Detection

Various methods have been used to determine change points in time series by many researchers such as Pettitt (1979), Buishand (1982), Cumulative Sum (CUSUM) (Page 1954), Neumann (1941), Standard Normal Homogeneity Test (SNHT) (Alexandersson 1986) and many more. However, the most popular is the Pettitt test. The Pettitt test is a non-parametric test useful for evaluating the occurrence of abrupt changes in climatic records. In this study, the non-parametric Pettitt change point test is used to detect the occurrence of abrupt changes. It is preferred because it is rank-based and distribution-free, making it particularly useful when no hypothesis is required about the location of the change point. This test detects shifts in the average and calculates their significance in a hypothesis test (Meddi et al. 2010). The null hypothesis is that the data are homogeneous, as opposed to the alternative hypothesis that there is a datum at which there is a change in the data. The Pettitt's test statistics have been extensively explained by Samy et al. (2019), Getahun et al. (2021), El Hafyani et al. (2023) and many others. The empirical significance level (p-value) was computed using the XLSTAT software. The test was performed at a significance level of 5%.

## Results and discussion

### Descriptive statistics

The descriptive statistics of annual rainfall are shown in Table 2. The results show that mean annual rainfall in the Niger Delta ranges from 1969 mm in Akure to 2385 mm in Port Harcourt. Port Harcourt has the highest mean rainfall, indicating a generally wet climate in the city. Calabar and Port Harcourt experience the highest maximum rainfall (4,062.7 mm/year and 3,726.8 mm/year, respectively) (Fig. 2), indicating vulnerability to heavy precipitation and potential flooding. The spread of rainfall data, as indicated by the standard deviation, varies among the towns. Uyo has the highest standard deviation (559.41 mm/year), suggesting greater variability in annual rainfall. Conversely, Benin City has the lowest standard deviation (376.96 mm/year), indicating a more consistent rainfall pattern. The skewness varies between 1.18305 and –0.05046. The predominantly positive skewness in most of the cities indicates that annual rainfall during the period under analysis is asymmetric, lying to the right of the mean over all the stations, indicating a tendency for heavier rainfall events in the region. Owerri, with slight negative skewness, faces occasional light rainfall. The kurtosis ranges from –0.992 to 1.574. This suggests a range of kurtotic behaviors among the cities, with some having relatively flat distributions and others having sharper peaks. Positive kurtosis (as seen in Akure) indicates heavier tails and a sharper peak compared to a normal distribution. Negative kurtosis (as seen in Benin City and Owerri) indicates lighter tails and a flatter peak.

Table 2. Descriptive statistics of annual rainfall in the selected stations (mm)

| Statistic | Akure | Benin City | Calabar | Owerri | Port Harcourt | Umuahia | Uyo |
|---|---|---|---|---|---|---|---|
| Median | 1,473.2 | 1,856.4 | 2,886.1 | 2,102.5 | 2,283.1 | 2,097.3 | 2,269.4 |
| Max | 2,249.4 | 2,609.1 | 4,062.7 | 3,064 | 3,726.8 | 2,743.3 | 3,855.5 |
| Mean | 1,507.648 | 1,884.184 | 2,900.581 | 2,136.660 | 2,385.039 | 2,110.412 | 2,464.433 |
| Mode | 1,405 | 1,410 | 2,890 | 2,670 | 2,350 | 1,805 | 2,230 |
| Std Deviation | 233.516 | 376.956 | 428.452 | 448.379 | 464.945 | 265.863 | 559.414 |
| Coeff Skewness | 0.722702 | 0.128658 | 0.576415 | -0.05046 | 1.183053 | 0.158542 | 0.935463 |
| Kurtosis | 1.57416 | -0.79969 | -0.0764 | -0.99204 | 0.878474 | -0.40553 | 0.08336 |
| No. of data | 42 | 51 | 51 | 51 | 51 | 43 | 46 |

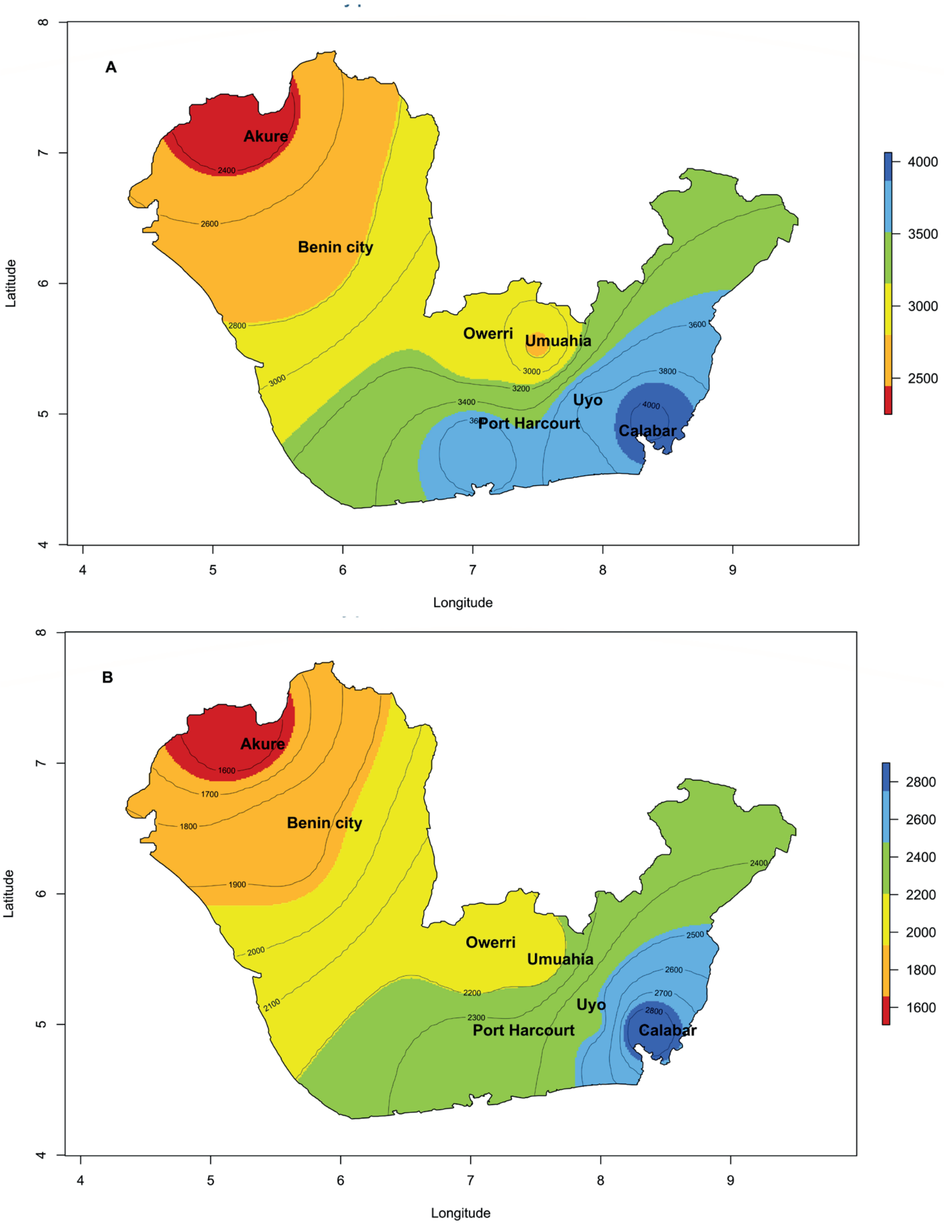

Fig. 2. (A) Annual maximum and (B) Annual mean precipitation in the Niger Delta (1972–2022)

## Linear Regression Analysis

The annual rainfall data from the linear regression analysis revealed an upward trend in some stations and a downward trend in others. However, most of the results indicated a statistically insignificant trend in the annual rainfall and a very weak correlation between rainfall and year. Additionally, the *R*-square statistic in most of the stations also showed a very weak relationship between the variables, rainfall and year.

To provide a clearer assessment of the changes in the time series, LOWESS smoothing was used. Figure 3 shows the LOWESS regression curves and the linear regression of annual rainfall in the selected stations. The LOWESS regression curves for all stations generally reveal consistent trends. In Akure, rainfall patterns fluctuate notably over time, with discernible peaks in the early 1990s and early 2010s, and troughs evident in the mid-1980s and late 2000s. Despite these fluctuations, there isn't a clear long-term trend observed. Benin City's rainfall, on the other hand, demonstrates a gradual decline from the 1970s until the mid-2000s, followed by a more marked decrease in recent years. Meanwhile, Calabar shows a slight upward trend until the early 2000s, followed by a period of fluctuation, with a slight decline noted in the most recent years. Both Uyo and Owerri experience fluctuating rainfall patterns, with increasing variability noted in recent years and a decline in rainfall towards 2020–21. In Port Harcourt, rainfall displays significant variability without a discernible overarching trend, though recent years suggest an increase. Similarly, Umuahia's rainfall trends fluctuate without a distinct long-term trajectory, with recent years showing a decline. Comparison of the linear trend with the results of other available studies shows a general agreement with the results of these studies. The slight decreasing trend observed in Akure agrees with Mosunmola et al. (2020) whose study observed a slight downward trend in annual rainfall in Akure. Similarly, the results of the trend analysis in Benin City aligns with the result of the study carried out by Odiana and Idahosa-Ohio (2013), who observed a steady trend of neither decreasing nor increasing rainfall pattern in Benin City. The linear pattern in Calabar showed a non-significant increasing trend, which is in consonance with the results of rainfall trend analysis in Calabar by Amadi et al. (2021) and Ekwueme and Agunwamba (2021) whose studies suggested that there is an increasing but non-significant rainfall in Calabar.

## Trend analysis

It is important to note that the LOWESS curves are used to show patterns and do not explain statistically significant trends in the time series; hence, the Mann–Kendall and Spearman (Rho) tests were utilized. Results of the applied Mann–Kendall's and Spearman's (Rho) statistical tests for the seven stations are presented in Table 3 and Figure 4.

The Mann–Kendall's test provides insight about the trend of annual precipitation data for the Niger Delta. Akure, Benin City, Calabar, Owerri, and Port Harcourt show an increasing trend in rainfall. Conversely, Umuahia and Uyo exhibit a decreasing trend in rainfall. The Mann–Kendall test indicates that the increase in rainfall is not statistically significant in Akure, Benin City, Calabar, and Port Harcourt. However, Owerri shows a statistically significant increase in rainfall. Umuahia and Uyo, with decreasing trends, showed no statistically significant changes. Akure, Benin City, Calabar and Port Harcourt have p-values above the critical value (0.075, 0.226, 0.697 and 0.057, respectively), indicating non-significant changes. Owerri has a low p-value of 0.002, suggesting statistically significant changes in the increasing trend. Umuahia and Uyo both have p-values (0.225 and 0.421, respectively) above the significance threshold, showing non-significant changes in their decreasing rainfall trends.

Spearman's Rho test was applied to the data set based on the 95% confidence interval (alpha = 0.05). The analysis for Akure indicated a weak positive relationship (Spearman's Rho = 0.2832) between precipitation and time, but this relationship was not statistically significant (p-value = 0.0694). Benin City exhibited a very weak positive relationship (Spearman's Rho = 0.1078), which was also not statistically significant (p-value = 0.4515). Calabar showed a negligible positive relationship (Spearman's Rho = 0.0270), and this relationship was not statistically significant (p-value = 0.8507). In contrast, Owerri displayed a statistically significant positive relationship with a strong correlation coefficient (Spearman's Rho = 0.4099) and a p-value of 0.0015. Port Harcourt showed a weak positive relationship (Spearman's Rho = 0.2628) similar to Akure, but it was also not statistically significant (p-value=0.0627). Umuahia and Uyo presented weak negative relationships (Spearman's Rho =

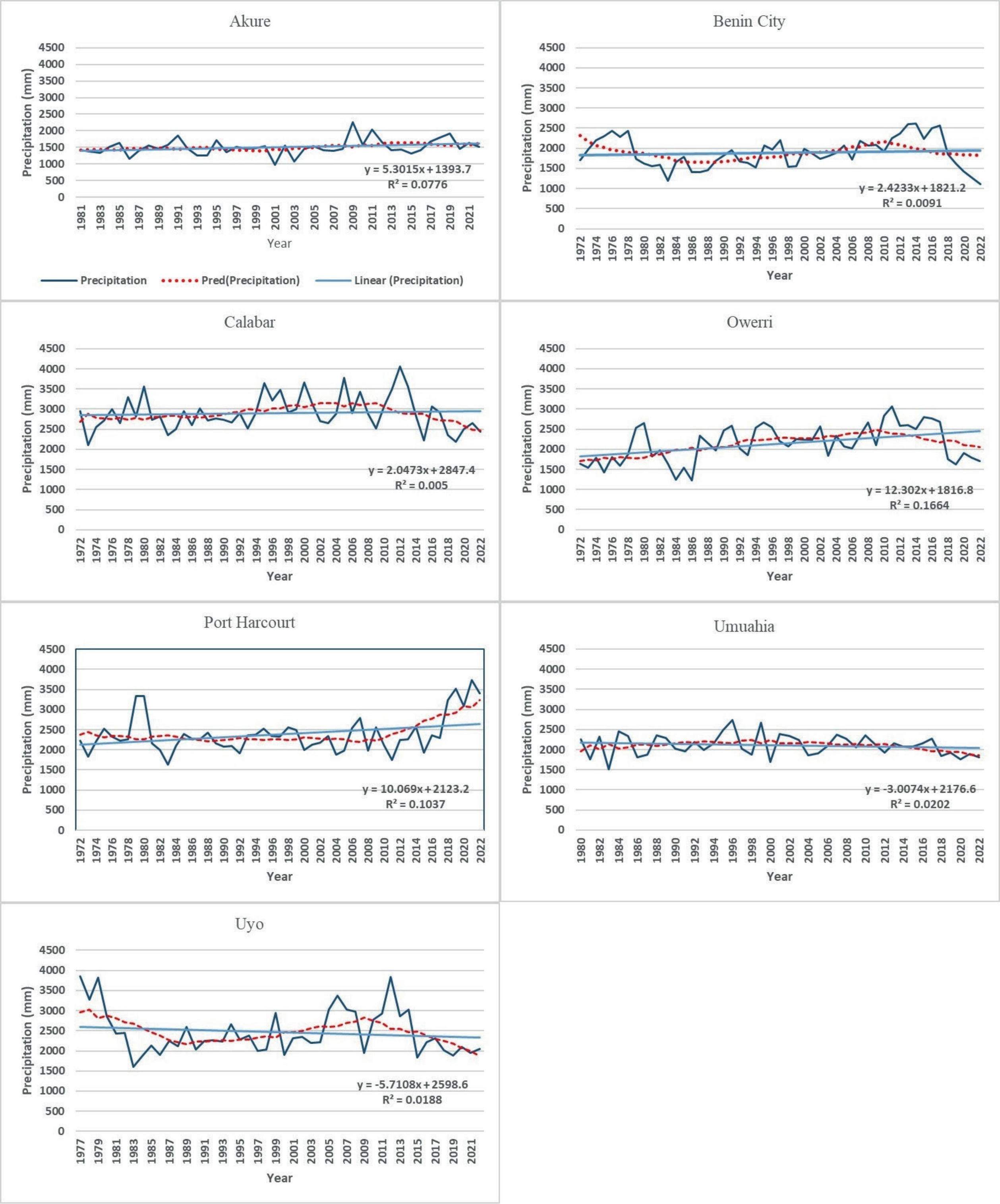

Fig. 3. LOWESS and regression lines for annual rainfall in the study stations in the Niger Delta

−0.1720 and −0.1436, respectively), both lacking statistical significance (p-values=0.2691 and 0.3411).

In summary, the study revealed different results across the seven locations. Only Owerri demonstrated a statistically significant trend, while other cities showed different trends with none been statistically significant. The statistically significant increasing trend in Owerri could be attributed to

Table 3. Results of the Mann–Kendall and Rho trend test for the selected stations

| Location | Kendall's tau | S | p-value (Mann Kendall) | p-value (Rho) | Rho |
|---|---|---|---|---|---|
| Akure | 0.192 | 165 | 0.076 | 0.069 | 0.283 |
| Benin City | 0.118 | 150 | 0.226 | 0.451 | 0.108 |
| Calabar | 0.038 | 49 | 0.697 | 0.852 | 0.027 |
| Owerri | 0.300 | 383 | 0.002 | 0.002 | 0.410 |
| Port Harcourt | 0.184 | 235 | 0.057 | 0.063 | 0.263 |
| Umuahia | -0.130 | -117 | 0.226 | 0.269 | -0.172 |
| Uyo | -0.083 | -86 | 0.421 | 0.341 | -0.144 |

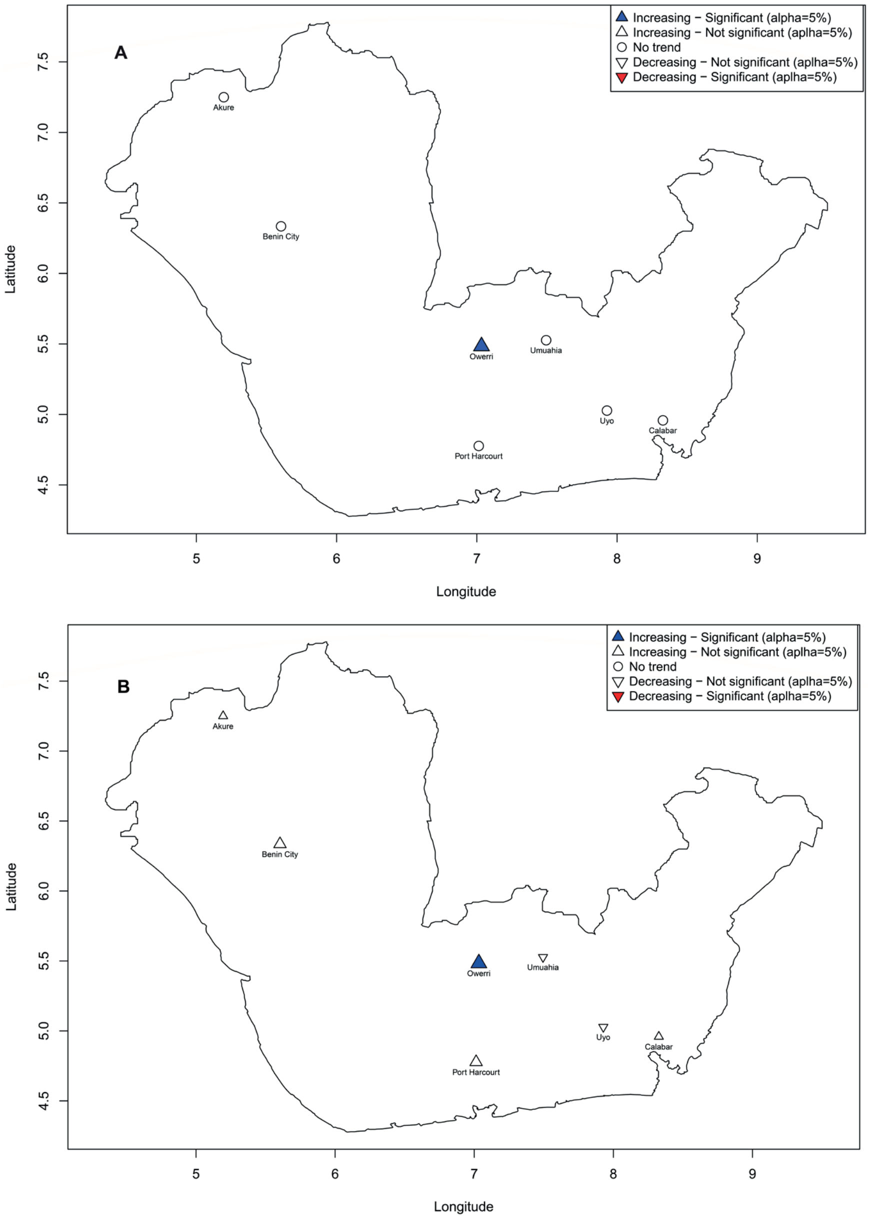

Fig. 4. Spearman's test (A) and Mann–Kendall test (B) precipitation trend in the study stations in the Niger Delta

several factors. Changes in land use patterns, such as increased urbanization and deforestation, can alter local climate conditions and potentially lead to increased precipitation. Additionally, shifts in regional atmospheric circulation patterns, possibly linked to larger-scale climate change phenomena, might be contributing to this trend.

### Sen Slope

The Sen's slope provides vital information on the long-term precipitation trend in selected cities across the Niger Delta region. Table 4 shows that Akure has a positive Sen's slope of 3.83, suggesting a moderate increase in annual precipitation. Benin City has a Sen's slope of 5.85, which represents a relatively higher increase in annual precipitation. Calabar's Sen's slope is 1.95, representing a comparatively lower increase in annual precipitation. Conversely, Owerri has a high sen's slope of 15.58, signifying a significant annual precipitation increase. Port Harcourt has a Sen's slope value of 6.94, indicating a significant annual increase in precipitation. While, two stations, Umuahia and Uyo have negative Sen's slopes of –4.38 and –4.11 indicating a decline in annual precipitation in the two locations.

The variations in precipitation trends across the Niger Delta region, as indicated by the Sen's slope values, can be attributed to a combination of factors. The increasing trends observed in Akure, Benin City, Calabar, Owerri and Port Harcourt might be linked to intensification of the West African Monsoon system, which is a primary driver of rainfall in the region. Climate-change-induced warming of the Atlantic Ocean could be enhancing moisture transport to these areas, leading to increased precipitation in certain areas in the Niger Delta.

### Change detection

The homogeneity of the annual precipitation data was examined for the selected cities using the Pettitt test. The results of the Pettitt's tests for the annual precipitation data (in mm) are presented in Table 5 and Figure 5. The results shows that there is generally a level of stability in precipitation trend across most of the region. Benin City, Calabar, Port Harcourt, Umuahia and Uyo all show p-values above the significance level, indicating that there is no significant evidence for abrupt shift in the precipitation patterns in these cities during the period under analysis. However, Owerri is a notable exception, as it is the only town with a statistically significant positive trend in rainfall. The Kendall's tau value (0.300) establishes a positive tendency, and the p-value (0.002) is well below the alpha level of 0.05, indicating a statistically significant finding.

### Discussion

The descriptive statistics provide an overview of precipitation characteristics in the selected cities. Port Harcourt had the highest mean and maximum rainfall, confirming wetter conditions and increased vulnerability to heavy rainfall and flooding in the city. Conversely, Benin City showed a stable rainfall pattern, as proved by its lower standard deviation. These variations emphasize differing climatic conditions in the different areas in Niger Delta region and hence the need for tailored adaptation strategies in the region.

The result of the Mann–Kendall test carried out in Akure closely aligns with that of Ihimekpen et al. (2018) whose non-parametric test result revealed

Table 4. Sen's slope values for the selected cities

| Town | Akure | Benin City | Calabar | Owerri | Port Harcourt | Umuahia | Uyo |
|---|---|---|---|---|---|---|---|
| Sen's slope | 3.828 | 5.850 | 1.954 | 15.584 | 6.942 | -4.375 | -4.114 |

Table 5. Results of Pettitt change detection test for the selected stations

| Town | Akure | Benin City | Calabar | Owerri | Port Harcourt | Umuahia | Uyo |
|---|---|---|---|---|---|---|---|
| Pettitt's Test p-value | 0.115 | 0.202 | 0.224 | 0.001 | 0.109 | 0.344 | 0.154 |

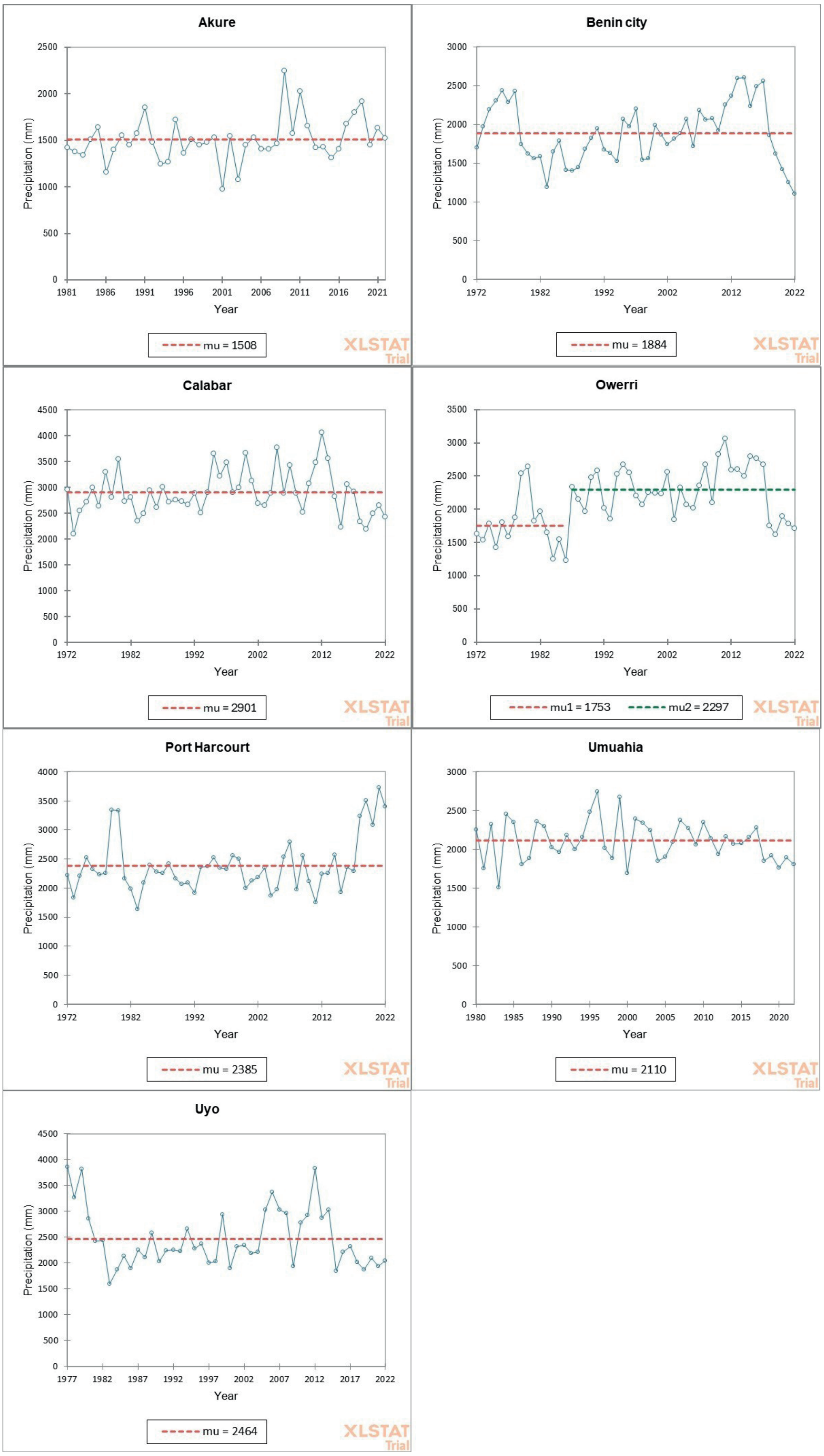

Fig. 5. Result of the Pettitt trend detection test in the study stations in the Niger Delta

statistical evidence of a decreasing trend with an M-K value index of −129. The Mann–Kendall test result in Calabar was also in line with Ihimekpen et al. (2018), who observed that there was inadequate statistical evidence of a significant trend in annual rainfall in Calabar. For Benin City, the Mann–Kendall results tally with those from Edokpa (2020) which indicated an increasing but non-significant ($p>0.05$) trend in annual rainfall in Benin City. The result of the Mann–Kendall test for Uyo does not align with that of Udokpoh and Garba (2013), whose studies showed that, at a 5% confidence level, the MK test revealed significant increasing trends in the annual rainfall in Uyo.

Also, findings from the change detection analysis were compared to those of Ihimekpen and Joseph (2018), whose study used the Pettitt test to identify abrupt change in the rainfall trend in different towns in southern Nigeria. Similar to this study, their results revealed that there was no abrupt change in rainfall trend in Akure, Port Harcourt, Uyo and Calabar. However, the results of the Pettitt test in Benin City and Owerri were dissimilar to results in this study. Their studies found a significant change point for rainfall trend in Benin City, while the current study found no change; their study also showed that there was no significant change in rainfall in Owerri, while this study revealed a clear change in rainfall in Owerri.

The findings of this research have significant implications for rainfall-related hazards and adaptation needs in the Niger Delta region. Cities with increasing trends, particularly Owerri and Port Harcourt, face increased flood risks. Owerri's potential increase of 794.58 mm over 51 years significantly raises the flood hazard. The city may need to upgrade its drainage systems to handle an additional 15.58 mm of rainfall per year. Port Harcourt, with the highest mean (2385.04 mm) and maximum (3,726.8 mm) rainfall, coupled with an increasing trend (+6.94 mm/year), requires robust flood management infrastructure. Benin City's relatively stable pattern (lowest standard deviation of 376.96 mm/year) suggests a need for resilient agricultural practices that can withstand both wet and dry years. Calabar, with the highest recorded annual rainfall (4,062.7 mm), needs adequate early warning systems capable of predicting extreme events.

The changes in precipitation patterns have multifarious implications for the Niger Delta's environmental and socio-economic stability. Increased rainfall trend between 1972 to 2022 (51 years), as seen in Port Harcourt and Owerri, may drastically increase the risk of flooding, thereby threatening livelihoods, infrastructure, food security and even human settlements. On the other hand, decreasing rainfall trends in certain areas could reduce water availability and agricultural productivity and affect ecosystem health. For instance, the potential decrease of over 200 mm in annual rainfall in Umuahia over the study period could lead to significant water scarcity issues, affecting both agriculture and domestic water supply.

## Conclusions

While the research does not definitively prove climate change in the Niger Delta, it provides solid evidence of variations in precipitation patterns. The annual rainfall pattern established in the selected cities have multifaceted consequences for the Niger Delta region ranging from increased flood risks in areas with significant increase in precipitation, reduced agricultural productivity, impact on water resources to threatrening infrastructural stability. Considering the above results, proactive strategies are essential to adapt and mitigate adverse impacts of climate change in the Niger Delta.

In terms of limitations, this study covered only seven towns in the Niger Delta region. Although this offers localized insights, it might not have captured the full range of precipitation patterns across the entire region. While the study aimed for the longest and most complete records possible, some stations lacked data for the full 1972–2022 period, limiting the temporal scope of analysis. Analysis at a finer spatial and temporal resolution could provide a deeper understanding of precipitation trends and patterns in the Niger Delta; however, due to data paucity and limitations, this was not feasible. This research highlights the need for more in-depth studies on precipitation in the Niger Delta, as this would foster a deeper understanding of climate dynamics in the region and assist stakeholders in developing evidence-based strategies to enhance resilience against changing precipitation patterns, thereby improving the region's socio-economic and environmental stability

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