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, 0.0314^{o}C/year, 0.013oC/year, -0.104%/year, -8.78MJ/m2/year, -1.440mm/year, and 0.028m3/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.

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 [1]. CC has also hampered global management of both natural and human systems [2]. Climate change is presently viewed as one of the most pressing issues facing the world [3]. CC includes changes in climate parameters such as rainfall, temperature, wind speed, humidity, sunshine, among others [4]. Although climate change has occurred on a global scale, its impacts frequently differ from place to place [5]. 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 [6]. Both natural and manmade activities contribute to the rise in greenhouse gas (GHG) concentrations in the atmosphere [7]. 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 [8, 42,43]. Industries, according to Jeswani et al. [8], 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 [9,44,65].

CC has caused a significant threat to all life on Earth, not just humans [10]. Developing countries are vulnerable to climate change due to their inability to adapt with extreme events [11]. 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 [12]. 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 [12]. Increased Earth temperature induces convectional current and boosts the rate of evaporation, resulting in cloud formation and increased precipitation [12]. 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 [9].

Meteorological and hydrological datasets are crucial climate factors whose extreme variations can cause droughts, extensive flooding, and, in the worst-case scenario, death [13-14]. 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 [5]. 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 [15]. 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 [16-21]. The Mann-Kendall test is one of the most often used non-parametric tests for detecting trends in time series [19-20]. The Mann-Kendall trend test develops from Kendall's rank correlation test for two pairs of observations. 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 [15]. Mann-Kendall (MK) trend test is used for trend detection in hydro-meteorological records such as temperature, rainfall, evaporation, evapotranspiration, streamflow and water quality [22-29].

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 [30] 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. [31] 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. [32] obtained similar results when they examined surface temperature and relative humidity trends in Canada from 1953 to 2005.

Jiang et al. [33] 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. [34] 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. [35] 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. [36] 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. [37] 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 [5] 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. [12] 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 [38] 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 [39-40]. 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 [41]. 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^{o}3'5"	7^{o}56'1"	186m
Uyo (CRBDA)	5^{o}10'0"	7^{o}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$_{max}$ (^{o}C)	Temp$_{min}$ (^{o}C)	R/H (%)	S/R (MJ/m^2/day)	PET (mm)	Runoff (m^3/s)
2706$\pm$777	31.3$\pm$0.64	23.1$\pm$0.52	78.6$\pm$5.2		6474$\pm$228	1466$\pm$40.3
3.726$\pm$1.1						

R/H=Relative Humidity; S/R=Solar Radiation; PET=Potential Evapotranspiration

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.

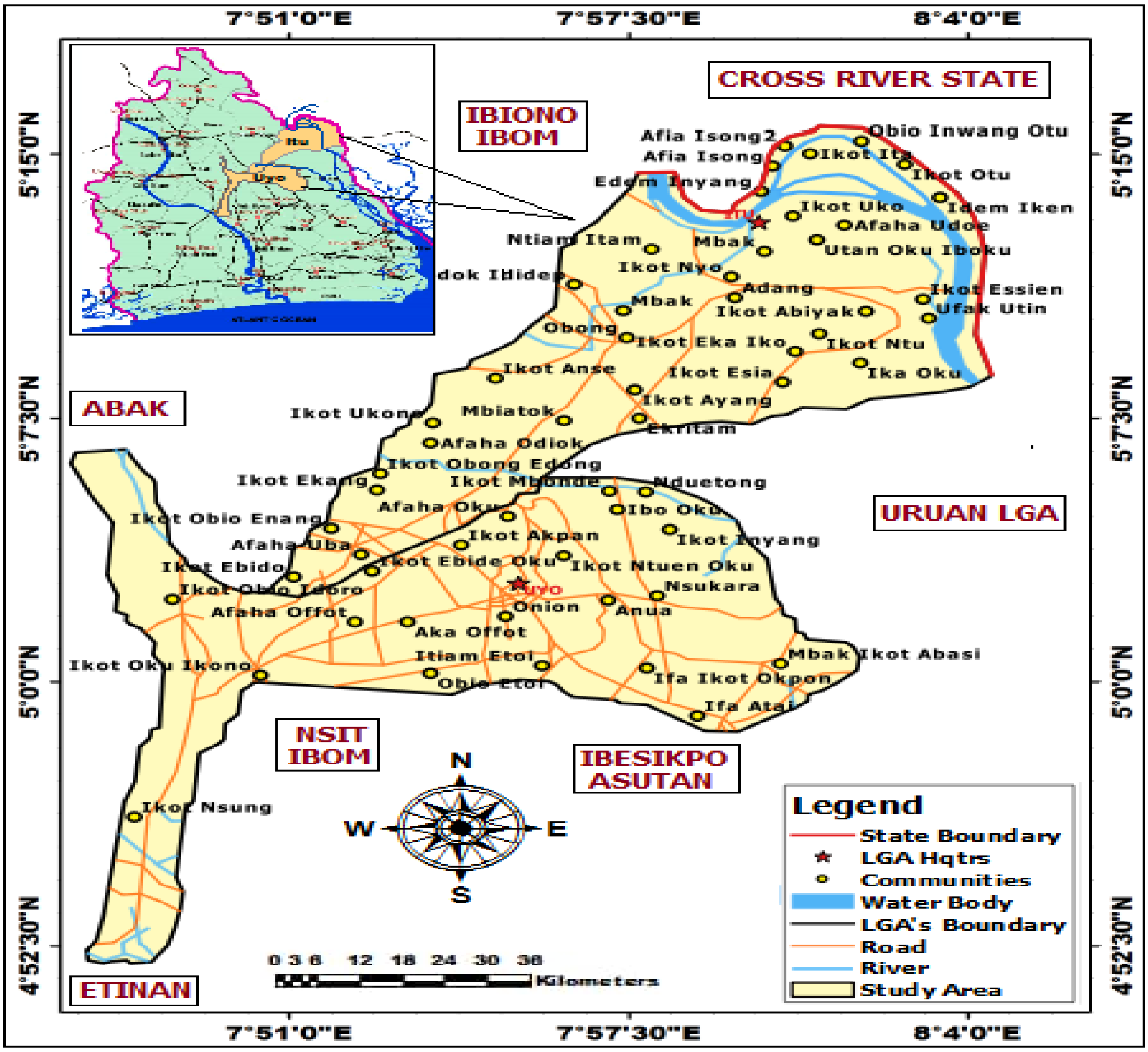

Figure 1: Study Area Map

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 [45]. Recent research has made extensive use of the MK technique to analyse trends in time series of temperature, rainfall, runoff, and water quality [46]. 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).

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

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 [47]. Yue and Wang [48] 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 $X = \{x_1, x_2, \dots \dots x_n\}$ are independent, by Equation (2), the MK test statistics (S) and signs was determined as follows:

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

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

where n is the number of the variable set, x_j and x_k are the sequential variables at times j and k, and 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 tk is the number of measured variability in the kth group. After the variance Var(S) is calculated from Equation (4), the standardized test statistic (Z_S) was determined by Equation (5).

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

where Z_S demonstrates the significance of the trend. The Z_S is employed to test the null hypothesis, H_0 if $Z_S > \frac{Za}{2}$ and "a" indicates the confidence level. The trend is significant at the 90% (α = 0.1), 95% (α= 0.05), and 99% (α = 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 α 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 [25,49-50].

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:

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

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):

$$\text{Sen's Estimator } = Q_{\frac{n+1}{2}} \text{ if n is odd,} \quad (7a)$$

$$\text{SE} = \frac{1}{2}\left[Q_{\frac{n}{2}} + Q_{\frac{n+1}{2}}\right] \text{ if n is even,} \quad (7b)$$

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_1th largest and the (M_2+1)th largest of the *N* ordered slope estimates [64]. The slope *Qmed* 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 [25,30,34,50-51].

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

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

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 [52].

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 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.

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 [53]. However, Pendergrass et al. [54] 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.

Months, Seasonal, Annual, Decade	Rainfall (mm)							
	First Year	Last Year	CV (%)	p-value	Z- test	Sen's slope		
						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

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

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	-	-

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 [5]. 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, Seasonal, Annual, Decade	Maximum Temperature (^oC)							
	First Year	Last Year	CV (%)	p-value	Z- test	Sen's slope		
						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^{o}C/month but not greater 0.0176^{o}C/month were detected in February to December, while a rate of mean monthly decrease for January was -0.009^{o}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. [55] in Kofarnihon River Basin. Their results revealed an increasing trend in annual temperature in the regions at a rate of 0.023^{o}C/year and 0.0108^{o}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 [50] and Khosravia et al. [56] 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 [51]. For the monthly data set, the Sen's slope rate of average monthly maximum temperature increased at an average of 0.035^{o}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, Seasonal, Annual, Decade	Minimum Temperature (^{o}C)							
	First Year	Last Year	CV (%)	p-value	Z- test	Sen's slope 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	50	4.29	0.0864	1.715	0.652	-

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 [5] 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, Seasonal, Annual, Decade	Relative Humidity (%)							
	First Year	Last Year	CV (%)	p-value	Z- test	Sen's slope 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	-	-

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 MJ/m^2 per year, while the non-significant decreasing trend in decade solar radiation was -940.2

MJ/m^2 per decade. Also, the Sen's slope rate of decrease for seasonal datasets were -0.577 MJ/m^2 and -8.001 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 -0.206MJ/m^2 to -1.520MJ/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 -0.032MJ/m^2 to -0.613MJ/m^2 per month. According to Sarkar et al. [57], 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. [58], 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 [59] 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, Seasonal, Annual, Decade	Solar Radiation (MJ/m^2/day)							
	First Year	Last Year	CV (%)	p-value	Z- test	Sen's slope 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	-171	-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	-	-

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. [60] 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 [61]. 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, Seasonal, Annual, Decade	Evapotranspiration (mm)							
	First Year	Last Year	CV (%)	p-value	Z- test	Sen's slope 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

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 $0.028m^3/s$ per year, while that of the mean decade increase was $5.139m^3/s$ per decade. On the monthly data series, the mean monthly runoff increased from $0.0005m^3/s$ to $0.0057m^3/s$ per month from January to November. Conversely, the Sen’s slope of mean a monthly decrease of -0.0002 m^3/s per month was observed in December. Moreover, the Sen’s slope rate of increase for seasonal datasets were -0.0025 m^3/s and 0.0315 m^3/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. [62] 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. [63] 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, Annual, Decade	Runoff (m^3/s)							
	First Year	Last Year	CV (%)	p-value	Z- test	Sen's slope 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	-	-

4.0 CONCLUSION

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, Nigera, 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^{o}C/year, 0.013^{o}C/year, -0.104%/year, -8.78MJ/m^2/year, -1.440mm/year and 0.028m^3/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.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgment

The authors wish to thank NiMet and CRBDA for providing the data used in the study.

Authors' contributions

This work was carried out in collaboration among all authors. Author SSR conceptualised, investigated the study, did data curation and analysis, and drafted the original version. Authors HG and UUU conceptualised and supervised the study and performed data validation. All authors read and approved the final manuscript.

REFERENCES

1. Tawari-Fufeyin P, Paul M, Godleads AO. Some aspects of a historic flooding in nigeria and its effects on some Niger-Delta communities. American Journal of Water Resources. 2015;3(1):7-16.
2. Wardekker JA, Wildschut D, Stemberger S, Van der Sluijs JP. Screening regional management options for their impact on climate resilience: An Approach and Case Study in the Venen-Vechtstreek Wetlands in the Netherlands. SpringerPlus. 2016;5(1):750.
3. Adger WN, Barnett J, Brown K, Marshall N, O'Brien K. Cultural dimensions of climate change impacts and adaptation. Nature Climate Change. 2013;3(2):112-117.
4. Nile BK, Hassan WH, Ghofran A, Alshama GA. Analysis of the effect of climate change on rainfall intensity and expected flooding by using ANN and SWMM programs. ARPN Journal of Engineering and Applied Sciences. 2019;14(5):975-984.
5. Gocic M, Trajkovic S. Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. Global and Planetary Change. 2013; 100:172-182.
6. IPCC. Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change. Cambridge University Press. 2021.
7. Stocker TF, Dahe Q, Plattner GK. Climate change 2013: The physical science basis. Working Group I contribution to the fifth assessment report of IPCC: Summary for policymakers. 2013.
8. Jeswani HK, Wehrmeyer W, Mulugetta Y. How warm is the corporate response to climate change? evidence from Pakistan and the UK." Business Strategy and the Environment. 2008;18:46-60.

9. Shadmani M, Marofi S, Roknian M. Trend analysis in reference evapotranspiration using Mann-Kendall and Spearman's Rho tests in arid regions of Iran. Water Resources Management. 2012;26:211-224.
10. Meena PK, Khare D, Nema MK. Constructing the downscale precipitation using ANN model over the Kshipra River Basin, Madhya Pradesh." Journal of Agrometeorology. 2016;18(1):113-119.
11. Pouliotte J, Smit B, Westerhoff L. Adaptation and development: livelihoods and climate change in Subarnabad, Bangladesh. Climate and Development, 2009;1(1):31-46.
12. Alhaji UU, Yusuf AS, Edet CO, Oche CO, Agbo EP. Trend analysis of temperature in Gombe State using Mann Kendall trend Test. Journal of Scientific Research and Reports. 2018;20(3):1-9.
13. Choubin B, Malekian A, Samadi SS, Khalighi-Sigaroodi S, Sajedi-Hosseini F. An ensemble forecast of semi-arid rainfall using large-scale climate predictors. Meteorological Applications. 2017;24:376-386.
14. Sigaroodi SK, Chen Q, Ebrahimi S, Nazari A, Choobin B. Long-term precipitation forecast for drought relief using atmospheric circulation factors: a study on the Maharloo Basin in Iran. Hydrology and Earth System Sciences. 2014;18(5):1995-2006.
15. Yadav R, Tripathi SK, Pranuthi G, Dubey SK. Trend analysis by Mann-Kendall test for precipitation and temperature for thirteen districts of Uttarakhand. Journal of Agrometeorology. 2014;16(2):164-171.
16. Spearman C. The proof and measurement of association between two things. The American Journal of Psychology. 1987;100(3-4):441-471.
17. Sen PK. Estimates of the regression coefficient based on Kendall's Tau. Journal of the American Statistical Association. 1968;63(324):1379-1389.
18. Sen Z. Innovative trend analysis methodology. Journal of Hydrological Engineering. 2012 17(9):1042-1046.
19. Mann HB. Non parametric tests against trend. Econometrica. 1945;13:245.
20. Kendall MG. Rank correlation methods. London: Charles Griffin. 1975.
21. Torrence C, Compo GP. A practical guide to wavelet analysis. Bulletin of the American Meteorological Society. 1998;79:61-78.
22. Bohm R, Auer I, Brunetti M, Maugeri M, Nanni T, Schoner W. Regional temperature variability in the European Alps: 1760-1998 from homogenized instrumental time series. International Journal of Climatology. 2001;21(14):1779-1801.
23. Burn DH, Hag-Elnur MA. Detection of hydrologic trends and variability. Journal of Hydrology. 2002;255(1-4):107-122.
24. Jhajharia D, Shrivastava SK, Sarkar D, Sarkar S. Temporal characteristics of pan evaporation trends under the humid conditions of Northeast India. Agricultural and forest Meteorology. 2009;149(5):763-770.
25. Partal T, Kahya E. Trend analysis in Turkish precipitation data. Hydrological Processes. 2006;20:2011-2026.
26. Chang H. Spatial analysis of water quality trends in the Han River basin, South Korea. Water Research. 2008;42(13):3285-3304.
27. Jhajharia D, Dinpashoh Y, Kahya E, Singh VP, Fakheri-Fard A. Trends in reference evapotranspiration in the humid region of Northeast India. Hydrological Processes. 2012;26(3):421-435.
28. Frimpong BF, Koranteng A, Molkenthin F. Analysis of temperature variability utilising Mann–Kendall and Sen's slope estimator tests in the Accra and Kumasi Metropolises in Ghana. Environmental Systems Research. 2022;11(1):1-3.
29. Singla C, Aggarwal R, Kaur S, Sharma R. Analysis of meteorological parameter changes using Mann-Kendall statistical tests in Indian Punjab. MAUSAM. 2023 Jan 1;74(1):207-13.
30. Yunling H, Yiping Z. Climate change from 1960 to 2000 in the Lancang River Valley, China. Mountain Research and Development. 2005;25(4):341-348.

31. Singh P, Kumar V, Thomas T, Arora M. Changes in rainfall and relative humidity in river basins in northwest and central India. Hydrological Processes. 2008;22(16):2982-2992.
32. Vincent LA, Wijngaarden WA, Hopkinson R. Surface temperature and humidity trends in Canada for 1953–2005. Journal of Climate. 2008;20(20):5100-5113.
33. Jiang Y, Luo Y, Zhao Z, Tao S. Changes in wind speed over China during 1956–2004. Theoretical and Applied Climatology. 2010;99(3-4):421-430.
34. ElNesr MN, Abu-Zreig MM, Alazba AA. Temperature trends and distribution in the Arabian Peninsula. American Journal of Environmental Sciences. 2010;6:191-203.
35. Karaburun A, Demirci A, Kara F. Analysis of spatially distributed annual, seasonal and monthly temperatures in Istanbul from 1975 to 2006. World Applied Sciences Journal. 2011;12(10):1662-1675.
36. Tao H, Gemmer M, Bai Y, Su B, Mao W. Trends of streamflow in the Tarim River Basin during the past 50 years: human impact or climate change? Journal of Hydrology. 2011;400(1-2):1-9.
37. Xu Z, Liu Z, Fu G, Chen Y. Trends of major hydroclimatic variables in the Tarim River Basin during the past 50 years. Journal of Arid Environments. 2010;74(2):256-267.
38. Agbo EP, Ekpo CM. Trend analysis of the variations of ambient temperature using Mann-Kendall test and Sen's estimate in Calabar, Southern Nigeria. Journal of Physics: Conference Series. 2021;1734:012016.
39. Udokpoh UU, Ndem UA, Abubakar ZS, Yakasi AB, Saleh D. Comparative assessment of groundwater and surface water quality for domestic water supply in rural areas surrounding crude oil exploration facilities. Journal of Environment Pollution and Human Health. 2021;9(3):80-90.
40. Afangideh CB, Udokpoh UU. Environmental impact assessment of groundwater pollution within cemetery surroundings. Indian Journal of Engineering. 2022;19(51):101-115.
41 Afangideh CB, Udokpoh UU. Spatiotemporal variability assessment of rainwater quality in oil and gas exploration region of Nigeria. Journal of Human, Earth, and Future. 2021;2(4):355-370.
42. Akeke GA, Nnaji CC, Udokpoh UU. Compressive strength optimisation of rice husk ash concrete using Scheffe's mathematical model. Epitoanyag-Journal of Silicate Based & Composite Materials. 2022;74(4).
43. Akeke GA, Udokpoh UU. Spatial Variation of the Chemical Properties of Rice Husk ASH. American Journal of Civil Engineering and Architecture. 2021;9(4):156-164.
44. Akeke GA, Udokpoh, UU. Improvement in the Properties of Concrete Containing Rice Husk Ash as A Partial Replacement for Portland Limestone Cement, International Journal of Engineering Research & Technology (IJERT). 2022:11(02).
45. Hamed KH. Trend detection in hydrologic data: The Mann–Kendall trend test under the scaling hypothesis. Journal of Hydrology, 2008;349:350-363.
46. Yue S, Pilon P, Cavadias G. Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. Journal of Hydrology 2002;259(1-4):254-271.
47. Mavromatis T, Stathis D. Response of the water balance in Greece to temperature and precipitation Trends. Theory Applied Climatology. 2011;104:13-24.
48. Yue S, Wang CY. Applicability of Prewhitening to eliminate the influence of serial correlation on the Mann-Kendall test. Water Resources Research. 2002;38(6):41-47.
49. Modarres R, Silva VPR. Rainfall trends in arid and semi-arid regions of Iran. Journal of Arid Environments. 2007;70, 344-355.
50. Tabari H, Marofi S. Changes of pan evaporation in the west of Iran. Water Resources Management. 2011;25:97-111.

51. Tabari H, Talaee PH. Analysis of trends in temperature data in arid and semi-arid regions of Iran. Global and Planetary Change. 2011;79(1-2):1-10.
52. Asfaw A, Simane B, Hassen A, Bantider A. Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. Weather and Climate Extremes. 2018;19:29-41.
53. Getahun YS, Li M-H, Pun I-F. Trend and change-point detection analyses of rainfall and temperature over the Awash River basin of Ethiopia. Heliyon. 2021;7:6:e08024.
54. Pendergrass AG, Knutti R, Lehner F, Deser C, Sanderson BM. Precipitation variability increases in a warmer climate. Scientific Reports. 2017;7:17966.
55. Gulahmadov N, Chen Y, Gulakhmadov A, Rakhimova M, Gulakhmadov M. Quantifying the relative contribution of climate change and anthropogenic activities on runoff variations in the Central Part of Tajikistan in Central Asia. Land. 2021;10(5):525.
56. Khosravia H, Sajedi-Hosseinib F, Nasrollahic M, Gharechaeid HR. Trend analysis and detection of precipitation fluctuations in arid and semi-arid regions. Desert. 2016;22(1):77-84.
57. Sarkar KA, Kumar RR, Dhakre DS, Bhattacharya D. Analysis of spatio-temporal trend of solar radiation in the agro climatic Zone-I of Bihar. The Pharma Innovation Journal. 2022;11:9:431-438.
58. Ohunakin OS, Adaramola MS, Oyewola OM, Matthew OJ, Fagbenle FO. The effect of climate change on solar radiation in Nigeria. Solar Energy. 2015;116, 272-286.
59. Russak V. Changes in solar radiation and their influence on temperature trend in Estonia (1955-2007). Journal of Geophysical Research. 2009;114:10.
60. Oderinde FO, Ayelokun O, Aiyelokun O. Decadal and trend analysis of potential evapotranspiration in Oluyole, LGA, Oyo State Nigeria.” Journal of Meteorology and Climate Science. 2021;19(1):1-9.
61. Wang P, Yamanaka T, Qiu GY. Causes of decreased reference evapotranspiration and pan evaporation in the Jinghe River catchment, northern China. The Environmentalist. 2012;32:1-10.
62. Yao Y, Dai Q, Gao R, Gan Y and Yi X. Effects of rainfall intensity on runoff and nutrient loss of gently sloping farmland in a karst area of SW China. PLoS ONE. 2021;16:3.
63. Kumari R, Mayoor M, Mahapatra S, Parhi PK, Singh HP. Estimation of rainfall-runoff relationship and correlation of runoff with infiltration capacity and temperature over East Singhbhum District of Jharkhand. International Journal of Engineering and Advanced Technology. 2019;9:2:461-466.
64. Gilbert RO. Statistical Methods for Environmental Pollution Monitoring. John Wiley and Sons, New York. 1987.
65. Udokpoh UU, Nnaji CC. Reuse of Sawdust in Developing Countries in the Light of Sustainable Development Goals. Recent Progress in Materials. 2023;5(1):1-33.

APPENDIX

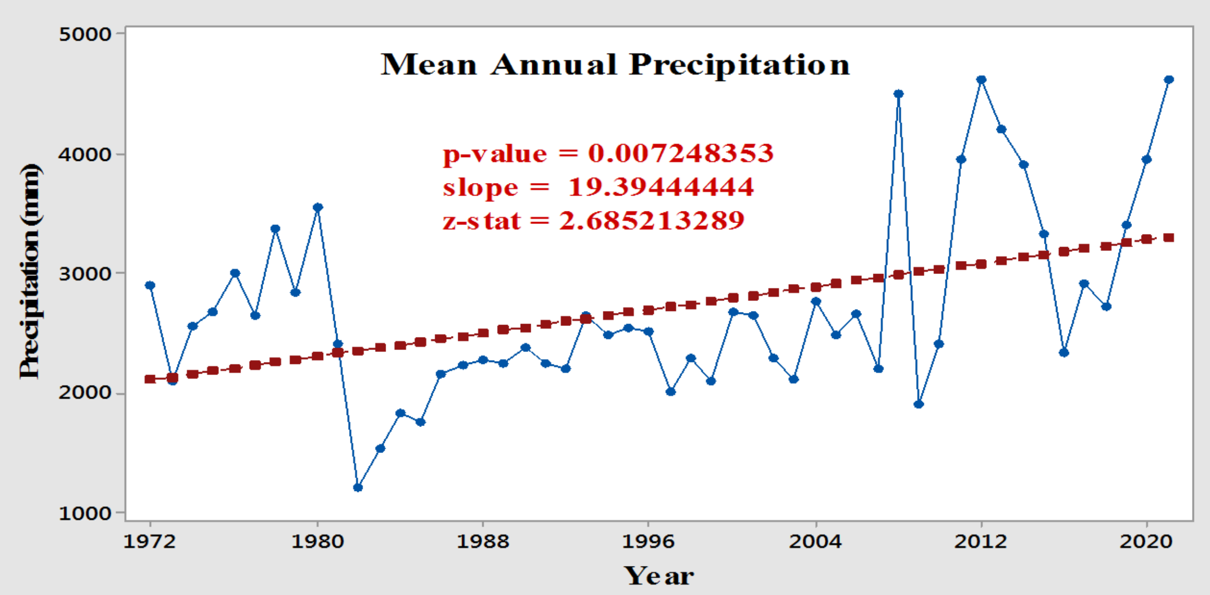

Figure 2: Mann-Kendall trend test for mean annual rainfall

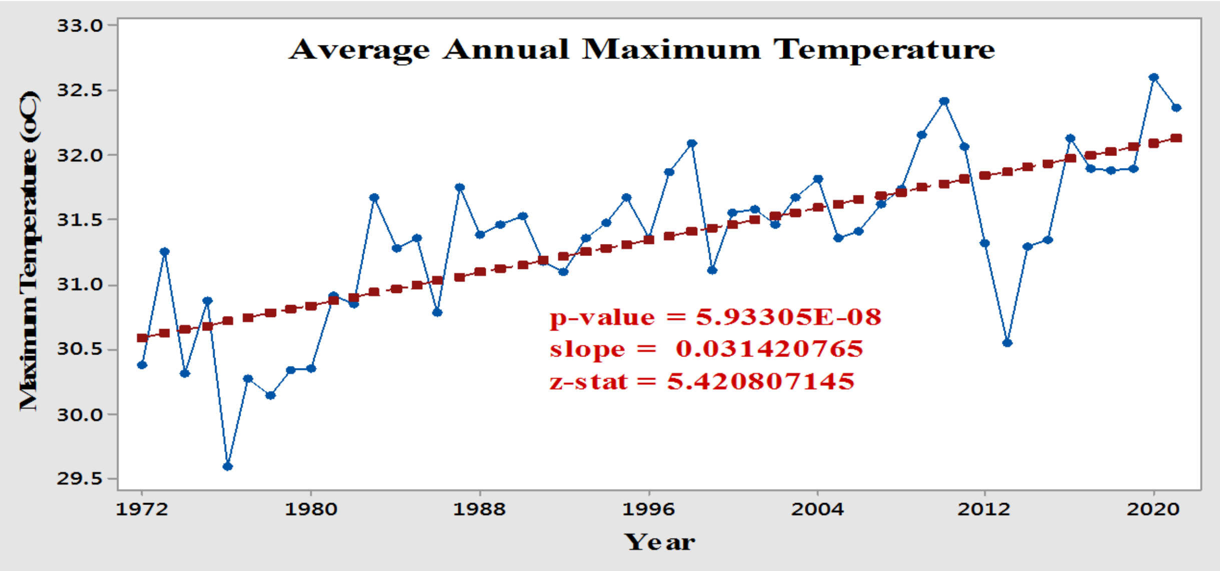

Figure 3: Mann-Kendall trend test for average annual maximum temperature

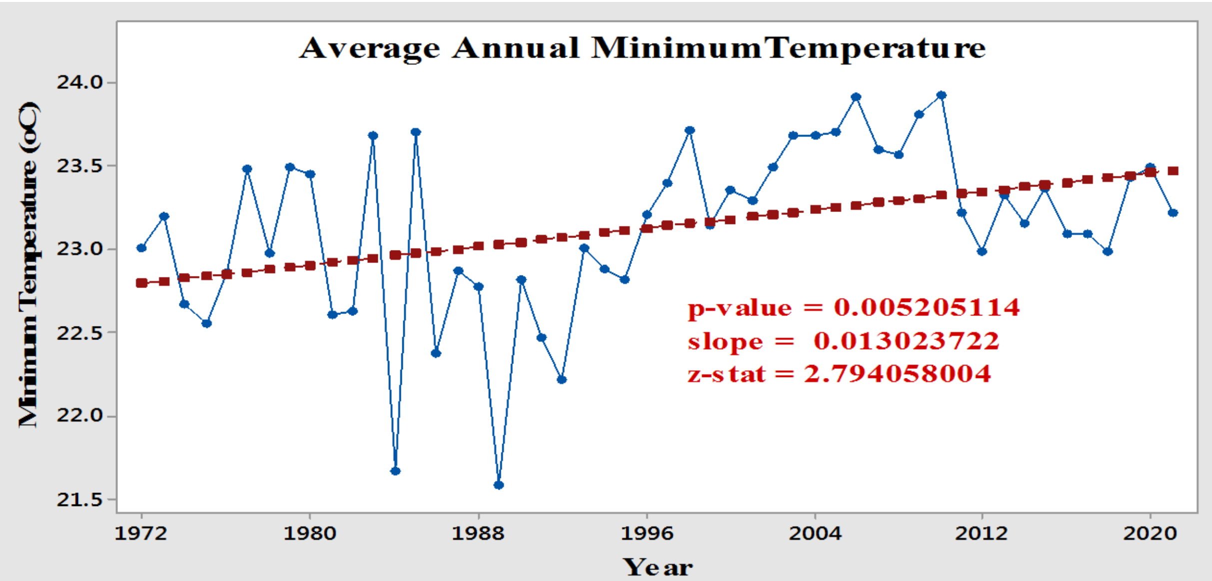

Figure 4: Mann-Kendall trend test for average annual minimum temperature

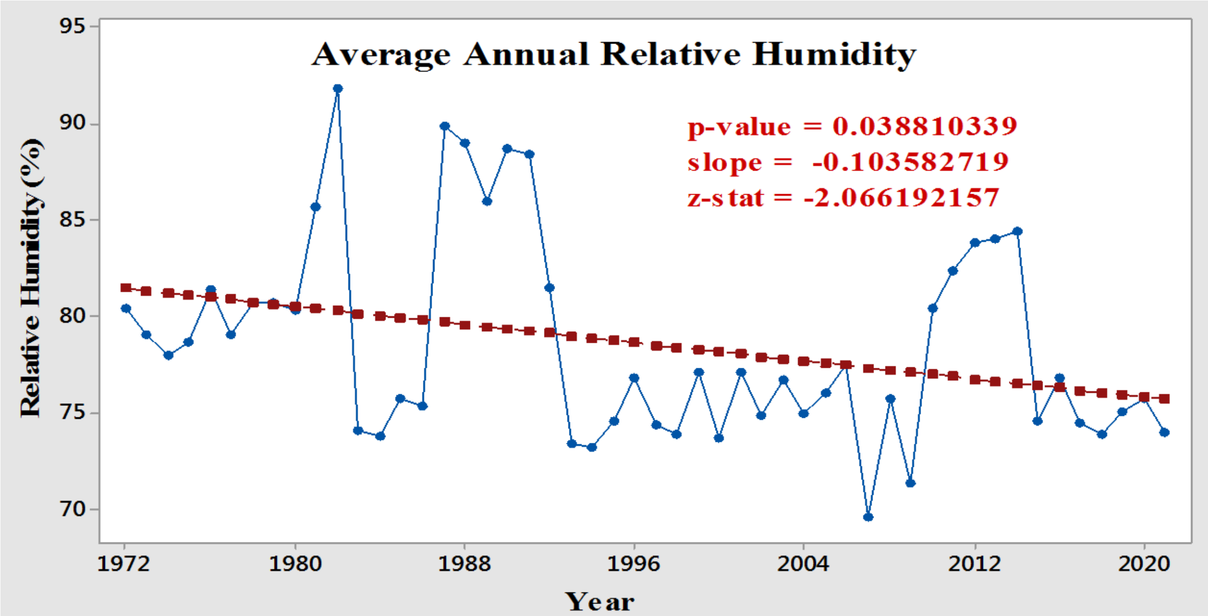

Figure 5: Mann-Kendall trend test for average annual relative humidity

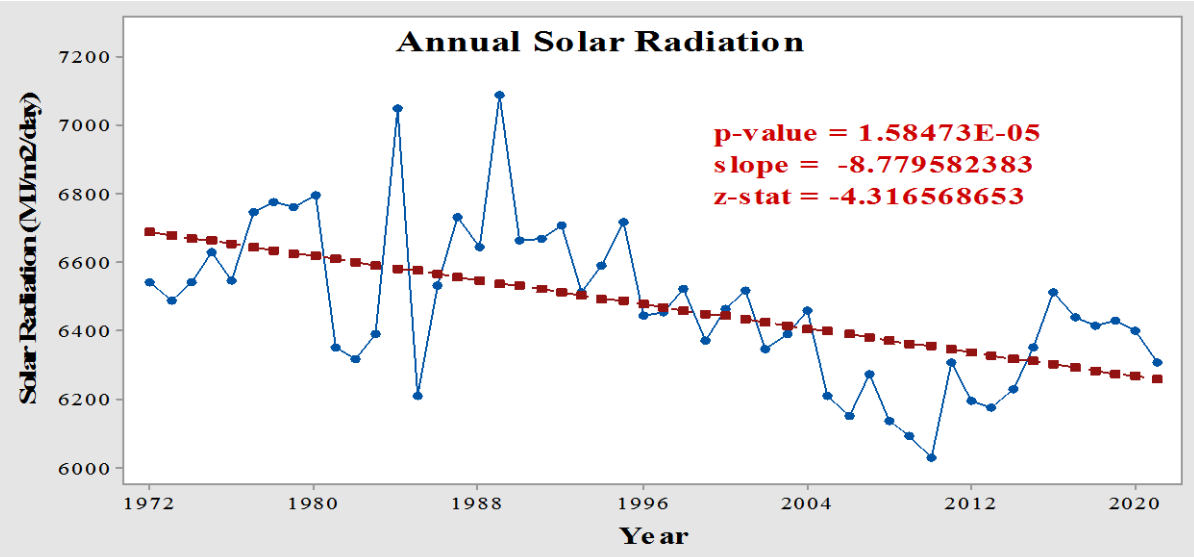

Figure 6: Mann-Kendall trend test for mean annual solar radiation

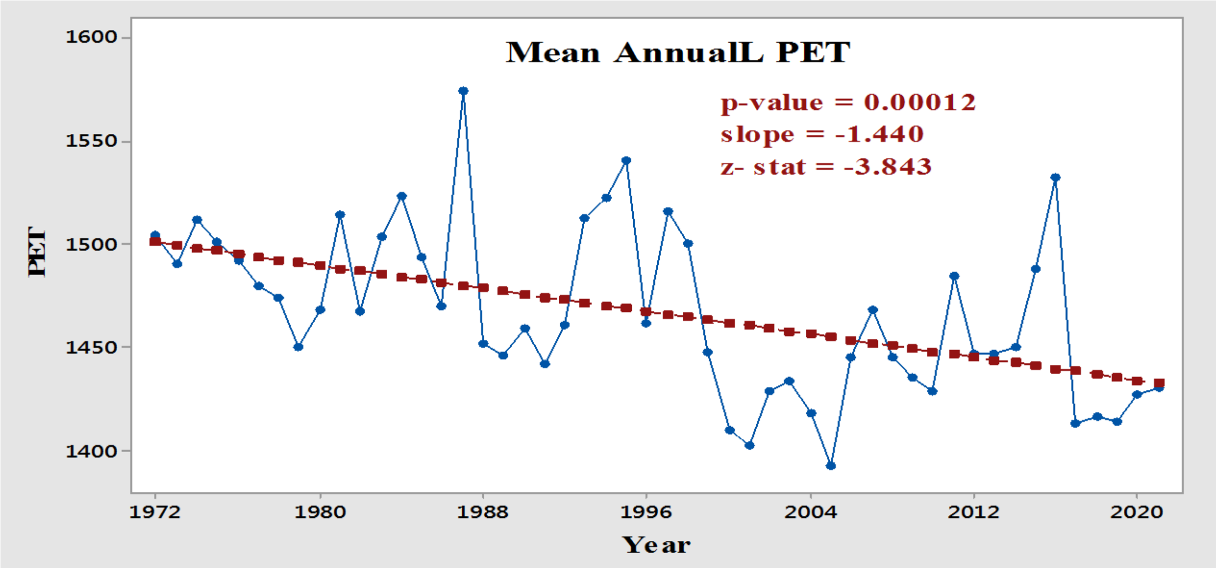

Figure 7: Mann-Kendall trend test for mean annual PET

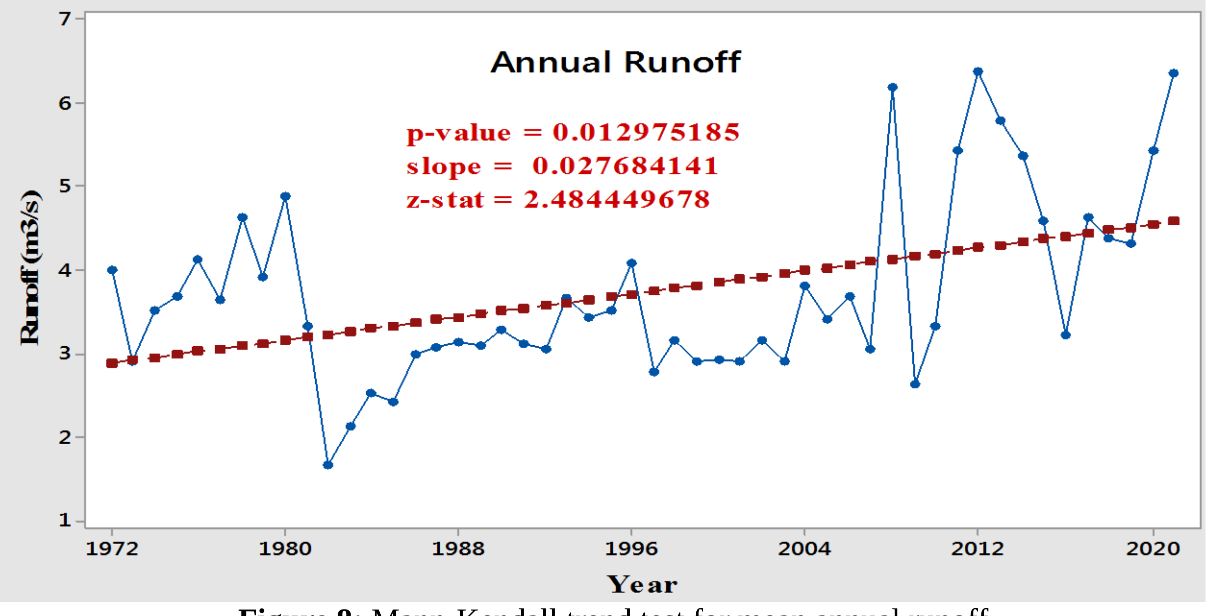

Figure 8: Mann-Kendall trend test for mean annual runoff