



Assessment of Hydro-climatic Trends and Variability over the Black Volta Basin in Ghana

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Abstract

The present study examines the trends of hydro-climatic parameters over the Black Volta Basin in Ghana. Trend analysis was carried at different time scales (i.e., monthly, seasonal, and annual) from 1961 to 2016. Modified Mann–Kendall (MMK) test, Sen's slope estimates, and Pettit–Mann–Whitney test were applied to compute the existence of a trend, the degree of change, and probable change point, respectively. The results revealed that there are warming trends over the entire Black Volta Basin. Both temperature extremes, i.e., highest and lowest (annual, seasonal, and monthly scale), for upstream and downstream region revealed an increasing trend. The annual rainfall in the upstream region depicted a downward trend, while downstream showed an increasing trend in the Basin. The seasonal trend analysis for rainfall depicted a falling trend (@ Sen's slopes -0.47 and -0.69) with a percentage change over the 56 years -19.66% and -19.30% , respectively, for upstream and downstream regions during the dry periods. While, the rainy season showed a decreasing rainfall trend (@ Sen's slope -0.71 and percentage change -4.41%) for the upstream region and increasing (@ $+0.71$ & 4.39%) for the downstream. However, annual rainfall for the sites in the Basin depicted a decreasing trend (@ -0.88 and -4.76%) for upstream and an increasing trend (@ $+0.16$ with 0.81% change) for downstream region. Annual streamflow revealed an increasing trend (@ $+0.02$ with a 1.53% change) over the 43 years for upstream and a decreasing trend (@ -0.41 and -15.04% change) for downstream region at Chache-Bole. Therefore, this study output will be helpful for different stakeholders and policymakers within the Black Volta Basin of the West African sub-region toward improving decisions on water resources management.

Keywords Black volta basin · Ghana · Hydro-climatic variables · MK test · PMW test · West Africa

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1 Introduction

Changes in global atmospheric conditions in recent decades have raised concerns about the current and forthcoming weather patterns. Atmospheric temperatures may increase up to $4\text{ }^{\circ}\text{C}$ by 2100 (IPCC 2014). Increasing temperature has a consequence on rainfall, which translates into losses in agricultural production. High temperatures also affect water availability (Modal et al. 2015). Reports indicate declining rainfall throughout the West African sub-region for the past 50 years (Weldeab et al. 2007). Rahman et al. (2017) revealed that annual precipitation did not depict any significant change in trend except some locations. However, monthly rainfall indicated increasing or decreasing trends.

Hydro-climatological predictions indicate burgeoning climate change patterns with consequential effects on water availability. It is estimated that within the twenty-first century, average annual runoff will reduce by 10–30% (IPCC 2007). Notable changes have been detected in West Africa.

Observed annual rainfall is declining in Côte d'Ivoire (e.g., Owusu and Waylen 2009; Soro et al. 2016) and Ghana (Owusu and Waylen 2009). Anthropogenic and naturally induced changes have been noted to be the major causes of the observed low rainfall in the sub-region of West Africa (Giannini et al. 2003; Owusu and Waylen 2009).

In addition to the role played by climate change, the variations in rainfall and temperature can also be affected by land-use/land-cover changes (Feddemba et al. 2005; Kunstmann and Jung 2007; Trenberth 2011; Bagley et al. 2014). Changes in precipitation and temperature may affect surface water flows significantly (Akpoti et al. 2016). Tekleab et al. (2013) revealed that there are significant changes in trends and probable change points in rainfall, temperature, and streamflow across the Abay/Upper Blue Nile Basin in Ethiopia. Logah et al. (2013) observed that there was an overall decrease in average annual precipitation in Ghana from 1981 to 2010 and found significant changes in rainfall in the southwestern region of the country. In addition, the seasonal change in rainfall patterns is exceptionally fluctuating than temperature changes and consistent with variation in streamflow. Temperature increases are also evident that there is a decrease in the total number of frost days in the mid-latitudes and an increment in the number of warm days (Modal et al. 2015).

The research revealed that climate change directly affects water resources, agriculture, and disaster management sectors (e.g., Kabat et al. 2002; FAO 2017; Bekele et al. 2019). In the long term, climate change will revamp the distribution and intensity of rainfall and other atmospheric parameters such as temperature and evaporation at global level and regional level (Xia et al. 2017). The impacts of these changes will be more severe in developing countries (Richard 2015). Mainly, their economies are primarily dependent on agriculture, which depends on freshwater availability. World Bank reports (2006) show that unmitigated hydro-meteorological variability increases the poverty rate by 25% with a corresponding cost to the economy of Ethiopia of up to 38% of its growth potential. It is predicted that there will be a reduction in runoff and rainfall in the Volta Basin (Kasei 2009; Bhatt and Mall 2015). It is also anticipated that warmer weather will influence an increase in water demand, while water supply is expected to decrease (Thornton 2012). This will lead to intense competition for water between the primary water user groups (irrigation, industry, and hydroelectric power) within the Black Volta basin (Amisigo et al. 2015). Therefore, the influence of changes in rainfall on streamflow will require due consideration in the planning, design, and management of water harvesting structures (Nalley 2012).

Some studies have been conducted to assess the potential implication of climate change and variability on water resource systems, especially in Sub-Saharan Africa (Jin et al. 2018). In Ghana, rainfall has mainly concentrated over

particular regions (e.g., Owusu and Waylen 2009; Nkrumah et al. 2014). To ensure sustainable water management strategies in future, the effects of climate change on the water resources need to be quantified at both regional and local levels (Kumar et al. 2017). Fluctuations in climatic conditions and increasing water demand have resulted in the computation of regional and global precipitation (Kalra and Ahmad 2012; Jiang et al. 2013, 2019).

Oguntunde et al. (2006) revealed that there had been a 10% reduction in precipitation over the Volta basin during the period 1901–2002, which emerge in some 16% decrement in the runoff. Furthermore, annual precipitation trend was assessed using Mann–Kendall (MK) test for the period and no significant changes was found during 1960–2005. Still, there was a decrement in the number of rainy days and a lag in the onset of the rainy season for some locations throughout the country, thereby increasing the dry periods during the rainy season (Lacombe et al. 2012; Akpoti et al. 2016). However, MK test is having limitations on identifying the significant trends (Dinpashoh et al. 2014; Zamani et al. 2017), and detail studies on trends and variability of hydro-climatic variables are lagging in the Ghana part of the Black Volta Basin. Therefore, the main objective of this study is to investigate the trend and abrupt changes in streamflow and meteorological variables over the Black Volta Basin. The statistical techniques [i.e., Modified MK test and Sen's slope estimates and Pettit–Mann–Whitney (PMW) test] were used in this study. The comprehensive analysis has been carried out to guide water resource planning and development activities in the Basin. Besides, the study also tries to identify the percentage change in the variables over the period to ensure sustainable water resource development and management in the Basin.

2 Materials and Methods

2.1 Study Area

The Black Volta River Basin is one of the trans-boundary river systems in West Africa (Fig. 1). The Basin lies between 7°00'100" N and 14°30'100" N latitude and 5°30'100" W and 1°30'100" W longitude, and extent an area approximately 130,400 km². Agriculture account for the dominant land use in the Basin with the land rotation system being the most practiced. Basin has Tain and Poni as main tributaries, which run out of Bougouriba, VounHou, Gbongbo, Sourou, Wenare, Bambassou, Bondami, Mouhoun (Black Volta), and Grand Bale.

As of year 2000, the population of the Basin stood at 4.5 million people and could reach 8 million by the year 2025 (All waters 2012). Studies show that the Burkina Faso part of the Basin is more developed for agricultural production

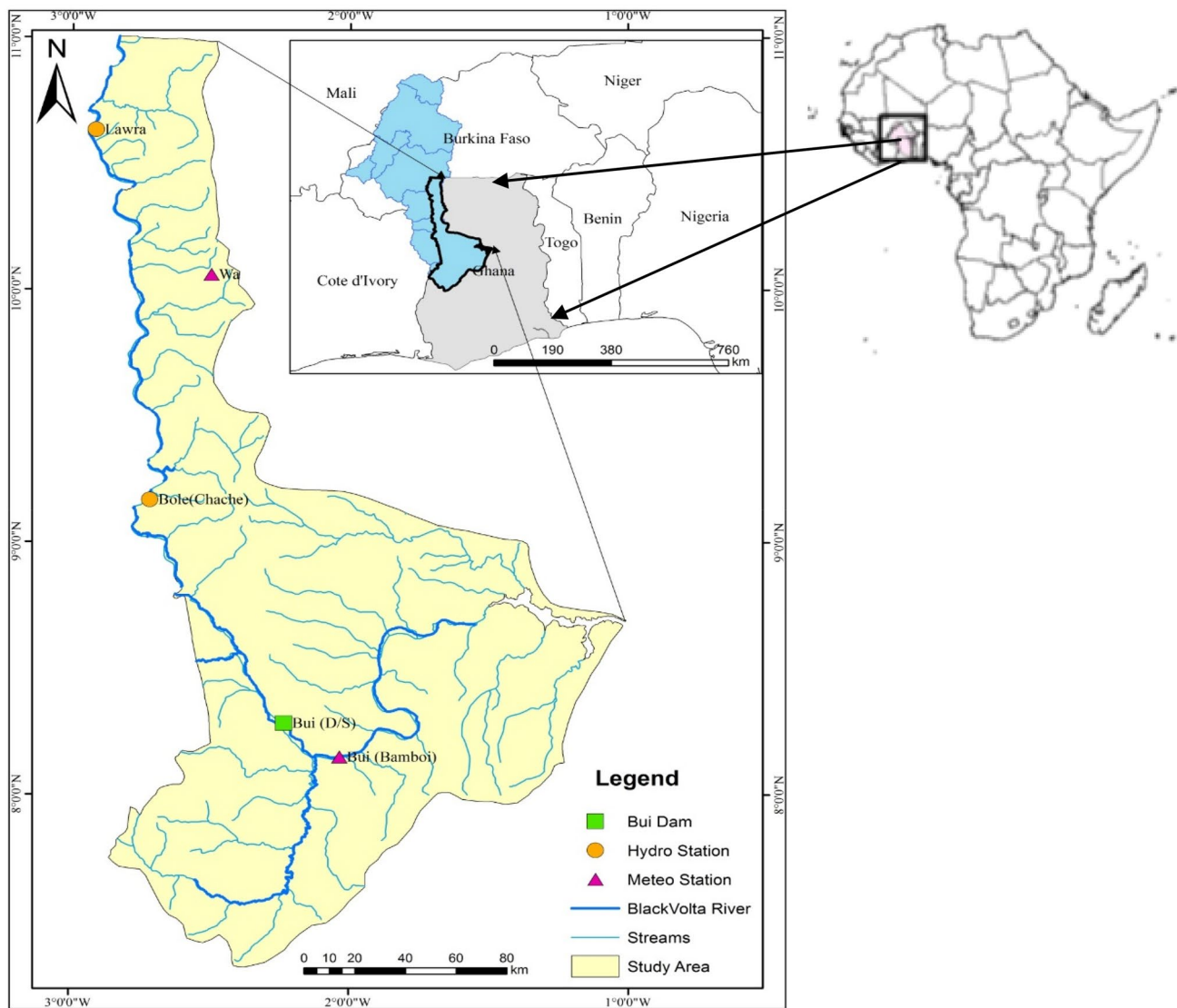


Fig. 1 The location of the study area in the Black Volta Basin, Ghana

as compared to the Ghana portion (Akpoti et al. 2016). The vegetation zones in the Basin are covered from the north to south with the Sahel being sparsely vegetated to savannah areas and the Guinea forest portion in the extreme South. The dominant soil type in the Black Volta basin covers mainly Luvisols and Gleysols (All waters 2012).

The rainfall pattern is highly erratic in the Basin, and annual rainfall ranges between 400 and 1500 mm. Most of the rainfall (about 70%) occurs between July and September in most parts. Three-quarters of the annual rainfall falls in the month of May and September (Obuobie et al. 2017). Mean monthly potential evapotranspiration for the Basin exceeds the mean monthly rainfall for the more significant part of the year in the Basin (Shaibu et al. 2012; Akpoti et al. 2016). The annual rainfall for the entire Basin is characterized by two distinct seasons, the rainy season and the dry

season. Rainfall pattern for the northern part of the Basin is mono-modal, which peaks between August and September, while the South consists of a bimodal pattern, which also peaks in May and September.

2.2 Data Used

Data utilized in the study included rainfall, temperature and streamflow. These data sets were collected from two stations in the Basin, namely, Lawra, Babile, and Wa (upstream sites), and Bole Bamboi (downstream sites). The temperature and rainfall data are monthly distribution for 56 years (1961–2016) and streamflow records for the years 1965–2008, collected from Ghana Meteorological Agency (GMET) and Hydrological Service Department (HSD). Before undertaking the investigation, all data sets

were subjected to quality checks such as missing values, normalization, and auto-correlation analysis. The normalized time series of selected variables were employed in detecting outliers in the data series using the procedure given by Rai et al. (2010). Similarly, the auto-correlation test was used to check the randomness and periodicity in the time series at 5% level of significance (Modarres da Silva et al. 2007; Luo et al. 2008; Karpouzou et al. 2010; Pingale et al. 2016).

2.3 Methodology

2.3.1 Modified Mann–Kendall (MMK) Test

The MMK test utilized in this study is a non-parametric trend detection method (Mann 1945; Kendall 1975), which is distribution-free and robust against outliers. This method is widely used for the study of trends in many variables such as rainfall, temperature, runoff, etc. (e.g., Pingale et al. 2016; Aziz and Obuobie 2017). The outcomes of such studies are vital inputs for basin modeling and analyzing watershed characteristics over a long period for basin water resource planning (Kothawale and Kumar 2005).

In the present study, the MK statistic (S) was estimated by (Mann 1945; Kendall 1975),

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \quad (1)$$

The investigation of the trend was performed using time series x_i , ranked from $i = 1, 2, 3, \dots, n-1$ and x_j , which is ranked from $j = i + 1, 2, 3, \dots, n$. Each datum is series x_i , which was taken as a reference point and then differentiated with the rest of other data in x_j , so that:

$$\text{Sgn}(x_j - x_i) = \begin{cases} +1, & (x_j - x_i) > 0 \\ 0, & (x_j - x_i) = 0 \\ -1, & (x_j - x_i) < 0 \end{cases} \quad (2)$$

when $n \geq 8$, the statistic S is around normally distributed with the mean $E(S) = 0$.

The variance was given as:

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^m t_i(i-1)(2i+5)}{18} \quad (3)$$

Trend Z_c was estimated as:

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & S > 1 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & S < 0 \end{cases} \quad (4)$$

The existence of a statistically significant trend is generally assessed using the Z_c statistics, which is normally distributed. A positive value of Z_c depicts an increasing trend, whereas a negative Z_c value depicts a decreasing trend. At significance level α , $Z_c \geq Z_{\alpha/2}$, then the trend of the data is assumed to be significant. Furthermore, MMK test was adapted for trend analysis of auto-correlated series (Hamid and Rao 2003). The significant value of the MK test was utilized for computation of variance (Eq. 5) and variance correction factor:

$$\frac{n}{n_z^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{m=1}^{n-1} (n-k)(n-k-1)(n-k-2)m_k, \quad (5)$$

where n represents the actual number of observation, n_z^* represents an effective number of observations to count for the auto-correlation in the data, and m_k was considered as the auto-correlated function for the ranks of the observation. The corrected variance was then estimated as:

$$*V(S) = V(S) \times n / (n_z^*), \quad (6)$$

where $*V(S)$ is from Eq. 3. Remaining procedures in MMK test are utilized the same as in the MK test.

2.3.2 Sen's Slope Estimator

The true slope of an existing trend was estimated using Sen's Slope method (Sen 1968):

$$f(t) = Qt + B, \quad (7)$$

where Q is the slope and B is the constant.

The slope estimates for all the data value pairs were calculated using:

$$Q_i(T) = \frac{x_i - x_j}{j - k} \quad \text{for } i = 1, 2, 3, \dots, N, \quad (8)$$

where X_j and X_k is the values for j and k times of a period, where $j > k$.

The median is computed from the N observations of the slope Q_i . The N values of Q_i are ranked from minimum to maximum, and then, Sen's estimator was calculated:

$$Q_i = T_{\frac{N+1}{2}} \text{ for } N \text{ is odd, and } Q_i = \frac{1}{2} \left(T_{\frac{N}{2}} + T_{\frac{N+1}{2}} \right) \text{ for } N \text{ is even.} \quad (9)$$

When the N is Odd, this allows for the Sen's estimator which is estimated as $Q_{\text{med}} = (N+1)/2$, and for even observations, it is estimated as $Q_{\text{med}} = [(N/2) + ((N+2)/2)]/2$. The two-sided test was utilized to obtain the true slope of time series (Mondal et al. 2012). The positive or negative slope (Q_i) depicts increasing and decreasing trends.

The percentage change (%) was then calculated based on a linear trend for which magnitude by Theil and Sen’s median slope and a mean were used (You and Hashino 2003; Pingale et al. 2014). It can be expressed as:

$$\% \text{ change} = \frac{(\text{Median slope} \times \text{length of period})}{\text{Mean}} \times 100 \tag{10}$$

2.3.3 Pettit–Mann–Whitney (PMW) Test

PMW test is usually applied in detecting probable change points in time series (Pettit 1979). The analysis was done using the XLSTAT evaluation version 2019. Several researchers used this method to identify change point in the time series, which was explained using PMW statistics (e.g., Basistha et al., 2009; Pal et al. 2017; Ahmadi et al. 2017). Assuming that T is the length for the time series, while r is the year of the most probable change point. Considering, two time series samples and represented by; $x_i \dots x_r$ and $x_{r+1} \dots x_T$, the index V_i is defined as :

$$V_i = \sum_{j=i}^T \text{sgn}(x_i - x_j). \tag{11}$$

Then, let a further U_T be defined as :

$$U_T = \sum_{(i-1)}^r \sum_{(j-i)}^T \text{sgn}(x_i - x_j). \tag{12}$$

By plotting U_T against r for a time series of no change point will result in a continually increasing value of $|U_r|$. However, for any variation in change point, no matter how local it is, then $|U_r|$ would bring an increase to the change point and then begins to decline. The most significant of this change point, r , can be defined as the point where the value of $|U_r|$ is maximum and can be determined using the relation:

$$K_T = \text{Max}|U_r| \ 1 \leq r_t \leq T. \tag{13}$$

The probability of a change-point year where $|U_r|$ the maximum is computed using the relation:

$$p = 1 - \exp \left[\frac{-6K_T^2}{T^3 + T^2} \right] \tag{14}$$

Furthermore, for $1 \leq r \leq T$, the series is,

$$\hat{U}(r) = |U_r|. \tag{15}$$

$p(r)$ is introduced, and defined as:

$$p(r) = 1 - \exp \left[\frac{-6\hat{U}(r)^2}{T^3 + T^2} \right]. \tag{16}$$

Using Eqs. 11–16, probable change points were identified in the time series at annual and seasonal scales for the Black Volta Basin.

3 Results and Discussion

Statistical analysis was carried out for the annual, seasonal and monthly rainfall, temperature (minimum and maximum), and streamflow for upstream and downstream region of the Black Volta Basin (Table 1). The results of the MMK test and the Sen’s slope estimates for the upstream and downstream part of the Basin are presented in Table 2. The Sen’s slope estimator was later employed to estimate the percentage change per unit time of the trends observed for all the climatic variables (Table 3). The computed means and standard deviations of all the variables are shown in Table 4. They represent the changes and variations for the hydro-climatic variables over the 56 years and 43 years for climatic (temperature and rainfall) and hydrologic (stream-flow) variables, respectively.

3.1 Trend Analysis of Temperature

3.1.1 Maximum Temperature

Observed maximum temperature in the upstream of the Basin varies between 32.49 °C (1962) and 34.47 °C (2006), and the mean annual maximum temperature is 33.54 °C with a standard deviation of 0.52 °C. The skewness of the average value of -0.07 indicating annual maximum in the upstream of the Basin shows asymmetrical, and it is left to the mean. The kurtosis value of -0.94 reveals the platykurtic shape of annual data variation (Table 1).

The results depict an upward trend in the maximum temperatures from January to December for upstream and downstream of the Basin (Table 2). The months of March, April, and July to September show an upward trend at a 0.001 level of significance, whereas May, November, and December depict a maximum increasing trend of temperatures at a 0.01 level of significance. February, June, and October had increasing trends at the significance of 0.05. Only January had significance greater than 0.1. Similarly, for the downstream part of the Basin, the months of March, September, and December depict an increasing trend at a 0.001 significance level. In contrast, May, August, October, and November also represent maximum upward trends in temperature at a significance level of 0.01. In addition, maximum temperature had increasing trends during January, February, April, June, and July at the significance of 0.05. The annual average maximum temperature for upstream and downstream catchments of the Black Volta Basin showed a significant increasing trend (Z value of $+5.28$ and $+5.23$,

Table 1 Statistical analysis of rainfall, temperature, and streamflow for upstream and downstream of Black Volta Basin

Series	Mean	Minimum (Year)	Maximum (Year)	SD	CV	Skewness	Kurtosis
Annual and seasonal Temperature (°C) for Wa							
Annual	33.54	32.49 (1962)	34.47 (2006)	0.52	1.54	- 0.07	- 0.94
Dry Season	35.24	34.02 (1976)	36.48 (2001)	0.59	1.68	0.02	- 0.61
Wet Season	31.85	30.32 (1996)	33.43 (2015)	0.60	1.88	- 0.24	0.32
Annual and seasonal maximum temperature (°C) for Bole							
Annual	32.83	31.86 (1962)	34.01 (1973)	0.47	1.44	0.24	0.03
Dry Season	34.58	33.47 (1976)	35.82 (2001)	0.58	1.67	0.06	- 0.79
Wet Season	31.03	29.4 (1961)	32.9 (1973)	0.59	1.91	0.31	2.20
Annual and seasonal minimum temperature (°C) or Wa							
Annual	22.38	21.32 (1961)	23.42 (2005)	0.58	2.61	- 0.09	- 1.20
Dry Season	21.84	21.65 (1970)	23.22 (2005)	0.70	3.19	0.01	- 1.15
Wet Season	22.92	21.98 (1961)	24.05 (1998)	0.53	2.32	0.00	- 0.82
Annual and seasonal minimum temperature (°C) for Bole (downstream part of the Basin)							
Annual	20.67	18.93 (2005)	21.93 (2005)	0.50	2.44	- 0.50	2.36
Dry Season	19.52	18.37 (1961)	21.08 (2005)	0.58	2.96	0.15	0.02
Wet Season	21.85	20.6 (1961)	22.77 (2005)	0.45	2.05	- 0.13	0.60
Annual and seasonal rainfall (Wa)—Upstream							
Annual	1035.61	523.7 (1986)	1542.8 (1963)	198.08	19.13	0.28	0.67
Dry Season	134.74	26.0 (2001)	302.3 (1976)	66.51	49.36	0.61	- 0.04
Wet Season	900.87	486.2 (1986)	1266.7 (1963)	167.62	18.61	0.07	- 0.06
Annual and seasonal rainfall for the downstream part of the Basin (Bole)							
Annual	1100.24	762.0 (1983)	1818.9 (1968)	207.89	18.90	0.97	2.09
Dry Season	199.61	87.9 (1970)	428.0 (1969)	80.62	40.39	0.85	0.48
Wet Season	900.63	598.9 (1976)	1412.5 (1968)	171.33	19.02	0.43	0.83
Annual and seasonal streamflow (Lawra)							
Annual	80.27	28.20 (1972)	284.10 (1988)	45.91	57.20	2.50	9.97
Dry Season	98.92	1.69 (1979)	284.10 (1988)	64.39	65.09	0.68	0.46
Wet Season	50.27	3.74 (1989)	165.91 (1971)	50.84	101.14	1.16	0.15
Annual and seasonal streamflow (Bole-Chache)							
Annual	151.21	3.33 (1993)	974.60 (1989)	183.93	121.64	3.32	12.17
Dry Season	84.7	0.64 (1993)	496.08 (1989)	102.10	120.52	2.60	7.59
Wet Season	188.73	7.37 (1993)	1213.86 (1989)	214.78	113.80	3.45	14.41

SD standard deviation, CV coefficient of variation

respectively). Figure 2 and S1 depict the maximum temperature variability for the period 1961–2016 for the upstream and downstream sites of the Black Volta Basin. Increasing maximum temperature in the rainy season could change the soil properties such as moisture content (Raju et al. 2014). This may affect crop growth and total yield. Increasing maximum temperatures in both dry season and the wet season may result in more evapotranspiration, causing a reduction in the groundwater table. This affects the overall surface and groundwater availability in the Basin (Thornton 2012; Shaibu et al. 2012; Logah et al. 2013; Akpoti et al. 2016).

3.1.2 Minimum Temperature

Minimum temperatures varies between 21.32 °C (year 1961) and 23.42 °C (year 2005) in the upstream part of the

Basin. While, downstream part of the Basin varies between 18.93 °C and 21.93 °C in the year 2005. The mean minimum temperature found to be 22.38 °C (upstream part) and 20.67 °C (downstream part) with a standard deviation of 0.58 and 0.50, respectively. Similarly, the annual minimum temperature indicates predominantly negative coefficient of skewness (symmetric in nature) for upstream (- 0.09) and downstream (- 0.50). It has a kurtosis value of annual frequency distribution - 1.20 (downstream part) and 2.36 (downstream part) indicating platykurtic shape (Table 1).

The results depict a rising trend for the upstream parts of the Basin in all months with the significance of 0.001 for the months from March to November. In contrast, January and December show a significance level of 0.01 and only February shows a significance level of 0.05 (Table 2). Similarly, the downstream parts of the Basin show an increasing trend

Table 2 Annual and seasonal trend analysis for upstream and downstream parts of the Black Volta Basin using the MIMK test

Time series	Maximum temperature (upstream)			Maximum temperature (downstream)			Minimum temperature (upstream)			Minimum temperature (downstream)			Rainfall (upstream)			Rainfall (downstream)			Streamflow (upstream)			Streamflow (downstream)		
	Z	Q	Sign.	Z	Q	Sign.	Z	Q	Sign.	Z	Q	Sign.	Z	Q	Sign.	Z	Q	Sign.	Z	Q	Sign.	Z	Q	Sign.
Wet	5.12	0.030	***	4.03	0.023	***	5.49	0.028	***	3.70	0.018	***	-0.49	-0.709		0.56	0.707		-4.51	-2.742	***	0.38	0.589	
Dry	4.61	0.028	***	5.11	0.033	***	5.80	0.043	***	4.44	0.028	***	-0.80	-0.473		-0.79	-0.688		3.34	3.333	***	-	-	
Annual	5.28	0.028	***	5.23	0.025	***	6.04	0.034	***	4.60	0.024	***	-0.46	-0.880		0.13	0.159		0.07	0.022		-	-	
January	1.54	0.016		2.45	0.025	*	3.29	0.047	**	3.46	0.052	***	0.31	0.000		0.93	0.000		4.39	6.950	***	1.50	0.081	
February	2.25	0.025	*	2.24	0.020	*	2.07	0.032	*	0.93	0.013		0.59	0.000		-0.78	0.000		3.35	1.469	***	1.70	0.051	+
March	4.23	0.046	***	4.42	0.052	***	4.31	0.045	***	1.78	0.021	+	-2.02	-0.375	*	-1.87	-0.592	+	2.16	0.363	*	3.78	0.057	***
April	3.30	0.033	***	2.56	0.032	*	4.09	0.037	***	3.40	0.028	***	0.45	0.146		0.37	0.175		1.13	0.117		2.35	0.089	*
May	2.70	0.029	**	2.72	0.029	**	4.33	0.029	***	3.44	0.020	***	0.00	0.000		0.78	0.408		-1.67	-0.178	+	1.63	0.178	
June	2.50	0.028	*	2.21	0.014	*	3.69	0.024	***	2.80	0.016	**	-1.02	-0.515		0.11	0.107		-2.91	-0.523	**	1.99	0.409	*
July	3.86	0.025	***	2.23	0.016	*	3.93	0.022	***	2.24	0.010	*	-2.06	-1.008	*	-1.49	-1.450		-4.39	-1.505	***	1.36	0.867	
August	4.45	0.029	***	2.77	0.018	**	4.24	0.022	***	1.95	0.010	+	0.74	0.620		0.75	0.445		-4.29	-4.993	***	0.56	1.677	
September	4.11	0.030	***	3.56	0.025	***	4.57	0.027	***	3.31	0.017	***	-0.04	-0.029		0.95	0.692		-4.66	-9.407	***	0.57	2.305	
October	1.99	0.018	*	2.81	0.027	**	4.93	0.034	***	3.86	0.021	***	1.10	0.440		-0.28	-0.154		-2.49	-4.272	*	-	-	
November	2.93	0.025	**	3.03	0.029	**	3.77	0.048	***	2.82	0.036	**	-1.21	-0.008		0.80	0.000		3.18	3.614	**	-	-	
December	3.05	0.031	**	3.79	0.030	***	3.21	0.038	**	1.49	0.022		-2.52	0.000	*	-0.39	0.000		3.72	8.211	***	0.12	0.010	

***:is for 0.001 significance level, **:is for 0.01 significance level, *:is for significance level of 0.05, + is for a significance level greater than 0.1. Note 2: z= MK statistic (Z value), Q= Sen's slope (Q value), Sign. L=significance level

Table 3 Sen's slope and percentage change over 56 years for climatic variables and 43 years for streamflow

Parameter/season	Wet season		Dry season		Annual	
	Sen's slope	% change	Sen's slope	% change	Sen's slope	% change
Rainfall upstream (mm)	- 0.71	- 4.41	- 0.47	- 19.66	- 0.88	- 4.76
Rainfall downstream (mm)	0.71	4.39	- 0.69	- 19.30	0.16	0.81
Max. Temp. upstream (°C)	0.03	5.28	0.03	4.45	0.03	4.68
Max. Temp. downstream (°C)	0.02	4.15	0.03	5.34	0.03	4.26
Min. Temp. upstream(°C)	0.03	6.84	0.04	11.03	0.03	8.51
Min. Temp. downstream (°C)	0.02	4.61	0.03	8.03	0.02	6.50
Streamflow upstream (m ³ /s)	- 2.74	- 305.46	3.33	188.69	0.02	1.53
Streamflow downstream (m ³ /s)	0.59	17.48	- 1.08	- 71.54	- 0.41	- 15.04

Table 4 Summary of statistics of hydro-climatic variables for the Black Volta Basin

Parameter/season	Wet season		Dry season		Annual	
	Mean	SD	Mean	SD	Mean	SD
Rainfall upstream (mm)	900.87	167.62	134.74	66.51	1036	198
Rainfall downstream (mm)	900.63	171.33	199.61	80.62	1100	208
Max. Temp upstream (°C)	31.85	0.60	35.24	0.59	33.54	0.52
Max. Temp downstream (°C)	31.03	0.59	34.58	0.58	32.83	0.47
Min. Temp upstream (°C)	22.92	0.53	21.84	0.70	22.38	0.58
Min. Temp downstream (°C)	21.85	0.45	19.52	0.58	20.67	0.50
Streamflow upstream (m ³ /s)	50.27	50.84	98.92	64.39	80.27	45.91
Streamflow downstream (m ³ /s)	188.73	214.78	84.7	102.10	151.21	183.93

in all months at the significance of 0.001 in January, April, May, September, and October, whereas June and November are within significance level of 0.01. July shows a significance of 0.05, while that of March and August shows of 0.1 level of significance. Only December shows a significance level higher than 0.1. The annual mean minimum temperature in the Basin (upstream and downstream) depicted an increasing trend (*Z* value of +6.04 and +4.60, respectively). An increasing trend with extremely significant lowest minimum temperature in the dry and rainy seasons will increase the duration of the seasons, thereby enhancing global warming (Trenberth 2011; Xia et al. 2017). Increasing annual minimum temperatures will heavily support global warming causing climate change (Xia et al. 2017). This depicts that the temperature trend is increasing, which could affect the hydrological processes of the Basin (Logah et al. 2013; Akpoti et al. 2016; Jin et al. 2018). The minimum temperature variability is presented in Figs. S2 and S3 for the upstream and downstream catchment, respectively. It showed that the linear trend line overlaid on the data time series for the different seasons and months.

3.2 Trend Analysis for Rainfall

Annual precipitation of upstream and downstream in the Basin varies between 523.7 mm (1986) and 1542.8 mm (1963) and 762 mm (1983) and 1818.9 mm (1963), with a

standard deviation of 198.08 and 207.89 mm, respectively. Skewness measure of the asymmetry of the frequency distribution about the mean was significantly positive skewness of average values of 0.28 and 0.97 for both upstream and downstream of the Basin, respectively, indicating that annual precipitation within the Basin is asymmetric and lies to the right of the mean, i.e., right skewed. Kurtosis evaluates the peakedness of the frequency distribution. The values of 0.67 and 2.09 for downstream and upstream indicate that the frequency distribution has a platykurtic shape. The coefficient of variance (CV) shows the spread of the data points in the data set around the mean, which is found to be 19.13% and 18.90%, respectively, for upstream and downstream. All the statistical indicators for upstream and downstream catchments of the Basin are given in Table 1.

The results indicate a falling trend for the month's March, July, and September with a significance of 0.05 and June, September, and November at a significance greater than 0.10 level of significance, whereas January, February, April, May, August, and October indicate a rising trend with a significance level greater than 0.10 (Table 2). The annual precipitation in the upstream and downstream part of the Basin shows a decreasing and increasing trend (*Z* value of - 0.46 and +0.13, respectively) (Figs. 3 and 4). Similarly, the downstream parts of the Basin results (Table 2) indicate a falling trend for March at 0.10 level of significance. Similar falling trend was observed for the months February,

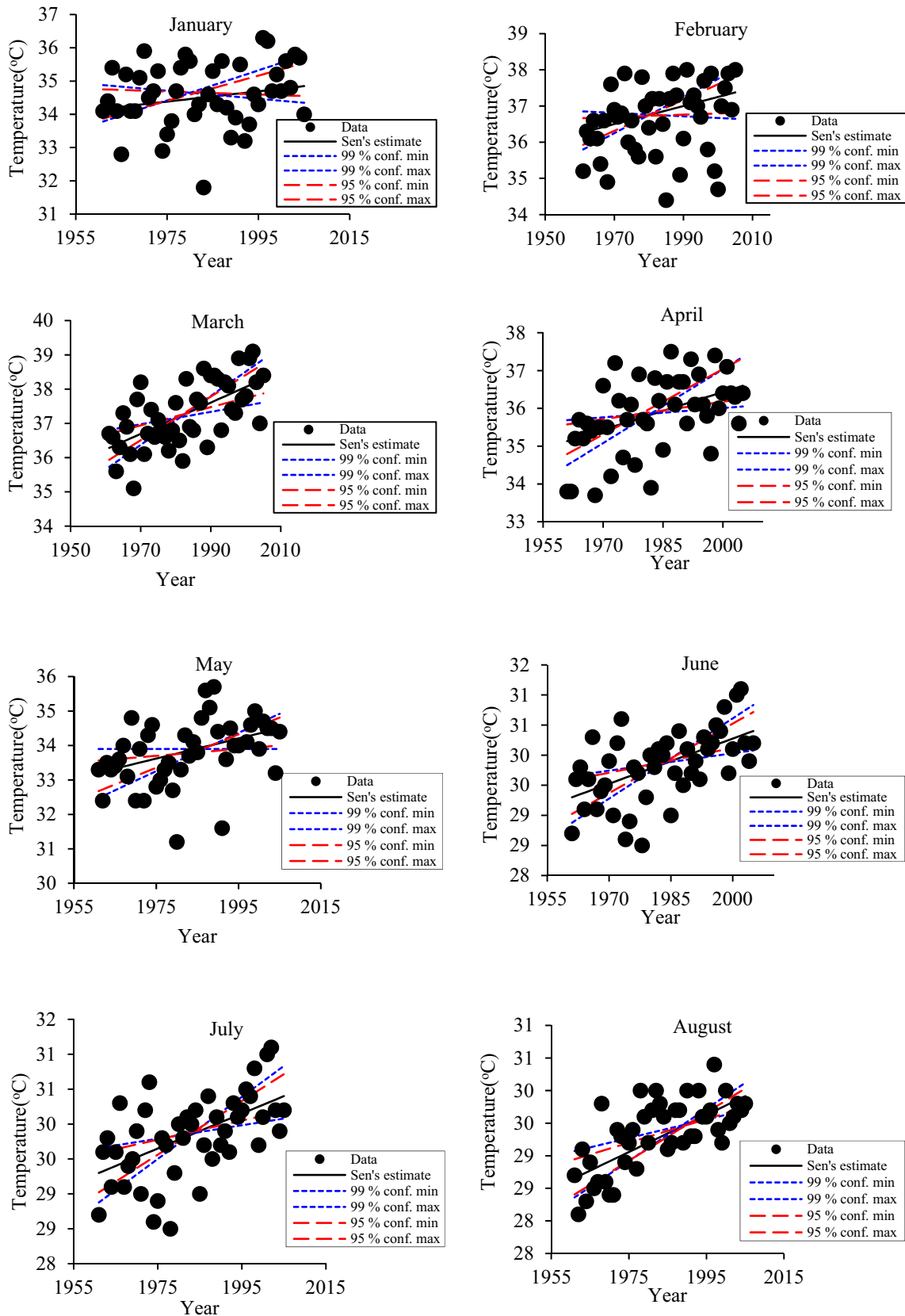


Fig. 2 The trends in highest maximum temperature on monthly, seasonal, and annual scale during the period 1961–2016 in the upstream part (Wa) of the Basin

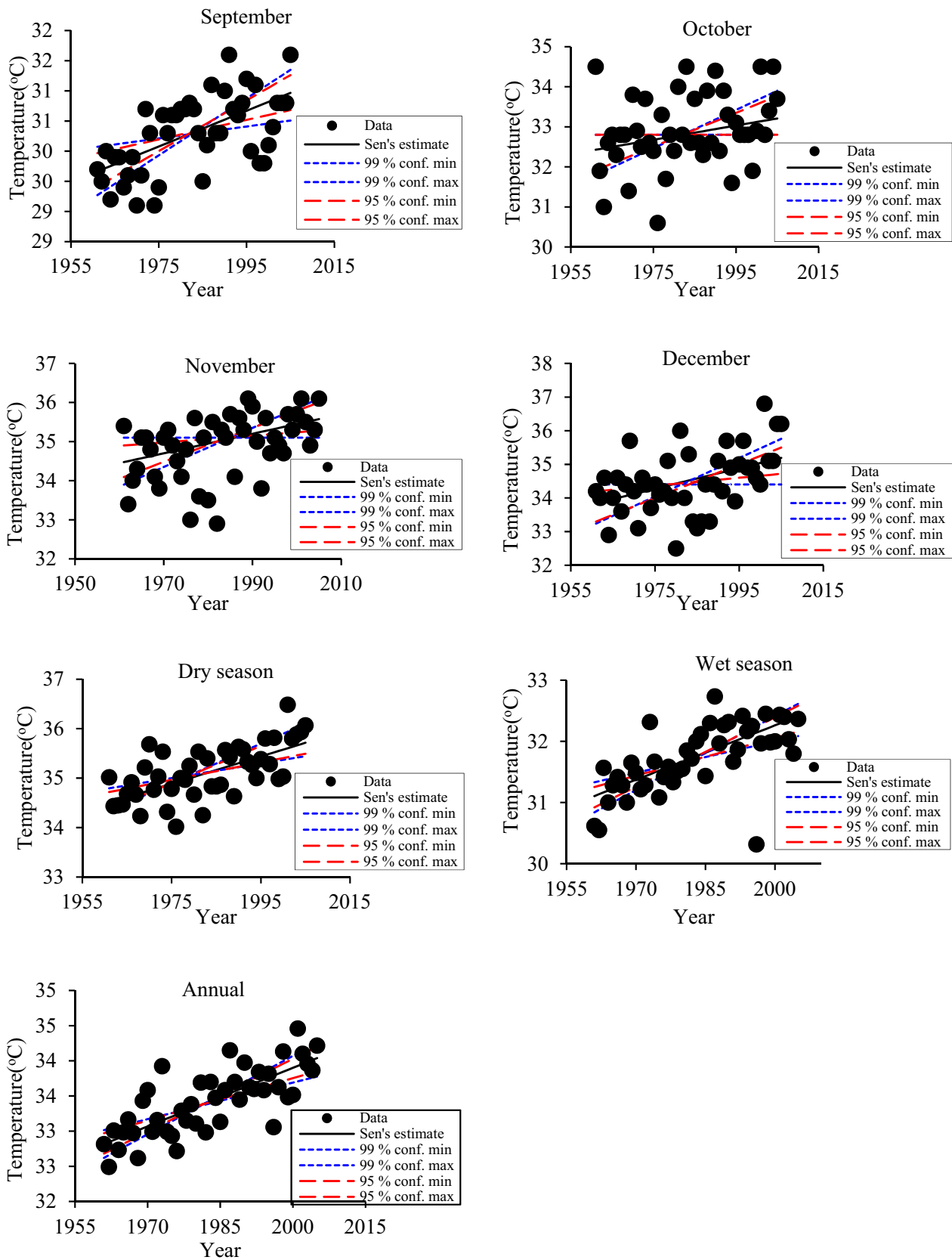


Fig. 2 (continued)

Fig. 3 Rainfall MK statistic and Sen's slope for different months and seasons for upstream

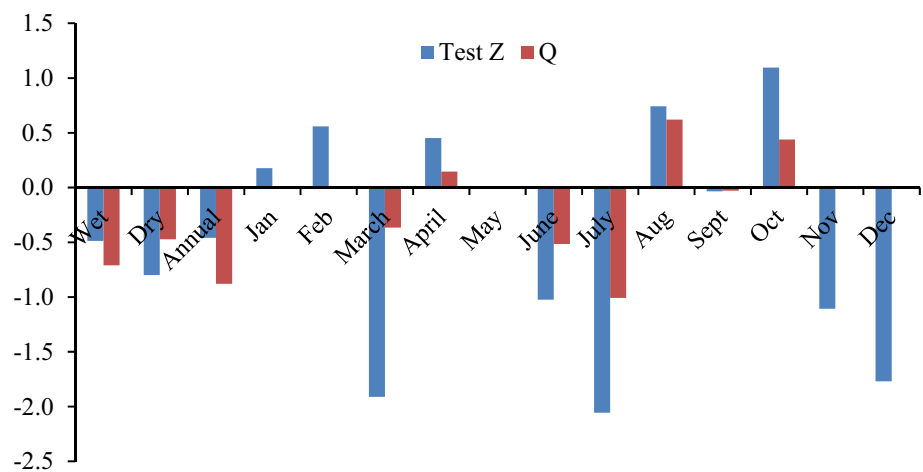
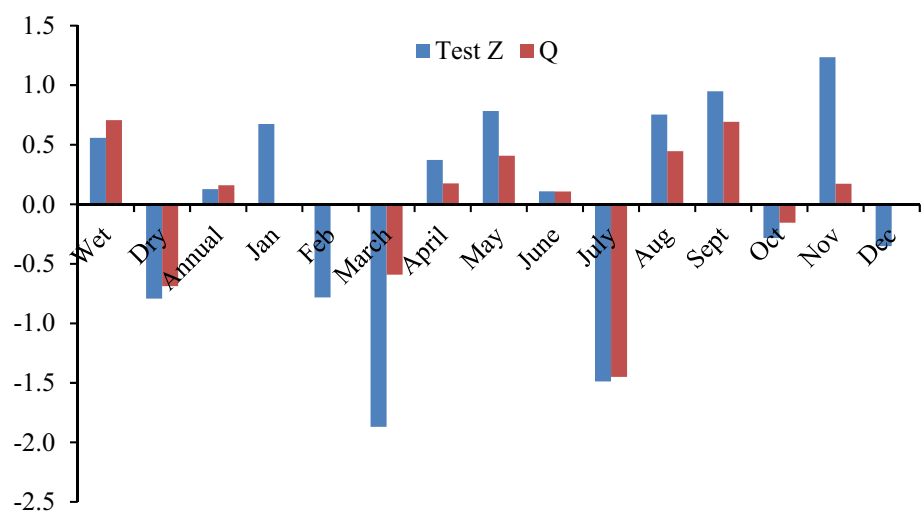


Fig. 4 Rainfall MK statistic and Sen's slope for different months and seasons for downstream



July, October, and December at a level of significance more significant than 0.10. The months January, April, May, June, August, September, and November indicates a rising trend at significance level higher than 0.10. Figures S4 and S5 depict the rainfall variability for the period 1961–2016. Both seasons (wet and dry) show a decrease in trend, which implies a reduction in water availability for both seasons of the upstream catchments of the Basin. This decrease in trend is particularly severe for the wet season, because the Basin is Agrarian in nature with most farmer's dependent on rain-fed agriculture. A reduction in water availability, therefore, will affect crop patterns and ultimately crop yields in the Basin. However, dry season shows a decrease in trend, which implies a decrease in the water availability for the downstream catchments of the Basin. This decrease in trend is particularly severe for the Bui Dam, which is downstream and requires enormous volumes of water to maintain proper head for hydropower production. The decline in trend within the dry season will increase evapotranspiration and, hence, soil moisture in the Basin.

3.3 Trend Analysis of Streamflow

The annual streamflow in the Basin varies between 28.20 m³/s (1972) and 284.10 m³/s (1988) with mean streamflow of 80.27 m³/s and a standard deviation of 45.91. The annual streamflow upstream and downstream within the Basin is asymmetric (2.50 and 3.32, respectively), and it lies to the right of the mean. The kurtosis value of 9.97 and 12.17 indicates that the annual frequency distribution has a platykurtic shape in upstream and downstream of the Basin. Similarly, the annual streamflow in the downstream part of the Basin varies between 3.33 m³/s (1993) and 974.60 m³/s (1989) with a mean annual runoff of 151.21 m³/s and a standard deviation of 183.93. All other statistical parameters covering the period of 1965–2008 are shown in Table 1.

The results in Table 2 indicate a rising trend for the months January, February, and December with a significance of 0.001 level of significance, whereas July, August, and September indicate a falling trend with a significance of 0.001 significance level. The annual streamflow in upstream and

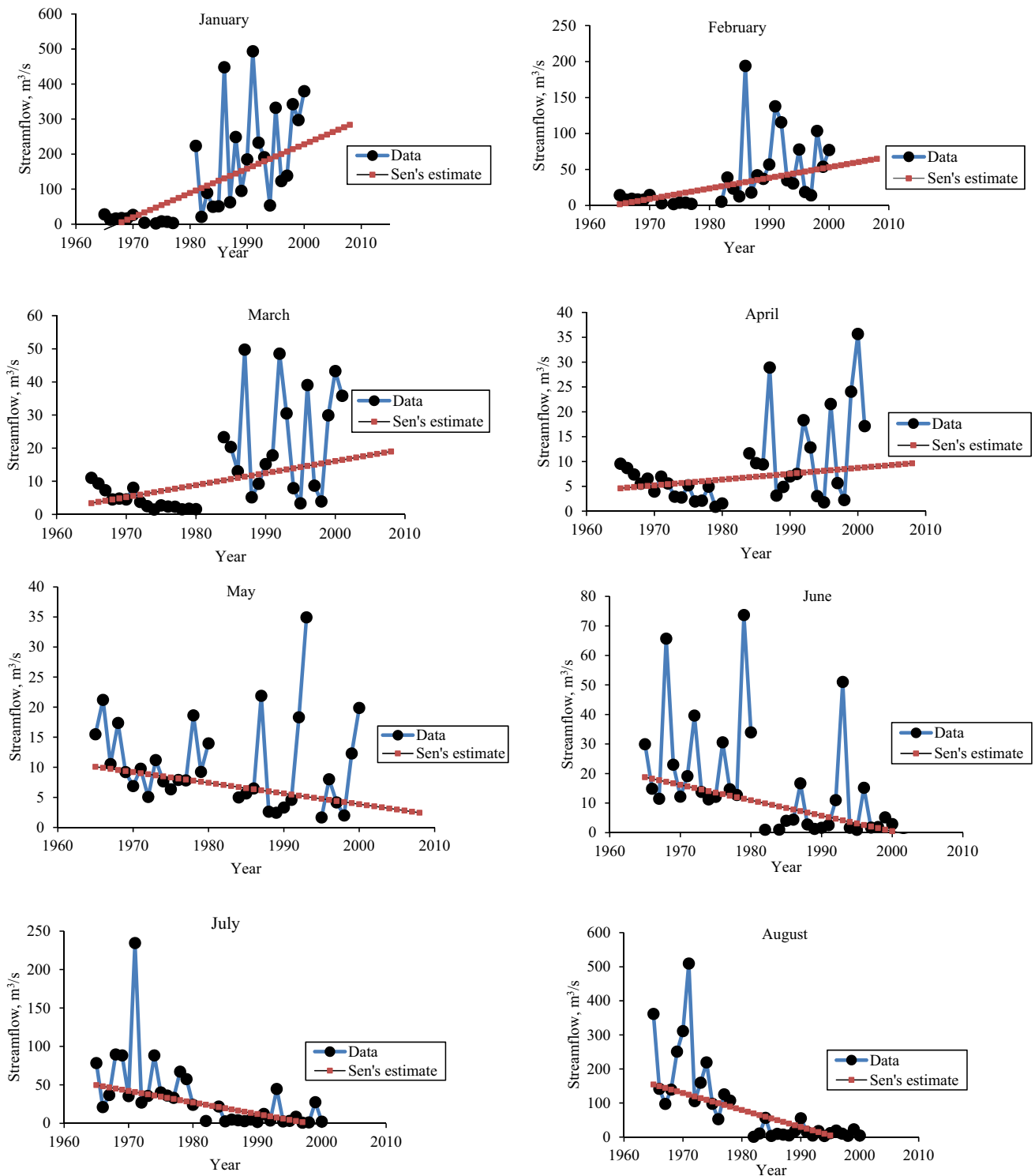


Fig. 5 Trends analysis of streamflow at different temporal scales for the upstream part of the Basin

downstream sites of the Basin shows an increasing marginal trend (Z value of $+0.07$ and -0.38 , respectively) (Jaweso et al. 2019). A decrease in trend in the rainy season will increase the water table level of the upstream catchment of the Basin.

An increase in the trend covering the dry season will increase water availability for downstream use. A general decrease in trend covering the rainy season could be a result of reservoir filling during the wet season that limits the available water into

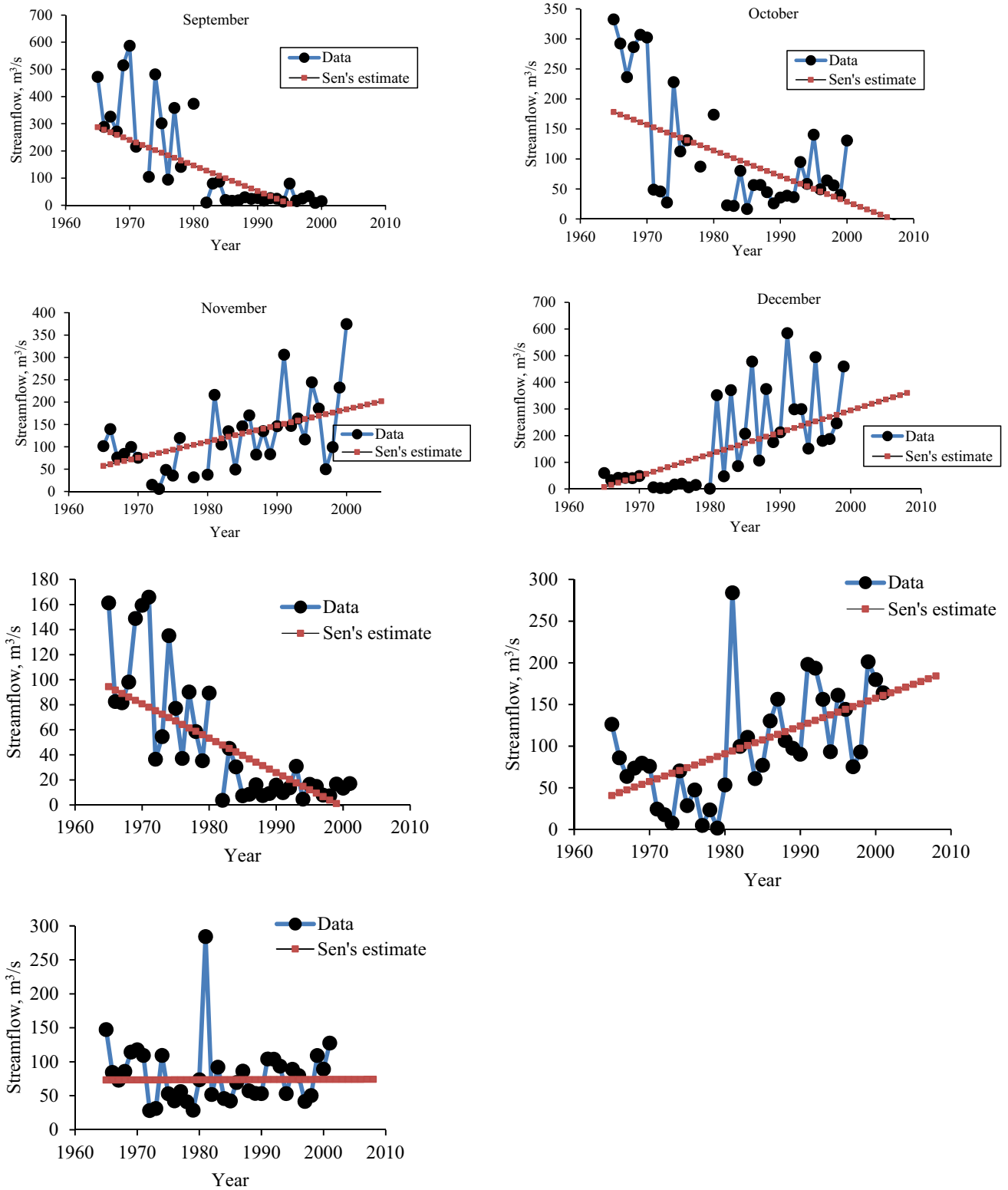


Fig. 5 (continued)

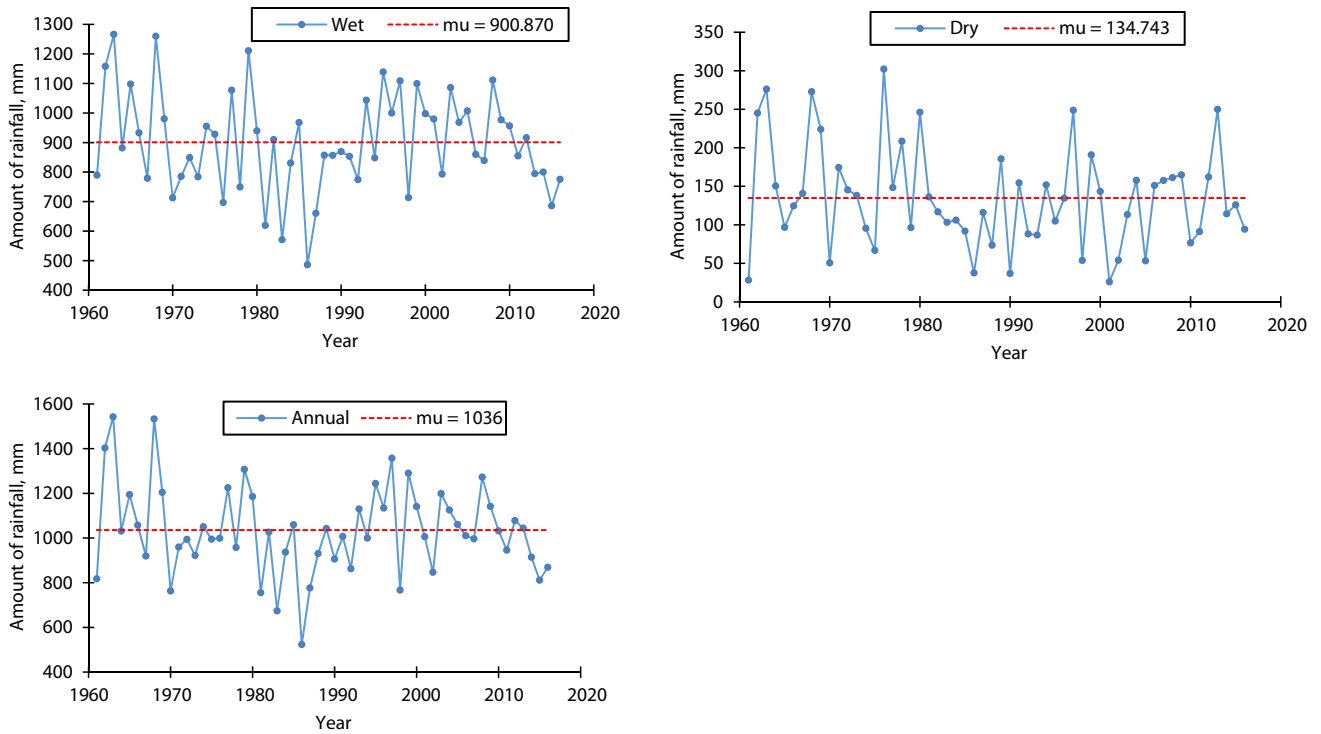


Fig. 6 Shift detection of upstream (Wa) wet, dry, and annual rainfall

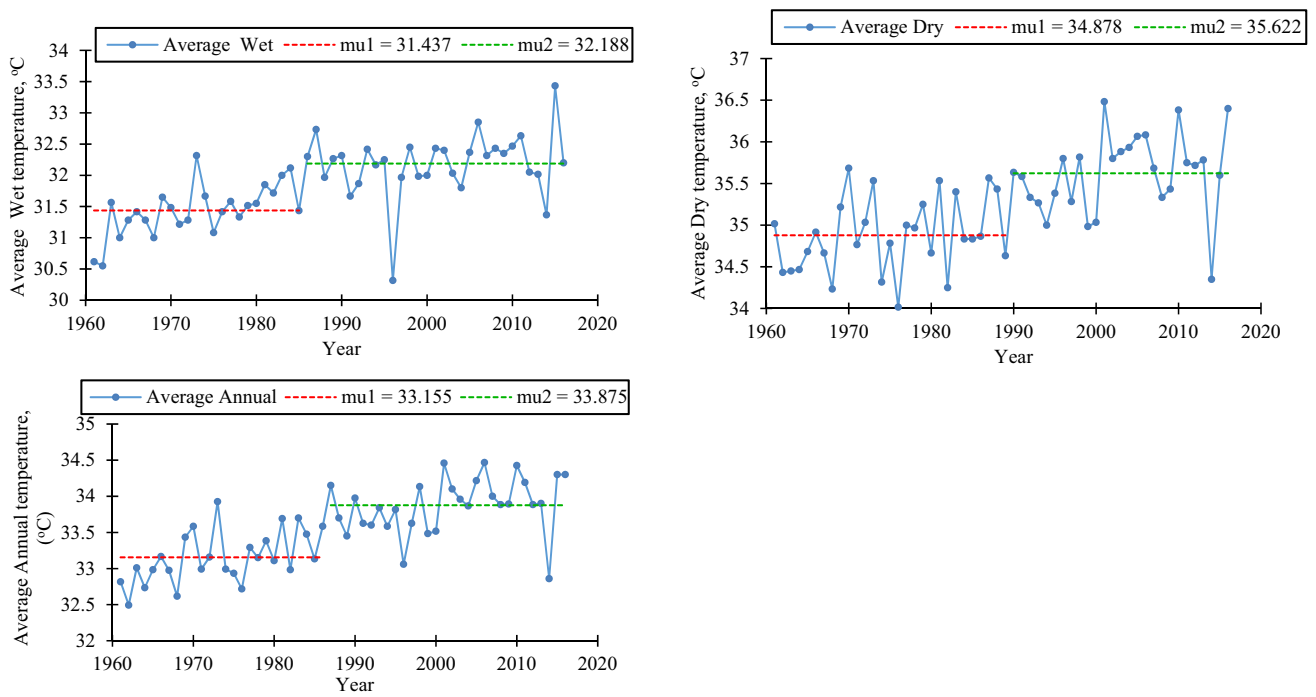


Fig. 7 Shift detection of upstream (Wa) wet, dry, and average maximum temperature

the river. Figure 5 (upstream) and S6 (downstream) reveal the streamflow variability for the period 1965–2008.

Similarly, results indicate a rising trend for the month of March with a significance of 0.001 level of significance. In contrast, the months October, November, and December indicate a falling trend with a significantly higher than 0.1 significance level (Table 2). A positive trend for the rainy season will increase the streamflow, which may trigger erosion of cropland close to the river. A decrease in trend depicted for the dry season will decrease water availability for downstream use. A general increase in trend in the annual could be a result of releases from the upstream dam in Burkina Faso that will increase in available water into the river. However, storage in the Bui hydroelectric Dam may result a decline in the annual average streamflow at downstream side.

3.4 Probable Change Point Analysis

The detection of change point is crucial for recognizing an indication of climate change, and it also provides valuable inputs for the planning of adaptation strategies. The analysis was carried out using the PMW test on the annual and seasonal time scales for the hydro-climatic variables. The results cleared that there was no shift observed, which is statistically significant for rainfall within the Black Volta Basin for both upstream and downstream (Figs. 6 and 7). The surface temperatures (highest maximum and lowest minimum) covering the dry season had a significant shift in 1989 (Fig. S7), 1982 (Fig. S8), 1982, 1994 (Fig. S9), and (Fig. S10). There were significant observable changes in surface temperatures for the annual and wet (rainy) season. Shifts in climatic variables could be due to global climate alteration of dynamics such as the weakening global circulation, declining in forest vegetation, and increasing in the levels of aerosol within the atmosphere as a result of anthropogenic activities (Giannini et al. 2003; Owusu and Waylen 2009; Pingale et al. 2016).

4 Conclusions

The study area is unique in the sense that the Basin is a trans-boundary one, shared between Burkina Faso, Cote d'Ivoire, and Ghana. In this regard, the rainfall and temperature data taken from 1961 to 2016 as well as runoff from 1965 to 2008 for upstream and downstream capture this uniqueness of the Basin. The study revealed that there is substantial annual and seasonal variability in rainfall pattern and the pattern is generally erratic. There is variation in each of the hydro-climatic variables on a monthly scale

within a year. The mean annual rainfall and minimum and maximum temperature show an increase in trend in temperatures for the entire Basin, whereas the mean annual streamflow shows a decreasing trend for downstream and a rising marginal trend upstream of the Basin. A large portion of the study area has fertile land for agricultural activities; some are undergoing urbanization and are seeing some land-use changes; fragile ecosystems, especially along the river banks and further study, may look at assessing the present agricultural practices and upstream water development, land-use changes, sedimentation, topsoil removal rates, and their impacts on the Basin. The analysis of the data sets gives a clearer picture of any severe event; hence the assessment of trend of data sets would be beneficial to water resources managers toward minimizing the effects of vulnerable disasters.

Rainfall is considered the most critical and reliable agro-climatic variable, which determines the cropping pattern, as well as crop productivity for rain-fed areas in Ghana and so falling (decreasing) trend as depicted for rainfall in the upstream of the Basin on an annual and seasonal basis, can affect agriculture enormously. Rising (increasing) trend in the downstream catchment on an annual basis can be used for a better planning of water resource utilization and management schemes especially for the Bui Hydroelectric Dam as well as conservation of soil moisture in the upstream part of the study area. The Sen's slope magnitude of change and percentage change in the climatic variables were also estimated over the 56 year duration and 43 years for the streamflow. The trend analysis revealed that downward rainfall trend during wet and dry seasons. There are statistically significant decreasing trends observed in the upstream of the Basin. The annual rainfall shows an upward trend, whereas a statistically upward trend for the rainy season and a statistically downward trend for the dry season were found at downstream side. Surface temperatures (minimum, average, and maximum) depicted statistically significant upward trend with both seasons and annual time scales over the study area. Generally, there were no shifts detected in the rainfall for both seasonal and annual scales in upstream and downstream of the Basin. Surface temperatures, however, show a statistically significant shift for maximum as well as minimum temperatures over the study area. Hence, this study could be beneficial in the development of sustainable water resource management for the Black Volta Basin. This could also help policymakers and scientists to focus on the sub-basin-level planning measures considering climate change.

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Compliance with Ethical Standards

Conflict of interest There is no conflict of interest.

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