

Detecting Changes in Hydro-Climatic Variables during the Last Four Decades (1975-2014) on Downstream Kaduna River Catchment, Nigeria

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Abstract

This study aimed to detect trends in the long-term hydro-climatic series using non-parametric methods. The annual and seasonal linear trends of rainfall, temperature, runoff, water level and evaporation were analysed for stations in downstream Kaduna River Basin during 1975-2014. The non-parametric Mann-Kendall and Sen's estimator of slope procedures were adopted to identify if there exists an increasing or decreasing trend with their statistical significance at 95% level of confidence. The datasets were checked to account for auto-correlation prior to determining trends using Mann-Kendall test. The existence of abrupt changes was detected by means of Cumulative Sum Charts and Bootstrapping analysis. The results of study indicated increasing trends for seasonal and annual temperature and runoff series. Water level and evaporation revealed statistically decreasing trends both on annual and seasonal periods. However, for the period 1975 to 2014 no significant distinctive trend was observed for rainfall at the investigated stations. Change-points in time series were identified in all the investigated hydro-climatic records for the sub-basin. Generally, the detection of the trend for hydro-climatic variables by Mann-Kendall test conforms to Sen's test results. It is concluded that the basin is sensitive to climate variability and water stress impacts which will affect food security. So, it would be necessary to make adjustments in the adaptive water-use strategies being adopted at present in the catchment.

Keywords

Hydro-Climatic Variables, Kaduna River, Trend Analysis, Mann-Kendall Test, Theil-Sen's Slope Estimator

1. Introduction

Global and regional changing climate and variabilities including their societal impacts over the past three decades have received a considerable concern from the scientific community. Some of the major impacts of climate change consist of changes in precipitation patterns, average and maximum temperatures, mean sea level, and altered frequencies and intensities of extreme weather. The fifth Intergovernmental Panel on Climate Change assessment stated Africa surface temperature already increased by 0.5°C - 2°C over the past hundred years and an observed drop in average annual rainfall of approximate 25 - 50 mm each decade from 1951-2010 in some parts of West Africa while globally averaged combined land and ocean surface temperature show a warming of 0.85°C over the period 1880 to 2012 [1] [2]. In general, [3] [4] projected an increase in temperature between 3°C and 6°C at the end of the 21st century as compared with the previous century. Further, 40% reduction of rainfall is projected for arid and semi-arid locations but, a slight increase in the tropics [2] [3].

In recent years, investigations on present and plausible future climate change patterns and impacts on water resources have become of great interest in different parts of the world because of their serious effects imparted on both human society and the natural environment. The world is projected to become increasingly water stressed under climate impacts and population growth [5] [6]. Interconnections between the climate system, water cycle, biophysical and socio-economic systems are complex, so a change in any one invariably induces change in others. Notably, climate change is likely to accelerate the global hydrological cycles, and a greater increase is expected in extreme rainfall as compared to the mean [7] and higher temperatures it will increase evaporation. In fact, temperature, evapo-transpiration and rainfall changes mainly influence the distribution of river flows and groundwater recharge [8]. With respect to climate variability and change impact on water resources, recent detected decreasing trend in water resources will continue in the future due to warming and rainfall declines [9] and a decrease in runoff is expected for 2050 [10].

Temperature and rainfall are fundamental components of climate, and so, the analysis of changes in these climatic variables characterizes key task in detecting climatic changes. Substantial efforts have been devoted to the study of hydro-climate variables [11]-[16]. Moreover, understanding the variations of rainfall, temperature and runoff at the basin scale provides opportunity to study the changing climate impact on water resources and hydrological cycle [17] [18] [19] [20]. For example, identified significant positive uptrend in rainfall is reflected in surface runoff yield [21] and rainfall effectiveness is considerably reduced due to high rate of water loss by evapotranspiration especially in the drier tropics. In addition, high agreement has been observed between historical observations and indigenous perceptions on impacts of climate change in the communities [11].

Despite the recent progress, hydro-climatic investigations and hydrological studies in Nigeria are still relatively scanty and mostly in small river basins especially in

northern Nigerian basins. In fact, most of the previous studies have focused on temporal and spatial trends [22], magnitude and frequency of rainfall and runoff occurrence for various return periods [23], response patterns of hydrological parameters [24], effects of climate change [14] [25], and flood analysis [27].

Understanding the spatial and temporal variability of rainfall and runoff is challenging and requires high quality observed datasets. The trends of observational and historical hydro-climatic data reflect variations in climate and are generally used to determine appropriate adaptation strategies and also in the planning and designing of water resources projects. Over the country, extensive studies of hydrological phenomena have been limited because the spatial distribution of gauge stations is not adequate enough to allow the description of local and large-scale hydrological phenomena. The problems of scarce hydro-climatic data and limited hydrological studies are also applicable in the Kaduna basin. Reference [24] studied 30 hydro-climatic variables generated from 30 sub basins of the Upper Kaduna Catchment covering 10 years (1979-1989). The research revealed that behaviour of hydrological variables in the tropics and indeed, in Nigeria is largely misunderstood as different basin variables explained response patterns of individual flow types.

A variety of statistical analyses such as reduction method, standardized anomaly indices (SAIs), multivariate analysis, simple to multiple regression statistics have been applied to determine trends and inconsistencies of hydro-meteorological variables with the purpose of studying climate change impacts on hydrology and water resources [26] [27] [28] [29]. The Mann-Kendall (MK) non-parametric test is widely used for detecting a trend in hydro-climatic time series [15] [26] [30] [31]. At 5% significance level, [27] revealed increasing statistically significant trends in temperature and rainfall for 9 states in the North-eastern U.S for the time period (1900 to 2011) using the modified Mann-Kendall test. Similarly, [32] showed that the trend pattern of stream flow, rainfall, temperature and evaporation from 2002-2012 was particularly on the increase when compared to previous decades for River Kaduna. However, they did not look at abrupt changes or seasonal variations. In this study, the Mann-Kendall, Sen's estimator of slope and Cumulative Sum Charts and Bootstrapping analysis are employed to detect trends and abrupt changes in the hydro-climatic series.

Overall investigations of trends of hydro-climatic variables at sub-catchment level in Nigeria and their implications on watersheds in previous studies were largely unexplored, though it's very pertinent for sustainable water resources usage. Similarly, inadequate availability of reliable hydro-climatic data limits such studies in the watershed. Uncertainties in the climate system and the complexities of hydrological processes add new challenges in the management of water resources. Thus, a study on hydro-climatic variables should be examined in support of efforts to adapt to changing climate in Nigeria and provide a base for further climate change research for the study location. Therefore, the aim of present study is to identify existing hydro-climatic trends and variation in Kaduna River at the sub-catchment level with focus on its impact on water availability. The study attempts to address the following: a) Are there evidence of trends or long term

changes in temperature, runoff, rainfall, water level and evaporation in the downstream Kaduna river basin? b) What are the patterns of variation? Are they increasing or decreasing or are they characterized by abrupt changes?

2. Methodology

2.1. Study Area

The Kaduna River is one of the tributary to Niger River in Nigeria originating from the Jos Plateau flowing through Kaduna town into Niger State, where it meets the Niger River at Nupeco. The downstream basin of the river is situated on the eastern part of Niger state (also known as Power State) comprises of Shiroro reservoir watershed and stretches to Lavun in Niger state (**Figure 1**). Kaduna river is situated between latitudes $09^{\circ}06'32.64''\text{N}$ and $10^{\circ}30'12.64''\text{N}$, and longitudes $05^{\circ}30'39.34''\text{E}$ and $07^{\circ}04'44.34''\text{E}$. The basin general climate has typical dry and wet seasons which are strongly influenced by highly variable topographic structure and low relief. The catchment receives on average annual rainfall is about 1204.91mm/year, which gradually increases from north to south and temperature of 27.46°C . On average there are 110 days/year with more than 0.1 mm of rainfall. The Shiroro dam reservoir (320 km^2), was built primarily for purpose of supplying needed energy to power the country's growing economy

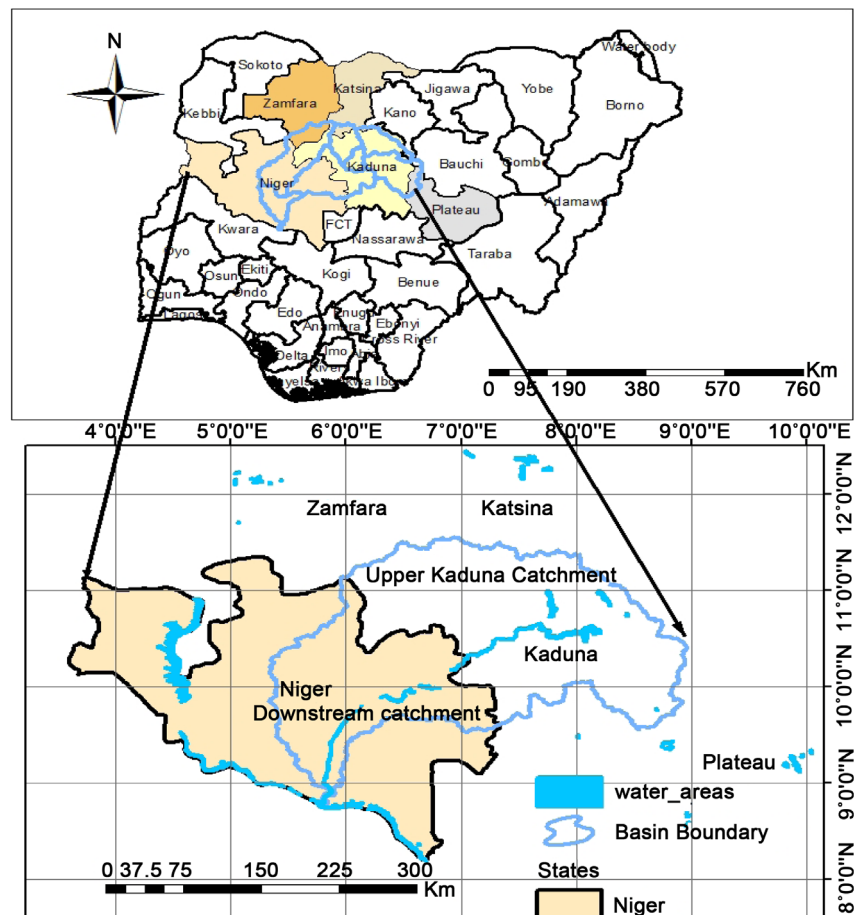


Figure 1. Location of downstream Kaduna river basin in Niger state.

about 500 MW commissioned in 1990. Rain-fed and irrigated agriculture is the mainstay and the primary livelihood of the locals living within the watershed.

2.2. Materials and Methods

Series of daily maximum and minimum Temperatures, and Rainfall data obtained from Nigerian Meteorological Agency NIMET Abuja were used for this study. The stations used have continuous observations span the period 1975-2014. Similarly, daily runoff, water level and evaporation records of Kaduna river were obtained from Shiroro Hydro-Electric Power Station for a 25-year period (the maximum length of records that was made available) from 1990 to 2014. The daily values of temperature (minimum, average and maximum), rainfall and runoff were averaged over each month to assess trends in seasonal and annual scales. The seasons are thus defined as; rainy months: April to October & dry season: months of November to March. Visual inspection has been used to detect outliers and ensure internal consistency. After data completion, the methods to determine serial correlation in the data series were observed.

This research based on statistical trend analysis to identify variations (gradual trends) and abrupt shifts in the data series of five hydro-climatic variables. Although, the linear trend tests results may sometimes suggest absence of significant trends, it is very valuable for determining potential explanations on the changing hydrological response of the river system.

2.2.1. Normalization and Serial Correlation

To test the presence of outliers in the time series data, the annual and seasonal time series of temperature, rainfall and runoff were tested to be normally distributed by using the Anderson-Darling test for normality at $\alpha = 0.05$ significance level. In time series analysis using Mann Kendall rank method, it is essential to consider serial correlation [33] to check for randomness and periodicity in the series [34]. Serial correlation (also referred to as autocorrelation) increases variance of trend estimates and the odds of detecting significant trends even when absent and otherwise. A positive serial correlation can overestimate the likelihood of a trend and a negative correlation may result in underestimation. Serial correlation in the data series and description of the different methodologies used to correct climate data have been investigated and reported [35] [36] [37] [38]. The autocorrelation in the residuals of the annual temperature and rainfall series was checked using the ACF (autocorrelation) and PACF (partial autocorrelation) function at $\alpha = 0.05$ significance level.

2.2.2. The Mann-Kendall Trend Test

To study the trend in the variables time series, the present study employed two non-parametric methods (Mann-Kendall rank correlation and Sen's slope estimator) in MAKESENS trend model to detect monotonic changes over time in climatic and hydrological data of the study area. The MAKESENS—a computer model introduced by [39] was developed using Microsoft Excel 97 and macros coded with the Microsoft Visual Basic.

The non-parametric rank test was considered appropriate because no underlying frequency distribution of data could be assumed, and has been widely adopted to detect changes in hydro-climatic data time series [30] [31] [40]. In comparison to other non-parametric procedures, such as Spearman’s rho test, the power of the Mann Kendal test is robust and similar to the extent of giving indistinguishable results in practice [36]. The Mann-Kendall statistic (S) [41] [42], theoretical calculation is shown in Equation (1).

$$S_{mk} = \sum_{i=1}^n \sum_{j=i+1}^n \text{sgn}(X_j - X_i) \tag{1}$$

X_j and X_i are the annual data values in years j and i , such that ($j > i$) and where the sgn function is given as;

$$\text{sgn}(X_j - X_i) = \begin{cases} 1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0 \end{cases} \tag{2}$$

Under the null hypothesis of no trend and independence of the series terms, the variance of the Mann-Kendall statistic is calculated as:

$$\text{Var}(S_{mk}) = \frac{N(N-1)(2N+5) - \sum_{i=1}^M U_i(i-1)(2i+5)}{18} \tag{3}$$

in which M is the number of tied groups and U_i denotes size of the M^{th} group. The summation term in the numerator is used only if the data series contains tied values. For sample size $n \geq 10$, the statistic S assumes normal distribution, the standard normal test statistic Z_s is computed using

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}}, & \text{for } s > 0 \\ 0, & \text{for } s = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}}, & \text{for } s < 0 \end{cases} \tag{4}$$

The trend results in this study have been evaluated at 5% significant level (the corresponding threshold value is ± 1.96). This implies that the null hypothesis is rejected when $|Z_s| \geq Z_{\alpha/2}$ in Equation (4) at $\alpha = 0.05$ level of significance. The alternate hypothesis is that a trend exists in the data. A positive Z_s value indicates an increasing trend, while a negative Z_s value indicates a decreasing trend. The significance levels (p -values) for each trend test can be obtained from the relationship given as:

$$p = 0.5 - \varphi(|Z_s|) \tag{5}$$

where $\varphi()$ denotes the cumulative distribution function (CDF) of a standard normal variate. At a significance level of 5%, if $p \leq 0.05$ then the existing trend is considered to be statistically significant.

2.2.3. Thiel-Sen’s Slope Analysis

The trend magnitude is estimated using an unbiased median based slope esti-

mator as initially proposed by [43] and modified by [30]. The slope estimation is given by:

$$Q_i = \frac{(X_j - X_k)}{(j - k)} \text{ for all } k < j \text{ and } i = 1, \dots, N \quad (6)$$

where Q_i = slope between data points X_j and X_k , X_j = data values at time j , X_k = data values at time k . $N = \frac{n(n-1)}{2}$ for single observation in each time period or $N < \frac{n(n-1)}{2}$, where $1 < k < j < n$, and n is the total number of observations for each period. The N values of Q_i are ranked from least to largest and median of these N values of Q_i is the Sen's estimate of slope computed as:

$$Q_{med} = \begin{cases} Q[(n+1)/2], & \text{when } N \text{ is odd} \\ Q\left(\frac{N}{2}\right) + Q\left[\frac{N+2}{2}\right], & \text{when } N \text{ is even} \end{cases} \quad (7)$$

The Q_{med} sign reflects direction of trend in the data, while the value indicates steepness of the trend. By obtaining the confidence interval of Q_{med} at specific probability, we determine whether the median slope is statistically different than zero. The confidence interval about the time slope [44] [45] can be computed as:

$$C_\alpha = Z_{\alpha/2} \sqrt{V(S)} \quad (8)$$

where $\text{Var}(S)$ is defined in Equation (3) and $Z_{\alpha/2}$ is obtained from the standard normal distribution table.

2.2.4. Cumulative Sum Charts and Bootstrapping

A number of methods can be applied in determining shifts in the mean and variance of a time series. In this study, Cumulative Sum Charts (CUSUM) and Bootstrapping [46] were used to detect existence of abrupt change in climate series, when the point of change in the theoretical distribution of the statistic of interest is not well-known or if no parametric method is available. Application of the CUSUM and Bootstrapping methods in climatological studies can be found in studies such like [8] and [47].

The cumulative sums S_0, S_1, \dots, S_n of sample data (X_1, X_2, \dots, X_n) , where n is the sample size, are calculated iteratively as follows: First, Compute mean of the sample data (\bar{x}); set $S_0 = 0$; and calculate S_i recurrently as $S_i = S_{i-1} + (X_i - \bar{x})$; $i = 1$; 2; ...; n . This study was done based on 1000 bootstrap samples. Where the CUSUM chart follows a relatively straight line, it indicates a period when the average did not change, and while an abrupt change in the direction of the CUSUM signifies an abrupt shift in the average. The confidence level can be determined by performing bootstrap analysis. First, the magnitude of change S_{diff} is calculated by $S_{diff} = S_{max} - S_{min}$, where $S_{max} = \max_{i=1; \dots; n} S_i$ and $S_{min} = \min_{i=1; \dots; n} S_i$, and then, the bootstrap analysis can be performed as illustrated in the following steps:

- 1) Create bootstrap sample of n units, denoted as $X_1^0, X_2^0, \dots, X_n^0$, by ran-

domly reordering the original n values from your data. 2) Using the bootstrap sample, calculate the bootstrap CUSUM, denoted as $S_1^0, S_2^0, \dots, S_n^0$. 3) Find the maximum, minimum and the difference of the bootstrap CUSUM, S_{max}^0, S_{min}^0 and S_{diff}^0 , respectively. 4) Then determine the bootstrap difference S_{diff}^0 and check if it's less than the original difference S_{diff} . 5) Repeat the above procedure (1)-(4) n times. 6) if X is the number of bootstraps for which $S_{diff}^0 < S_{diff}$, then, the confidence level (CL) at which the change point occurred is

$$CL = 100 * \frac{X}{n} (\%)$$

Slope change ratio of cumulative quantity (SCRCQ).

To estimate the location of the change point, define m such that: $|S_m| = \max_{i=1, \dots, n} |S_i|$, which is the point furthest from 0 in the CUSUM chart. The point “m” estimates the last point before the change point occurred.

3. Analysis and Results

The Mann-Kendall test and Sen’s slope estimator were applied to the time-series of rainfall and temperature (1975-2014), runoff, water level and evaporation (1990-2014). The outcomes of the statistical test are summarized in **Table 1** and **Table 2**. Evaluation of the change point results was mainly based on the results computed by CUSM Charts and Bootstrapping.

3.1. Serial Correlation of the Hydro-Climatic Data

Autocorrelation plots for the stations are presented in **Figure 2**. At lag 1, temperature, rainfall, runoff, evaporation and water level series are normalised and not auto-correlated.

Table 1. Statistical trend test results for the series of rainfall and temperature (1975-2014).

	Minna			Bida		
	Rainfall					
Statistical test	Annual	Rainy	Dry	Annual	Rainy	Dry
Mk statistics (Z_S)	0.41	0.69	-2.71**	0.10	0.41	-0.64
p	0.68	0.49	0.01	0.92	0.68	0.52
Q_{med}	0.95	2.15	-0.41	0.34	1.01	-
	Average Temperature					
Z_S	3.75***	2.04**	4.72***	0.10	2.82**	-1.51
p	0.00*	0.01*	<0.0001	0.37	0.00*	0.16
Q_{med}	0.02	0.02	0.031	0.00	0.02	-0.02
	Maximum Temperature					
Z_S	3.04**			4.14***		
Q_{med}	0.02			0.03		
	Minimum Temperature					
Z_S	2.71**			-1.95		
Q_{med}	0.02			-0.02		

Z_S : MK test, p-value, Q_{med} : Sen’s Slope estimator. *, **, ***Significant trends ($\alpha = 0.10, 0.05$ & 0.01 Sig. level).

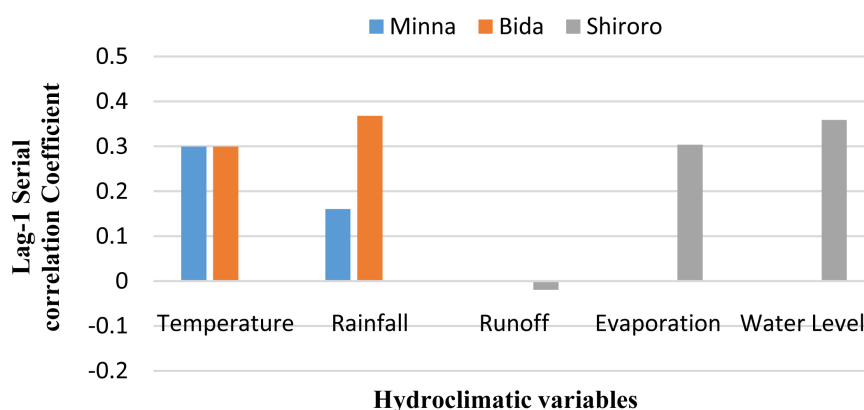


Figure 2. Serial correlation at lag-1.

Table 2. Annual runoff, water level and evaporation trend test statistic results at Shiroro gauging station (1990-2014).

Statistical test	Average Runoff		
	Annual	Rainy	Dry
Mk statistics (Z_s)	2.51*	1.66	2.08*
p -value	0.02*	0.08	0.07
(Q_{med})	2.14	2.06	1.68
Kendell tau (τ)	0.33	0.25	0.26
	Average Water level		
(Z_s)	-3.90***	-4.09***	-2.87**
(Q_{med})	-6.45	-7.17	-5.49
	Average Evaporation		
(Z_s)	-4.09***	-2.64**	-3.62***
(Q_{med})	-1.30	-0.33	-0.83

Source: Statistical test.

3.2. Temporal Trends in Annual and Seasonal Rainfall and Temperature Analysed Using Mann-Kendall and Sen's Slope Statistics

On running the MK statistic to test for the presence of trends, on rainfall and temperature data for 1974-2014 in the downstream Kaduna River basin, the following results as shown in **Table 1** were obtained for annual, rainy and dry season periods at Minna, Bida and Shiroro stations. The test statistic Z_s was used as measure of significance in the trend. A positive Z_s specifies an increasing trend, while decreasing trends are denoted by negative values. The null hypothesis (H_0) is rejected when $|Z_s| > 1.96$ and the result is held to be statistically significant. If the p -value is less than the significance level $\alpha = 0.05$, H_0 is rejected. Rejecting H_0 shows that a trend exists in the time series, while accepting H_0 indicates no trend was identified.

On the annual basis, it is seen from the results of the MK-statistics and P -value that no trend was detected in rainfall data in the catchment at $\alpha = 0.05$ sig-

nificance level. On the seasonal scale, no significant trend (positive nor negative) was spotted by the trend tests except for dry seasonal values at Minna station, which showed statistically significant decreasing trend with $Z_s = -2.71$ and p -value = 0.01 (less than 0.05). Temperature results in **Table 1** indicated statistically increasing trends in both annual and seasonal temperature series for Minna station. Similar results were obtained from trend analysis for maximum and minimum temperatures. However, non-statistical declining trend was observed at Bida station in dry season and minimum temperature for period of study while annual and rainy season values show increasing trends. The results of trend analysis in rainfall on this research conforms with previous study by [14] and such a shift in the temperature distribution is generally consistent with previous trend studies that reported increasing mean temperature in the region [48]. However, [49] using observation and RCM data have predicted no trend in rainfall time series (from 2001-2065) and definite increasing temperature trend over the entire country in the period 1976-2065.

3.3. Trend Direction (Z_s), Magnitude (Q_{med}) and Significance of Runoff, Water Level and Evaporation at Shiroro Gauging Station

The values of the Mann–Kendall statistics (Z_s), Sen’s slope (Q_{med}), and the p -value statistics are given in **Table 2** to show time-based trends (annual and seasonal) runoff, water level and evaporation tested at 5% significance level (two-tailed). The statistical tests showed an increasing significant trend in annual runoff with the Z -value = $2.51 > Z_{0.05/2} = 1.96$, and by the p -value $0.02 < 0.05$. On seasonal basis, increasing trends that is statistically significant was identified for the dry season runoff series. Overall, the prevalent increasing trend in runoff was observed in the Kaduna River for the period 1990-2014 as seen by applying Mann–Kendall test. This can be attributed to the increases during the wet season as storm rainfall that runoff as flood and annual accumulation available during the dry season. However, water level and evaporation revealed statistically decreasing trends both on annual and seasonal periods. The differences in hydrological variables have been similarly observed by [32].

3.4. Mann-Kendall Test in Comparison with the Sen’s Slope Estimator for Detecting Trends in Hydro-Climatic Variables

The Sen’s estimator ($Q_{mm}/year$) summarises change per unit time results of the trends identified. The Sen’s slope estimator results obtained for annual and seasonal hydro-climatic series during the period 1975-2014 were shown in **Table 1** and **Table 2**. Sen’s estimator values ranges from -0.41 mm/year at Minna station to -77.39 mm/year at Shiroro. This latter result implies the existence of a non-monotonic temporal pattern (both increasing and decreasing trends) in the time series. Variables having a negative trend (-0.41 , -0.02 , -6.45 and -1.3 mm/year) were identified as dry season rainfall for Minna station, minimum and dry season temperature for the Bida stations, water level and evaporation at Shiroro. In general, there is pronounced similarity between the Mann-Kendall and Sen’s

statistical results shown in this study at the 5% significance level. [47] arrived at similar conclusion.

3.5. Result of Change Points Identification in Time Series

Change point analysis results performed for the hydro-climatic variables during the periods 1975-2014 and 1990-2014 were summarized in Table 3. As shown, change point can be seen for all hydro-climatic variables. Time series of temperature shows a change from negative to positive direction (increasing), while the other variables had the change from positive to negative direction (Figure 3).

Based on the results of the bootstrap analysis, the confidence level for the change point in temperature is 75%. The confidence level for precipitation, water level, evaporation and runoff is 55%.

4. Discussion and Conclusion

Mann-Kendall trend analysis and Sen’s slope estimator are used in determining the changes in the hydro-climatic variables. In this study, the analysis of the MK test revealed that the series of temperature and runoff exhibited positive trends

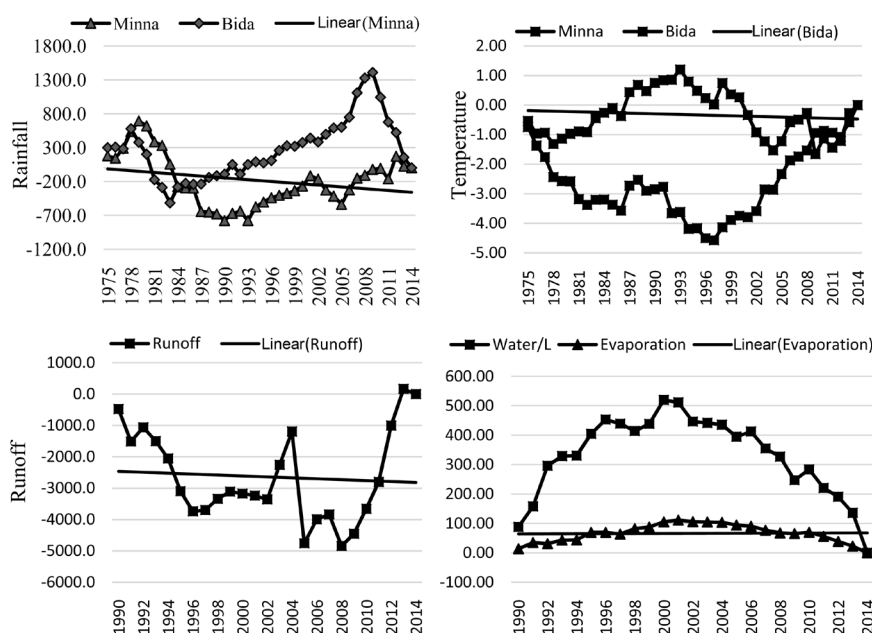


Figure 3. CUSUM charts for variables.

Table 3. Change point analysis in the hydro-climatic variables.

Station	Rainfall	T _{ave}	T _{max}	T _{min}
Minna	1990 (+→-)	1997 (-→+)	1994 (-→+)	1997 (-→+)
Bida	2009 (+→-)	2009 (+→-)	1993 (+→-)	1993 (+→-)
	Runoff	Water/L	Evaporation	
Shiroro	2008 (+→-)	2008 (+→-)	2001 (+→-)	

-→+: change from negative to positive direction. +→-: change from positive to negative direction.

which are statistically significant at $\alpha = 0.05$. This implies that both variables have tended to increase. The warming in the area mainly resulted from significant increases in rainy season temperature. However, there is no significant distinctive trend observed for rainfall at the investigated climate stations except for decreasing dry season rainfall at Bida. In general, the changes in the indices of rainfall, temperature, runoff, water level and evaporation showed the possibility of the occurrence of drier climate and flood events. These hydrological changes are resulting from collective effects of temperature and rainfall variations. As expected, significant increasing runoff trends, especially during the dry season may be attributed to storm rainfall and inflows from tributaries such as rivers Dinya, Sarkin Pawa, Erena and Muiyi into Shiroro reservoir and release from the dam.

The results clearly revealed there is existence of climatic variability due to variations in the downstream Kaduna basin, which, may have impacted negatively on the water resources and livelihoods of inhabitants in the area. Hence, it is of immense importance to quantify the environmental, economic, and social impacts that may well emanate from variable hydro-climatic trends in the area. Study should further be conducted to indisputably attribute the observed trends to the changing climate as well as provide a better explanation of the trends experienced in numerous hydrological variables. The study recommends adequate water resources management and strategies as an adaptive measure to the changing climate in the basin.

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