

### **Analysis of Trend in Meteorological and Hydrological Time-series using Mann-Kendall and Sen's Slope Estimator Statistical Test in Akwa Ibom State, Nigeria**

#### **Abstract**

The monthly, seasonal, annual, and decadal trends of seven hydro-meteorological variables were analysed for stations in Akwa Ibom State, Nigeria, controlled by the Nigerian Meteorological Agency (NiMet) and the Cross River Basin Development Authority (CRBDA) from 1972 to 2021. At the 5% statistical significance level, the non-parametric Mann-Kendall and Sen's slope estimator techniques were used to detect if there was a positive or negative trend and the magnitude of the trend in hydro-meteorological data. In the present study, there was a significant statistically increasing (positive) trend in mean seasonal and annual rainfall, maximum temperature, minimum temperature, and runoff. However, there was a significant statistically decreasing (negative) trend in average annual relative humidity, solar radiation, and potential evapotranspiration. The magnitudes of the trends were 19.39mm/year, 0.0314oC/year, 0.013oC/year, -0.104%/year, -8.78MJ/m<sup>2</sup>/year, -1.440mm/year, and 0.028m<sup>3</sup>/s/year for annual rainfall, maximum temperature, minimum temperature, relative humidity, solar radiation, PET, and runoff, respectively. The rising trends in precipitation, temperature, and runoff in this research area show that this region is subject to climatic variability. The results of the Mann-Kendall and Sen's slope estimator statistical tests revealed the consistency of performance in the detection of the trend for the hydro-meteorological variables. Further research comparing Mann-Kendall and other trend detection tests is recommended.

**Keywords:** Climate change, Hydro-meteorology, Mann-Kendall Test, Sen's Slope Estimator, Time Series, Trend Analysis

#### **1.0 Introduction**

Climatic change (CC) is described as significant fluctuations in climate averages that last for decades or even centuries. CC is occurring, according to the international scientific community, and its impacts are already being seen in certain locations (Tawari-Fufeyin et al., 2015). CC has also hampered global management of both natural and human systems (Wardekker et al., 2016). Climate change is presently viewed as one of the most pressing issues facing the world (Adger et al., 2013). CC includes changes in climate parameters such as rainfall, temperature, wind speed, humidity, sunshine, among others (Nile et al., 2019). Although climate change has occurred on a global scale, its impacts frequently differ from place to place (Gocic and Trajkovic, 2013). Many researchers believe that the temperature of the Earth's surface air increased over the 20th century. Because of an increase in greenhouse gases (GHGs), the atmosphere and seas have warmed, the amount of snow and ice on the land has reduced, and sea level has risen (IPCC, 2021). Both natural and manmade activities contribute to the rise in greenhouse gas (GHG) concentrations in the atmosphere (Stocker et al., 2013). Global greenhouse gas concentrations have increased in recent decades, leading to global warming. Human activity has been identified as the primary cause of the continuing global warming (Jeswani, et al., 2008). Industries, according to Jeswani et al. (2008), are the primary cause of rising GHG concentrations in the atmosphere (including power and nuclear plants). The majority of the warming in the latter part of the 20th century was driven by human emissions of GHGs (Shadmani et al., 2012).

CC has caused a significant threat to all life on Earth, not just humans (Meena, et al., 2016). Developing countries are vulnerable to climate change due to their inability to adapt with extreme events (Pouliotte et al., 2009). CC affects temperature regimes in most places of the world. Temperature is a fundamental climatic characteristic, and variations in its pattern can have an impact on the earth's living components (Alhaji et al., 2018). Heat waves can occur when temperature increases, causing disease and death in less robust populations. Furthermore, temperature variations can trigger changes in species of animals and plants (Alhaji et al., 2018). Increased Earth temperature induces convectional current and boosts the rate of evaporation, resulting in cloud formation and increased precipitation (Alhaji et al., 2018). Increases in precipitation patterns can also lead to a rise in the frequency of floods, affecting water quality. Almost all biosphere activities are impacted in some way by climate change events, and the effects of climate change on the environment and water resources are of particular significance in this regard (Shadmani et al., 2012).

Meteorological and hydrological datasets are crucial climate factors whose extreme variations can cause droughts, extensive flooding, and, in the worst-case scenario, death (Choubin et al. 2017; Sigaroodi et al. 2014). Water resource management, hydrological modelling, flood forecasting, climate change studies, water balance computations, soil moisture modelling for crop production, irrigation scheduling, and other applications necessitate quantitative estimation of hydro-meteorological time series. Analysing meteorological and hydrological dataset patterns yields useful information for improving water resource management, environmental protection, agricultural productivity, and overall economic growth in the region (Gocic and Trajkovic, 2013). One of the most serious consequences of climate change caused by increased greenhouse gas emissions would be uncertainty in the temporal and geographic distribution and variation of meteorological data (Yadav, 20014). In the context of climate change, it is important to determine if the change is visible in Nigeria. Meteorological and hydrological variables have a significant role in shaping the economy of Nigeria, and understanding of their patterns helps us in the country's economic development, disaster management, and hydrological planning.

For trend detection, a variety of parametric and non-parametric tests were used. It is typical to apply both parametric and non-parametric tests. Nonparametric trend tests are less effective than parametric trend tests, but they need independent and normally distributed data. Non-parametric trend tests, on the other hand, require that the data be independent and can accept outliers. Trend identification approaches such as conventional linear regression, Mann-Kendall, Sen slope estimator (SSE), Sen innovative trend analysis, Spearman rho and wavelet analysis are available in the literature (Spearman, 1987; Sen 1968; Torrence and Compo, 1998; Mann, 1945; Kendall; 1975; Sen, 2012). The Mann-Kendall test is one of the most often used non-parametric tests for detecting trends in time series (Mann, 1945; Kendall, 1955). The Mann-Kendall trend test develops from Kendall's rank correlation test for two pairs of observations (1955). The Mann-Kendall trend test considers the relationship between the rank order of the observed values and their order in time. The null hypothesis for the Mann-Kendall test is that the data are independent and randomly ordered, implying that there is no trend or serial correlation structure among the observations. Because the Mann-Kendall trend test is based on the rankings of the observations rather than their actual values, it is unaffected by the actual distribution of the data and is less susceptible to outliers (Yadav, 20014). Mann-Kendall (MK) trend test is used for trend detection in hydro-meteorological records such as temperature, rainfall, evaporation, evapotranspiration, streamflow and water quality. (Bohm, et al., 2001; Partal et al., 2006; Jhajharia et al., 2009; Jhajharia et al., 2012; Burn and Hag Elnur, 2012; Chang, 2008).

Various studies have been carried out in recent years to detect possible climate change trends and changes. However, the most of these research have only focused at trends in maximum, minimum, or mean temperatures and rainfall. Yunling and Yiping (2005) examined climatic change patterns and features at 19 sites along the Lancang River (China) from 1960 to 2000 using archival data from monthly air temperature and precipitation series. They observed temperature increases and precipitation decreases. Singh et al. (2008) used the Mann-Kendall statistical test to assess the trend and variability of seasonal and annual rainfall and relative humidity on a basin scale in the northwest and central parts of India. According to the findings of this study, the most of river basins in India have a rising trend in relative humidity on both seasonal and annual periods. Vincent et al. (2008) obtained similar results when they examined surface temperature and relative humidity trends in Canada from 1953 to 2005.

Jiang et al. (2010) analysed wind speed patterns in China from 1956 to 2004 using two observational datasets and concluded that they all indicate decreasing trends over large areas of China. ElNesr et al. (2010) examined temperature trends in the Kingdom of Saudi Arabia over 29 years using data from 29 meteorological stations. They discovered an increasing trend in maximum, minimum, and average temperatures throughout the year, with the exception of the winter months of November to January, when they observed a non-significant decreasing trend. Karaburun et al. (2011) used the Mann-Kendall test and Sen's approach to examine the evolution of annual, seasonal, and monthly mean, minimum, and maximum temperatures in Istanbul from 1975 to 2006. Their findings revealed increasing trends in the months of July and August, as well as the annual mean and mean maximum temperatures. Tao et al. (2011) examine streamflow trends in the Tarim River Basin during the past 50 years. Temperature, precipitation, relative humidity, and real vapour pressure all showed positive trends, whereas wind speed, sunshine frequency, and potential evapotranspiration did not. Xu et al. (2010) achieved comparable findings. They discovered that the Tarim River Basin's mean annual air temperature and precipitation have both increased during the past five decades.

Gocic and Trajkovic (2013) examined the annual and seasonal trends of seven meteorological variables for twelve weather stations in Serbia from 1980 to 2010. The non-parametric Mann-Kendall and Sen's methods were used to assess the statistical significance positive or negative trend in meteorological data. Their findings revealed a significant agreement of performance in detecting trends in meteorological variables. Alhaji et al. (2018) also used the Mann-Kendall trend test and Sen's estimate in Nigeria to examine the nature of the trend and the level of significance of the annual average maximum and minimum temperatures in Gombe State. They discovered that maximum and average temperatures have positive Kendall's Z values, indicating an increasing trend and also implying an increasing trend over time. They attributed this to the impact of climate change, which can lead to weather extremes in the study area. A similar study by Agbo and Ekpo (2021) focused on analysing the temperature variations in Calabar, Southern Nigeria, for 20 years (1998-2018) using the Mann-Kendall trend test and Sen's slope estimator. Results from the Mann-Kendall test showed that the annual trends of the maximum and average ambient temperature were both increasing after displaying positive Kendall Z-values.

A review of the available literature revealed that this study has not been conducted in the region. As a result, a regional or local scale study of historical trends in hydro-meteorological variables is required. However, the purpose of this paper is to analyse the monthly, seasonal, annual, and decadal trends for six meteorological and one hydrological variables in Akwa Ibom State, Nigeria, from 1972 to 2021. Besides, the objectives of this study are: (i) to analyze and discuss the trend characteristics of hydro-meteorological variables in detail; (ii) to quantify the magnitude of trend and significance of change by using the Mann-Kendall test and the Sen's

slope estimator in the time series; and (iii) to determine the coefficient of variations in the time series variables.

## 2.0 Materials and Methods

### 2.1 The Study Area

The research was conducted in Itu and Uyo local government areas, Akwa Ibom State, Nigeria. Uyo is the capital of Akwa Ibom State, while Itu is a local government area that makes up Uyo capital metropolis (**Figure 1**). The study area has a latitude of 5.037740 and a longitude of 7.912795. The GPS coordinates for the area are 5° 2' 15.864" N and 7° 54' 46.062" E. It is located at an elevation of 64.122 metres above sea level over a massive underlain conglomerate sedimentary stratum (Udokpoh et al., 2021; Nnaji and Udokpoh 2022). The region has a tropical rainforest climate with two distinct seasons: a short dry season from December to February that has daytime temperatures of 34 to 38 degrees Celsius and lower nighttime temperatures of 23 to 25 degrees Celsius. The months of June and July typically have the highest annual precipitation rate, which ranges between 60 and 70 percent. Due to its proximity to the sea and location just north of the Equator in the humid tropics, the area is usually humid, as evidenced by relative humidity levels of 60 and 100 percent, respectively, in the dry and rainy seasons (Afangideh and Udokpoh 2021). Naturally, July has the highest levels of humidity, while January experiences the lowest levels.

### 2.2 Data Collection

The data used in this research were obtained from Nigerian Meteorological Agency (NiMet), Abuja, and the Cross River Basin Development Authority (CRBDA), Calabar respective. The daily meteorological datasets (rainfall, maximum and minimum temperatures, relative humidity, solar radiation and potential evaporation) were obtained from NitMet's meteorological station situated in the study area, while monthly runoff data were gotten from the CRBDA hydrological station during the period 1972-2021. Graphical position of the selected station in Akwa Ibom State map is shown in **Figure 1**, while the geographic description is given in **Table 1**. The location was chosen based on three criteria: (1) high-quality datasets; (2) reliable datasets; and (3) datasets with sufficient record duration. For each of the 7 hydro-meteorological variables, monthly data were averaged to get seasonal and annual values. Seasons were defined as follows: dry season = December, January and February; rainy season = March, April, May, June, July, August, September, October and November. Mean values with standard deviation of the annual variables used in this study for the observed period are summarized in **Table 2**.

**Table 1:** Geographic characteristics of the weather station sites used in the study

| Station name | Longitude (N) | Latitude (E) | Elevation (m.s.l.) |
|--------------|---------------|--------------|--------------------|
| Uyo (NiMet)  | 5°3'5"        | 7°56'1"      | 186m               |
| Uyo (CRBDA)  | 5°10'0"       | 7°59'0"      | 94m                |

m.s.l. = mean sea level

**Table 2:** Mean annual values with standard deviation of the hydro-meteorological variables used in this study during the period 1972–2021.

| Rainfall (mm) | Temp <sub>max</sub> (°C) | Temp <sub>min</sub> (°C) | R/H (%)  | S/R (MJ/m <sup>2</sup> /day) | PET (mm)  | Runoff (m <sup>3</sup> /s) |
|---------------|--------------------------|--------------------------|----------|------------------------------|-----------|----------------------------|
| 2706±777      | 31.3±0.64                | 23.1±0.52                | 78.6±5.2 | 6474±228                     | 1466±40.3 | 3.726±1.1                  |

### 2.3. Trend analysis methods

Parametric and non-parametric approaches can be used to conduct tests for the identification of significant trends in meteorological and hydrological time series. Non-parametric trend tests just need independent data, but parametric trend tests need independent and properly distributed data. Two non-parametric techniques (Mann-Kendall and Sen's slope estimator) were employed in this study to determine trends in the hydro-meteorological data.

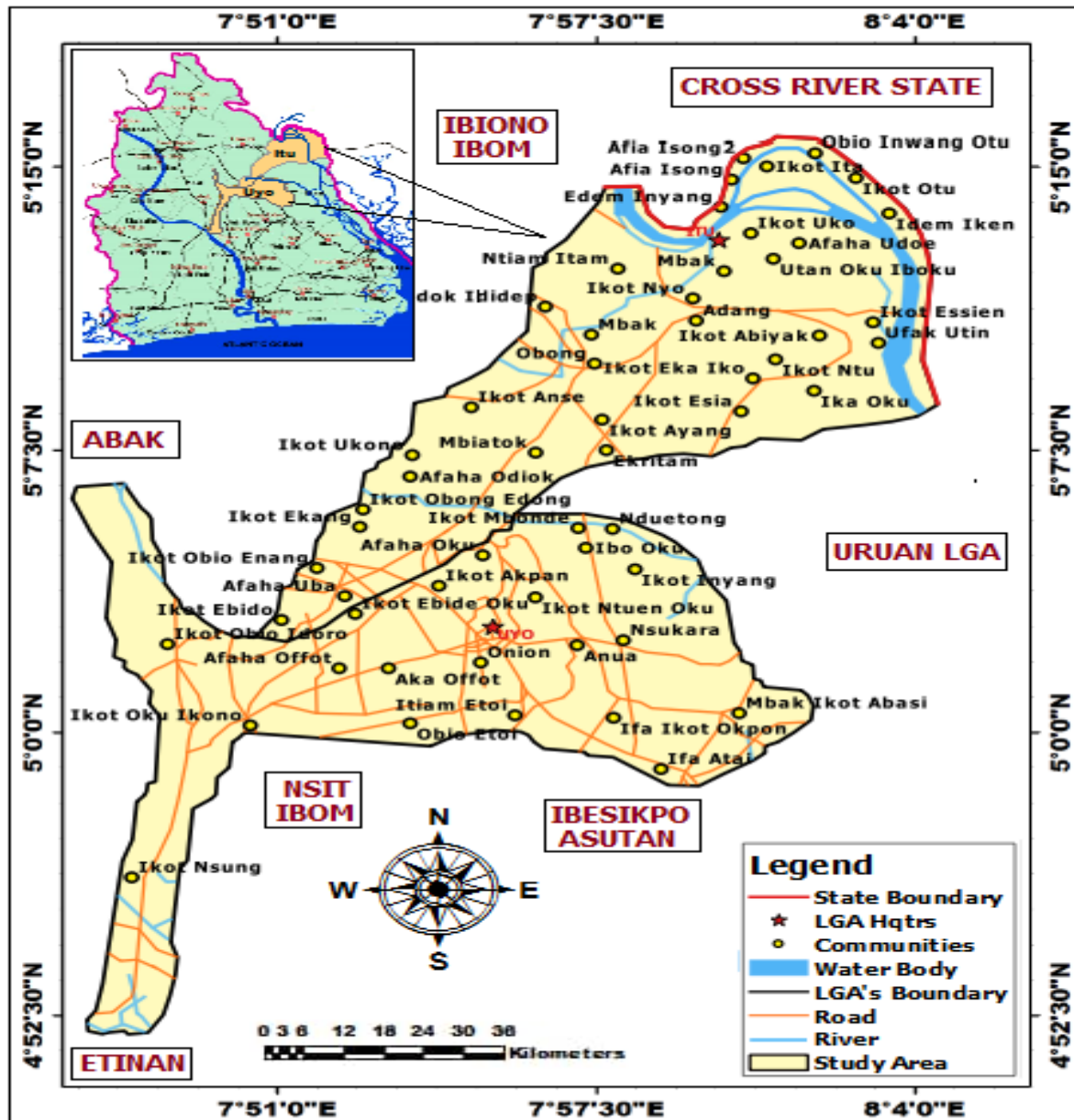


Figure 1: Study Area Map

#### 2.3.1. Mann-Kendall trend test

The Mann-Kendall (MK) test, a non-parametric test technique that is frequently used to identify patterns in datasets and is recommended by the World Meteorological Organization (WMO). It may be used to analyse data having non-normal distributions, including hydrologic and meteorological datasets (Hamed, 2008). Recent research has made extensive use of the MK technique to analyse trends in time series of temperature, rainfall, runoff, and water quality

(Yue et al. 2002). This study employed the MK test approach to evaluate the trends of time series data from the study region, including annual runoff, annual rainfall, annual mean temperature, relative humidity (RH), sun radiation (SR), and potential evapotranspiration (PET). Based on the linear regression the trend rate  $m_1$  was identified using Equation (1).

$$Y_t = m_1 x_t + c_0, \quad (1)$$

where  $x$  shows the runoff, rainfall, temperature, potential evapotranspiration at time  $t$  (1972-2021). The significance of  $m_1$  was verified by the t-test. The positive and negative values of  $m_1$  will indicate a growing and declining trend of PET, temperature, rainfall, and runoff in specific time series (Mavromatis and Stathis, 2011). Yue and Wang (2002) pointed out that the puissance of the trend depends on the sample size, magnitude of trend, the number of changes over a time series, and the adjusted significance level. Since  $x_j$  and  $x_k$  in time series  $X = \{x_1, x_2, \dots, x_n\}$  are independent, by Equation (2), the MK test statistics ( $S$ ) and signs was determined as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k}^n \text{sgn}(x_j - x_k), \quad (2)$$

$$\text{sng}(X_j - X_k) = \begin{cases} \text{if}(X_j - X_k) > 0, +1, \\ \text{if}(X_j - X_k) = 0, 0, \\ \text{if}(X_j - X_k) < 0, -1, \end{cases} \quad (3)$$

where  $n$  is the number of the variable set,  $x_j$  and  $x_k$  are the sequential variables at times  $j$  and  $k$ , and  $\text{sgn}$  is the sign function that takes on magnitudes of -1, 0, and +1. The subsequent value of  $S$  shows growing or declining trends in hydro-climatic variable sets.

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^p t_k(t_k-1)(2t_k+5)}{18}, \quad (4)$$

The tied group's number is shown by the  $p$ -value, and the  $t_k$  is the number of measured variability in the  $k$ th group. After the variance  $\text{Var}(S)$  is calculated from Equation (4), the standardized test statistic ( $Z_S$ ) was determined by Equation (5).

$$Z_S = \begin{cases} \frac{(S-1)}{\sqrt{\text{var}(S)}} & S > 0, \\ 0 & S = 0, \\ \frac{(S+1)}{\sqrt{\text{var}(S)}} & S < 0, \end{cases} \quad (5)$$

where  $Z_S$  demonstrates the significance of the trend. The  $Z_S$  is employed to test the null hypothesis,  $H_0$  if  $Z_S > \frac{Z_\alpha}{2}$  and "a" indicates the confidence level. The trend is significant at the 90% ( $\alpha = 0.1$ ), 95% ( $\alpha = 0.05$ ), and 99% ( $\alpha = 0.01$ ) confidence level if  $Z_S > 1.45$ ,  $Z_S > 1.96$ , and  $Z_S > 2.56$ . At the 1%, 5%, and 10% significance degree, the null hypothesis of no trend is rejected if  $Z_S > 1.45$ ,  $Z_S > 1.96$ , and  $Z_S > 2.56$ , respectively. Positive values of  $Z_S$  indicate increasing trends while negative  $Z_S$  values show decreasing trends. Testing trends is done at the specific  $\alpha$  significance level. When  $|Z_S| > Z_{1-(\alpha/2)}$ , the null hypothesis is rejected and a significant trend exists in the time series.  $Z_{1-(\alpha/2)}$  is obtained from the standard normal distribution table. In this study, significance level = 0.05 was used. The Mann-Kendall statistical test has been widely used to assess the significance of trends in hydro-meteorological

time series. (Partal and Kahya, 2006; Modarres and Silva, 2007; Tabari and Marofi, 2011; Tabari et al., 2011).

### 2.3.2. Sen's slope estimator

Sen (1998) developed the non-parametric approach for estimating the slope of trend in the sample of  $N$  pairs of data:

$$Q_i = \left( \frac{X_j - X_k}{j - k} \right) / dt \text{ for } i = 1, \dots, N, \quad (6)$$

where  $x_j$  and  $x_k$  show the data values at times  $j$  and  $k$  ( $j > k$ ), respectively.  $dt$  is the chosen time interval. If there is only one datum in each time period, then  $N = \frac{n(n-1)}{2}$  where  $n$  is the number of time periods. Otherwise,  $N < \frac{n(n-1)}{2}$ , where  $n$  is the total number of observations. The median of the “ $n$ ” values of  $N$  values of  $Q$  is Sen's estimator of slope. A positive value of  $Q$  shows an increasing trend, whereas a negative value shows a decreasing trend in the climatic time series data. The slope ( $Q$ ) of the “ $n$ ” values were sorted from smallest to the largest and the Sen's estimator was evaluated using Equation (7):

$$\text{Sen's estimator} = \frac{Q_{n+1}}{2} \text{ if } n \text{ is odd, } \frac{1}{2} \left[ \frac{Q_n}{2} + \frac{Q_{n+1}}{2} \right] \text{ if } n \text{ is even,} \quad (7)$$

where the sign of  $Q_{med}$  show the data trend pattern, whereas its value shows the steepness of the trend.

The lower and upper limits of the confidence interval,  $Q_{min}$  and  $Q_{max}$ , are the  $M_1$ th largest and the  $(M_2+1)$ th largest of the  $N$  ordered slope estimates (Gilbert, 1987). The slope  $Q_{med}$  is statistically different than zero if the two limits ( $Q_{min}$  and  $Q_{max}$ ) have similar sign. Sen's slope estimator has been widely used in hydro-meteorological time series (Yunling and Yiping, 2005; Partal and Kahya, 2006; ElNesr et al., 2010; Tabari and Marofi, 2011; Tabari et al., 2011a).

### 2.3.3 Coefficients of variation (CV) for all parameters

The coefficient of variation is a measure of how much the parameters deviate from the mean. The CV was calculated as

$$CV = \left( \frac{S}{\bar{y}} \right), \quad (8)$$

where,  $Y_i$  is the observed time series data of a particular time,  $\bar{y}$  is the average data from 1972 to 2021, and  $S$  is standard deviation. The degree of variability of rainfall was categorized as low when  $CV < 20\%$ , moderate when  $20\% < CV < 30\%$ , high when  $30\% < CV < 40\%$ , very high when  $40\% < CV < 70\%$ , and extremely high when  $CV > 70$  (Asfaw et al., 2018; Afangideh and Udokpoh, 2022).

## 2.4 Data processing

To examine time series trend analysis, the Mann Kendall test was used. To analyse the variations of these parameters, graphs were plotted using the Minitab 17 software, and the Mann Kendall Test was performed using "XLSTAT," an inbuilt tool in Excel used for statistical analysis. The data was analysed to see whether there were any climatic changes. The data was logically analysed, and basic tables, charts, and graphs were used. The hydro-meteorological data were used to analyse the trends that have occurred in Akwa Ibom State during the last 50 years. XLSTAT 2022 was used for the Mann-Kendall (MK) test and Sen's

slope statistical test to determine whether or not there are any statistically significant trends in the datasets, as well as the magnitudes of such trends. The null hypothesis ( $H_0$ ) assumes that there is no trend in the data, whereas the alternative hypothesis ( $H_1$ ) assumes that there is an increasing or decreasing trend over time.

### 3.0 Results and Discussion

The trend, slope and coefficient of variation analyses of rainfall, average maximum and minimum temperatures, relative humidity, solar radiation, evapotranspiration and runoff were carried out for the data collected from the meteorological and hydrological stations on a monthly, seasonal, annual and decadal basis during 1972-2021.

#### 3.1 Analysis of Rainfall

Monthly seasonal annual and decadal trends of rainfall obtained by Mann- Kendall test and Sen's slope estimator are given in **Table 3**. According to these results, the significant increasing trend in annual rainfall series was detected at the at the 5% significance level, while decadal. The significant increasing trends were observed in the month of January, February, March, May, June, July, August, September, and October, while April and November times series had no significant increasing trends at the 5% significance level. December data series witnessed a significant decreasing (negative) trend at the 5% significance level, which is the peak of the dry season in the study area. On the seasonal scale, there were the increasing trends in both dry and rainy seasons rainfall series. The Sen's slope rate of mean annual rainfall increase was 19.39 mm/y, while the rate of mean decadal increase was 3419.01mm/decade as shown in **Table 3**. On a monthly basis, the Sen's slope rate of mean monthly rainfall increase varies from 0.659mm/month to 4.135mm/month from January to November.

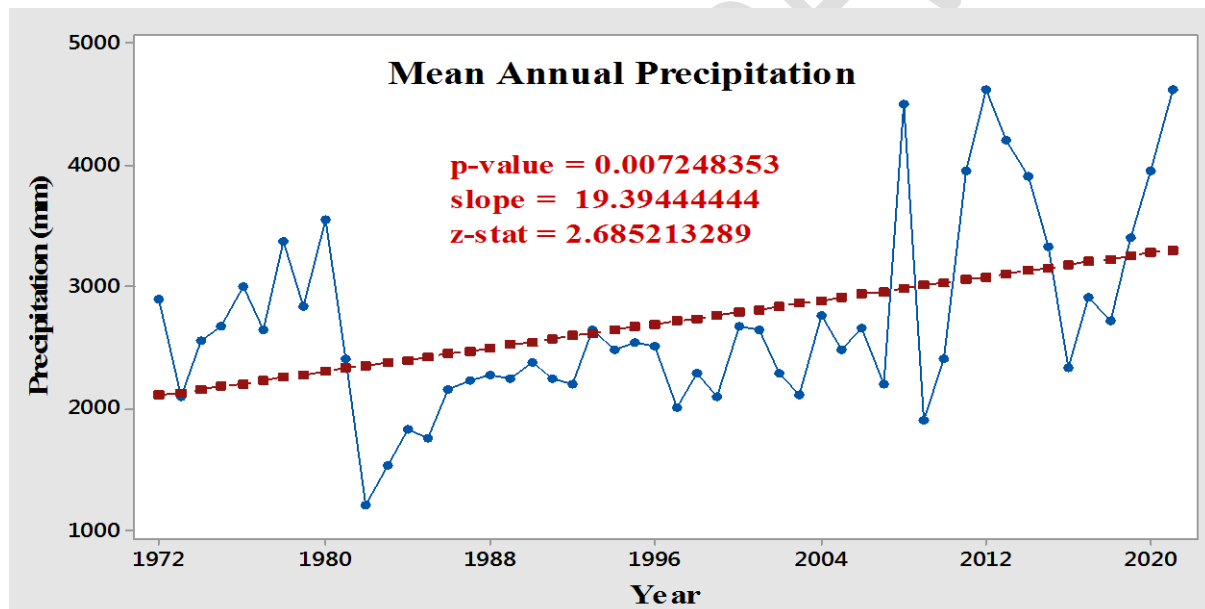
**Table 3:** Mann-Kendal test, Sen's slope estimator and CV analyses for rainfall.

| Months,<br>Seasonal,<br>Annual,<br>Decade | Rainfall (mm) |      |        |         |         |             |       |       |
|---|---------------|------|--------|---------|---------|-------------|-------|-------|
|   | First         | Last | CV     | p-value | Z- test | Sen's slope |       |       |
|   | Year          | Year | (%)    |         |         | Q           | Qmin  | Qmax  |
| January                                   | 1972          | 2021 | 129.8  | 0.01531 | 2.4248  | 0.659       | 0     | 1.48  |
| February                                  | 1972          | 2021 | 118.8  | 0.02109 | 2.30634 | 1.26        | 0.02  | 2.671 |
| March                                     | 1972          | 2021 | 46.24  | 0.04124 | 2.0411  | 1.0923      | 0.08  | 2.30  |
| April                                     | 1972          | 2021 | 38.09  | 0.24493 | 1.16277 | 0.983       | -0.47 | 2.763 |
| May                                       | 1972          | 2021 | 31.65  | 0.04040 | 2.0496  | 1.8571      | 0.05  | 3.75  |
| June                                      | 1972          | 2021 | 52.53  | 0.02094 | 2.3090  | 3.0815      | 0.5   | 6.291 |
| July                                      | 1972          | 2021 | 50.55  | 0.01673 | 2.3927  | 4.135       | 0.61  | 8.727 |
| August                                    | 1972          | 2021 | 40.92  | 0.0284  | 2.1917  | 3.30        | 0.3   | 6.46  |
| September                                 | 1972          | 2021 | 36.70  | 0.05228 | 1.9408  | 2.381       | -0.02 | 4.478 |
| October                                   | 1972          | 2021 | 40.86  | 0.04291 | 2.02463 | 2.275       | 0.04  | 4.996 |
| November                                  | 1972          | 2021 | 79.38  | 0.13205 | 1.50608 | 1.6786      | -0.4  | 3.889 |
| December                                  | 1972          | 2021 | 192.80 | 0.02199 | -2.2906 | -0.1103     | -0.32 | 0     |
| Dry season                                | 1972          | 2021 | 106.1  | 0.0027  | 3.000   | 2.868       | 0.821 | 5.376 |
| Wet season                                | 1972          | 2021 | 29.28  | 0.0031  | 2.961   | 28.04       | 12.13 | 42.54 |
| Annual                                    | 1972          | 2021 | 28.7   | 0.00725 | 2.6852  | 19.394      | 4.39  | 35.44 |

|        |      |      |       |         |         |         |   |   |
|--------|------|------|-------|---------|---------|---------|---|---|
| Decade | 1972 | 2021 | 22.07 | 0.46243 | 0.73485 | 3419.01 | - | - |
|--------|------|------|-------|---------|---------|---------|---|---|

Maximum increase rates above 2mm/month were seen in June, July, August, September and October while minimum increase rates below 2mm/month were observed in January, February, March, April, May and November. However, the Sen’s slope of a mean monthly decrease of -0.1103mm/month was detected in December. The rate of mean seasonal increase in dry season was observed to be far lesser than in rainy season.

The annual and decadal rainfall CVs were 28.7% and 22.07%, implying moderate variability of rainfall (**Table 3**). The monthly CVs showed high variability in April, May and September, while it showed very high variability in March, June, July, August and October. During the dry season, there was extremely high variability in January, February, November and December respectively. On seasonal scale, moderate and extremely high variabilities were seen in rainy and dry seasons datasets respectively. The extremely high variability in precipitation indicates high uncertainty in precipitation in a given year and also presents greater challenges for water management, in particular at field scales (Getahun et al., 2021). However, Pendergrass et al. (2017) reported in their study that higher variability in monthly precipitation is a result of seasonality and climatic conditions. Rainy seasons and wet climates tend to have less precipitation variability than dry seasons and warm climates.



**Figure 2:** Mann-Kendall trend test for mean annual rainfall

### 3.1 Analysis of Maximum and Minimum Temperatures

The MK trend test and Sen’s slope estimator were used to assess the average monthly, seasonal, annual and decadal maximum and minimum temperatures. Results of applying statistical tests for data series over the period 1972 to 2021 are presented in **Tables 4** and **5**. The MK test showed a statistically significant increasing trend in the maximum temperature of decade-long, annual, seasonal and monthly basis. The increasing trends in air temperature series have been caused by several factors, such as global warming, increased urbanisation and changes in atmospheric circulation (Gocic and Trajkovic, 2013). For the minimum temperature, significant increasing trends were also witnessed in seasonal, annual and selected monthly datasets at a 95% confidence level. February, November and December were among the few months that had non-significantly increasing trends in their datasets, including decadal data series. A non-significant decreasing trend was observed in the January datasets at a 95%

confidence level. This could be attributed to the fact that these months fall within the period of the dry season in Akwa Ibom State. The Sen's slope rate of average annual maximum temperature increase was 0.0314 degrees Celsius per year, while the rate of mean decadal increase was 0.5021 degrees Celsius per decade.

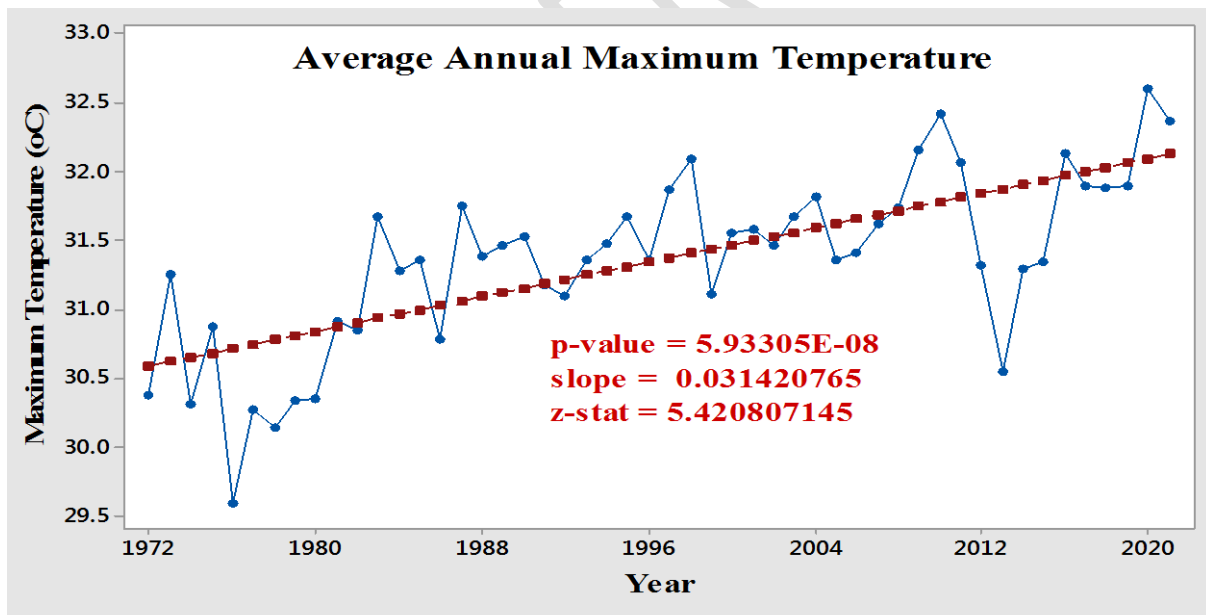
**Table 4:** Mann-Kendal test, Sen's slope and CV analyses for Maximum Temperature.

| Months,<br>Seasonal,<br>Annual,<br>Decade | Maximum Temperature (°C) |      |       |          |         |             |       |       |
|---|--------------------------|------|-------|----------|---------|-------------|-------|-------|
|   | First                    | Last | CV    | p-value  | Z- test | Sen's slope |       |       |
|   | Year                     | Year | (%)   |          |         | Q           | Qmin  | Qmax  |
| January                                   | 1972                     | 2021 | 2.99  | 8.60E-09 | 5.757   | 0.051       | 0.04  | 0.062 |
| February                                  | 1972                     | 2021 | 3.04  | 0.0028   | 2.990   | 0.036       | 0.01  | 0.056 |
| March                                     | 1972                     | 2021 | 3.45  | 0.0009   | 3.321   | 0.036       | 0.02  | 0.055 |
| April                                     | 1972                     | 2021 | 2.40  | 0.00025  | 3.665   | 0.027       | 0.01  | 0.037 |
| May                                       | 1972                     | 2021 | 2.17  | 2.40E-06 | 4.720   | 0.032       | 0.02  | 0.043 |
| June                                      | 1972                     | 2021 | 2.51  | 0.0136   | 2.4690  | 0.019       | 0     | 0.033 |
| July                                      | 1972                     | 2021 | 2.96  | 0.002    | 3.088   | 0.027       | 0.01  | 0.044 |
| August                                    | 1972                     | 2021 | 4.20  | 0.0142   | 2.452   | 0.022       | 0.01  | 0.039 |
| September                                 | 1972                     | 2021 | 14.64 | 8.68E-05 | 3.925   | 0.028       | 0.02  | 0.043 |
| October                                   | 1972                     | 2021 | 14.68 | 6.23E-10 | 6.185   | 0.051       | 0.04  | 0.06  |
| November                                  | 1972                     | 2021 | 14.64 | 2.77E-08 | 5.556   | 0.041       | 0.03  | 0.053 |
| December                                  | 1972                     | 2021 | 2.96  | 2.99E-09 | 5.932   | 0.051       | 0.04  | 0.063 |
| Dry season                                | 1972                     | 2021 | 2.487 | 4.41E-09 | 5.805   | 0.045       | 0.034 | 0.056 |
| Wet season                                | 1972                     | 2021 | 5.170 | 4.75E-07 | 5.036   | 0.031       | 0.021 | 0.041 |
| Annual                                    | 1972                     | 2021 | 2.03  | 5.90E-08 | 5.421   | 0.0314      | 0.02  | 0.041 |
| Decade                                    | 1972                     | 2021 | 2.59  | 0.0275   | 2.204   | 0.5021      | -     | -     |

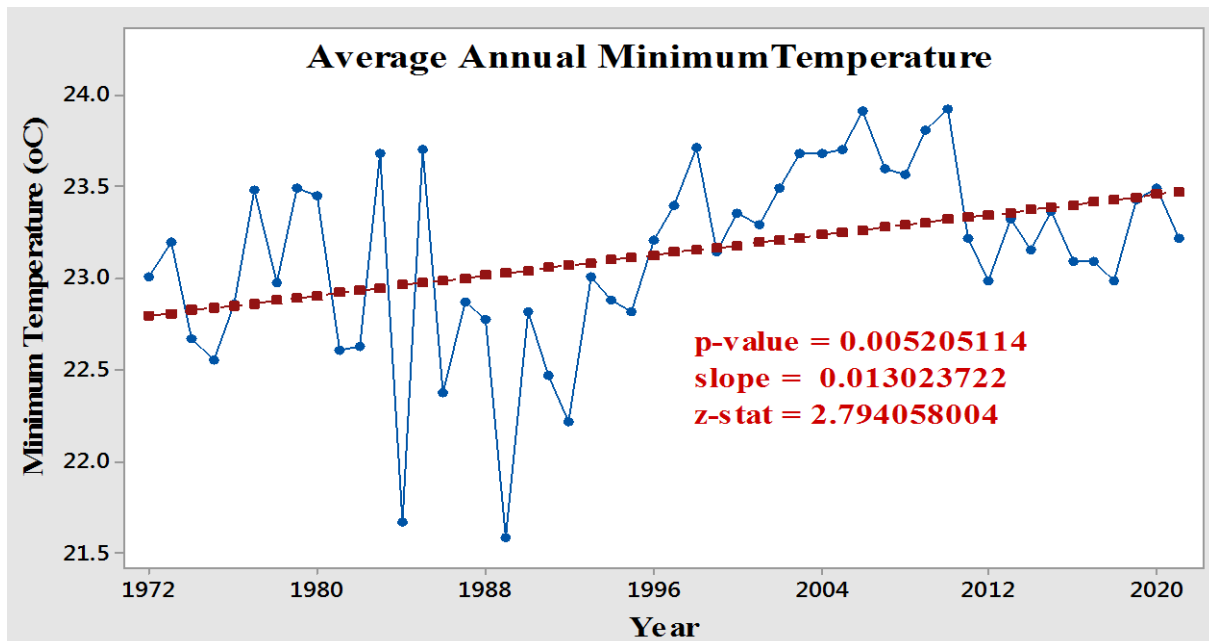
The Sen's slope of average annual minimum temperature increase was 0.013 degrees Celsius per year, while the rate of mean decade increase was 0.652 degrees Celsius per decade. Maximum increase rates for average minimum temperature above 0.0002°C/month but not greater 0.0176°C/month were detected in February to December, while a rate of mean monthly decrease for January was -0.009°C/month. The coefficient of variation for average decade, annual, seasonal and monthly data series for both maximum and minimum temperatures were below 20% indicating low variability, according to Asfaw et al. (2018). This implies that all the datasets have far less variation relative to their means. The result of trend analysis for temperature are in comparison with the research of Gulahmadov et al. (2021) in Kofarnihon River Basin. Their results revealed an increasing trend in annual temperature in the regions at a rate of 0.023°C/year and 0.0108°C/year. They attributed these increased trends in air temperature to global warming. Also, the results obtained for maximum and minimum temperature series are in line with Tabari and Marofi (2011) and Khosravia et al. (2016) who detected increasing of air temperature in the western part of Iran and in Serbia, respectively. The increasing trends in air temperature series have been caused by several factors such as global warming, increased urbanized area and changes in atmospheric circulation (Tabari et al., 2011a). For the monthly data set, the Sen's slope rate of average monthly maximum temperature increased at an average of 0.035°C/month with maximum and minimum values in January, October, December and August.

**Table 5:** Mann-Kendal test, Sen's slope and CV analyses for Minimum Temperature.

| Months,<br>Seasonal,<br>Annual,<br>Decade | Minimum Temperature (°C) |      |       |          |         |             |       |        |
|---|--------------------------|------|-------|----------|---------|-------------|-------|--------|
|   | First                    | Last | CV    | p-value  | Z- test | Sen's slope |       |        |
|   | Year                     | Year | (%)   |          |         | Q           | Qmin  | Qmax   |
| January                                   | 1972                     | 2021 | 5.256 | 0.327    | -0.979  | -0.009      | -0.03 | 0.011  |
| February                                  | 1972                     | 2021 | 3.431 | 0.94     | 0.075   | 0.0002      | -0.01 | 0.015  |
| March                                     | 1972                     | 2021 | 2.726 | 0.0056   | 2.770   | 0.015       | 0     | 0.028  |
| April                                     | 1972                     | 2021 | 2.414 | 0.0099   | 2.578   | 0.0162      | 0     | 0.024  |
| May                                       | 1972                     | 2021 | 2.438 | 1.40E-03 | 3.180   | 0.0175      | 0.01  | 0.028  |
| June                                      | 1972                     | 2021 | 2.133 | 0.0026   | 3.015   | 0.014       | 0.01  | 0.021  |
| July                                      | 1972                     | 2021 | 2.898 | 1.40E-05 | 4.343   | 0.022       | 0.01  | 0.032  |
| August                                    | 1972                     | 2021 | 2.204 | 2.23E-04 | 3.691   | 0.014       | 0.01  | 0.021  |
| September                                 | 1972                     | 2021 | 2.363 | 2.39E-05 | 4.225   | 0.0173      | 0.01  | 0.025  |
| October                                   | 1972                     | 2021 | 2.463 | 3.89E-04 | 3.547   | 0.0176      | 0.01  | 0.026  |
| November                                  | 1972                     | 2021 | 2.751 | 0.0543   | 1.924   | 0.0131      | 0     | 0.028  |
| December                                  | 1972                     | 2021 | 4.20  | 0.273    | 1.096   | 0.0101      | -0.01 | 0.03   |
| Dry season                                | 1972                     | 2021 | 3.502 | 0.007    | 2.676   | 0.0194      | 0.007 | 0.0356 |
| Wet season                                | 1972                     | 2021 | 2.089 | 0.0006   | 3.430   | 0.0162      | 0.008 | 0.0243 |
| Annual                                    | 1972                     | 2021 | 2.23  | 5.20E-03 | 2.794   | 0.013       | 0     | 0.022  |
| Decade                                    | 1972                     | 2021 | 4.29  | 0.0864   | 1.715   | 0.652       | -     | -      |



**Figure 3:** Mann-Kendall trend test for average annual maximum temperature



**Figure 4:** Mann-Kendall trend test for average annual minimum temperature

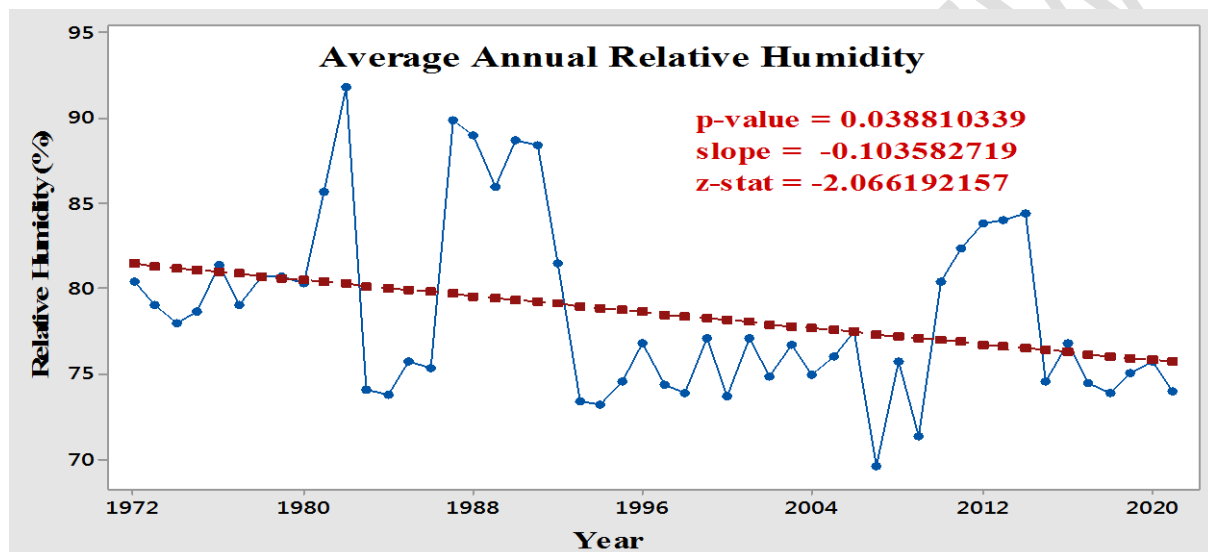
### 3.3 Analysis of Relative Humidity

The output of the analysed relative humidity series is summarised in **Table 6**. The MK test for relative humidity showed a significant decreasing trend in the average annual and rainy season dataset, while a non-significant decreasing trends were observed in the average decade and monthly datasets at a 95% confidence level. The significant decreasing trend in the annual relative humidity series was found to be -0.104% per year and a non-significant trend in decade relative humidity was -2.194% per decade. However, the rate of decrease for seasonal were -0.153% and -0.104% for dry and rainy season respectively. On the monthly time scale, non-significant trends were found in the twelve months and varied from -0.009% to -0.148% per month, following no particular order. The decreasing trend in relative humidity is due to the fact that increase in temperature increases the amount of water vapour the air can hold, therefore decreasing relative humidity. The coefficient of variation for decadal, annual, seasonal and monthly data series of relative humidity were below 20 percent, indicating low variability. Gocic and Trajkovic (2013) analysed the changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. They analysed the annual and seasonal trends of seven meteorological variables from twelve weather stations in Serbia for 30 years of datasets (from 1980-2010). The result of their analysis showed a significant decreasing trend in the annual series of relative humidity at four out of the seven observed stations and they attributed to increase in atmospheric temperature.

**Table 6:** Mann-Kendal test, Sen's slope and CV analyses for Relative Humidity.

| Months,<br>Seasonal,<br>Annual,<br>Decade | Relative Humidity (%) |              |           |         |         |        |       |       |
|---|-----------------------|--------------|-----------|---------|---------|--------|-------|-------|
|   | First<br>Year         | Last<br>Year | CV<br>(%) | p-value | Z- test | Q      | Qmin  | Qmax  |
| January                                   | 1972                  | 2021         | 16.87     | 0.255   | -1.138  | -0.101 | -0.30 | 0.063 |
| February                                  | 1972                  | 2021         | 17.59     | 0.153   | -1.431  | -0.148 | -0.41 | 0.050 |
| March                                     | 1972                  | 2021         | 11.49     | 0.371   | -0.895  | -0.089 | -0.27 | 0.110 |
| April                                     | 1972                  | 2021         | 7.00      | 0.340   | -0.954  | -0.048 | -0.14 | 0.05  |
| May                                       | 1972                  | 2021         | 5.90      | 0.427   | -0.795  | -0.034 | -0.09 | 0.053 |

|            |      |      |       |        |        |        |        |       |
|------------|------|------|-------|--------|--------|--------|--------|-------|
| June       | 1972 | 2021 | 5.22  | 0.412  | -0.820 | -0.027 | -0.11  | 0.037 |
| July       | 1972 | 2021 | 4.57  | 0.808  | -0.243 | -0.009 | -0.09  | 0.062 |
| August     | 1972 | 2021 | 4.26  | 0.394  | -0.853 | -0.029 | -0.11  | 0.044 |
| September  | 1972 | 2021 | 4.720 | 0.700  | -0.384 | -0.015 | -0.09  | 0.073 |
| October    | 1972 | 2021 | 6.23  | 0.303  | -1.029 | -0.045 | -0.12  | 0.057 |
| November   | 1972 | 2021 | 8.94  | 0.315  | -1.004 | -0.060 | -0.22  | 0.068 |
| December   | 1972 | 2021 | 12.08 | 0.738  | -0.335 | -0.026 | -0.19  | 0.116 |
| Dry season | 1972 | 2021 | 12.13 | 0.064  | -1.849 | -0.153 | -0.292 | 0.007 |
| Wet season | 1972 | 2021 | 5.194 | 0.039  | -2.066 | -0.071 | -0.130 | 0.007 |
| Annual     | 1972 | 2021 | 6.66  | 0.0339 | -2.066 | -0.104 | -0.18  | -0.01 |
| Decade     | 1972 | 2021 | 5.26  | 0.086  | -1.714 | -2.194 | -      | -     |



**Figure 5:** Mann-Kendall trend test for average annual relative humidity

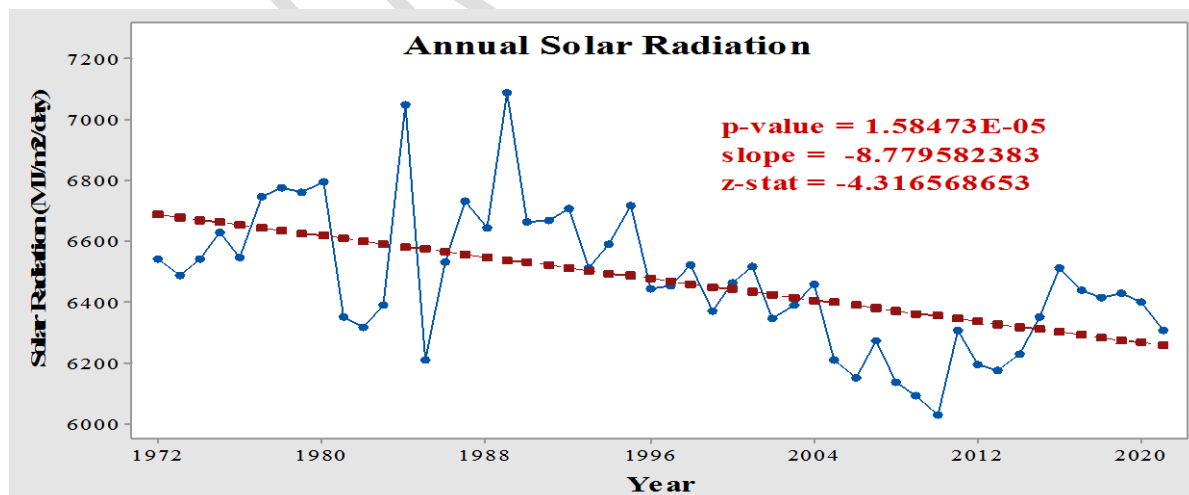
### 3.4 Analysis of Solar Radiation

Solar radiation is another important climate parameter that was considered in this study. The results of the MK test and Sen's slope estimate for solar radiation of decade, annual and monthly data series are presented in **Table 7**. The MK test for solar radiation revealed a significant decreasing trend of mean annual, rainy season and selected monthly (March-October) datasets, while a non-significant decreasing trends were also found in average decade, dry season and selected monthly (November, December, January and February) datasets at a 95% confidence level over the period 1972-2021. The significant decreasing trend in mean annual solar radiation was  $-8.78 \text{ MJ/m}^2$  per year, while the non-significant decreasing trend in decade solar radiation was  $-940.2 \text{ MJ/m}^2$  per decade. Also, the Sen's slope rate of decrease for seasonal datasets were  $-0.577 \text{ MJ/m}^2$  and  $-8.001 \text{ MJ/m}^2$  for dry and rainy season respectively. On the monthly time series, statistically significant decreasing trends were observed from March to October and varied from  $-0.206 \text{ MJ/m}^2$  to  $-1.520 \text{ MJ/m}^2$  per month. These months represent months with high and excessive rainfall in the study area. Also, statistically non-significant decreasing trends were observed in January, February, November, December and varied from  $-0.032 \text{ MJ/m}^2$  to  $-0.613 \text{ MJ/m}^2$  per month. According to Sarkar et al. (2022), significant decreasing trend in solar radiation is likely due to atmospheric changes when increases in cloudiness, precipitation, heavy fog, and aerosol concentration occur. However, the findings are consistent with the findings of Ohunakin et al. (2015), who predicted a decrease in

solar radiation towards the end of the century, with the greatest reduction in the south zone of Nigeria and the least in the north. Russak (2009) has also reported on a statistically significant decrease in the annual totals of global solar radiation that was detected from 1955 to the beginning of the 1990s with the annual mean temperature continuously increasing. This shows that the results obtained in this study are in line with global outcomes. However, the coefficient of variation for decade, annual, seasonal and monthly data series of solar radiation was below 10 percent, indicating low variability.

**Table 7:** Mann-Kendal test, Sen’s slope and CV analysis for Solar Radiation.

| Months,<br>Seasonal,<br>Annual,<br>Decade | Solar Radiation (MJ/m <sup>2</sup> /day) |      |      |          |         |             |        |        |
|---|--|------|------|----------|---------|-------------|--------|--------|
|   | First                                    | Last | CV   | p-value  | Z- test | Sen's slope |        |        |
|   | Year                                     | Year | (%)  |          |         | Q           | Qmin   | Qmax   |
| January                                   | 1972                                     | 2021 | 5.61 | 0.547    | -0.602  | -0.256      | -0.81  | 0.392  |
| February                                  | 1972                                     | 2021 | 6.17 | 0.056    | -1.907  | -0.613      | -1.38  | 0.006  |
| March                                     | 1972                                     | 2021 | 5.44 | 5.15E-05 | -4.049  | -1.158      | -1.71  | -0.594 |
| April                                     | 1972                                     | 2021 | 4.11 | 1.89E-08 | -5.622  | -1.161      | -1.51  | 0.882  |
| May                                       | 1972                                     | 2021 | 5.34 | 4.04E-06 | -4.610  | -1.179      | -1.72  | -0.605 |
| June                                      | 1972                                     | 2021 | 7.44 | 1.08E-05 | -4.400  | -1.520      | -2.18  | -0.88  |
| July                                      | 1972                                     | 2021 | 7.53 | 0.005    | -2.828  | -1.021      | -1.75  | 0.270  |
| August                                    | 1972                                     | 2021 | 6.57 | 0.0002   | -3.731  | -1.052      | -1.600 | -0.557 |
| September                                 | 1972                                     | 2021 | 5.01 | 0.0016   | -3.154  | -0.821      | -1.3   | -0.338 |
| October                                   | 1972                                     | 2021 | 2.85 | 0.0365   | -2.091  | -0.206      | -0.44  | -0.014 |
| November                                  | 1972                                     | 2021 | 5.62 | 0.639    | -0.468  | -0.101      | -0.59  | 0.304  |
| December                                  | 1972                                     | 2021 | 6.55 | 0.933    | -0.084  | -0.032      | -0.58  | 0.655  |
| Dry season                                | 1972                                     | 2021 | 4.01 | 0.389    | -0.862  | -0.577      | -1.931 | 0.821  |
| Wet season                                | 1972                                     | 2021 | 4.04 | 2.38E-06 | -4.718  | -8.001      | -11.53 | -5.328 |
| Annual                                    | 1972                                     | 2021 | 5.61 | 1.58E-05 | -4.317  | -8.780      | -12.75 | -4.89  |
| Decade                                    | 1972                                     | 2021 | 2.69 | 0.221    | -1.225  | -940.2      | -      | -      |



**Figure 6:** Mann-Kendall trend test for mean annual solar radiation

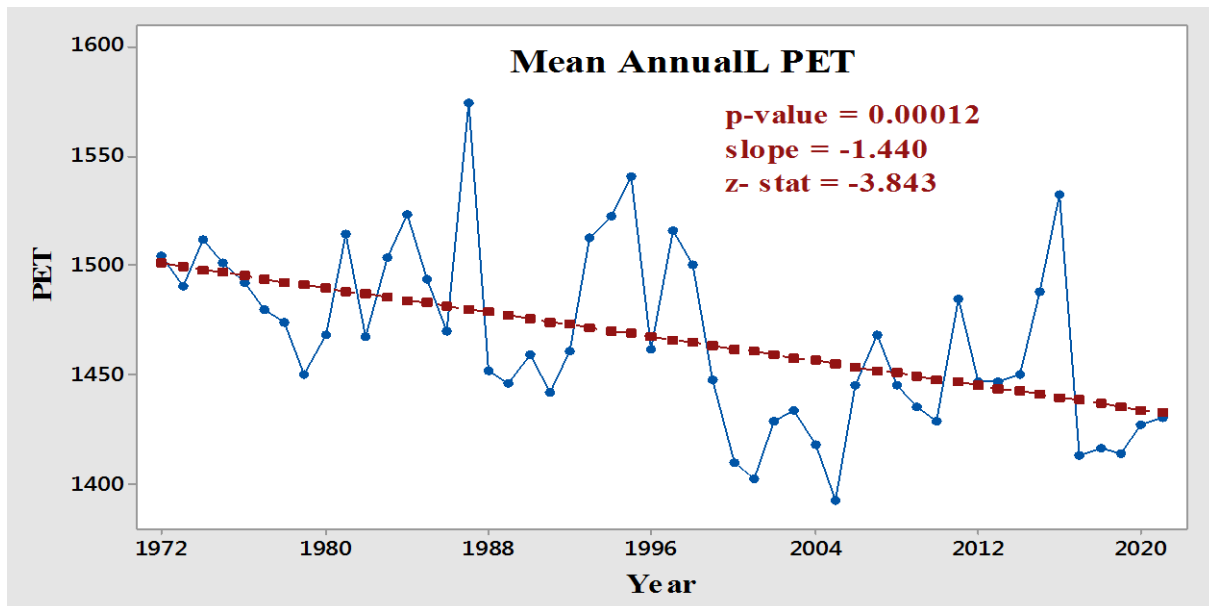
### 3.5 Analysis of Potential Evapotranspiration (PET)

The results of the MK test and Sen’s slope estimate for potential evapotranspiration using mean decade, annual seasonal and monthly data series are presented in Table 8. The MK test for PET

revealed a statistically significant decreasing trend in the mean annual dataset, whereas a non-significant decreasing trends were found in the average decade, seasonal and monthly (except December) data series at a 95% confidence level. The significant decreasing trend in mean annual evapotranspiration was seen to be -1.440mm per year and a non-significant decreasing trend in decade evapotranspiration was -11.31mm per decade. The coefficient of variation for decadal, annual, seasonal and monthly data series of PET were below 20 percent, indicating low variability. Potential evapotranspiration is an important element of the hydrological cycle, and changes in PET are of great significance for water resources management. Oderinde et al. (2021) evaluated the trend and decadal variability of the potential evapotranspiration in the Oluyole Local Government Area for one climatic period ranging between 1991 and 2020, using the MK method, for data obtained from the NASA Langley Research Center POWER Project portal. Their results revealed that the annual trend of potential evapotranspiration for the period analysed showed a positive statistically non-significant ( $p > 0.05$ ) trend. However, the findings of their study contradict the outcome of this present study. The decreasing trend observed in potential evapotranspiration is attributed to a significant decrease in solar radiation (Wang et al., 2012). PET is dependent primarily on the availability of solar energy to vaporise. Nevertheless, solar radiation is considered one of the positive factors that affect PET.

**Table 8:** Mann-Kendal test, Sen's slope and CV analyses for PET.

| Months,<br>Seasonal,<br>Annual,<br>Decade | Evapotranspiration (mm) |      |       |         |         |             |        |        |
|---|-------------------------|------|-------|---------|---------|-------------|--------|--------|
|   | First                   | Last | CV    | p-value | Z- test | Sen's slope |        |        |
|   | Year                    | Year | (%)   |         |         | Q           | Qmin   | Qmax   |
| January                                   | 1972                    | 2021 | 5.58  | 0.7128  | -0.368  | -0.029      | -0.039 | -0.018 |
| February                                  | 1972                    | 2021 | 4.48  | 0.0657  | -1.840  | -0.087      | -0.092 | -0.079 |
| March                                     | 1972                    | 2021 | 3.48  | 0.170   | -1.372  | -0.063      | -0.072 | -0.058 |
| April                                     | 1972                    | 2021 | 3.34  | 0.581   | -0.552  | -0.022      | -0.029 | -0.017 |
| May                                       | 1972                    | 2021 | 3.41  | 0.947   | -0.067  | -0.002      | -0.007 | 0.0005 |
| June                                      | 1972                    | 2021 | 4.18  | 0.616   | -0.502  | -0.016      | -0.020 | -0.010 |
| July                                      | 1972                    | 2021 | 5.88  | 0.867   | -0.167  | -0.013      | -0.025 | -0.004 |
| August                                    | 1972                    | 2021 | 4.48  | 0.255   | -1.138  | -0.563      | -0.060 | -0.051 |
| September                                 | 1972                    | 2021 | 3.73  | 0.146   | -1.455  | -0.054      | -0.063 | -0.049 |
| October                                   | 1972                    | 2021 | 2.92  | 0.581   | 0.552   | 0.018       | 0.014  | 0.024  |
| November                                  | 1972                    | 2021 | 5.08  | 0.115   | 1.572   | 0.071       | 0.063  | 0.078  |
| December                                  | 1972                    | 2021 | 5.44  | 0.018   | 2.376   | 0.094       | 0.090  | 0.102  |
| Dry season                                | 1972                    | 2021 | 3.58  | 0.4029  | -0.836  | -0.147      | -0.166 | -0.133 |
| Wet season                                | 1972                    | 2021 | 2.64  | 0.2996  | -1.037  | -0.320      | -0.346 | -0.346 |
| Annual                                    | 1972                    | 2021 | 2.751 | 0.00012 | -3.848  | -1.440      | -2.061 | -0.842 |
| Decade                                    | 1972                    | 2021 | 1.564 | 0.086   | -1.715  | -11.31      | -22.57 | -5.46  |



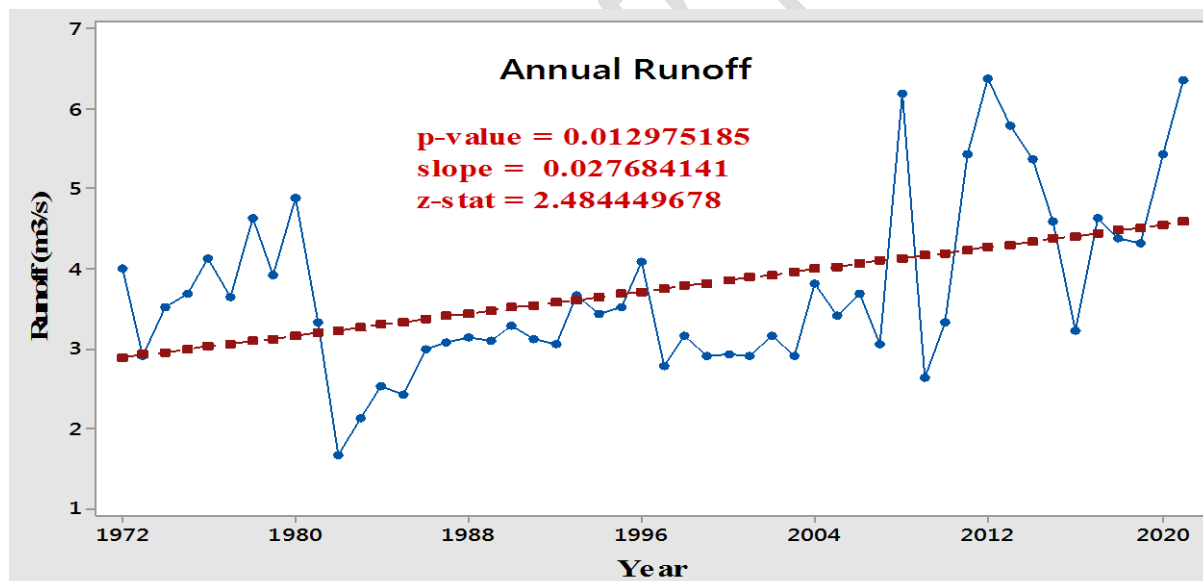
**Figure 7:** Mann-Kendall trend test for mean annual PET

### 3.6 Analysis of Runoff

The MK trend test and Sen's slope estimator were also used on mean monthly, seasonal, annual and decadal runoff data series. The MK test revealed a significant increasing trend in the runoff of annual, seasonal and monthly series, except for the decade, April and November, which had a non-significant statistical trend. On the contrary, a significant decreasing (negative) trend was observed in December, which is a month of less or no precipitation in the study area (**Table 9**). The Sen's slope rate for mean annual runoff increase was  $0.028\text{m}^3/\text{s}$  per year, while that of the mean decade increase was  $5.139\text{m}^3/\text{s}$  per decade. On the monthly data series, the mean monthly runoff increased from  $0.0005\text{m}^3/\text{s}$  to  $0.0057\text{m}^3/\text{s}$  per month from January to November. Conversely, the Sen's slope of mean a monthly decrease of  $-0.0002\text{m}^3/\text{s}$  per month was observed in December. Moreover, the Sen's slope rate of increase for seasonal datasets were  $-0.0025\text{m}^3/\text{s}$  and  $0.0315\text{m}^3/\text{s}$  for dry and rainy season respectively. The mean annual and decade-long precipitation CV were 29.18% and 25.28%, implying moderate variability in runoff (**Table 9**). On seasonal scale, moderate and extremely high variabilities were seen in rainy and dry seasons datasets respectively. The monthly CV showed high variability in May (31.71%), while March (51.01%), Aril (40.02%), June (50.48%), July (48.27%), August (40.71%), September (52.01%), October (46.59%) showed very high variability. During the period of less or no rain, there was extremely high variability in January, February, November and December. Accordingly, extremely high variability in runoff indicates high uncertainty in the runoff a given period. The results of trend and CV analysis show similar pattern to that of precipitation, which indicates that runoff is greatly influenced by precipitation. Yao et al. (2021) reported a strong relationship between rainfall intensity and runoff in their research. Their findings revealed that when the rainfall intensity increases to 50mm/hr, both the surface and beneath the ground generate runoff. Rainfall is the most important meteorological parameter for hydrological responses, as it controls other processes such as infiltration, runoff, detention storage, and evapotranspiration (Kumari et al., 2019). However, Kumari et al. (2019) analysed the correlation between annual rainfall and annual runoff over a period of 118 years (1901-2018) for Jamshedpur of East Singhbhum district, Jharkhand, through graphical analysis method and found that the values of annual rainfall and runoff were strongly correlated. The value of their Pearson correlation coefficient ( $r$ ) was almost equal to +1, which is a perfect positive correlation and signifies that both variables move in the same direction.

**Table 9:** Mann-Kendal test, Sen's slope and CV analyses for Runoff.

| Months,<br>Annual,<br>Decade | Runoff (m <sup>3</sup> /s) |      |        |         |         |             |         |       |
|------------------------------|----------------------------|------|--------|---------|---------|-------------|---------|-------|
|                              | First                      | Last | CV     | p-value | Z- test | Sen's slope |         |       |
|                              | Year                       | Year | (%)    |         |         | Q           | Qmin    | Qmax  |
| January                      | 1972                       | 2021 | 127.8  | 0.033   | 2.135   | 0.0005      | 0       | 0.002 |
| February                     | 1972                       | 2021 | 123.9  | 0.040   | 2.055   | 0.0015      | 0       | 0.003 |
| March                        | 1972                       | 2021 | 51.01  | 0.035   | 2.100   | 0.0017      | 1E-04   | 0.004 |
| April                        | 1972                       | 2021 | 40.02  | 0.284   | 1.071   | 0.0012      | -0      | 0.004 |
| May                          | 1972                       | 2021 | 31.71  | 0.003   | 3.003   | 0.0038      | 0.001   | 0.006 |
| June                         | 1972                       | 2021 | 50.48  | 0.0132  | 2.476   | 0.0053      | 1E-03   | 0.009 |
| July                         | 1972                       | 2021 | 48.27  | 0.0006  | 3.422   | 0.0083      | 0.003   | 0.014 |
| August                       | 1972                       | 2021 | 40.71  | 0.0278  | 2.200   | 0.0051      | 0.004   | 0.009 |
| September                    | 1972                       | 2021 | 52.01  | 0.0160  | 2.410   | 0.0057      | 0.001   | 0.011 |
| October                      | 1972                       | 2021 | 46.59  | 0.020   | 2.318   | 0.0043      | 6E-04   | 0.009 |
| November                     | 1972                       | 2021 | 76.11  | 0.106   | 1.615   | 0.0023      | -0      | 0.005 |
| December                     | 1972                       | 2021 | 192.80 | 0.021   | -2.300  | -0.0002     | -0      | 0     |
| Dry season                   | 1972                       | 2021 | 99.99  | 0.015   | 2.443   | 0.0025      | -0.0033 | 0.009 |
| Wet season                   | 1972                       | 2021 | 29.53  | 0.016   | 2.392   | 0.0315      | -0.026  | 0.096 |
| Annual                       | 1972                       | 2021 | 29.18  | 0.013   | 2.484   | 0.028       | -0.026  | 0.096 |
| Decade                       | 1972                       | 2021 | 25.28  | 0.086   | 1.715   | 5.139       | -       | -     |

**Figure 8:** Mann-Kendall trend test for mean annual runoff

#### 4.0 Conclusion and Recommendation

The variability of the climate has not been greatly investigated in Nigeria. Because of that, the aim of this study was to perform an analysis of the monthly, seasonal, annual and decadal trends and coefficients of variation of seven hydro-meteorological variables in Akwa Ibom State, Nigeria, from 1972 to 2021. The analysis was obtained by applying the non-parametric Mann-Kendall and Sen's slope estimator methods to the time series. The hydro-meteorological data used were from NiMet and CRBDA stations, which had good-quality datasets with reliable data and adequate record length.

The results of Mann-Kendall and Sen's slope analysis reveal a significant statistically increasing (positive) trend in average seasonal and annual rainfall, maximum temperature, minimum temperature and runoff. However, a significant statistically decreasing (negative) trend was observed in average annual relative humidity, solar radiation and potential evapotranspiration. The magnitude of the trends was 19.39mm/year, 0.0314°C/year, 0.013°C/year, -0.104%/year, -8.78MJ/m<sup>2</sup>/year, -1.440mm/year and 0.028m<sup>3</sup>/s/year for annual rainfall, maximum temperature, minimum temperature, relative humidity, solar radiation, PET and runoff, respectively. The increasing trends in precipitation, temperatures and runoff in this study area indicate that this region faces climate variability.

In general, the results of using Mann-Kendall and Sen's slope estimator statistical tests pointed out the agreement of performance that exists in the detection of the trend for the hydro-meteorological variables. Changes in atmospheric temperature and rainfall amounts will have significant impacts on water resource structures, biodiversity and food security in Nigeria. Therefore, substantial reductions of heat-trapping gas emissions and adaptation strategies are crucial in Nigeria. Besides, further research comparing Mann-Kendall with another trend identification test is recommended. Finally, additional meteorological and hydrological stations should be established in the catchment area by the authorities concerned in order to carry out an attribution study of hydro-meteorological trends in specific locations and analyse the spatial distribution of trends.

## 5 References

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