Climatic trends over tropics of Africa, A case of the Pra River Basin in Ghana

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Abstract

The likelihood of changing trends in climatic time series over the Pra River Basin in Ghana was examined. Trend analyses were carried out on monthly, seasonal, and annual timescales for temperature and rainfall from 1950 to 2010. The use of Modified Mann–Kendall, Sen's slope and Pettit tests revealed warming trends over the Pra River Basin. Maximum and Minimum annual temperature time series revealed a statistically significant increasing trend over 60% of the stations with Sen's slopes varying from 0.006 to 0.035 ^{o}C/yr. Monthly temperature extremes revealed a statistically significant increasing trend over 80% of the stations. Seasonality revealed both increasing and decreasing trends for both dry and wet seasons, while annual rainfall experienced a decreasing trend in four out of the five stations with only one station being statistically significant at a 0.05 level. Both dry and wet season rainfall experienced statistically significant decreasing trends for all stations except one at 0.05 level. Strong downward trends in rainfall were observed for the dry season while weak downward trends were observed for the wet season. Moreover, increasing change points ranging between 0.76°C– 0.93°C on average were experienced mostly for T_{MAX} around the mid-1960s through to the early 1980s. While decreasing change points within a range of between − 0.99°C and − 0.61°C on average were also observed for T_{MIN} around the late 1950s through to the mid-1970s.

1. Introduction

Scientific evidence shows that climate is changing under human influences owing to a global increase in temperature and variability in precipitation patterns (Abungba et al., 2020; Gentilucci et al., 2019; Snyder, 2017; Roboaa and Al-Barazanji, 2015; Mishra et al., 2014). According to Gautam et al. (2018), Intergovernmental Panel on Climate Change (IPCC) reported increases in mean surface temperature of between 0.3 and 4.8 ^{o}C by 2081–2100 relative to 1986–2005. In Ghana, scientific researchers working in the Volta River Basin (VRB) have identified changing patterns in climate. For instance, Kunstmann and Jung (2004) predicted a mean annual increase of 1.2°C in temperature and 5% in rainfall between the present (1991–2000) and the near future (2030–2039) in the VRB of Ghana. Neumann et al., (2007) analyzed the present trends in precipitation and temperature for the VRB and observed clear positive trends with high levels of significance for temperature time series, but a weak decreasing trend for precipitation. Recently, Abungba et al., (2020) examining trends of hydro-climatic parameters over the Black Volta Basin in Ghana confirmed that there are warming trends over the entire Black Volta Basin. These reviews have shown that establishing trends in long term temperature and precipitation time series is very essential in making inferences as to whether the climate is indeed changing (Marengo and Souza, 2019; Roboaa and Al-Barazanji, 2015) and to what extent it has changed in the Pra River Basin (PRB) of Ghana (Neumann et al., 2007). Changes in temperature and rainfall correlates strongly with the availability of water resources as Awotwi et al., (2015) have shown that small increase of 8% and 1.7% in mean annual precipitation and temperature result in significant increment of 26%, 24% and 6% in annual surface runoff, baseflow and evapotranspiration respectively. Thus, the outcome of this study will form the basis for advanced research in modeling the effect of climate change on the spatial distribution of ET over the PRB, as it is a key indicator in estimating agricultural water use. This is because agricultural development has been identified as the most lucrative and vital business to replace small-scale illegal alluvial gold mining (also known as Galamsey) and ensure sustainable food security within the PRB in the near future (Awotwi et al., 2019).

This study aims to investigate the likelihood of changing trends in climate within the PRB of Ghana. In this study, annual, seasonal, and monthly rainfall and temperature time series were derived from the daily measurement from five weather stations ranging between 1950 to 2019 to investigate the existence of trends and change points in these time series. The non-parametric Modified Mann-Kendall (MMK) test, to remove the influence of serial correlation, was used to detect the presence and/or otherwise of statistically significant trends in the above-mentioned time series. While the occurrence of abrupt change points in annual and seasonal temperature and rainfall were detected using the Pettitt homogeneity test.

The Mann-Kendall test (Mann 1945, Kendall 1975) is one of the most widely used non-parametric statistical tests for detecting a trend in hydroclimatic time series (Abungba et al., 2020; Ackom et al., 2020; Jaweso et al., 2019; Da Silva et al., 2015; Roboaa and Al-Barazanji, 2015; Awotwi et el., 2015). Amongst the several authors, Mishra et al. (2014) determined trend in annual mean and monthly temperature time series using non-parametric methods (Mann-Kendall and Sen's T-tests) and found out that the annual mean, maximum and minimum temperatures have increased by 0.62ºC, 0.60ºC, and 0.60ºC respectively, over the past 101 years. Comparative studies by Roboaa and Al-Barazanji (2015) also revealed that annual maximum, minimum, and mean of time series showed statistically significant increasing trends over 81.8%, 100%, and 100% of the stations at 0.001 level with a corresponding increase of 0.50, 0.67, and 0.58°C/decade, respectively. Moreover, Da Silva et al. (2015), analyzed trends in annual precipitation at a regional scale over 40 years (1960–2000) with daily precipitation recorded in eight rainfall stations using the non-parametric Mann-Kendall and Sen's methods. The results although revealing an overall decrease in the annual rainfall amount for the period studied (1960–2000), also showed that rainfall is highly temporally variable. All these studies do indeed confirm that there is some form of climate change and these changes are not by chance.

Serial correlation has been identified as 'fool's gold' in trend tests; increasing the chances of detecting significant trends even if they are absent and vice versa (Ahmad et al., 2015; Zhang and Zwiers, 2004; Hamed and Rao, 1998). The null hypothesis (H_o) for the Mann-Kendall test stipulates that the time series data are randomly ordered and serially independently distributed with no trend or serial correlation structure among the observations. However, in many real situations, the observed data are serially correlated and if this observed self-correlation is not removed, it will result in misinterpretation of trend tests result. To consider and account for the effect of autocorrelation, Hamed and Rao (1998) suggest a Modified Mann-Kendall test, which calculates the autocorrelation between the ranks of the data after removing the apparent trend. This technique divides the time series into separate classes according to seasons and applies the Mann-Kendall test on the sum of the statistics from each season taking into account the presence of lag one autocorrelation (AR (1)). This modification is very reliable because it may reject H_O only if it is statistically significant at the required level (Zhang and Zwiers, 2004). Another important statistical indicator to identify shifts or any abrupt change point in time series is the homogeneity test. Homogeneity tests are performed on hydroclimatic time series to assess whether changes in these data set indeed reflect actual changes caused by climatic factors and not by non-climatic external conditions. Potential non-climatic influences on hydroclimatic time-series observations include changes in local ground conditions around an observation site, changes in instruments' location as well as observation procedures (Yatim et al., 2019; Trewin, 2010 & 2013; Aguilar et al. 2003). Although inhomogeneities have only a marginal impact on observed temperature trends at the global scale (Jones and Wigley, 2010), they can have a much more substantial effect on outcomes at the local and regional scale (Trewin, 2013). As such, several homogeneity tests such as the Pettitt, Buishand, Standard Normal Homogeneity Test (SNHT), and the von Neumann tests, have been deployed in the scientific world to determine discontinuities in time series with the view of assessing the impact of climate change or anthropogenic contributions to the cause of the change.

These reviews convincingly imply that in-depth knowledge and understanding of the variability in long-term hydro-climatic data can help make conclusive deductions as to whether climate change is a reality or a fallacy. This will indeed have immense scientific and practical importance to water resources planning and management which is the mandate of this research carried out in the Pra River Basin (PRB) located in the south-western part of Ghana.

2. Study Area

The PRB is geographically situated in the south-western part of Ghana, within Latitudes 5^{o}N and 7^{o} 30' N, and Longitudes 2^{o} 30' W, and 0^{o} 30' W with a surface area of 23,256.4 km^{2} (Fig.1). The topography is almost flat in the southern part whilst the middle portion of the basin is interspersed with minor peaks with an outstanding peak of about 848 m above sea level situated at the northern part. The basin consists of four main tributaries namely; Anum, Birim, Ofin, and Oda River, which originate from the Mampong-Kwahu Plateau and flows southwards for about 240 km before joining the Gulf of Guinea at Shama in the Western Region of Ghana (Water Resources Commission, 2012).

Figure 1. Location, DEM, weather stations, and river flow patterns of the PRB.

The basin falls within the subtropical wet climatic zone, with double rainfall (wet) seasons (May-July and September-November) and a single dry season spanning from December-April (Awotwi et al., 2019). The mean annual rainfall ranges between 1300 mm and 1900 mm, increasing westwards and south-westwards. The spatio-temporal distribution of rainfall seems to decrease toward the northern part of the study area with a recorded yearly mean rainfall of 1550 mm. Long-term air surface maximum and minimum temperatures of 23°C and 33°C have been recorded respectively. According to Awotwi et al. (2017), surface temperatures decrease toward the southern section of the study area.

2.1 Materials and methods

2.2 Data Collection

Daily maximum and minimum air temperature at five weather stations within the PRB of Ghana over 51 years (1950–2000) were obtained from Ghana Meteorological Agency (GMet) for this study. Daily rainfall amount over 70 years (1950–2019) was also obtained from GMet as part of the data for this study. Annual, monthly, and seasonal (wet and dry season) deductions were derived from the collected data before statistical testing. The stations were chosen based on the availability of data.

2.3 Trend Estimation and Change Point Detection

In this study, the modified Mann-Kendall (MMK) and homogeneity (Pettitt) tests were performed using an excel-based Addinsoft's XLSTAT evaluation version 2019. Trends in the time series were estimated using Kendall's tau-based slope estimate, compared with the p-value, and confirmed with Sen's slope by applying the continuity correction. The significance of the trend was assessed using the Z statistics to test the null hypothesis (H_o) against the alternative hypothesis (H_1) at the 5% level. Shifts or change points and the year of change in the time series were also detected using Pettit's *K* and t values. These runs were executed using 10000 Monte Carlo Simulations at a 99% confidence interval on the p-value at 5% significance level in Addinsoft's XLSTAT 2019.

2.3.1 Trend Estimation

The non-parametric Modified Mann-Kendall (MMK) test is used to determine the presence of a monotonic (increasing or decreasing) trend while the Sen's slope is used to estimate the slope of linear trend. The advantages of this method especially over the parametric ones `are that the variance of the residuals is assumed to be constant in time, data need not conform to any particular distribution, is not affected by single data errors or outliers, and missing values are permitted (Hamed and Rao, 1998;). The MMK test statistics S is given by:

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} sgn(x_j - x_k)$$

1

where n is the length of the time series $x_j, \ldots, x_n$, and sgn(.) is a sign function, x_j and x_k are values in years' j and k, for j > k, respectively. The expected value of S is positive for increasing trend, negative for decreasing trend but zero for series without trend, and the variance is computed as:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p-1}^{q} t_p(t_p - 1)(2t_p + 5)\right]$$

2

Here q is the number of tied groups and t_p is the number of data values in p^{th} group. The test statistic Z is then given as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} ifS > 0 \\ S = 0 ifS = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} ifS < 0 \end{cases}$$

3

The Z statistic is used to test the null hypothesis, H_0, that the data are randomly ordered in time, against the alternative hypothesis, H_1, that there is an increasing or decreasing trend. A positive (negative) value of Z indicates an upward (downward) monotone trend. H_0 is rejected at the required level of significance if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal distribution tables. The MMK test which calculates the autocorrelation between the ranks of the data after removing the apparent trend is expressed as the adjusted variance given by:

$$Var(S) = \frac{1}{18}[N(N-1)(2N+5)]\frac{N}{NS}$$

4

Where, $\frac{N}{NS*} = 1 + \frac{2}{N(N-1)(N-2)} \sum_{t-1}^{p} (N-i)(N-i-1) P_s(i)$ (5)

Where N is the number of observations in the sample, NS* is the effective number of observations to account for autocorrelation in the data, $p_s(i)$ is the autocorrelation between ranks of the observations for lag i, and p is the maximum time lag under consideration. The corrected variance was then estimated as:

$$Var(S)* = Var(S) x \frac{N}{N*}$$

6

The true slope of an existing trend in the time series was estimated using Sen's non-parametric method (Sen, 1968):

$$f(t) = Q + B$$

7

where Q is the slope and B is the constant. The slope estimates for all the data value pairs were calculated using:

$$Q_t(t) = \frac{X_{j-X_k}}{j-k} for I = 1,2,3, \ldots .\, n,$$

8

where x_j and x_k are the values for j and k times of the 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 the Sen's estimator calculated as:

$$Q_t = T\frac{n+1}{2}$$

9

for n is odd, and

$$Q_{i=\frac{1}{2}} \left(T\frac{n}{2} + T\frac{n-1}{2} \right)$$

10

for n is even.

When n is odd, it allows for the Sen's estimator to estimate slope as;

$Qmed = (n+1)/2$ (11) and for even observations, it is estimated as;

$$Qmed = [\left(\frac{n}{2}\right) + (n+2)/2)]/2$$

12

The two-sided test was used to obtain the true slope of the time series plot. A positive or negative slope (Q_i) indicates increasing and decreasing trends respectively.

To remove inherent serial correlation, the option of Hamed and Rao (1998) was chosen during the 10000 Monte Carlo Simulation in XLSTAT. This option takes account of the lag one autocorrelation by disaggregating the time series into a linear trend with AR (1) component and noise. This approach was used in other works describing changes in climate extremes (Aziz and Obuobie, 2017; You et al., 2008; Zhang et al., 2005) and a detailed description of the procedure is provided by Hamed and Rao (1998).

2.3.2 Change-Point Detection

Identifying breaks or change points in hydroclimatic time series is essentially important for assessing the contributions of climate variability and human activities to climate change (Awotwi et al., 2019; Akpoti et al., 2016; Ho and Yusof, 2012). This study used the Pettitt test to assess changes in hydroclimatic time series within the PRB. This test was chosen because, it is a non-parametric rank test that does not depend on the assumption of normality (Pettitt, 1979) and is easier to identify breaks in time series (Ho and Yusof, 2012; Firat et al., 2010). The Pettit test compares the mean of the first y years with that of the last n-y years of a test statistic T(y) as:

$$T_y = \overline{yz_1} + (n-y)\overline{z_2}\ y = 1,2,\dots\dots,n \tag{13}$$

$$\text{Where, } \overline{z_1} = \frac{1}{y}\sum_{t-1}^{n}\frac{(Y_t-\overline{Y})}{s} \tag{14}$$

and

$\bar{z}_2 = \frac{1}{n-y}\sum_{i-y+1}^{m}\frac{(Y_t-\bar{Y})}{s}$ (15) There is a breakpoint in year y if T is maximum. To reject the null hypothesis, the test statistic,

$T_0 = \max T_y$ for $1 \le y \le n$ (16)

is greater than the critical value, which depends on the sample size.

The Pettitt test is based on the rank, r_i of the Y_i and ignores the normality of the time series by the following:

$$X_y = 2\sum_{t-1}^{y} r_t - y(n+1)\ ; y = 1,2,\dots\dots.\,,n$$

17

The break point occurs in year k when

$X_k = \max\left|X_y\right|$ for $1 \le y \le n$ (18)

The value of the test statistic is then compared with the critical value by Pettitt (1979).

3. Results And Discussions

The analysis of temperature and rainfall time series revealed some consistent changes in annual, monthly, and seasonal trends during the past 50 to 71 years within the PRB basin. The results of the MMK test and Sen's slope estimates for annual maximum and minimum temperature (T_{MAX} and T_{MIN}) as well as the geographical locations of the five weather stations within the basin are presented in Table 1 and Fig. 2 respectively. Table 2 and Fig. 3 present the results of monthly maximum and minimum temperature (T_{MAX} and T_{MIN}) while Fig. 4 presents the results of seasonal (dry and wet) maximum and minimum temperature time series. Also, the results of annual and seasonal (wet and dry) rainfall are presented in Table 3 and Fig. 5 respectively. Change points in annual (Fig. 6) and seasonal temperature (Fig. 7), as well as annual and seasonal rainfall (Fig. 8), are also presented. They represent the changes and variations of climatic variables over the 51 years for temperature and 70 years for rainfall variables respectively.

3.1 Trend analysis of Temperature

3.1.1 Annual Temperature

Annual maximum and minimum temperature (T_{MAX} and T_{MIN}) for all stations depicted a monotonic increasing trend except AO which experienced a slightly decreasing trend (Table 1 and Fig. 2). These slight decreases (T_{MAX} = -0.013 ^{o}C/yr and T_{MIN} = -0.012 ^{o}C/yr) were however, not statistically significant at 0.05 level as shown in Table 1. It is also clear that T_{MIN} for station DO experience a decreasing trend (-0.023 ^{o}C/yr) which was statistically significant at a 0.05 level of significance (Table 1).

Table 1
Mann–Kendall test and Sen's slope estimate for annual temperature (T_{MAX} and T_{MIN}) for all stations within the PRB over the period 1950–2000.

Time series	Kendall's Tau & p-value	VAR(S)	Sen's slope
T_{A_MAX}_AO	**0.151**(-), 0.444	63004.3	**-0.013**
T_{A_MAX}_B	0.619(+), 0.000	15158.3	0.025
T_{A_MAX}_DO	0.365(+), 0.065	63004.3	0.018
T_{A_MAX}_MN	0.65(+), 0.000	11678.3	0.032
T_{A_MAX}_TP	0.373(+), 0.038	52055.2	0.035
T_{A_MIN}_AO	**0.203(-)**, 0.21	42325.1	**-0.012**
T_{A_MIN}_B	0.101(+), 0.598	59003.3	0.006
T_{A_MIN}_DO	**0.388(-)**, 0.037	55873.5	**-0.023**
T_{A_MIN}_MN	0.705(+), 0.000	2316.43	0.032
T_{A_MIN}_TP	0.162(+), 0.195	25309.5	0.006

The bolded tau's and Sen's slope indicate a decreasing trend. (+) indicates an upward trend and (-) indicates a downward trend at 0.05 level significance.

Notwithstanding, an overall 60 % of the time eries of annual temperature (T_{MAX} and T_{MIN}) for all five stations experienced a statistically significant increasing trend with Sen's slopes varying from 0.006 to 0.035 ^{o}C/yr as shown in Table1.

Figure 2: MMK trend and Sen's slope estimate for the annual temperature at stations AO and DO within the PRB over the period 1950–2000.

However, three time-series data ($T_{A–MIN}$_B, $T_{A–MIN}$_TP, and $T_{A–MAX}$_DO) indicating an increasing trend were not statistically significant at 0.05 level (Table 1). It was also observed that while T_{MAX} generally followed an increasing trend, T_{MIN} exhibited both increasing and decreasing trends for the annual time series.

3.1.2 Monthly temperature

Observed maximum and minimum temperature (T_{MAX} and T_{MIN}) for all months revealed that over 80 % of the time eries experienced an increasing trend for all stations (Table2 and Fig.3). However, only station AO showed an estimated 83.3 % of time seris with decreasing trend, which is statistically significant at 0.05 level (Table2).

Figure 3: MMK trend and Sen's slope estimate for monthly maximum and minimum temperature at selected stations within the PRB over the period 1950–2000.

It can be seen in Table 2 that station DO experience both increasing and decreasing trends with only 37.5% being statistically significant at 0.05 level. Three stations (B, MN, and TP) out of the five which were experiencing increasing trend were 58.3%, 91.7%, and 45.8% statistically significant at 0.05 level. As shown in Table 2, maximum temperature (T_{MAX}) for stations B and MN were similar, showing statistically significant increasing trends at 0.05 level of significance for all months.

Table 2
MMK and Sen's slope for monthly temperature (T_{MIN} and T_{MAX}) for all stations within the PRB over the period 1950–2000.

Month	Time series	T_M_AO_(ºC)	T_M_B_(ºC)	T_M_DO_(ºC)	T_M_MN_(ºC)	T_M_TP_(ºC)
Jan	T_{MIN}	0.25(-), 0.01	0.053(-), 0.722	0.44(-), 0.000	0.272(+), 0.00	0.037(-), 0.758
	T_{MAX}	0.09(-), 0.54	0.55(+), 0.00	0.466(+), 0.000	0.575(+), 0.000	0.219(+), 0.062
Feb	T_{MIN}	0.44(-), 0.00	0.021(+), 0.89	0.415(-), 0.000	0.511(+), 0.000	0.068(-), 0.541
	T_{MAX}	0.01(-), 0.95	0.578(+), 0.00	0.433(+), 0.003	0.55(+), 0.000	0.33(+), 0.004
Mar	T_{MIN}	0.09(-), 0.41	0.164(+), 0.261	0.195(+), 0.18	0.669(+), 1.00	0.034(-), 0.733
	T_{MAX}	0.138(-), 0.36	0.466(+), 0.00	0.36(+), 0.016	0.484(+), 0.000	0.245(+), 0.042
Apr	T_{MIN}	0.019(+), 0.82	0.273(+), 0.005	0.157(-), 0.166	0.635(+), 0.000	0.021(+), 0.833
	T_{MAX}	0.169(-), 0.30	0.41(+), 0.00	0.31(+), 0.001	0.394(+), 0.000	0.274(+), 0.000
May	T_{MIN}	0.003(+), 0.98	0.296(+), 0.013	0.103(-), 0.251	0.612(+),0.000	0.147(+), 0.213
	T_{MAX}	0.333(-), 0.047	0.344(+), 0.004	0.166(+), 0.087	0.38(+), 0.000	0.362(+), 0.003
Jun	T_{MIN}	0.092(-), 0.4	0.239(+), 0.051	0.027(-), 0.782	0.597(+), 0.000	0.242(+), 0.005
	T_{MAX}	0.142(-), 0.259	0.384(+), 0.000	0.258(+), 0.039	0.496(+), 0.000	0.566(+), 0.000
Jul	T_{MIN}	0.173(-), 0.134	0.191(-), 0.087	0.112(-), 0.499	0.415(+), 0.000	0.238(+), 0.014
	T_{MAX}	0.158(-), 0.275	0.238(+), 0.001	0.012(+), 0.889	0.365(+), 0.00	0.336(*), 0.00
Aug	T_{MIN}	0.084(-), 0.411	0.126(-), 0.292	0.311(-), 0.045	0.424(+), 0.00	0.252(+), 0.009
	T_{MAX}	0.212(-), 0.202	0.341(+), 0.000	0.155(+), 0.142	0.429(+), 0.000	0.238(+), 0.071
Sep	T_{MIN}	0.039(-), 0.7	0.016(+), 0.9	0.208(-), 0.176	0.434(+), 0.000	0.402(+), 0.001

Month	Time series	T_M_AO_(ºC)	T_M_B_(ºC)	T_M_DO_(ºC)	T_M_MN_(ºC)	T_M_TP_(ºC)
	T_{MAX}	0.278(-), 0.099	0.426(+), 0.00	0.187(+), 0.179	0.332(+), 0.000	0.217(+), 0.103
Oct	T_{MIN}	0.007(-), 0.948	0.034(+), 0.773	0.299(-), 0.002	0.479(+), 1	0.3(+), 0.022
	T_{MAX}	0.129(-), 0.342	0.446(+), 0.000	0.078(+), 0.631	0.293(+), 0.003	0.181(+), 0.23
Nov	T_{MIN}	0.162(-), 0.109	0.172(+), 0.225	0.216(-), 0.107	0.542(+), 0.000	0.315(+), 0.03
	T_{MAX}	0.057(-), 0.72	0.431(+), 0.000	0.109(+), 0.494	0.333(+), 0.001	0.201(+), 0.242
Dec	T_{MIN}	0.346(-), 0.02	0.089(+), 0.566	0.189(-), 0.118	0.351(+), 0.000	0.01(+), 0.922
	T_{MAX}	0.249(-), 0.157	0.579(+), 0.000	0.217(+), 0.198	0.479(+), 0.000	0.139(+), 0.376

3.1.3 Seasonal Temperature

The seasonal extremes (maximum and minimum temperature) revealed heterogeneous results for both dry and wet seasons. Maximum and minimum temperature (T_{MAX} and T_{MIN}) for both dry and wet seasons for all stations experienced both increasing and decreasing trends (Fig.4 and Table3).

Figure 4: MMK test and Sen's slope for seasonal maximum and minimum temperature (T_{MAX} & T_{MIN}) at selected stations within the PRB over the period 1950–2000.

For the dry season, six out of the ten time-series data followed an upward trend and seven out of ten time series for the wet season followed an upward trend according to Kendall's tau and Sen's slope values as shown in Table 3. Moreover, T_{MIN} for both dry and wet seasons at station B experienced a slightly decreasing trend of -0.007 ºC/yr and − 0.041 ºC/yr respectively in terms of Sen's slope. But Kendall's tau, on the other hand, estimated a marginally increasing trend of 0.028 ºC/yr and 0.083 ºC/yr as presented in Table 3. They were however not statistically significant at 0.05 level. It was also observed in Table 3 that while dry season temperature mostly experienced an upward trend, wet season temperature experienced a downward trend. And this observed increasing and decreasing trends were statistically significant at 0.05 level.

Table 3
MMK trend test and Sen's slope for seasonal temperature (T_{MAX} and T_{MIN}) for all stations within the PRB over the period 1950−2000.

Dry Season	Kendall's tau & p-value	Sen's slope	Wet Season	Kendall's tau & p-value	Sen's slope
$T_{-DS-MAX-}$AO	0.294(-), 0.049	-0.375	$T_{-WS-MAX-}$AO	0.306(-), 0.039	-0.421
$T_{-DS-MAX-}$B	0.694(+), 0.000	0.373	$T_{-WS-MAX-}$B	0.583(+), 0.000	0.298
$T_{-DS-MAX-}$DO	0.528(+), 0.000	0.333	$T_{-WS-MAX-}$DO	0.056(+), 0.769	0.079
$T_{-DS-MAX-}$MN	0.75(+), 0.000	0.478	$T_{-WS-MAX-}$MN	0.556(+), 0.000	0.247
$T_{-DS-MAX-}$TP	0.306(+), 0.039	0.326	$T_{-WS-MAX-}$TP	0.306(+), 0.039	0.207
$T_{-DS-MIN-}$AO	0.556(-), 0.000	-0.697	$T_{-WS-MIN-}$AO	0.113(-), 0.488	-0.053
$T_{-DS-MIN-}$B	**0.028(+), 0.922**	**-0.007**	$T_{-WS-MIN-}$B	**0.083(+), 0.624**	**-0.041**
$T_{-DS-MIN-}$DO	0.444(-), 0.002	-0.453	$T_{-WS-MIN-}$DO	0.333(-), 0.024	-0.102
$T_{-DS-MIN-}$MN	0.694(+), 0.000	0.531	$T_{-WS-MIN-}$MN	0.833(+), 0.000	0.341
$T_{-DS-MIN-}$TP	0.028(-), 0.922	-0.056	$T_{-WS-MIN-}$TP	0.417(+), 0.004	0.176
Bolded tau's and Sen's slope indicate decreasing trend ap-value indicate significant trend at 5% level.					

3.2 Trend analysis of Rainfall

3.2.1 Annual rainfall

Annual rainfall experienced a decreasing trend in four out of the five stations (Table 4) with only one station (B) being statistically significant at 0.05 level.

Table 4
MMK test and Sen's slope for annual rainfall for all stations within the PRB over the period 1950−2019.

Time series	Kendall's tau	VAR(S)	P-value	A	Sen's slope
P_{t-A-}AO	-0.104	30786.999	0.153	0.050	-1.623
P_{t-A-}B	-0.467	64860.861	**< 0.0001**	0.050	-18.662
P_{t-A-}DO	0.098	185784.933	0.586	0.050	**3.948**
P_{t-A-}MN	-0.043	38905.333	0.602	0.050	-0.682
P_{t-A-}TP	-0.065	38905.333	0.426	0.050	-0.814

The only station (DO) that was observed to depict an increasing trend was however not statistically significant at 0.05 level as shown in Table 4.

3.2.3 Seasonal Rainfall

Both dry and wet season rainfall experienced decreasing trends for all stations and all months except DO which experienced an increasing and statistically significant trend at 0.05 level (Fig.5).

Figure 5: MMK test and Sen's slope for dry and wet season rainfall for selected stations within the PRB over the period 1950–2000.

With all the stations experiencing a decreasing trend, only station B was statistically significant at 0.05 level (Fig. 5). During the dry season, strong downward trends were observed in May and June while weak downward trends were observed in August, September, and October as shown in Fig. 5. The wet season, however, experienced very weak downward trends for July, August, September, and October while May and June experienced strong downward trends which were statistically significant trends at 0.05 level.

3.3 Change-Point Detection

3.3.1 Temperature Time Series

3.3.1.1 Annual temperature

The outcome from the Pettit test revealed that both statistically significant increasing and decreasing change points at 0.05 levels were experienced for annual maximum and minimum temperature (T_{MAX} and T_{MIN}) for all the stations.

Figure 6: Changepoint detection for annual maximum and minimum temperature time series plots for selected stations within PRB of Ghana 1950–2000. The dashed lines represented by red and green are the mean of the time series before and after the change point respectively.

Increasing change points experienced mostly for T_{MAX} occurred around the mid-1960s through to the early 1980s (Fig. 6). During these years, T_{MAX} increased about 0.76°C– 0.93°C on average. Decreasing change points were also observed mostly for T_{MIN} and occurred around the late 1950s through to the mid-1970s (Fig. 6). Annual temperature decreased similarly [-(0.99°C – 0.61°C)] on average.

3.3.1.2 Seasonal temperature

Maximum and minimum temperature (T_{MAX} and T_{MIN}) for both dry and wet seasons experienced both upward and downward change points for all stations. However, while T_{MAX} showed a statistically significant upward shift, T_{MIN} showed a statistically significant downward shift at 0.05 level for all stations (Fig.7).

Figure 7: Changepoint detection for both dry and wet season maximum and minimum temperature plots for selected stations within PRB of Ghana. The dashed lines represented by red and green are the mean of the time series before and after the change point respectively

T_{MAX} for both dry and wet seasons showed increasing change points ranging between 1969 and 1982. During these years, T_{MAX} increased about 0.76°C– 0.93°C on average (Fig. 7). Contrary, T_{MIN} for both dry and wet seasons showed decreasing change points ranging between 1958 and 1976 (Fig. 7). During this period, the temperature decreased between − 1.39°C and − 0.51°C on average. However, two stations ($T_{_WS_MIN_}$AO and $T_{_DS_MIN_}$TP) did not show any significant change points (homogeneous) in the data.

3.3.2 Change Point Detection for Rainfall

3.3.2.1 Annual and Seasonal Rainfall

The Pettit test indicated no significant change point (homogeneity in time series) in annual rainfall for all the stations. However, two stations (BO and D) did show a slightly downward and upward trend respectively, which were statistically significant at 0.05 level (Fig.8).

Figure 8: Changepoint detection for annual rainfall time series plots for selected stations within the PRB of Ghana. The dashed lines represented by red and green are the mean of the time series before and after the change point respectively

Similarly, seasonal rainfall exhibited homogeneity with no significant change point in both dry and wet seasons for all the five weather stations. However, both wet and dry season analysis indicated a statistically significant downward shift at stations B (1975 for wet and 1999 for dry season) and upward shift at DO (1962 for wet and 1961 for dry season) respectively.

4. Discussion

The statistical tests results revealed significant trends and abrupt change points in seasonal, monthly, and annual temperature (T_{MAX} and T_{MIN}) and rainfall time series for the PRB from 1950 to 2019. Generally, the test results were characterized by statistically significant increasing trends in annual and monthly temperature, decreasing trends in annual and seasonal rainfall, and a mixture of increasing and decreasing trends in seasonal temperature. The increases were more pronounced in the dry than in the wet season. An increase in temperature can be attributed to inherent climatic variability and anthropogenic activities leading to an increase in atmospheric carbon concentration. The significant warming trend in annual temperature within the PRB for the period of study is in agreement with studies conducted by Abungba et al., (2020); Gentilucci et al., (2019); Liuzzo et al., (2017), and Roboaa and Al-Barazanji (2015). This statistically significant warming trend is further observed in the monthly temperature (over 80%) trend for all five stations. The observed variations (increasing and decreasing trends) in seasonal temperature were also statistically significant at 0.05 level. And this further buttresses the assertion that climate is changing. These results agree with previous studies in Ghana and other parts of the world (Abungba et al., 2020; Gentilucci et al., 2019; and Roboaa and Al-Barazanji 2015).

Again, the issue of dry season temperature experiencing an upward trend while wet season temperature experiencing downward (Fig. 4) has also been reported in previous studies (Abungba et al., 2020; and Roboaa and Al-Barazanji 2015).

Contrary, annual rainfall experienced a decreasing trend in four out of the five stations while both dry and wet season rainfall experienced decreasing trends for all stations. This finding indeed points to the fact that climate change is certain within the study area. Remarkably, this finding has also been established in previous studies. During the dry season, strong downward trends were observed in March, April, and November while weak downward trends were observed in December, January, and February. This indicates that both pre-and post-monsoon rainfall is indeed taking a decreasing pattern over the 71 years of study within the PRB of Ghana. The wet season, however, experienced very weak downward trends for July, August, September, and October while May and June experienced strong downward trends which were statistically significant at 0.05 level.

The outcome from the Pettit test revealed that statistically significant increasing and decreasing change points at 0.05 levels were experienced for annual maximum and minimum temperature (T_{MAX} and T_{MIN}) for all five weather stations. Increasing change points were experienced mostly for T_{MAX} while decreasing change points were observed for T_{MIN}. These abrupt change points or shifts discovered in the time series might be attributed to the relocation of these weather stations, the building of infrastructural projects like roads, schools, and hospitals, or even industrial settings near these weather stations. The general consequence of urbanization (Awotwi et al., 2019) within the PRB might also be a possible cause of the appearance of linear trends or change points within the time series.

Dry and wet seasons experienced both upward and downward change points in maximum and minimum temperature (T_{MAX} and T_{MIN}) for all five weather stations. While T_{MAX} showed a statistically significant upward shift, T_{MIN} showed a statistically significant downward shift at 0.05 level. The Pettit test for annual rainfall indicated no significant change point (homogeneity in time series) for all the stations. However, stations BO and D did show a slightly downward and upward trend respectively, which were statistically significant at 0.05 level.

5. Conclusion And Recommendations

Trend and change-point analysis were carried out for five weather stations from 1950 to 2019 within the PRB of Ghana. The data were analyzed using Modified Mann-Kendall trend and Pettitt tests (change point). Generally, temperature showed a statistically significant increasing trend while precipitation experienced decreasing trend at 0.05 level of significance. Seasonality also showed both increasing and decreasing trends with seasonal maximum temperature (T_{MAX}) showing an increasing trend while seasonal minimum temperature (T_{MIN}) showed decreasing trend. Seasonality in rainfall depicted an overall decreasing trend which was statistically significant at 0.05 level.

While seasonal rainfall was taking a generally decreasing trend, seasonal temperature rather showed an overall increasing trend. The results of temperature analysis revealed that the investigated basin is getting warmer. The spatial distribution showed that an overall 60% of annual and over 80% of monthly maximum and minimum temperature (T_{MAX} and T_{MIN}) experienced a statistically significant increasing or upward trend at a rate ranging between 0.006 and 0.035 ^{o}C/yr across the study area over the 71 years. The increase in temperature was more pronounced during the dry season compared to the wet season. Moreover, the heterogeneous pattern of results for dry and wet season maximum and minimum temperature (T_{MAX} and T_{MIN}) revealed that dry season temperature mostly experienced an upward trend while wet season temperature experienced a downward trend which was statistically significant at 0.05 level. On the other hand, rainfall in the wet season experienced a weak downward trend whereas that of the dry season exhibited a strong downward trend. Annual rainfall also experienced a decreasing trend in four out of the five stations with only one station (B) being statistically significant at a 0.05 level of significance. Furthermore, dry and wet season rainfall experienced decreasing trends for all stations except one (DO), which experienced an increasing and statistically significant trend at 0.05 level. While dry season rainfall exhibited strong downward trends during March, April, and November, weak downward trends were observed in December, January, and February. On the contrary, however, the wet season experienced very weak downward trends for July, August, September, and October while May and June experienced strong downward trends which were statistically significant at 0.05 level.

The outcome from the Pettit test revealed that statistically significant increasing and decreasing change points at 0.05 levels were experienced for both annual and seasonal maximum and minimum temperature (T_{MAX} and T_{MIN}) for all the stations. Annual and seasonal rainfall on the other hand indicated no significant change point (homogeneity in time series) for all five stations. However, stations BO and D did show slightly downward and upward trends which were statistically significant at 0.05 level

Generally, the findings from this study provide important information on climatic changes within the study area. It can be deduced that the changes for the observed climatic time series might be attributed to both changes in climate variability and anthropogenic activities such as destruction of vegetation, land reclamation, and most especially, small-scale illegal alluvial mining activities over the investigated periods. Thus, the output of this study will be helpful for the various stakeholders and policymakers within the PRB of Ghana to make informed and improved decisions on water resources management

Declarations

Acknowledgment

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Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contribution statement

John Jackson Nsiah: Conceived and designed the model; collected the data; Analyzed and interpreted the data; wrote the paper.

Geophrey Kwame Anornu: Conceived the research idea and gave guidance through effective and efficient supervision.

Charles Gyamfi and Samuel Nii Odai: Analyzed and interpreted the data and discussed the results.

Ebenezer Boakye and Alfred Awotwi helped in the collection of data and analysis of the results.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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Figures

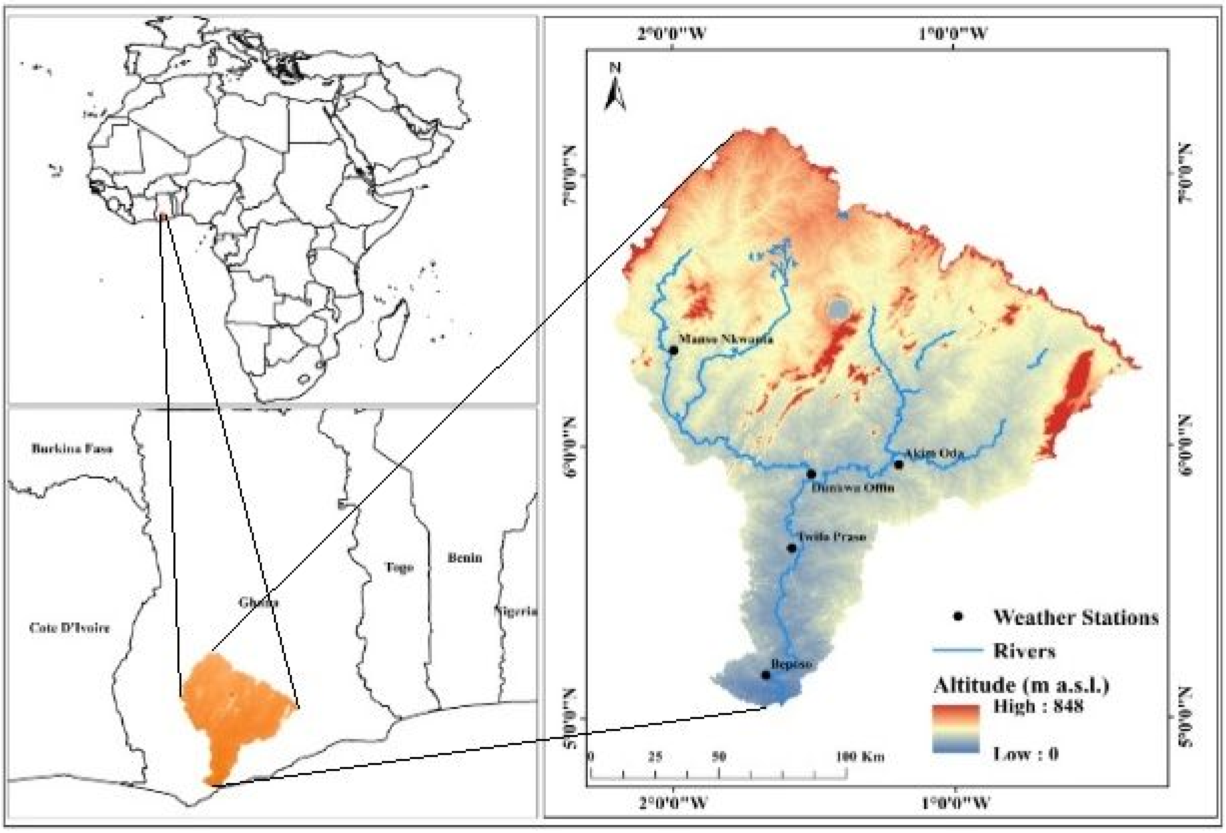

Figure 1

Location, DEM, weather stations, and river flow patterns of the PRB.

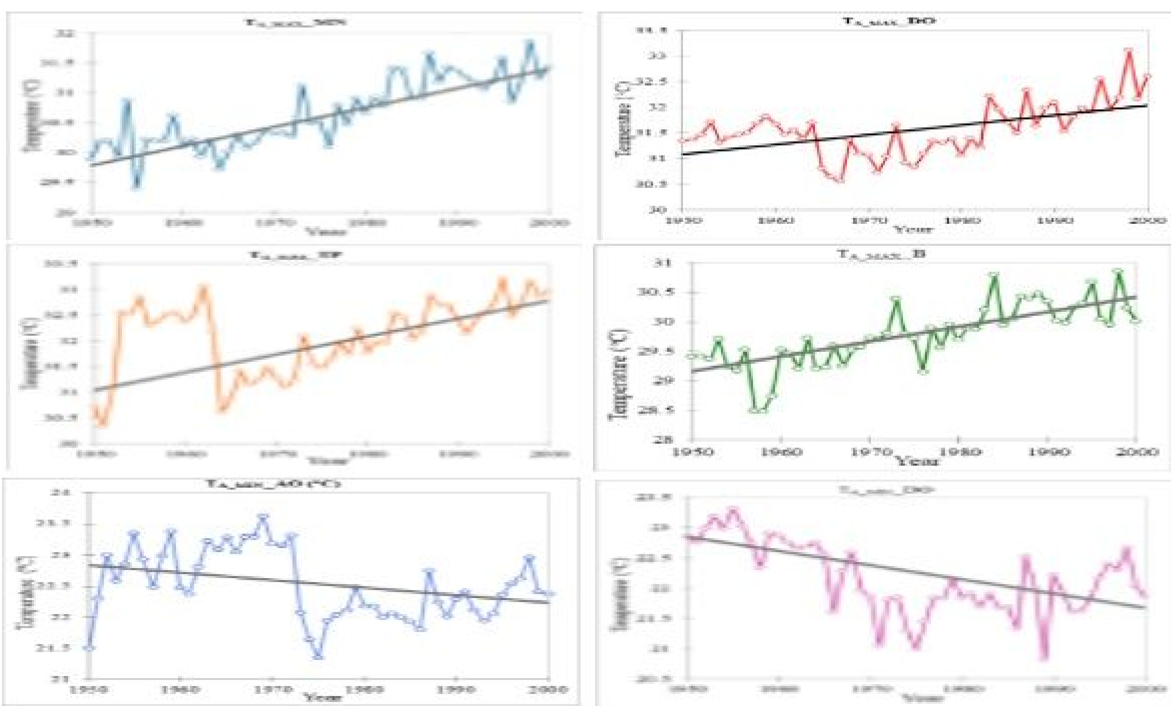

Figure 2

MMK trend and Sen's slope estimate for the annual temperature at stations AO and DO within the PRB over the period 1950–2000.

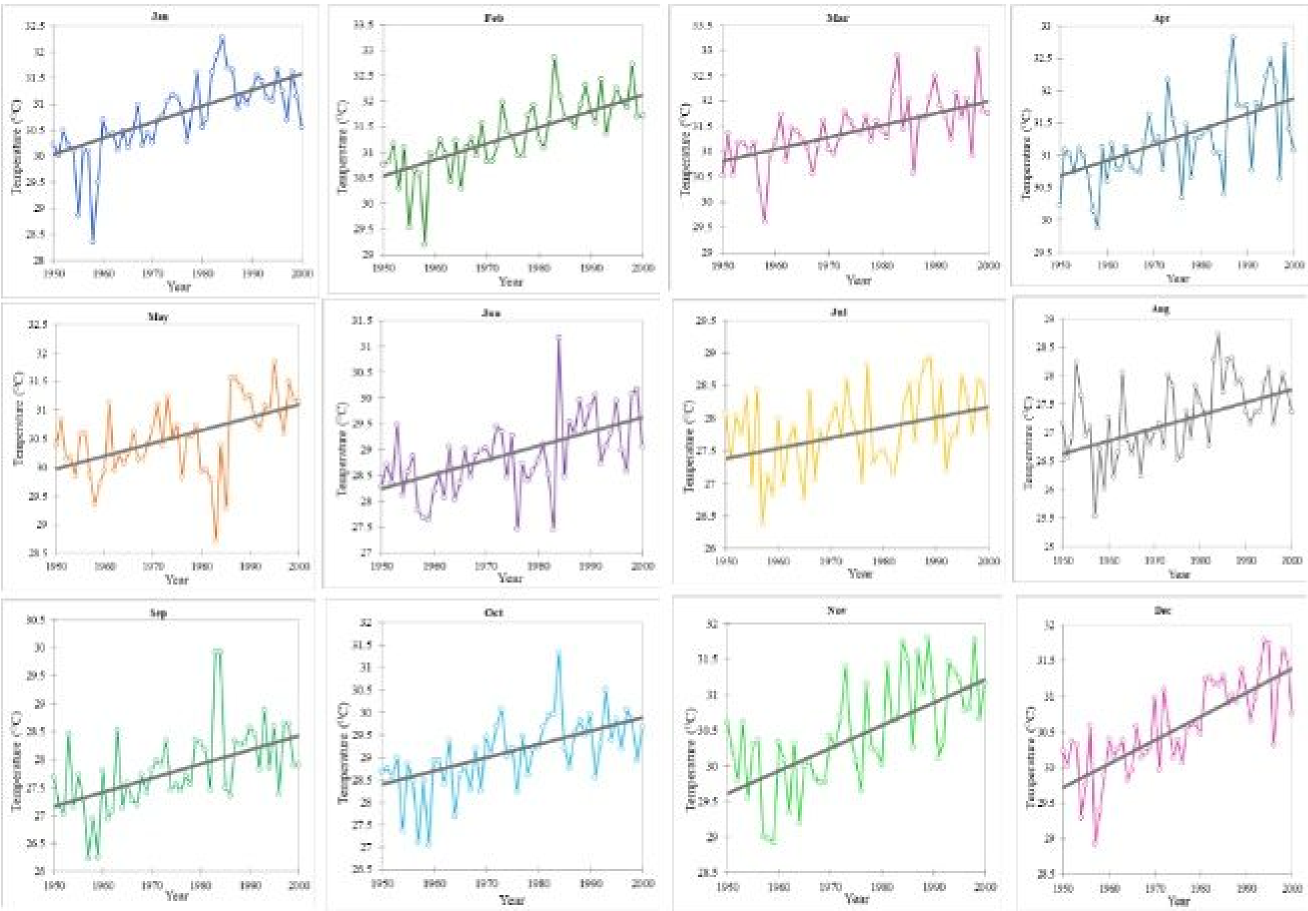

Figure 3

MMK trend and Sen's slope estimate for monthly maximum and minimum temperature at selected stations within the PRB over the period 1950–2000.

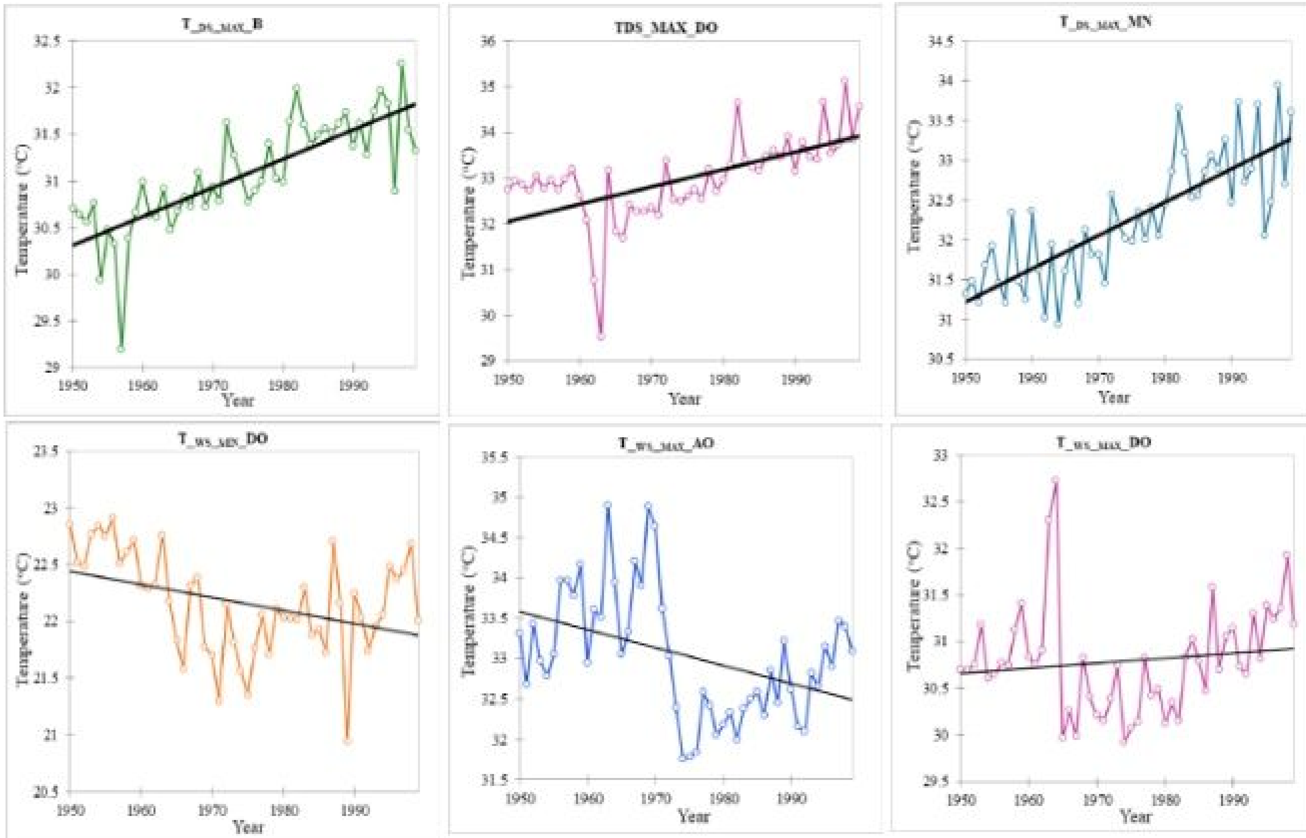

Figure 4

MMK test and Sen's slope for seasonal maximum and minimum temperature (T_{MAX} & T_{MIN}) at selected stations within the PRB over the period 1950−2000.

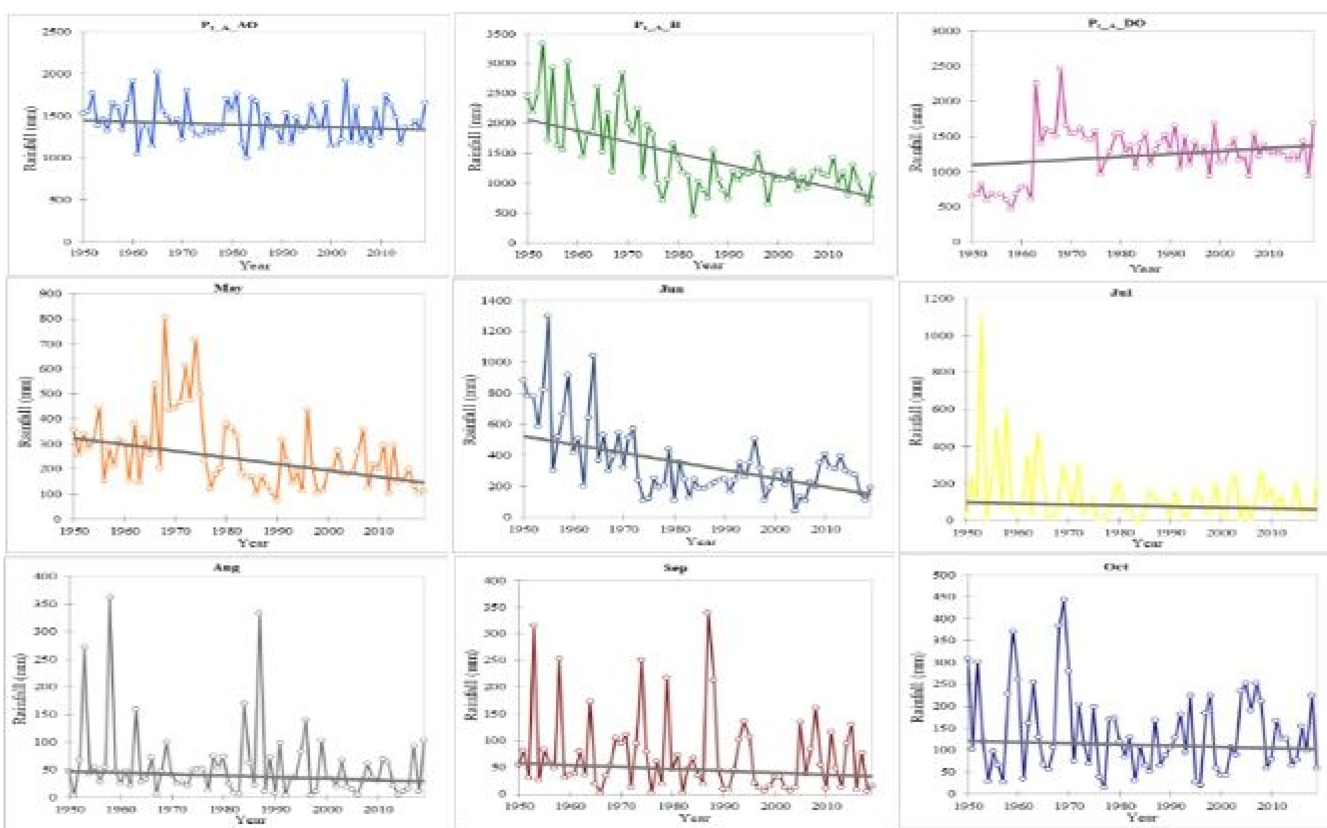

Figure 5

MMK test and Sen's slope for dry and wet season rainfall for selected stations within the PRB over the period 1950–2000.

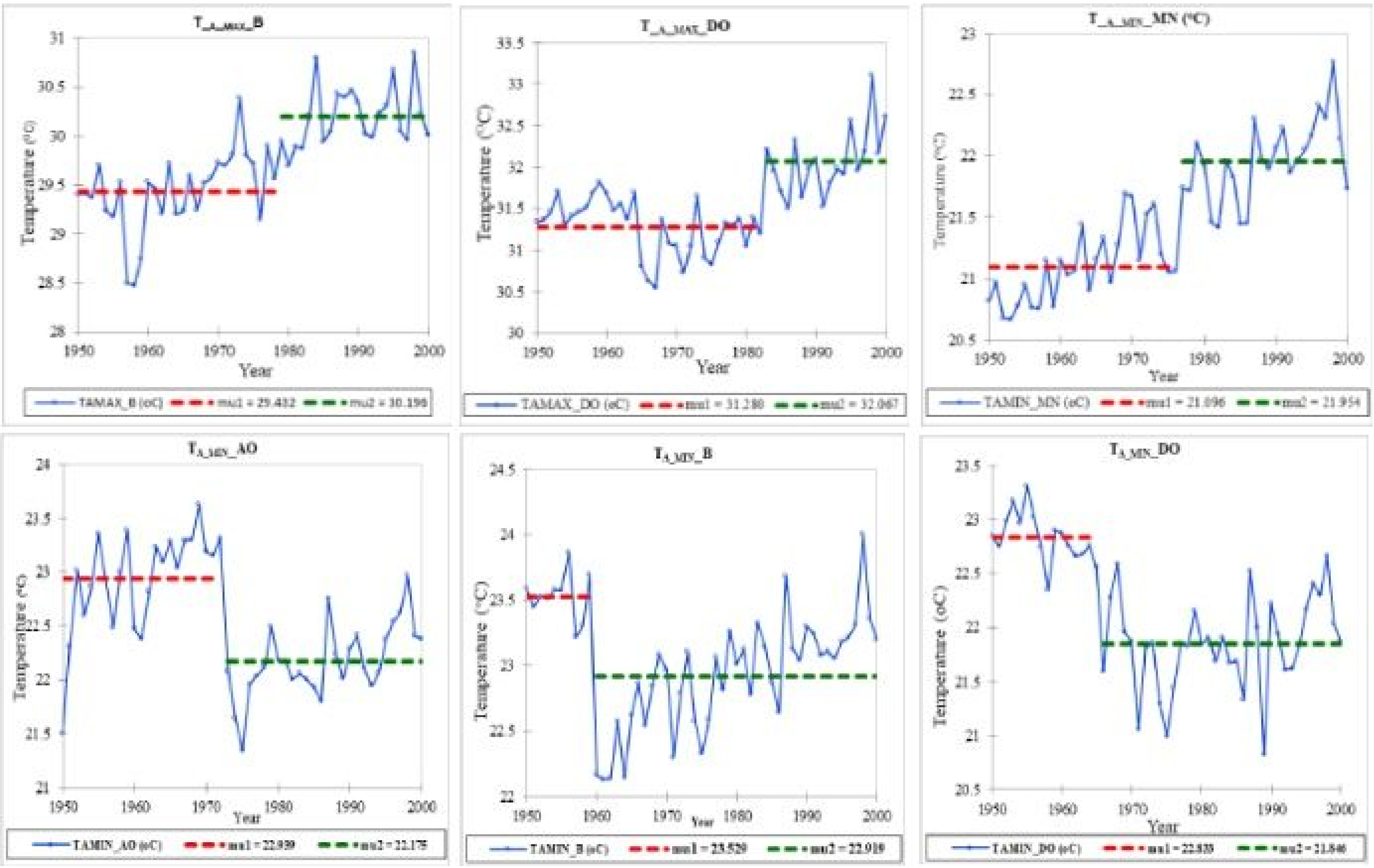

Figure 6

Changepoint detection for annual maximum and minimum temperature time series plots for selected stations within PRB of Ghana 1950 - 2000. The dashed lines represented by red and green are the mean of the time series before and after the change point respectively.

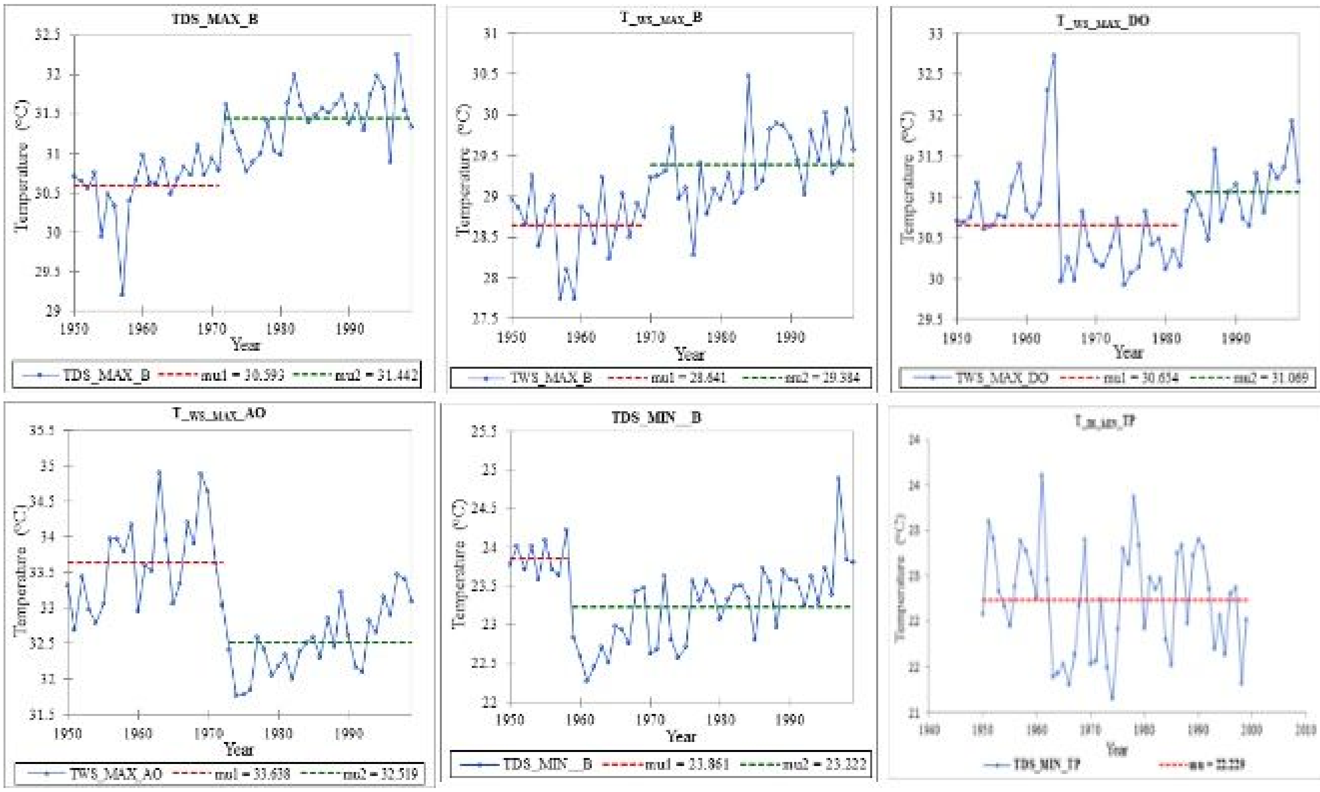

Figure 7

Changepoint detection for both dry and wet season maximum and minimum temperature plots for selected stations within PRB of Ghana. The dashed lines represented by red and green are the mean of the time series before and after the change point respectively

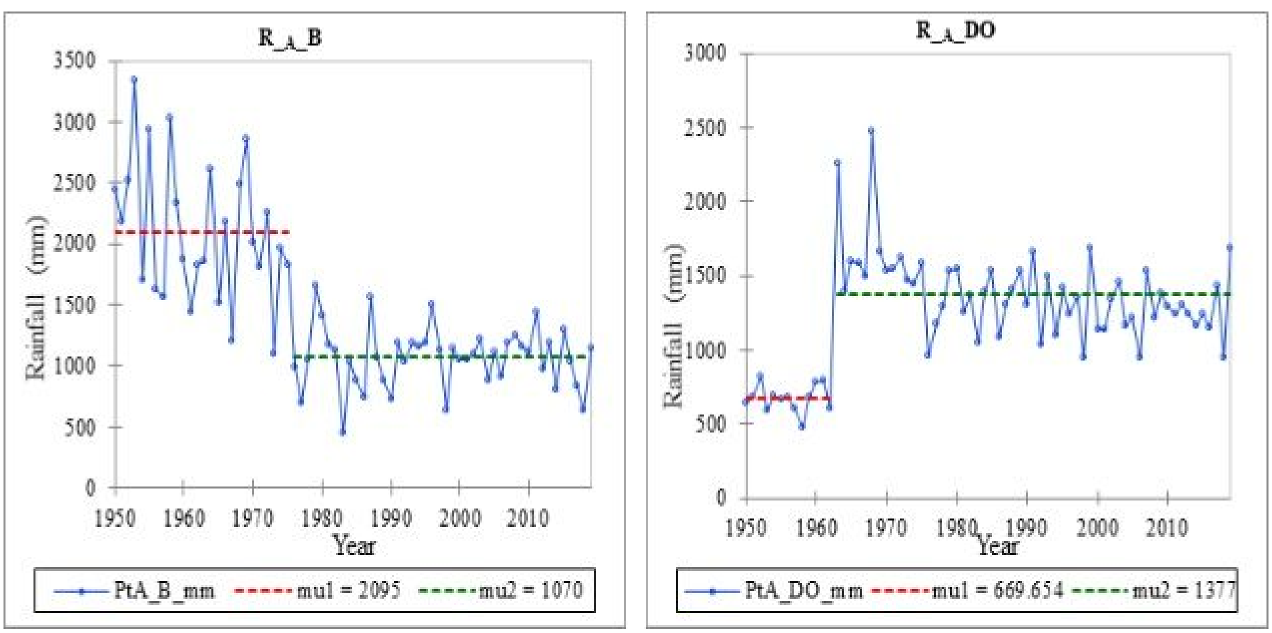

Figure 8

Changepoint detection for annual rainfall time series plots for selected stations within the PRB of Ghana. The dashed lines represented by red and green are the mean of the time series before and after the change point respectively