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Analysis of drought patterns in the Tano river basin of Ghana

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ABSTRACT

The objective of this study is to analyze drought patterns in the Tano River Basin (TRB) of Ghana using Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI). Precipitation data from 1981 to 2019 for the TRB was accessed from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), extracted into time Series using Python to four locations within the basin and used for the analysis together with the National Aeronautics and Space Administration (NASA) POWER (Prediction Of Worldwide Energy Resource) Temperature data. Anderson-Darling test was performed to check for the normality of the precipitation. Two separate station data sets from TAHMO and Earth Observation Research Innovation Centre (EORIC) were used to validate the CHIRPS data. The Scaler Index (SI) from the two data sets are respectively 0.383 and 0.016. This indicates the CHIRPS data extracted is sufficiently accurate. The SPI and RDI on the time scales of 1, 3, 6 and 12 months were calculated using the Drought Indices Calculator (DrinC) software and characterized into the magnitude, duration, and severity of the drought. Regression analysis was performed to compare RDI and SPI values. The results show that the coefficient of regression R^2 is 0.9789, 0.9689 and 0.8799 for 1, 6 and 12 months respectively. This indicates a stronger correlation between SPI and RDI values. However, R^2 is observed to decreases with increasing time scale, which means for shorter time scales, SPI and RDI are more similar than for longer time scales. To further examine the possible impacts of climate change on the drought profile of the basin, the Mann-Kendall trend test was conducted to compare the trends in SPI and RDI for 1, 6 and 12 timescales. Apart from RDI 6 for Tanoso which recorded a decrease in trend of – 0.17 as against 0.14 of SPI 6, all other timescales recorded an increase in trend for RDI as compared to SPI. Although most of these increases in trend is not significant at 10% significance level, a trend of 1.95 and 1.71 of RDI 1 for Buako and Sepremboi respectively were significant compared to that of SPI 1 for same stations. These increases in trend of RDI as compared to SPI suggests the possible impact of climate change since RDI estimation takes into consideration potential evapotranspiration (PET), which is a factor of temperature. This could have negative implications on agricultural production and drinking water supply within the basin considering that the basin solely relies on surface water for crop production and drinking water supply.

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1. Introduction

Drought is a natural hazard which occurs as a result of precipitation of water from the wet soils and surfaces of leaves. Droughts have in recent times attracted the attention of environmentalists, hydrologists, ecologists, meteorologists, agriculturists, water managers and geologists as it is now recognized as an environmental disaster [25]. They are known to occur in almost all climatic zones; both low and high rainfall areas and are mostly related to the reduction in the amount of precipitation received over an extended time period, such as a season or a year [25]. Factors such as temperatures; high winds; low relative humidity; timing and characteristics of precipitation, including distribution of precipitation days during crop growing seasons, intensity and duration of precipitation, and onset and termination, play a major role in the occurrence of drought. The onset of drought is slow but impacts most sectors of national economies [50].

This disaster is increasingly becoming a major challenge especially for developing countries [10] whose economies are basically driven by agriculture. Researchers predict that climate change may result in increases in the frequency of extreme events such as drought [8,38]. Drought is also considered as a threat to sustainable development [13] and an estimated 55 million people around the world are affected by droughts every year [38]. In recent times, many African countries in particular are beginning to experience seasonal drought events [10].

Historically, parallels of the West African drought periods (1910–1920, 1939–1949 and 1968–1983) occurred in Ghana. These droughts includes the 1918–1920 drought that affected the then Gold Coast colony, Ashanti and the Northern Territories; the 1939–1949 droughts also occurred in Navrongo between 1940 and 1949 and in Kumasi between 1939 and 1950. Consequently, there was an abnormally long period of drought in Kete Krachi which started gradually in 1950 and increased in intensity until 1983 [45]. A study by Asante & Amuakwa-Mensah [2] also revealed a general increase in drought frequency especially in the high rainfall zones of southern Ghana (Axim and Kumasi) and in the north (Bawku).

Drought is defined specifically by the nature of the hazard it causes and its variation in frequency from region to region. Wilhite & Glantz [49] identified four main types of drought; meteorological, hydrological, agricultural, and socio-economic. Meteorological, hydrological and agricultural droughts have been broadly studied [7,34].

Meteorological drought is deemed to occur when rainfall is below the range of values considered as normal and for an extended duration of dryness. Therefore, meteorological drought is region-specific since the atmospheric conditions leading to the deficiencies in rainfall varies from region to region [15,46]. Meteorological drought estimation is appropriate for regions characteristic of a year-round of rainfall such as tropical rainforest, humid subtropical climate or humid mid-latitude climate [34]. For regions with extended periods of no rainfall, the definition of drought based on the number of days with rainfall less than a certain standard is unrealistic. Hydrological drought addresses the effects of periods of precipitation shortfalls on both surface and groundwater supply; streamflow, reservoir and lake levels and groundwater levels [4]. The severity and frequency of hydrological drought is best defined on a basin or watershed scale [46]. Agricultural drought links the various components of meteorological drought and hydrological drought [36]. Socio-economic droughts relate to the demand and supply of some economic goods with elements of meteorological, agricultural and hydrological droughts [48]. Unlike meteorological, agricultural and hydrological droughts, the occurrence of socio-economic drought depends on the time and space processes of supply and demand to appropriately identify and classify it [14,48].

There are a variety of indices for characterizing different types of drought conditions which, in general, are data demanding and computationally intensive [27]. These indices are typically computed numerical representations of drought severity, assessed using climatic or hydrometeorological inputs including indicators, variables or parameters [53]. These parameters are precipitation, temperature, streamflow, groundwater and reservoir levels, soil moisture and snowpack.

All the indices for characterizing drought give a qualitative measure of drought on the landscape for a given time period. The Palmer Hydrological Drought Index (PHDI), or Surface Water Supply Index (SWSI) are generally data demanding and involve intensive computations [22]. However, for meteorological droughts, very simple and effective indices such as the Standardized Precipitation Index (SPI) and the Reconnaissance Drought Index (RDI) are extensively used [44]. There is no single index or indicator that can be used to assess all types of droughts [55]. The choice of the indicator therefore depends on the type of drought and the prevailing hydroclimate conditions [53].

Drought have several impacts on economic growth. For instance, in the years 2001, 2007 and 2013–2014, it was perceived that droughts affected water inflows into the Volta Basin resulting in low reservoir water levels in the Akosombo and Kpong hydro dams. This led to a reduction in the hydropower generation capacity of these dams. The consequence of this is an adversely impacted health, tourism and industrial sectors [45]. In addition, drought distorts the social architecture of societies. This is evident from a study by Jarawura, [16] on drought and migration in the Northern regions of Ghana.

Very few studies have sought to analyze drought patterns within specific basins in Ghana. Most of the hydrological studies are centered around the black and white volta basins [19,29]. These studies however do not analyze the drought profile within these basins. The purpose of this study is to analyze the Spatio-temporal drought patterns within the TRB using two drought indices; SPI and RDI for both short and long-term periods.

2.0. Materials and methods

2.1. The study area

The climate of the TRB falls partly under the wet semi-equatorial and partly under south-western equatorial climatic zones of Ghana. The TRB is located in the southwestern part of Ghana and lies between Latitudes 50 N and 70 40' N, and Longitudes 20 00' W and 30 15' W. The general topography of the entire basin ranges between 0 and 700 m above mean sea level. Arable lands occupy the highest percentage of the total landmass. Commercial farming of cocoa, plantain and other commercial and food crops are grown within the basin. Only about 10% of the landmass is used for human settlement. The forest cover represents the second highest land use pattern in the basin and follows closely after agricultural lands, occupying about 50% of the total landmass of the basin. The remaining 40% of the landmass is covered by forests which are largely protected areas [33]. The basin has its source within the forest in Pooyem, 4 km from Techiman, and flows roughly north-south into the sea. The main tributaries of the Tano River system are the Abu, Amama, Bo, Disue, Soro, Atronie, Sabom, Gaw, Kwasa, Sumre, and Totua. The TRB has a total catchment area of about 15,000 km^2 shared between Ghana and Cote D'Ivoire. About 93% of the drainage area is within Ghana whilst the remaining 7% is in the Cote D'Ivoire. The TRB constitutes a major source of domestic water supply from surface and groundwater [28,54]. Other uses include industrial, mining and irrigation.

The study was carried out in four selected locations in the TRB namely Tanoso, Buako, Kenyasi No2 and Sampreboi as shown in Fig. 1 below. These locations were carefully selected to spatially represent the entire TRB.

The climate of the TRB is sub-equatorial with two main wet seasons; May–July and October–November. The mean annual rainfall for the basin ranges from 15,300 mm to 25,000 mm from the northern part to the south respectively. Rainfall patterns increase from north to south with relative humidity ranging between 75% and 85% per year. The average annual rainy days is between 90 5and 140 days [47].

2.2. Sources of data and methods

Precipitation data was downloaded from CHIRPS from 1982 to 2019. CHIRPS station data is a 30+ year quasi-global rainfall dataset that incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for various uses such as trend analysis and seasonal drought monitoring. Minimum and maximum daily temperatures at 2 m was accessed from (https://power.larc.nasa.gov/data-access-viewer/) for the four locations sorted for the analysis. The choice of CHIRPS is informed by the fact that several studies have found a strong fit of CHIRPS data with gauged station data [56]–[57–59] (Dinku et al., 2018; Gao et al., 2018; Sulugodu & Deka, 2019; Wu et al., 2019). NASA POWER data consists of global meteorology, surface solar energy and climatology data. These data are freely available global meteorology and surface solar energy climatology data for download with a resolution of 1/2 by 1/2 arc degree longitude and latitude kind courtesy the NASA Earth Science Directorate Applied Science Program [1]. These set of data were chosen because traditional station-based data usually have insufficient long term recorded data and high missing values [42]. To validate the CHIRPS data for the basin, station data were acquired from TAHMO and EORIC for Kanyasi No2 and EORIC weather stations respectively. The TAHMO data is a record of daily rainfall data (January, 2016 to March, 2020) while the EORIC rainfall data are daily rainfall data measured at 30minutes intervals from January – February, 2018. CHIRPS data for both locations and within the same range were compared in the validation analysis using the root mean square error (RMSE).

2.3. Data analysis

To understand the nature of the data, normality test statistics was done. This was necessary to identify the best approaches and tools suitable for the analysis. Therefore, both the rainfall and temperature data were subjected to the Anderson-Darling (AD) normality test. The null hypothesis of normal sample distribution was considered. The AD test uses cumulative distribution function to determine the normality of a given set of data and is expressed as:

$$AD = -n - \frac{1}{2}\sum_{i=1}^{n}(2i-1)[lnF(x_i) + \ln(1 - F(x_{n-i+1}))],$$

Where n= sample size; F(x) is the cumulative distribution function for the distribution; I is the *i*th sample of the data in ascending order.

2.4. SPI & RDI

McKee, T.B., Doesken, N.J, and Kleist [22] developed the SPI for the purpose of defining and monitoring drought. The computation of SPI involves fitting a Probability Density Function (PDF) to a given frequency distribution of total precipitation for the stations [41]. The Alpha and Beta parameters of the Gamma distribution are predicted for each station, for each month of the year and for each timescale of interest (i.e. SPI 1, 2, 3… months). The Gamma distribution is defined by its

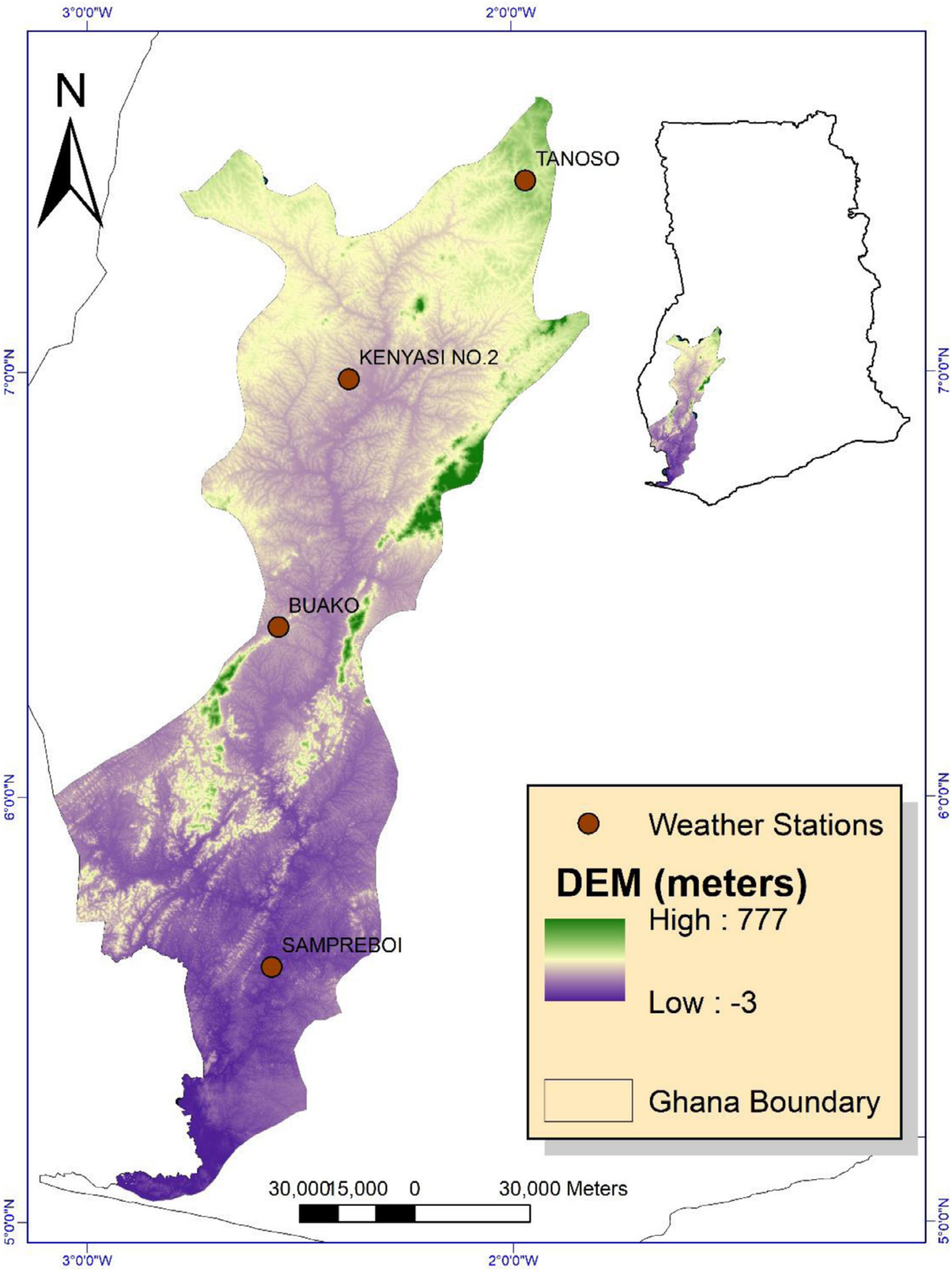

Fig. 1. Study Area with location of weather stations
Source: Authors construct by downloading elevation data from USGS (https://glovis.usgs.gov/).

frequency or PDF as follows [9,23,39]:

$$G(x) = \frac{1}{\beta^{\alpha}\beth\alpha}\ x^{\alpha-1}e^{-x/b} \tag{i}$$

Where $\alpha>0$, α is a shape factor, $\beta > 0$, β is a scale factor

$$\beth(\alpha) = \int_{0}^{\infty} y^{\alpha-1}e^{-y} \tag{ii}$$

Where $\daleth(\alpha)$ is the gamma function. By fitting the gamma probability density function to a given frequency distribution of precipitation total for a station. Using the maximum likelihood solutions, α and β are estimated as follows:

$$\alpha = \frac{1}{4A}\,(1 + \left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{iii}$$

$$\beta = \frac{x}{\alpha} \tag{iv}$$

$$A = \ln \bar{x} - \sum \frac{\ln(x)}{n} \tag{v}$$

n is the number of precipitation observations. The cumulative probability is therefore given by:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha t \alpha}} \int_0^x x^{\alpha-1} e^{-x/b} \tag{vi}$$

If we let t= x/β, it implies,

$$G(x) = \frac{1}{\daleth\alpha} \int_0^x t^{\alpha-1} e^{-t} dt \tag{vii}$$

The gamma function is undefined if x=0 and the precipitation distribution may contain zeros, therefore the cumulative probability equation becomes:

$$H(x) = q = (1-q)G(x) \tag{viii}$$

Where q is the probability of a zero. If m is the number of zeros in a precipitation time series, Shah et al. [39] states that q can be estimated by m/n. The cumulative probability, H(x), is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI. The gamma distribution function is preferable for this type of analysis as it fits well in rainfall time series data [5].

Computation of RDI follows similar procedure as the SPI but unlike the SPI that solely uses monthly precipitation, RDI applies the time series of the monthly ratio of Precipitation/Potential Evapotranspiration (PET) [23]. In this study, the Hargreaves method was used to estimate the PET. Maximum and minimum temperature data for each of the selected stations were inputted into DrinC version 1.7 to estimate the respective PETs. Both indices adopts the same drought classification.

RDI involves the use of PET, an important factor to consider under global warming for better representation of hydro-climatic changes. This is because evaporation of water from the surfaces of leaves and soil is an important climatic factor [43]. Therefore, RDI also gives an estimation of the possible impact of climate variability on the occurrence of drought and drought severity.

The SPI/RDI at a given location can be calculated for different temporal scales. In this study, four (4) time scales, i.e., 1, 3, 6 and 12-month, were considered to provide multiscalar information on drought characteristics on the TRB. 1-month SPI/RDI is to assess meteorological drought, 3- month SPI/RDI for agricultural drought while 6 and 12-month was used for the purposes of hydrological drought analyses and applications [52]. According to McKee, T.B., Doesken, N.J, and Kleist [22], the drought severity can be classified into five classes based the SPI/RDI values, i.e., non-drought when the SPI/RDI $\geq$ 0, mild drought when -1 $<$ SPI/RDI $<$ 0, moderate drought when -1.5 $<$ SPI/RDI $\leq$ -1, severe drought when -2.0 $<$ SPI/RDI $\leq$ -1.5, and extreme drought when SPI/RDI $\leq$ - 2.0.

2.5. Drought features

Drought duration, Magnitude and severity: The duration of a drought episode (drought duration) is estimated as the number of continuous months affected by drought while the magnitude of a drought is estimated as the positive sum of all the SPI or RDI values for all the months within a drought event [21]. The severity of a particular drought is estimated as the magnitude of the drought divided by the duration [3,11]. It is the accumulation of negative SPI values preceded and followed by positive SPI or RDI values [6].

Drought onset and end: For a given area, a drought event is noticed when the SPI/RDI is below a certain threshold (0) for the duration (usually defined as a period longer than three months) [21,26]. The onset and end of a particular drought is characterized by less than zero SPI/RDI values and greater than or equal to zero SPI/RDI values respectively.

Drought intensity and Frequency: Drought intensity annotates departure of a climate index from its normal value [11]. Drought intensity indicates the absolute value of SPI/RDI less than 0. Thus the lesser the value, the more the intensity. Drought frequency is used to assess the drought liability during a study period.

Table 1
Normality test of rainfall data.

Test	
AD	0.551
AD*	0.564
p-value	0.855

AD is the Anderson-Darling Statistic and AD* is the adjusted Anderson-Darling Statistic

2.6. The Mann-Kendall test

RDI is used in conjunction with SPI so as to assess the extent to with climate change is affecting drought characterization within the basin by comparing the trends of the two indices using Mann-Kendall test. The SPI and RDI trend tests were performed using the Mann-Kendall (MK) non-parametric test to assess the significance level of the observed trends. The Mann-Kendall test is a most widely used statistical tool for analyzing both climatologic and hydrologic time series [18]. The MK test is applicable in situations where the data values is assumed to follow:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\left(x_j - x_i\right) \tag{1}$$

$$sign\left(x_j - x_i\right)\begin{cases} +1 & x_j > x_i \\ 0 & x_j = x_i \\ -1 & x_j < x_i \end{cases} \tag{2}$$

Where n= number of data, x is the data point at times i and j (j> i). The variance S is given by:

$$\mathrm{Var}(S) = \left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i-1)(2i+5) \right]/18 \tag{3}$$

Where t_i is the number of ties of extent i and m is the number of tied groups. If n is larger than 10, the standard test statistic Z is computed as the MK test statistic as follows:

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

The presence of a statistically significant trend is evaluated by using the Z value. A positive Z value indicate increasing trends, while a negative Z value show decreasing trends. To test for either an increase or decrease monotonic trend at α, H_0 should be rejected if the $|Z| > Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is s obtained from the standard normal cumulative distribution table. Therefore, a higher magnitude of Z value indicates that the trend is more statistically significant.

3. Results and discussion

3.1. Normality Test for precipitation

Before fitting into the PDF for the SPI analysis, the annual rainfall data were subjected to the AD normality test. The test follows the null (H_0) and alternate (H_a) hypotheses for data that follows normal distribution and data that does not follow normal distribution respectively. 95% probability was taken. H_0 is accepted if $P > 0.05$ and rejected if $P < 0.05$. The results of the normality test are shown in Table 1. It is observed from the table that the p-value for rainfall is greater than 0.05 and therefore it is conclusive that there is no evidence to suggest that the data is non-normal.

3.2. Validation of CHIRPS data

To test the accuracy of the CHIRPS rainfall data, ground data from two different sources and for two different locations (both within the TRB) were acquired and an analysis of the root mean Square Error done to assess the correctness of the CHIRPS. Table 2 below is the results of the analysis.

3.3. Drought characteristics

The SPI drought characteristics for different time scales for four evenly distributed stations across the TRB are presented. The different timescales used for the analysis are SPI-1 (June), SPI-3 (Apr to Jun), SPI-6 (Apr to Sept) and SPI-12 (Oct–Sept) corresponding to 1, 3, 6, and 12 months respectively. The drought features identified in the analysis are the drought

Table 2
Validation of CHIRPS.

Data/Station	RMSE	SCALER INDEX (SI)
TAHMO(Kenyasi No2)	1.697	0.383
EORIC(EORIC weather station)	0.903	0.016

From the results above, the analysis for both scenarios presents a SI of less than 1. This suggests that the CHIRPS rainfall estimations for the TRB are acceptable.

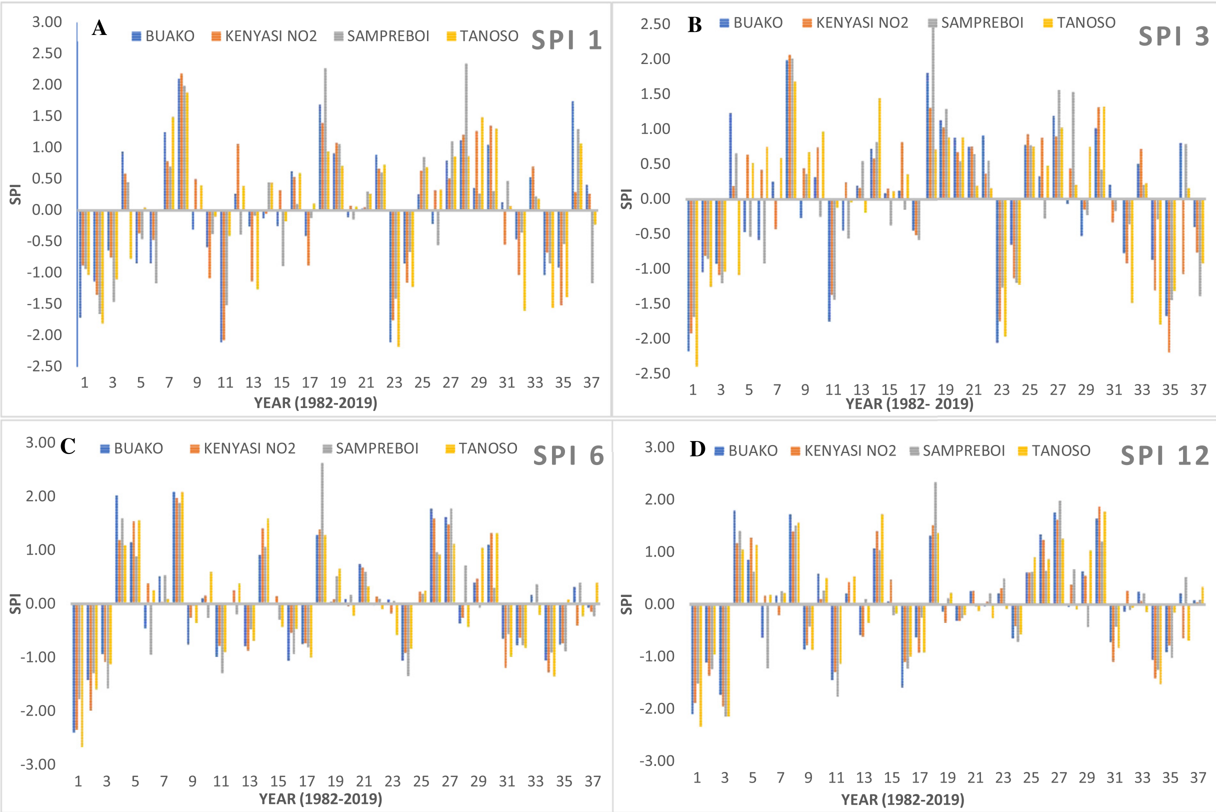

Fig. 2. SPI-1, 3, 6 and 12 (A-D) for Tanoso, Kenyasi No2, Buako and Sempreboi Compared.

duration, frequency, intensity, drought severity and magnitude. Similar to the findings by [20] on SPI analysis, the drought frequency changes with varying time scales; longer time scales are characterized by less frequent but longer drought events (see Fig. 2 (A-D)). As illustrated in Fig. 2(A-D), the onset and end of drought events are also pointed out. SPI-1 and SPI- 3 were used to analyze drought at shorter time scales. For both SPI-1 and SPI-3, Tanoso recorded the most extreme droughts in 2004 (with magnitude −2.18) and 1982 (with magnitude −2.39). This is probably because there was general low rainfall records in Ghana in 1982 and 2004 which affected food production. This lag in rainfall affected the soil moisture levels and this accounts for the drought profile in these years. This is consistent with the historical drought events across the entire country in 1982 and 2004 as outlined in the Ghana National Drought Plan [45]. SPI-1 and SPI-3 are significant for monitoring drought events for short periods and this has implications for agricultural production as these index values relate to the soil moisture content. Therefore, considering the SPI-3 values over the period (Apr–Jun), crop production with the TRB might have been affected over the catchments with less than 0 SPI values (see Fig. 2B) since the main planting season within the basin is around this period. The TRB is noted for the production of large tons of maize [47] and in particular, the Tanoso portion contributed significantly to the Ahafo recording the highest production rates between 2014 and 2016 [24]. Between 2014 and 2016 however, the annual growth rate for maize in Ghana was −1.34% [24]. This can be attributed to the short term droughts recorded around the Ahafo (Tanoso) portion of the TRB. In terms of drought frequency which measures the number of drought events which occurred at a given station [40], the results also showed an increase in drought frequency between 2000 and 2015 in respect to the (1990–1999) (see illustration in Fig. 2 A-D). This is not surprising as a recent study by Ding et al. [8] and Quenum et al. [35] predicted that drought frequency will increase in Africa in the coming years as a result of climate change. There was a general rise in air temperature in Ghana between 2000 and 2015 [51], which might be the reason for the increase in drought frequency.

Also, SPI-6 (Apr–Sept) analysis revealed an extreme drought event occurred in 1982 at the northern part of the basin (Tanoso) with a magnitude of −2.67. The other three stations Buako, Kenyasi No2 and Sampreboi equally recorded drought events at lower magnitudes of −2.4, −2.34 and −1.78 respectively. All the stations recorded very few wet years as compared to the number of drought years. The implication of this for the basin is low basin flows and this has hydrologic impacts for the basin. Reduced river flows is known to present escalating problems for water quality and habitats [30]. Reduced flows deteriorates water quality and destroys the natural habitats of aquatic organisms. The many negative SPI-6 values (Apr–Sept) recorded for all the stations implies more drought years as a result of precipitation deficit and reduced surface water availability for water supply. For instance, between 2006 and 2008, the Abesim Head works situated at Tanoso experienced a series of water shortages [60]. This was as a result of the droughts as shown in Fig. 2C. Reports on freshwater resources suggest that diminishing surface water availability could be as a result of climate change variability [17]. Also, changes in local temperature conditions is argued to be a major contributor to depleting surface water resources [37].

The results show variations in the magnitude of drought events across the various stations although the highest magnitude (−2.34) of drought event for the 12 month SPI was recorded at Tanoso in 1982 as against Sampreboi which recorded the wettest period (of magnitude 2.34) in 1999 over the duration. Temporal drought events for SPI-12 (between 1982 and 2018) occurred at Buako in the year(s) 1982–84,1987, 1990,1992,1994,1997–1998,2000–2001, 2003, 2005, 2009, 2012–13 and 2015-2016. Over the same duration Kenyasi No 2 experienced temporal drought events in 1982-84,1990, 1992, 1994, 1997-98, 2000–01, 2005, 2012 and 2015–17. The least number of drought events were recorded at Sampreboi and these occurred at 1982–84, 1987, 1990, 1992, 1996–98, 2001–02, 2005, 2012 and 2015-17. Tanoso recorded the highest number of drought events starting from the 1982-84 drought, 1990, 1992, 1994, 1996–98, 2001–2005, 2009 and 2012–17. In all the four stations, droughts occurred between 1982 and 1984. This is consistent with several other findings in Ghana relating to 1981-1983 nationwide drought [31,32]. However, there are variations in the magnitude of drought from station to station (see Fig. 2 (A-D)).

For all the different time scales used in this study, extreme wet conditions (see Fig. 2 A-D) was witnessed by all the stations in 1999. The year 1999 appeared to have experienced very high rainfall values as a similar study by Nyatuame & Agodzo [31] on extreme rainfall events over the Tordzie watershed in Ghana also identified a severe wet period in 1999. In all the time scales, the Sampreboi station (southern zone) recorded the highest magnitude of wetness. This suggests that food production over the period under study were affected, as water overflowing river banks have the tendency to destroy nearby farmlands through inundation with water.

The total number of drought incidences for all the stations from January to December as shown in Table 3 from 1982 to 2019 were compared in terms of magnitude, duration and severity. On average, the drought duration for Tanoso and Sampreboi appears to be higher than that of Kenyasi No2 and Buako. In terms of severity however, there is a slight declining trend from Tanoso (North) to Sampreboi (South) although this is relatively insignificant. Interestingly, Tanoso recorded the highest severity in June over the Period (see Fig. 3 below).

3.4. Comparison of SPI and RDI

The SPI and RDI values for the four locations within the TRB were compared. The SPI and RDI for the time scales 1, 6, and 12 are compared to represent short, medium and longer timescales respectively and presented in Fig. 4 below. Both indices have similar characteristics for all the stations under study except for some marginal differences. These differences may be due to the differences in climatic conditions such as temperature, altitude and wind speed that impact on precipitation, temperature as well as PET [23].

For all the four locations compared, the RDI is generally characterized by peak values both in terms of wetness and drought. Sampreboi (one of the four locations) was chosen to further compare the RDI and SPI values for the different time scales. Regression analysis was performed as shown below in Fig. 5 and the results show that the coefficient of regression R^2 is 0.9789, 0.9689 and 0.8799 for 1, 6 and 12 months respectively. This indicates a much stronger correlation between SPI and RDI values. However, R^2 is also observed to decrease with increasing time scale, which means for shorter time scales, SPI and RDI are more similar than for longer time scales.

Consistent with the findings of Hamed, Davar, Mehdi, & E. Zia, [12], SPI had lower values than the RDI. This implies that RDI has higher sensitivity to drought monitoring in the TRB than SPI. Therefore, the role of evapotranspiration as in the case of RDI cannot be ignored in assessing drought within the basin.

To further examine the possible impacts of climate change on the drought profile of the basin, the Mann-Kendall trend test was done to compare the trends in SPI and RDI for the four stations for 1, 6 and 12 timescales (see Table 4 below). Apart from RDI 6 for Tanoso which recorded a decrease in trend of – 0.17 as against 0.14 of SPI 6 for the same station, all other timescales for the four stations recorded an increase in trend for RDI as compared to SPI. Although most of these increases in trend is not significant at 10% significance level, a trend of 1.95 and 1.71 of RDI 1 for Buako and Sapremboi respectively were significant compared to that of SPI 1 for same stations. These increases in trend of RDI as compared to SPI may be due to the impact of climate change since RDI estimation takes into consideration PET, which is a factor of temperature.

Table 3
Drought characteristics of Tanoso, Kenyasi No2, Buako and Sampreboi from 1982 5 to 2019.

Months	Tanoso	Kenyasi no2					Buako			Sampreboi		
	Magnitude	Drought Duration (Months)	Severity	Magnitude	Drought Duration (Months)	Severity	Magnitude	Drought Duration (Months)	Severity	Magnitude	Drought Duration (Months)	Severity
January	14.19	22	0.65	14.25	21	0.68	14.77	20	0.74	13.60	22	0.62
February	15.29	20	0.76	15.28	17	0.90	15.20	18	0.84	15.49	15	1.03
March	15.77	17	0.93	14.36	15	0.96	14.18	18	0.79	14.40	19	0.76
April	15.44	19	0.81	16.60	19	0.87	15.87	16	0.99	14.58	16	0.91
May	12.03	18	0.67	14.72	19	0.77	15.72	18	0.87	15.33	15	1.02
June	14.87	14	1.06	15.76	16	0.99	14.98	19	0.79	14.76	19	0.78
July	14.36	18	0.80	15.64	17	0.92	15.39	17	0.91	15.75	20	0.79
August	15.65	19	0.82	15.20	18	0.84	15.19	19	0.80	16.00	23	0.70
September	14.54	19	0.77	14.23	14	1.02	15.16	16	0.95	15.63	18	0.87
October	13.75	18	0.76	16.04	18	0.89	15.76	19	0.83	15.28	16	0.96
November	14.85	15	0.99	15.27	19	0.80	16.01	16	1.00	16.66	20	0.83
December	13.02	21	0.62	15.93	19	0.84	15.87	19	0.84	14.62	20	0.73

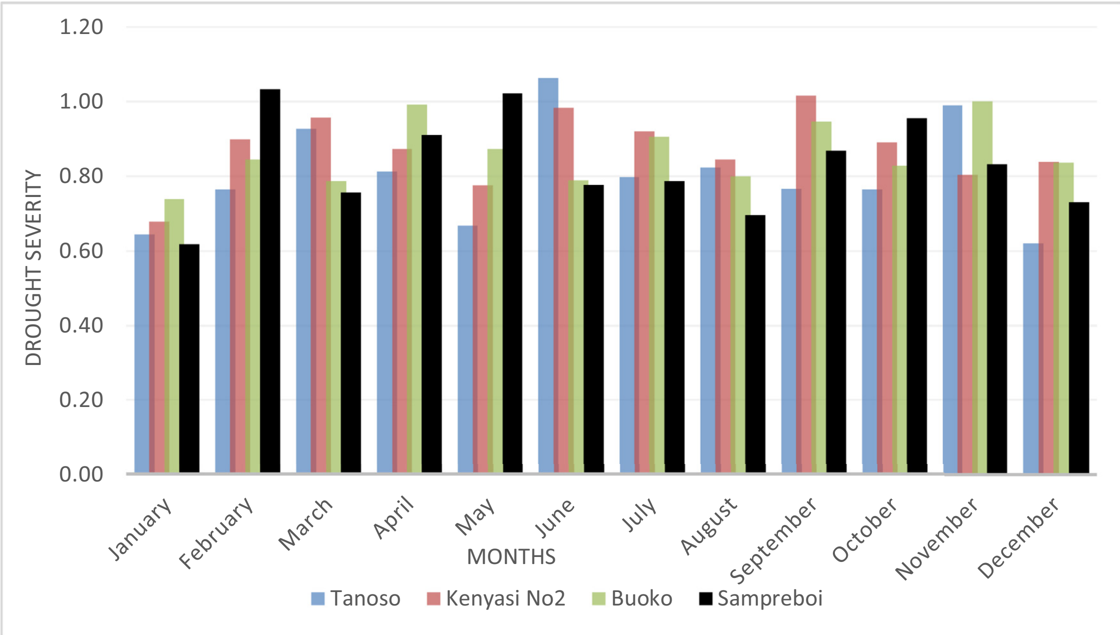

Fig. 3. Drought Severity of Tanoso, Kenyasi No2, Buako and Sampreboi from 1982 to 2019.

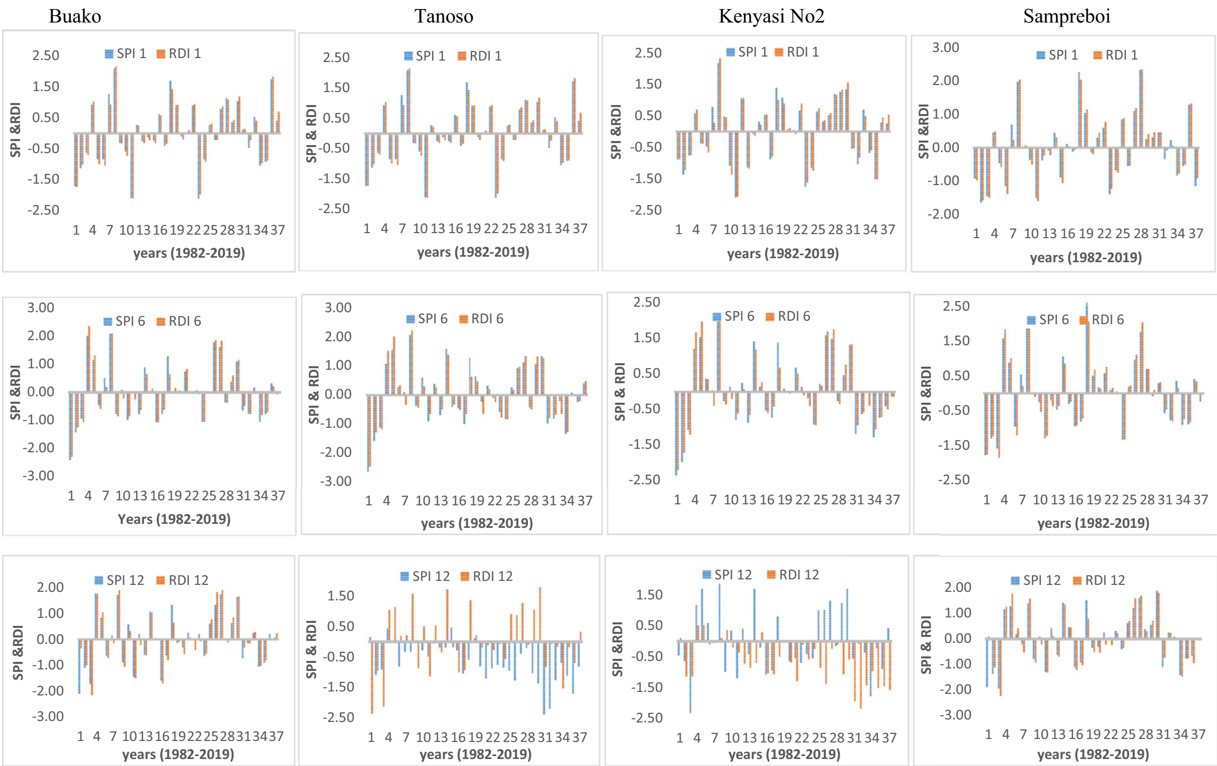

Fig. 4. Comparison of SPI and RDI for 1, 6 and 12 months' time scales.

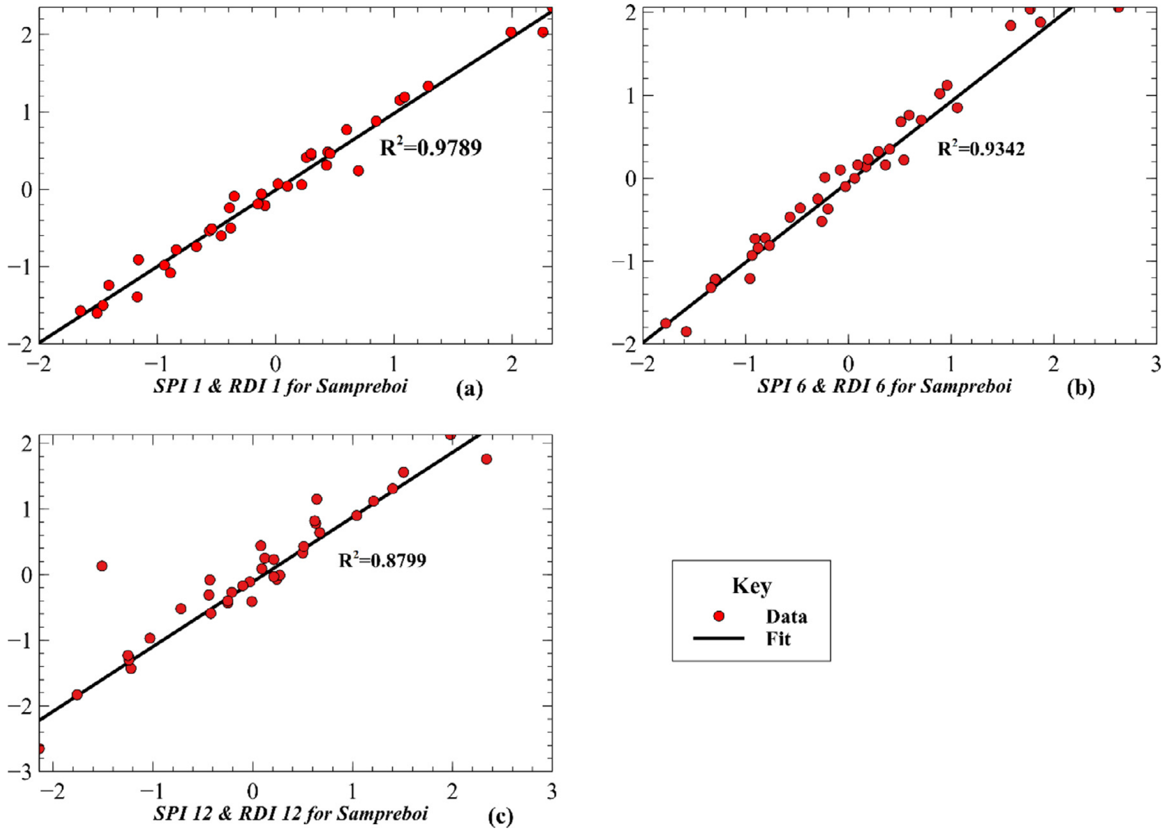

Fig. 5. SPI and RDI regression analysis for 1, 6 and 12 month time scales.

Table 4
Trend Tests for SPI and RDI.

Location name	Tests	Parameters					
		SPI 1	RDI 1	SPI 6	RDI 6	SPI 12	RDI 12
TANOSO	ZQ	1.060.023	1.150.025	0.140.003	−0.17−0.003	0.560.007	0.090.002
KENYASI NO2	ZQ	0.750.014	1.160.02	−0.43−0.006	−0.21−0.004	0.750.0015	0.250.005
BUAKO	ZQ	1.560.031	$1.95^{+}0.035$	0.350.006	0.750.010	0.850.018	1.060.016
SAMPREBOI	ZQ	1.400.023	$1.71^{+}0.030$	0.560.012	0.850.015	0.850.018	1.110.017

Table 4 shows the statistics of the trend test for each of the stations. Z: Mann-Kendall test, Q: Sen's slope estimator for SPI and RDI for 1, 6 and 12 time scales, + represents statistically significant trends at 10% significance level.

4. Conclusion

This study conducted an analysis of drought patterns within the TRB of Ghana using two drought indices; SPI and RDI. Both short term and long term SPI and RDI values have been estimated. The drought features identified in the analysis are the drought duration, frequency, intensity, drought severity and magnitude.

The study concluded that, Tanoso and Buako recorded more severe droughts within the basin over the duration of the study. The Mann-Kendall trends for SPI and RDI values were compared to establish the possible impact of climate change on drought. Albeit there is no significant increases in trends of RDI as compared to SPI, RDI 1 for Buako and Sempreboi recorded significant increase in trend at 10% significance level, suggesting climate change may have an impact on drought. The results indicate that, for both short term and long term periods, the northern portion of the basin is prone to more severe drought events than the southern portion.

Results from the validation of the CHIRPS data with two different station data from TAHMO and the EORIC weather station; both within the TRB suggests the CHIRPS data is sufficiently accurate and correlates with observed data and can therefore be very useful in drought analysis in locations within the basin where station data is not available.

In addition, it is clear from the study that, the drought frequency changes with varying time scales; longer time scales is characterized by less frequent but longer drought events. The study further established a very strong correlation between

SPI and RDI values which suggests that both indices can be very useful in assessing drought patterns within the basin. It was however noted that RDI is more sensitive to drought than SPI; implying that evapotranspiration plays a critical role in drought occurrence in the region. The results however, show a reducing correlation with longer time scales. The Mann-Kendall trend test suggests climate change may have possible impacts on the occurrence of drought within the basin.

The drought severity identified Tanoso and Buako as areas within the basin that are more prone to drought. There is therefore the need for water resources managers within the basin to take action to curb the occurrence of drought both in frequency and magnitude within the basin to ensure the availability of surface water for both agriculture and domestic water supply.

Declaration of Competing Interest

The authors declare no conflict of interest.

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