

Analysis of Extreme Rainfall Events (Drought and Flood) over Tordzie Watershed in the Volta Region of Ghana

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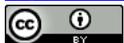
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Abstract

In regional water resources management and disaster preparedness, the analysis of extreme rainfall events is essential. The need to investigate drought and flood conditions is now heightened within the context of climate change and variability. The Standardised Precipitation Index (SPI) was employed to assess the extreme rainfall event on Tordzie watershed using precipitation data from 1984-2014. The SPI on the time scale of 3, 6, 9 and 12 months were determined using “DrinC” software. The drought was characterised into magnitude, duration, intensity, frequency, commencement and termination at the time scales of SPI-3, SPI-6, SPI-9 and SPI-12. Results indicated that the middle reaches (Kpetoe) of the watershed experienced less severe drought condition compared to the lower reaches (Tordzinu). Mann-Kendall (MK) test and Sen’s slope (SS) revealed general increasing drought trend but insignificant at 95% confidence interval. The SS indicated change in magnitude of 0.016 mm/year, 0.012 mm/year, 0.026 mm/year and 0.016 mm/year respectively at the mentioned time scales at 95% confidence interval at the Tordzinu and that of Kpetoe were 0.006 mm/year, 0.009 mm/year, 0.014 mm/year and 0.003 mm/year. These changes could have implication for agriculture and water resources management and engender food insecurity among smallholder farmers.

Keywords

Extreme Rainfall Characteristics, Standardised Precipitation Index (SPI), Trend Analysis, Tordzie Watershed, Volta Region, Ghana

1. Introduction

Global warming or climate change has been reported by [1] as the main contributor to variation in atmospheric circulation and the hydrological cycle and this alters the intensity and spatial distribution of precipitation. The authors further explained that the global warming in turn changes local drought and flood conditions and affects the regional agricultural sector. Rosenzweig *et al.* [2] added that change can also occur in the frequency of extreme weather events within the context of climate change. They further elaborated that the change can induce various meteorological hazards such as floods, droughts and rain-storms.

A prolonged period of water deficit is referred to as drought, which usually occurs when precipitation receives in an area falls below usual levels for several months. Depending on the components of the hydrological cycle affected by a drought event, the drought can be categorised as meteorological, agricultural or hydrological. The extended period with precipitation below normal levels, which generally appears before other drought types is called meteorological drought. The standardized precipitation index (SPI) proposed by McKee *et al.* [3] is employed to define meteorological drought in this study.

The other types of droughts such as agricultural, hydrological and economic ones are connected with meteorological droughts which records below normal rainfall. The deficit of soil moisture supply to the plants usually leads to agricultural droughts and the hydrological droughts are comparatively of long term and normally results in low flows in rivers and depleted reservoir storages.

The concept of drought may differ from place to place since rainfall varies significantly among different regions and localities. As such, for more effective assessment of the drought phenomena, the World Meteorological Organization [4] recommends adopting the Standardized Precipitation Index (SPI) to monitor the severity of drought events. Rainfall deficit are represented by negative SPI values, whereas positive SPI values indicate rainfall surplus [5]. The magnitude of negative SPI values is used to classify drought intensity such that the higher the negative SPI values are, the more serious the event would be. For example, negative SPI values greater than 2 are often classified as extremely dry conditions [5]. For the convenience and robustness of its application, the SPI has been used extensively in many countries and regions to characterize the dry and wet conditions. Some countries and regions where it has been used are United States [6], Canada [7], Italy [8] [9], Iran [10] [11] and Korea [12] [13]. According to Green [14], climate change is but one symptom of our past failure to achieve sustainable development, amongst many other symptoms.

Tordzie watershed is one of the key basins in the Volta Region of Ghana. However, this watershed is one of the least studied in terms of its hydrology in Ghana. Moreover, the temporal drought estimation using standardized precipitation index has not been employed to analyze drought occurrence on the mentioned basin. Additionally, there is no research evidence on drought analysis on

the watershed. Thus the investigation of the temporal variability of the extreme climate events is important in order to comprehend better the recent climatic oscillations and their manifestation in local level and to further monitor drought and flood occurrence.

Therefore, the main objective of this study was to assess temporal drought characteristics using standardized precipitation index (SPI) based on rainfall data from 1984 to 2014 for the middle and lower sections of the Tordzie watershed represented by the hydrological stations Kpetoe and Tordzinu respectively.

2. Materials and Method

2.1. Study Area

The study was carried out in selected network stations in the Tordzie watershed in Ghana. The climatic data from the network of meteorological stations covering two (2) different physiographic areas within the Tordzie watershed was collected for analysis. The selection of the physiographic sample area for the study was based on the data availability and the study requirements. Historical rainfall data were collected from the Ghana Meteorological Services Department.

The Tordzie watershed is shown in **Figure 1**. The network stations in the Tordzie watershed which data were analysed were Kpetoe ($6^{\circ}33'0''\text{N}$, $0^{\circ}42'0''\text{E}$) and Tordzinu ($5^{\circ}5'0''\text{N}$, $0^{\circ}45'0''\text{E}$) at elevation 69.2 and 5.4 m respectively.

Tordzie is a trans-boundary basin. The area in Ghana is 1865 km² which constitutes 83.7% and the remaining area in Togo is 363 km² which is 16.3%. The total area of the basin is 2228 km² [15].

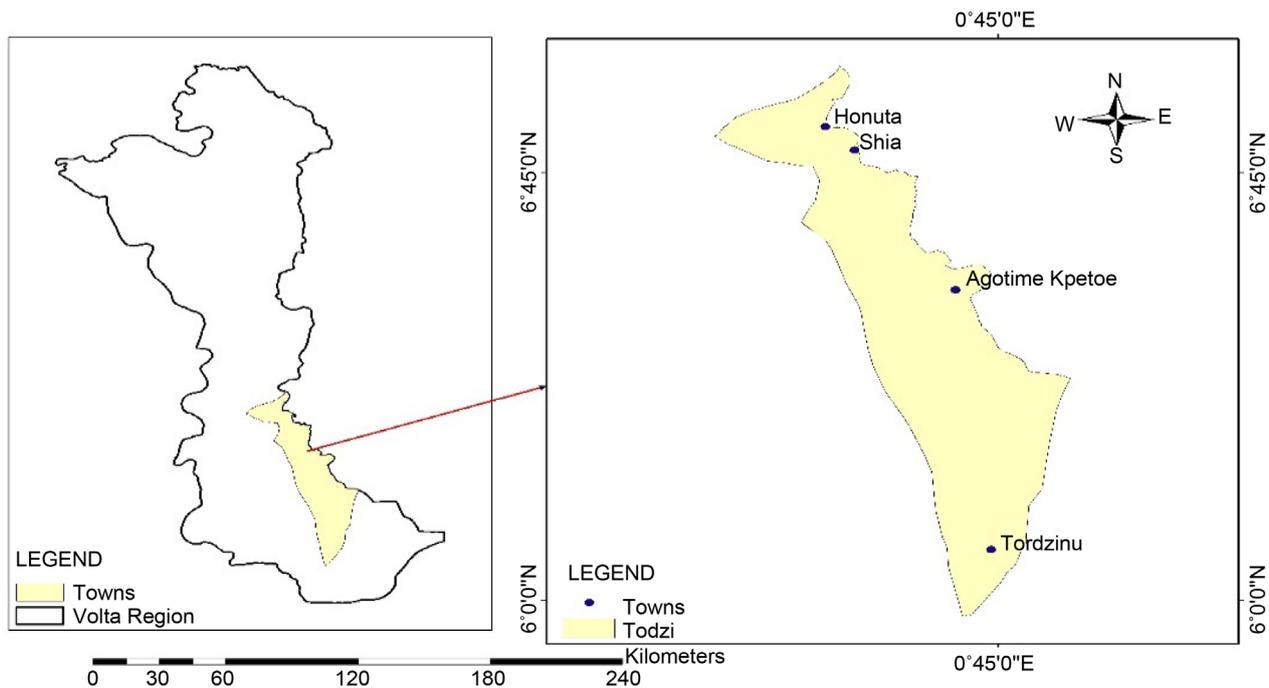


Figure 1. Tordzie watershed in relation to Volta region.

2.2. Data Description

The data was organised and tabulated in Excel and then imported to DrinC (Drought Indices Calculator), 2015 software to calculate the standardised precipitation index (SPI) at different time scales for all the stations using the data for the period 1984 to 2014 for Kpetoe and Tordzinu portion of the Tordzie watershed. Tigkas *et al.* [16] presented the overall design and the implementation of the DrinC (Drought Indices Calculator) software along with the utilization of various approaches for drought analysis.

2.3. Method Description

Computation of Standardised Precipitation Index (SPI)

The rainfall deficit within the Tordzie watershed was computed using the standardised precipitation index. A long term data for a period of 1984 to 2014 was used (31 years). The procedure used by McKee *et al.* [3] for fitting the rainfall data to a probability distribution function was adopted. Monthly rainfall data was aggregated into different time scale of 3, 6, 9 and 12 months respectively. The SPI values were subsequently computed and used in drought/flood assessment and classification. According to Bordi and Sutera [17] gamma distribution function is preferable for this type of analysis as it fits well in rainfall time series data. The procedure and formula for the computation of SPI is as follows:

The precipitation value is transformed into the SPI for the purpose of transforming: 1) mean of the precipitation value (adjusted to 0); 2) standard deviation of the precipitation (adjusted to 1.0); and 3) skewness of the existing data readjusted to 0).

The standardized precipitation index can be interpreted as mean 0 and standard deviation of 1.0 when the above goals have been achieved.

$$\text{Mean} = \bar{x} = \frac{\sum x}{N} \quad (1)$$

$$\text{Standard deviation, } S = \sqrt{\frac{\sum (x - \bar{x})^2}{N}} \quad (2)$$

$$\log \text{ mean } (x) = \bar{x} \ln = \ln(\bar{x}) \quad (3)$$

$$U = \bar{x} \ln - \frac{\sum \ln(x)}{N} \quad (4)$$

This is called U parameter, where; x is rainfall amount (mm), \bar{x} is the mean rainfall (mm) and N is the number of observations.

$$\beta = \frac{1 + \sqrt{1 + \frac{4U}{3}}}{4U} \quad (5)$$

This is referred to as shape parameter

$$\alpha = \frac{\bar{x}}{\beta} \quad (6)$$

This is called scale parameter.

The gamma distribution is expressed in terms of its probability density function as:

$$g(x) = \frac{1}{\alpha^\beta \Gamma(\beta)} x^{\beta-1} e^{-\frac{x}{\alpha}} \quad (7)$$

where; α is the scale parameters, β is the shape parameter and x is the rainfall amount (mm), $\Gamma(\beta)$ is the value of the gamma function and \bar{x} is the mean rainfall (mm).

The gamma function $\Gamma(\beta)$, a standard mathematical equation is stated as follows:

$$\Gamma(\beta) = \int_0^\infty y^{\beta-1} e^{-y} dy = \frac{1}{y^{\beta-1}} e^{-y} \quad (8)$$

where, y is the value computed from Equation (7) that is y is equal to $g(x)$.

The numerical method was used in evaluating the gamma function in Equation (8), by incorporating in the tabulated values that depended on the value taken by shape parameter β . A maximum probability was used in estimating the optimal values of α and β using Equations (5) and (6).

Equation (7) which is referred to as probability density function $g(x)$ is integrated with respect to x to obtain an expression for cumulative probability $G(x)$. This function is applicable to a certain amount of rainfall for a particular month of specific duration of time.

$$G(x) = \int_0^x x^{\beta-1} e^{-\frac{x}{\alpha}} dx \quad (9)$$

Equation (9) was used to compute values of cumulative probability for non-zero rainfall. The gamma function is applicable for rainfall values $x > 0$ for the rainfall time series of the watershed under study. For non-zero values, cumulative probability of both zero and non-zero are computed. This probability is denoted by a function $H(x)$ defined as:

$$H(x) = q + (1+q)F(x; \alpha, \beta) \quad (10)$$

where; $H(x)$ is the cumulative probability and q is the probability of zero rainfall. $q = m/n$; where m was taken as the number of zero rainfall entries in the time series rainfall data and n is number of observations.

After the above computations were carried out using the mentioned equations, the cumulative probability was transformed into a standard normal distribution. This was done in such a manner that the mean and variance of the SPI values were zero and one respectively.

$$Z = SPI = - \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \text{ for } 0 < H(x) \leq 0.5 \quad (11)$$

$$Z = SPI = + \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \text{ for } 0.5 < H(x) \leq 1 \quad (12)$$

where; t in the Equations (11) and (12) respectively were determined by:

$$t = \sqrt{\ln\left(\frac{1}{H(x)^2}\right)} \quad \text{for } 0 < H(x) \leq 0.5 \quad (13)$$

$$t = \sqrt{\ln\left(\frac{1}{1.0 - H(x)^2}\right)} \quad \text{for } 0.5 < H(x) \leq 1.0 \quad (14)$$

where; $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$,
 $d_2 = 0.189269$, $d_3 = 0.001308$

The criteria established by [3] was employed for the drought classification and the threshold value presented in **Table 1**.

Figure 2 summarizes the steps followed in the computation of the SPI.

2.4. Trend Analysis

2.4.1. Mann-Kendall Analysis

Considering the time series of n data points and T_i and T_j are two sub-sets of data where

$$i = 1, 2, 3, \dots, n-1 \quad \text{and} \quad j = i+1, i+2, i+3, \dots, n.$$

Each data point T_i was used as a reference point and compared with all the T_j data points such that:

$$\text{sign}(T) = \begin{cases} 1 & \text{for } T_j > T_i \\ 0 & \text{for } T_j = T_i \\ -1 & \text{for } T_j < T_i \end{cases} \quad (15)$$

The Kendal test's S-statistic was compared as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(T_j - T_i) \quad (16)$$

The variance for the S-statistic is defined as:

$$\delta^2 = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n-1} t_j(i)(i-1)(2i+5)}{18} \quad (17)$$

Table 1. Climatic classification according to Standardised Precipitation Index (*SPI*) provided by national drought mitigation centre at the university of nebraska-lincoln (USA).

Index value	Classification	Probability	Occurrence
$SPI \geq 2.00$	Extremely wet	0.977 - 1.000	2.3%
$1.50 \leq SPI < 2.00$	Very wet	0.933 - 0.977	4.4%
$1.00 \leq SPI < 1.50$	Moderate wet	0.841 - 0.933	9.2%
$-1.00 \leq SPI < 1.00$	Near normal	0.159 - 0.841	68.2%
$-1.50 \leq SPI < -1.00$	Moderately drought	0.067 - 0.159	9.2%
$-2.00 \leq SPI < -1.50$	Severe drought	0.023 - 0.067	4.4%
$SPI < -2.00$	Extremely drought	0.000 - 0.023	2.3%

Source: Adopted from [3].

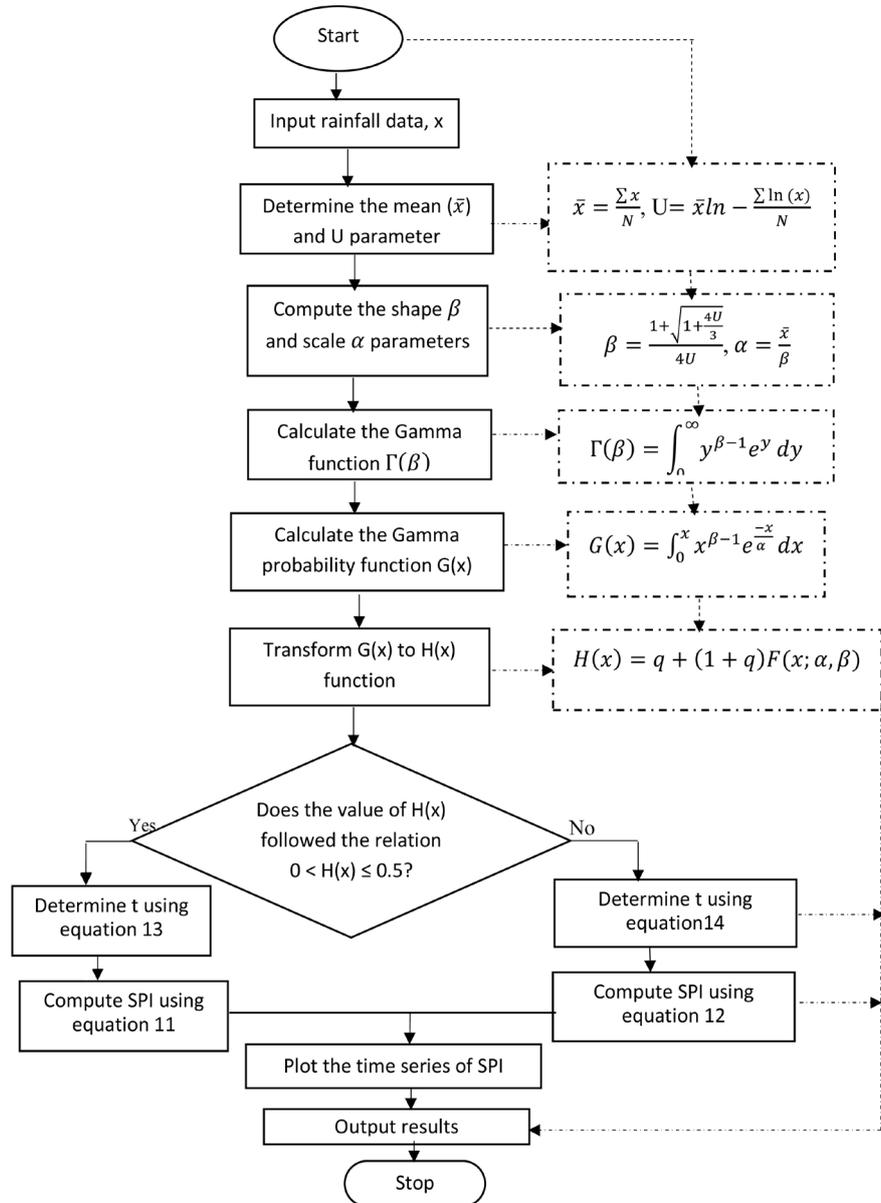


Figure 2. Flow chart for SPI computation.

In which t_i denote the number of ties to extent i . The test statistic Z_s was calculated as:

$$Z_s = \begin{cases} \frac{s-1}{\delta} & \text{for } s > 0 \\ 0 & \text{for } s = 0 \\ \frac{s+1}{\delta} & \text{for } s < 0 \end{cases} \quad (18)$$

Z_s is used as a measure of significance of trend. If Z_s is greater than $Z_{\alpha/2}$, where α represent the chosen significance level (5%, with $Z_{0.025}$), then the null hypothesis is invalid, meaning the trend is significant. The null hypothesis in Mann-Kendal test is that the data are independent and randomly ordered. The

Mann-Kendal test does not require the assumption of normality and only indicates the direction but not the magnitude of significant trends. Equation (15) implies that if T_i is greater than T_j the value of T will be 1, and the second condition shows that if T_i is less than T_j the value of T will be -1 , while the last condition implies that if $T_i = T_j$, then the value will be 0. Mann-Kendall analysis is started from the bottom and is computed towards the top values because the reference point is being compared with all the T_j values above.

2.4.2. Sen's Slope Method

The Sen's slope method was used to estimate the rate of change:

$$\Delta = \text{median} \left(\frac{X_j - X_i}{j - i} \right), \quad i < j \quad (19)$$

where X_j and X_i are the data values in times j and i respectively. The Δ sign represents the direction of change and its value indicates the steepness of change. According to Yue *et al.* [18], the slope estimated by Sen's slope estimator is a robust estimation of the magnitude of the trend.

3. Results and Discussion

The results of SPI at different time scales and the drought/flood characteristics at the mentioned network stations on Tordzie watershed are presented. The analysis revealed five (5) characteristics of historical temporal drought/flood condition of the mentioned watershed. The features of the dry/wet condition of the historical climate are: duration, frequency, intensity, severity and magnitude of the drought/flood at different time scales of SPI-3, SPI-6, SPI-9 and SPI-12 corresponding to 3, 6, 9 and 12 months respectively. Furthermore, the commencement and termination of the extreme climate events (drought and flood) are indicated in **Figure 3** and **Figure 4** respectively. The historical drought at the time scale of SPI-12 occurred in the following years; 1986, 1990, 1992-94, 1998, 2000-2001, 2005-2006, 2009, and 2013 at middle reaches (Kpetoe), of the Tordzie watershed. At the lower reaches of mentioned basin (Tordzinu), the droughts occurred in the years 1984, 1986, 1988, 1991-1995, 1998, 2000, 2003, 2005, 2010, and 2012 also at the temporal time scale of SPI-12.

The analysis also revealed that SPI-3 (short time scale) depicts frequency fluctuation below or above the zero line too frequently and the duration of the wet and dry period is very short compared to other time scales (longer time scales). The analysis of SPI-3 presented in **Figure 3** and **Figure 4** respectively from 1984-2014 revealed an extreme drought occurred in the years 2001-2002 at the Kpetoe side of the Tordzie with a magnitude of -3.25 and at the Tordzinu downstream the watershed in the year 1997 with a magnitude of -2.0 .

The implication of the above results is that the watershed experienced extreme drought for three (3) months in the aforementioned years. The consequence is its negative impact on agricultural production in the watershed since SPI-3 drought is associated with soil moisture. This implied there was not enough soil

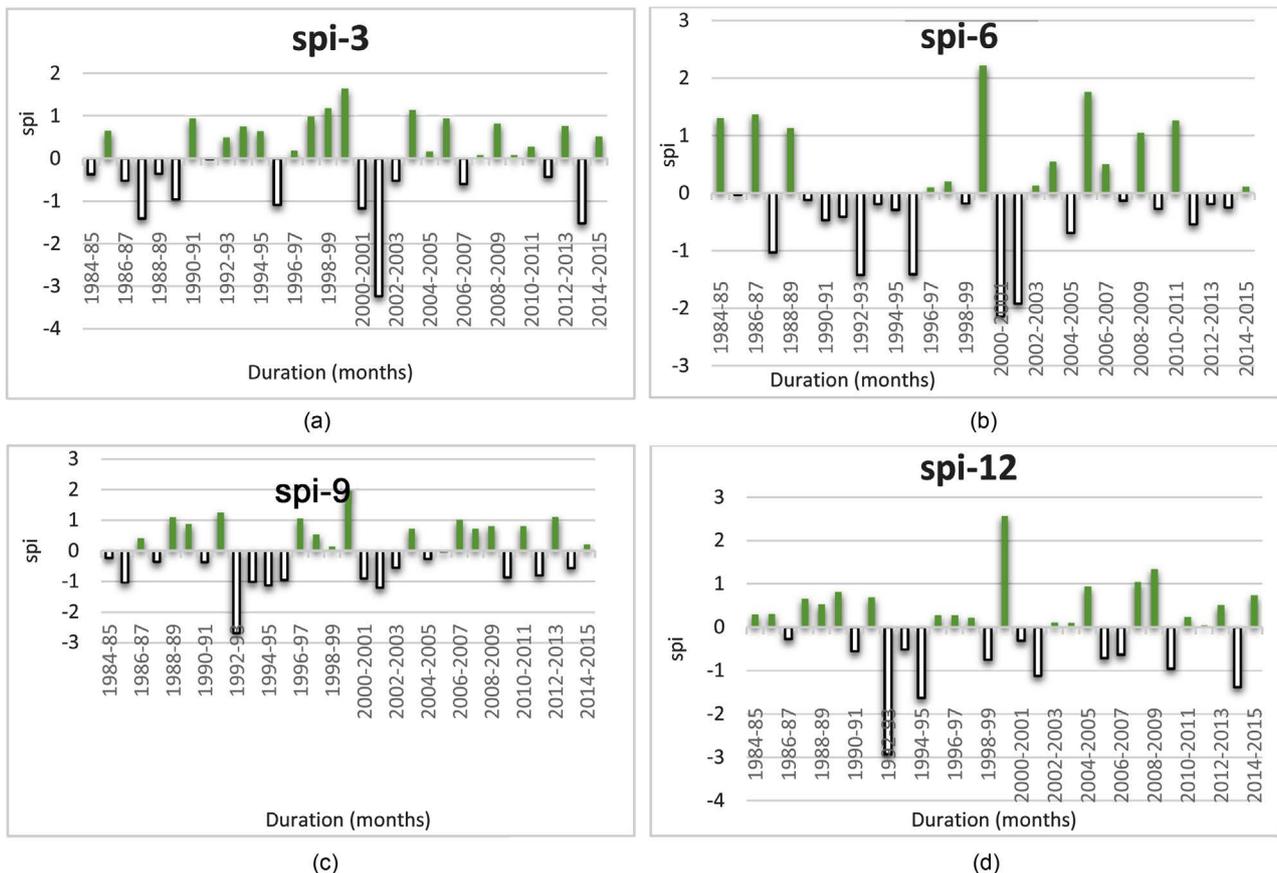


Figure 3. SPI values and drought/flood events in Kpetoe side of Tordzie watershed from 1984-2014.

moisture for plant production as a result of less than normal rainfall for the stated period (October-December) in the particular year. The soil moisture predominantly comes from rainfall which recharges the soil moisture deficit. The findings suggest crop losses could have occurred during the period which is normally the minor production season. The deduction is consistent with Williams *et al.* [19] who assessed the impact of climate variability on pineapple production in Ghana including Akatsi where Tordzinu is located using yield and climate data from 1984-2014 found out that above average yield was recorded only after 2010 production year employing standardised anomaly procedure. The standardised anomaly procedure was used for maize and cassava yield per area analysis for the stated period for both Kpetoe and Tordzinu and below average yield recorded corresponded with the drought years further validating the stated inference. This agrees with the finding of Tate and Gustard [20] on short temporal time scale drought.

Additionally, the analysis showed that SPI-6 of extreme drought event happened in the year 2000 with a drought magnitude of -2.14 at the Kpetoe part of the watershed, however, there was no extreme drought event at the downstream side (Tordzinu), of the watershed. Nevertheless, there was a wet event at both sides of the watershed, which occurred in the years 1999 with a magnitude of

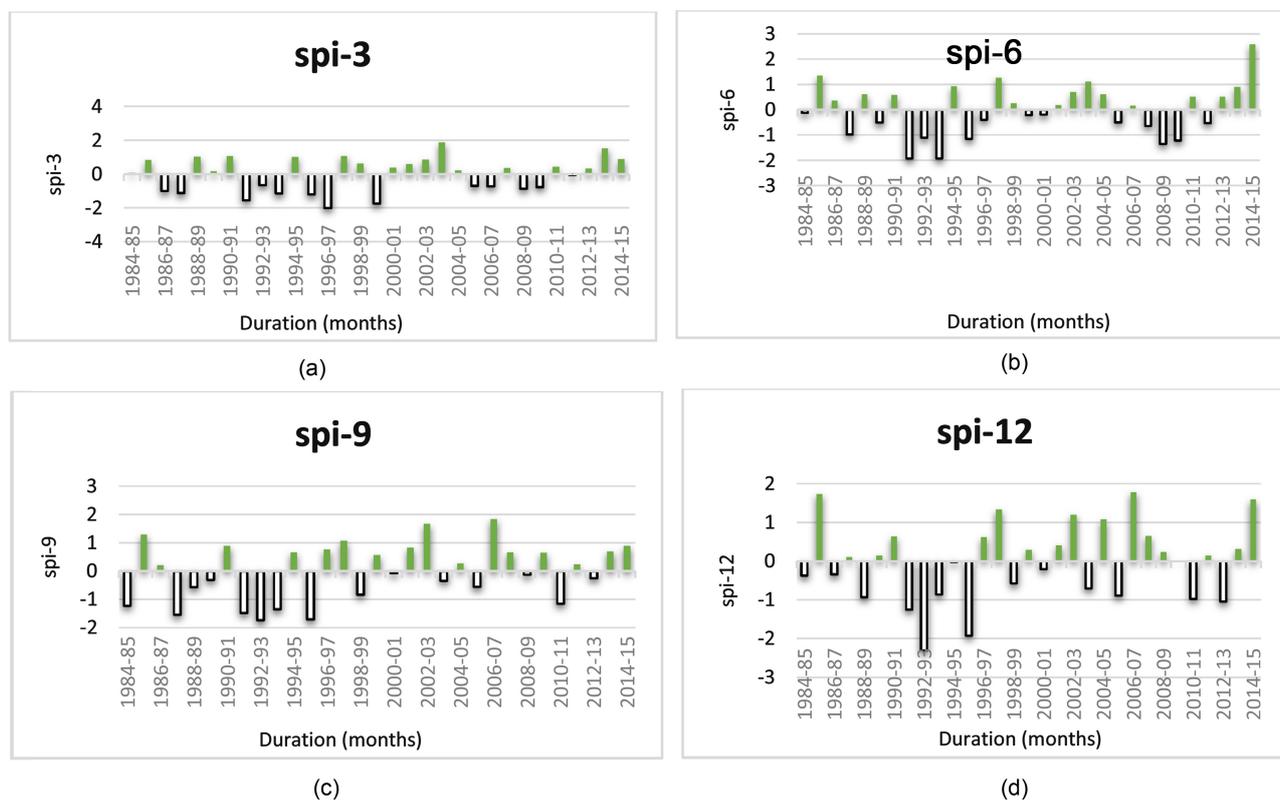


Figure 4. SPI values and drought/flood events in Tordzinu over Tordzie watershed for period 1984-2014.

2.22 and 2014 with a magnitude of 2.59 at Kpetoe and Tordzinu respectively. The implication for the SPI-6 drought is low basin flows that can be associated with it. The SPI-6 drought is typically a hydrological drought since it represents surface water availability conditions. This implies that years with negative SPI-6 values had low river flows (October-March). The drought years could be connected with low rainfall years and may be attributed to climate change and variability. The global warming could be responsible for this recurrent drought phenomenon. This assertion is agreed upon by IPCC [1], who reported that the global warming has a significant effect on atmospheric circulation and hydrological cycle which alters intensity, temporal and spatial distribution of precipitation. This in turn changes the local dry/wet conditions and affects the agricultural sector. Rosenzweig *et al.* [2] also attributed the frequency of extreme weather events to climate change.

Also, 9 months' time scale (SPI-9) rainfall analysis revealed that the extreme drought event occurred in the year 1993 with drought magnitude of 2.69 at Kpetoe and none occurring at Tordzinu. Finally, 12 months (SPI-12) drought analysis of the rainfall revealed that extreme droughts occurred in 1993 with a drought magnitude of -2.93 and -2.31 respectively at Kpetoe and Tordzinu. The longer time scales, SPI-9 and SPI-12 particularly relate to stream flows, reservoir levels and long term storage including ground water storage availability, thus resulting in low flow regimes in the basin. Besides, **Figure 3** and **Figure 4** reveals

drought/flood at different time scales.

Figure 3 and **Figure 4** further indicated the severity level of the droughts in terms of magnitude. The extreme wetness within the watershed shown by SPI time series indicated that the extreme wetness occurred at the middle reaches of the basin (Kpetoe), in 1999 at the time scales of SPI-6, SPI-9 and SPI-12. But at the lower reaches of the basin (Tordzinu), the only extreme wet event occurred in 2014 at the time scale of SPI-6 for the period under study. The mentioned extreme wet events occurred with SPI values being constantly above +2.00. The conceivable implication of the extreme wet/flood condition is flooding of farm lands and the basin overflowing its banks with its attended havoc engendered on life and property. The occurrence of this extreme wet situation could be explained as the effect of global warming. The global warming which is driving the rainfall variability and extreme climate condition could be associated with unsustainable development. The attribution made above is in agreement with Green [14] who reported that climate change is but one symptom of unsustainable development embarked upon in the past among other symptoms. Thus SPI at different time scale are useful in monitoring drought conditions in different hydrological sub-systems. It is also evident that temporal distribution of drought and its corresponding frequencies are different for different localities.

The total monthly drought characteristics in terms of magnitude, duration and severity for the period of 1984-2014 is display in **Table 2**. The average drought duration at the Tordzinu side appears higher to that of Kpetoe. However the magnitude and severity differences were not clear cut in terms of it following a particular trend or pattern. The observed clear cut differences in

Table 2. Monthly Drought Characteristics for Kpetoe and Tordzinu for the period 1984-2014.

Months	Kpetoe			Tordzinu		
	Magnitude	Duration (months)	Severity	Magnitude	Duration (months)	Severity
January	6.91	15	0.46	4.22	17	0.25
February	10.86	14	0.78	9.65	14	0.69
March	12.49	14	0.89	11.81	15	0.79
April	10.65	14	0.76	11.46	16	0.72
May	11.80	14	0.84	11.99	17	0.71
June	13.02	17	0.77	13.75	15	0.92
July	12.68	16	0.79	13.00	14	0.93
August	12.69	15	0.85	12.17	16	0.76
September	11.27	12	0.94	12.78	15	0.85
October	12.42	12	1.04	13.01	16	0.81
November	12.27	16	0.77	11.94	15	0.80
December	11.42	15	0.76	10.18	17	0.60

drought duration could be attributed to the differences in the ecological zones between the two areas.

An SPI of a short time step (SPI-3) reveals high volatility of change between dry and wet periods. When the time scale is increased the drought and flood periods indicated a lower volatility of change and longer duration. The drought and flood periods are clearly seen in SPI longer than 6 months. In **Figure 3** and **Figure 4**, the commencement and termination of the different drought/flood events are displayed graphically as well as the duration and magnitude. From the graph the drought on the scale of SPI-12 peaked in 1992 with a magnitude of -2.31 and -2.96 at Tordzinu and Kpetoe respectively.

It is also revealed that drought intensity is inversely proportional to its duration, meaning as drought frequency increases its corresponding duration decreases. Primarily, the global warming is responsible for the changes in the hydrological cycle, for instance the changes in the frequency and intensity of precipitation, temperature, evapotranspiration, soil moisture level and the underground water capacity [1].

3.1. Drought/Flood Frequency Distribution (Probability of Occurrence)

Figure 5 and **Figure 6** respectively presented the drought/flood frequencies of various categories, revealed by SPI over the watershed relating to the total number of drought events that occurred during the period under study. The above mentioned figures indicated the probability of occurrence (%) of drought events at different time scales and category for the two network stations over Tordzie watershed. It is clearly observed that for all the different time scales, the near normal droughts occurred most frequently and the severe drought events occurred least frequently. At Kpetoe side of the watershed, there was no severe drought at the time scale of SPI-3, SPI-6, SPI-9 and SPI-12. Besides the near normal drought (SPI-3 and SPI-12) was predominant at Kpetoe compared to Tordzinu. The possible explanation could be the differences in the ecological zones and geomorphology. The implication is that the extreme drought occurrence was higher at Tordzinu for SPI-3 and SPI-12. Thus soil moisture for agricultural production could be negatively impacted as well as the underground water availability. The aim of the drought frequency analysis is to identify the drought of different severity levels and their probability of occurrence. This revelation implies that the extreme climatic events are rare though drought frequency in general is on the ascendancy. In a related study by Kasei *et al.* [21] on the drought frequency in the Volta basin of Ghana they found out that 1983/84 drought affected the whole region of Ghana. In that study, the authors revealed that the drought intensity was lower than -2.0 for that particular year and affected about 75% of Ghana suggesting that a major part of the Ghana was under extreme drought conditions. It is also reported by Seneviratne *et al.* [22] that meteorological (rainfall) and agricultural (soil moisture) droughts have become

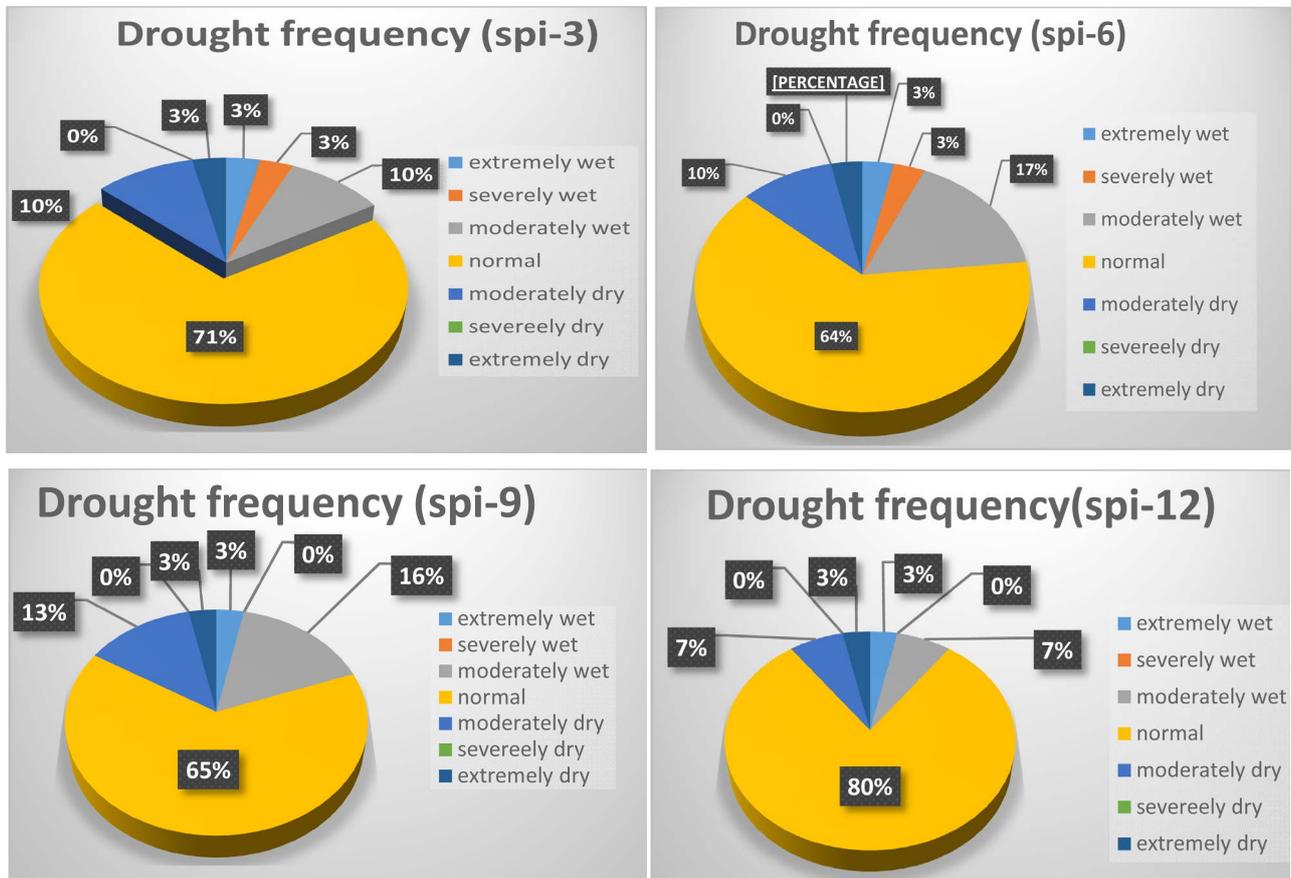


Figure 5. Probability of drought/flood occurrence at Kpetoe at the time scale of 3, 6, 9 and 12 months over Tordzie watershed.

more frequent since 1950 in some regions, including southern Europe and western Africa. It is worthy to note also that at Tordzinu area of the watershed, there was no extreme wet condition recorded at the time scale of SPI-3 and SPI-12 for the period under study.

3.2. Drought Magnitude and Duration

A drought event occurs whenever SPI values are continually negative and ends when the values become positive. Drought has a duration defined by its commencement and termination. The positive sum of the SPI values for all the months within a drought event is termed as drought magnitude. The intensity of drought event is defined as the ratio of event magnitude to its duration.

The historical drought characteristics like drought duration, magnitude and intensity are provided in the **Table 3** for Tordzinu and Kpetoe in Tordzie watershed. The drought in the year 1991 and 1992 were the longest droughts (8 months) with a magnitude of 7.05 and 8.72 respectively at Tordzinu. However, in terms of drought intensity, 1996 drought was the severest with an intensity of 1.12. This goes to imply that a longer drought period may not necessarily be the most severe. Dry spells impact greatly on agriculture (crop production) than more intense drought/flood occurrences. This finding is in agreement with

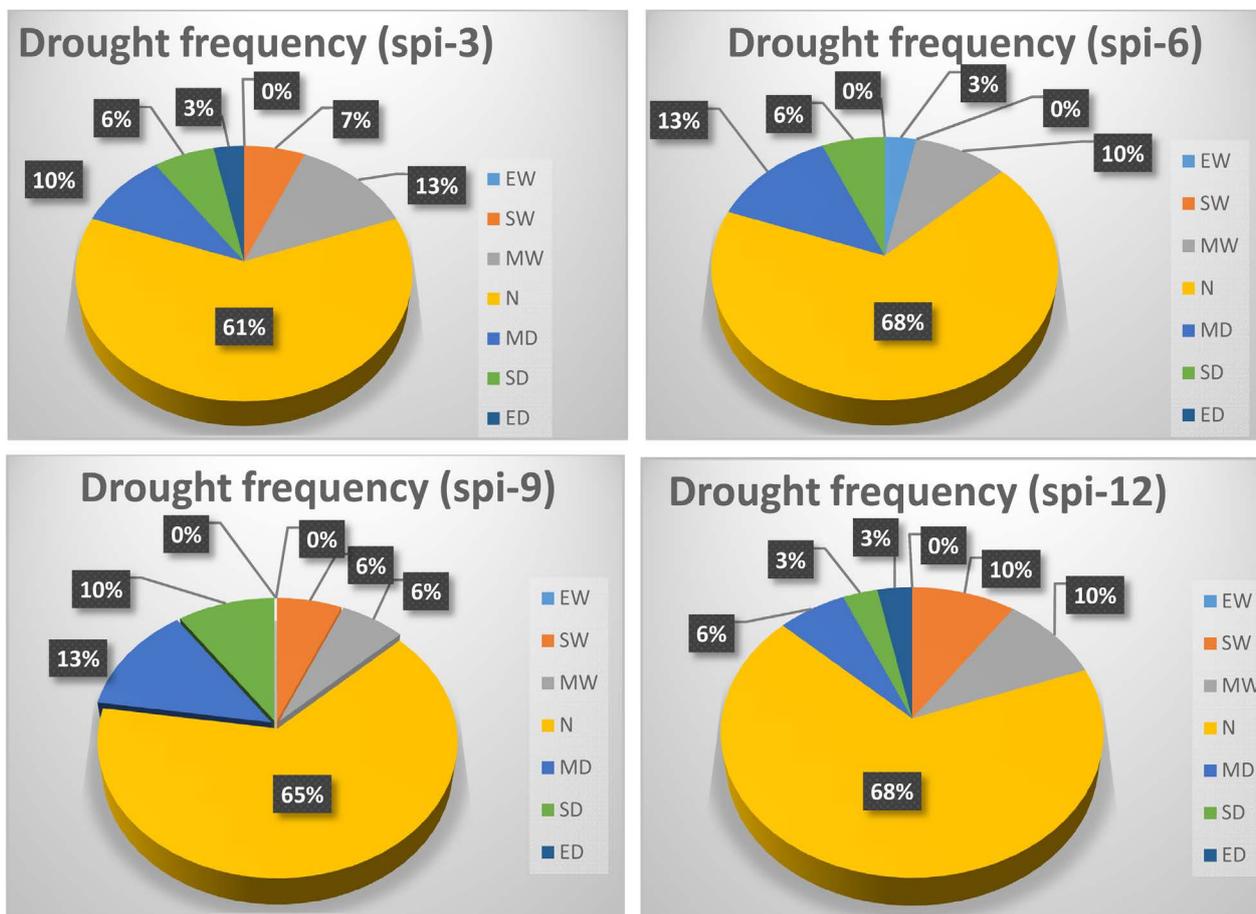


Figure 6. Drought/flood occurrence frequency at Tordzinu at the time scale of 3, 6, 9 and 12 months over Tordzie watershed.

Simelton *et al.* [23] who reported that small droughts can have bigger impacts than bigger droughts. This is because dry spells are erratic and can happen several times and at critical periods of the rainy season leading to severe plant water stresses and reduced yields. It is further revealed that 1985 was a wet year in Tordzinu as December is the only month of the year that experienced drought. On the other hand, 1988 and 1999 in Kpetoe were wet years with only two months experiencing drought. The months were August and October in 1988 and May and December in 1999. It is also noted that years with multiple hazards (droughts and floods) impact severely on agricultural production. That is, the concurrent occurrence of drought and flood in a year lead to severe crop losses. On the average the drought duration for the considered two network stations on the watershed were mostly (>90%) five or more months in the years 1984-2014 for SPI-12 time scale.

One purpose of the current study is to derive new information on the duration/number of drought events on the Tordzie watershed and to characterise its historical temporal pattern. For each SPI time scale, the number of droughts with a given duration was estimated. The results for duration 3, 6, 9 and 12 months are shown in Figure 7. At the middle reaches (Kpetoe) of the watershed,

Table 3. Drought characteristic (SPI-12) at Tordzinu and Kpetoe.

Year	Tordzinu				Kpetoe			
	Months	Duration (months)	Magnitude	Intensity	months	Duration (months)	Magnitude	Intensity
1984	1-2-4-5-6-8-11	7	4.20	0.60	1-2-4-9-12	5	6.83	1.37
1985	12	1	0.99	0.99	2-4-5-6-9-10-12	7	4.80	0.69
1986	1-5-7-8-9-10-11-12	8	4.58	0.57	1-4-6-8-9-12	6	5.42	0.90
1987	1-5-6-7-9-10	6	4.83	0.81	2-4-6-7-10-11-12	7	3.63	0.52
1988	1-3-4-5-6-7-12	7	5.16	0.74	8-10	2	2.39	1.20
1989	1-2-3-4-5-12	6	1.99	0.33	1-2-4-9-10-11-12	7	3.68	0.53
1990	3-5-8-9-10	5	5.30	1.06	2-3-5-6-7-8-11	7	4.52	0.65
1991	3-4-6-8-9-10-11-12	8	7.05	0.88	3-6-8-12	4	1.58	0.40
1992	1-2-4-6-7-8-10-11	8	8.72	1.09	1-2-3-4-5-6-7-8-9-10	10	10.96	1.10
1993	1-2-3-5-10-11	6	3.64	0.61	1-2-3-5-6-7	6	3.09	0.52
1994	2-4-6-7-9-12	6	5.42	0.90	3-4-6-7-8-9-11-12	8	7.35	0.92
1995	1-2-4-5-8-9-10-12	8	5.52	0.69	1-2-6-10-11	5	2.57	0.51
1996	1-9-10-11-12	5	5.60	1.12	1-5-9-11	4	4.01	1.00
1997	1-2-4-8-11	5	3.80	0.76	3-7-11-12	4	1.53	0.38
1998	1-3-4-5-6-7-10	7	5.20	0.74	1-3-6-7-9	5	5.20	1.04
1999	5-8-9-10-11-12	6	3.19	0.53	5-12	2	1.76	0.88
2000	1-2-3-4-7-9-12	7	3.27	0.47	2-3-6-10-11	5	5.64	1.13
2001	1-3-7-8-10	5	2.65	0.53	1-2-4-6-7-10-11-12	8	7.89	0.99
2002	3-8-9-12	4	3.27	0.82	2-4-5-9-11-12	6	2.38	0.40
2003	2-3-4-5-6-7-8	7	7.44	1.06	3-5-7-8	4	6.36	1.59
2004	4-6-7-10	4	2.93	0.73	1-2-3-4-6-8-10	7	2.96	0.42
2005	1-2-4-5-8-9-11-12	8	3.25	0.41	5-6-7-8-9	5	4.22	0.84
2006	1-2-4-6-7-8-11-12	8	5.67	0.71	4-7-8-9-11-12	6	7.07	1.18
2007	1-2-3-5-9-10-11	7	4.42	0.63	1-5-8-12	4	1.71	0.43
2008	2-3-10-11-12	5	2.29	0.46	1-4-5-9-11	5	2.09	0.42
2009	3-5-7-9-10	5	4.94	0.99	1-4-5-7-9-11	6	5.36	0.89
2010	4-5-6-7-12	5	4.86	0.97	3-5-7-8-11-12	6	3.49	0.58
2011	1-3-6-8-9-12	6	3.30	0.55	1-3-5-6-11-12	6	4.38	0.73
2012	5-6-7-8-9-11	6	3.77	0.63	1-3-7-8-10	5	3.48	0.70
2013	2-3-6-8-9-12	6	4.66	0.78	2-4-6-7-8-10-11	7	6.70	0.96
2014	4-5-6-10-11	5	2.83	0.57	2-3-6-7-8-10	6	5.45	0.91

NB: 1, 2, ..., 12 denote the months from January, February-December.

slightly higher number of hydrological droughts (SPI-6 and SPI-12) were recorded. Possible explanation could be that the upper reaches of the watershed experienced drought the previous wet season or the lag in phase between the occurrence of agricultural and meteorological droughts respectively. The implication of drought at the middle reaches of the watershed which received higher

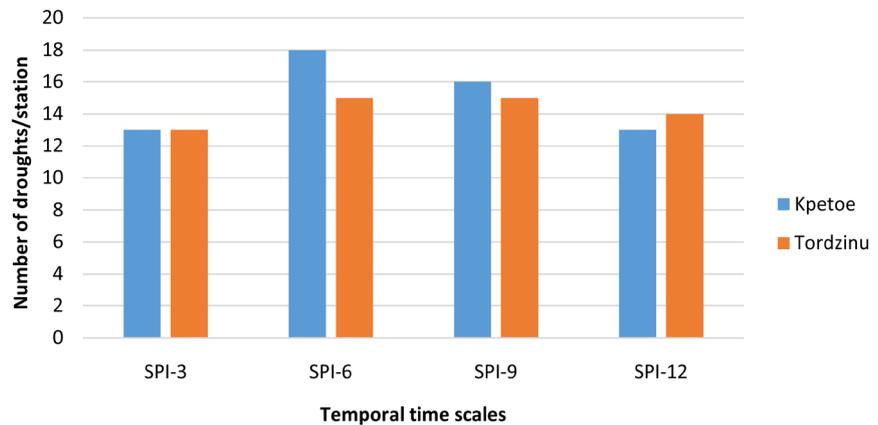


Figure 7. Number of drought occurrence at different time scale for the period of 1984-2014.

rainfall and maintains river flow during the dry season may be dry condition of river flow in the lower reaches of the basin. It is observed that SPI-3 and SPI-12 results were similar, revealing uniformity in distribution of events among the stations. As have been reported earlier, as the SPI time scale increased the number of drought events decreased, because the drought at longer time scales tend to be longer. Thus, the number of droughts at longer duration increased with longer SPI time scales. The total number of droughts for the period under study in case of SPI-12 was 175 and 187 months for Kpetoe and Tordzinu respectively.

3.3. Annual and Seasonal Trend Analysis of SPI Series

The analysis of the temporal drought trend and change at different time scales (SPI-3, SPI-6, SPI-9 and SPI-12) employing Mann-Kendal (MK) test and Sen's Slope (SS) to determine the magnitude of the change in drought from year to year indicated some changes though insignificant ($p \geq 0.05$), have already occurred in the watershed. The negative and positive values estimated by SS indicate dry and wet periods respectively. The MK test revealed that there was increasing trend in the drought at the time scale of SPI-3, SPI-6, SPI-9 and SPI-12 (**Figure 8 & Figure 9**). However, the SS estimator indicated a change in magnitude of 0.016 mm/year, 0.012 mm/year, 0.026 mm/year and 0.016 mm/year respectively at the time scale of SPI-3, SPI-6, SPI-9 and SPI-12 at 95% confidence interval at the Tordzinu part of the watershed. The corresponding SS estimator values at Kpetoe were 0.006 mm/year, 0.009 mm/year, 0.014 mm/year and 0.003 mm/year. All the time scales exhibited an increment in temporal drought. The increasing trend in drought could be associated with the general down trend and variability of rainfall related to climate change. This could further be attributed to land use/land cover change and the geomorphology of the studied area which is link to rainfall characteristics and climate change. The finding is consistent with that of Kasei *et al.* [21] who analysed temporal characteristics of meteorological drought in the Volta basin and found out that the frequency of drought

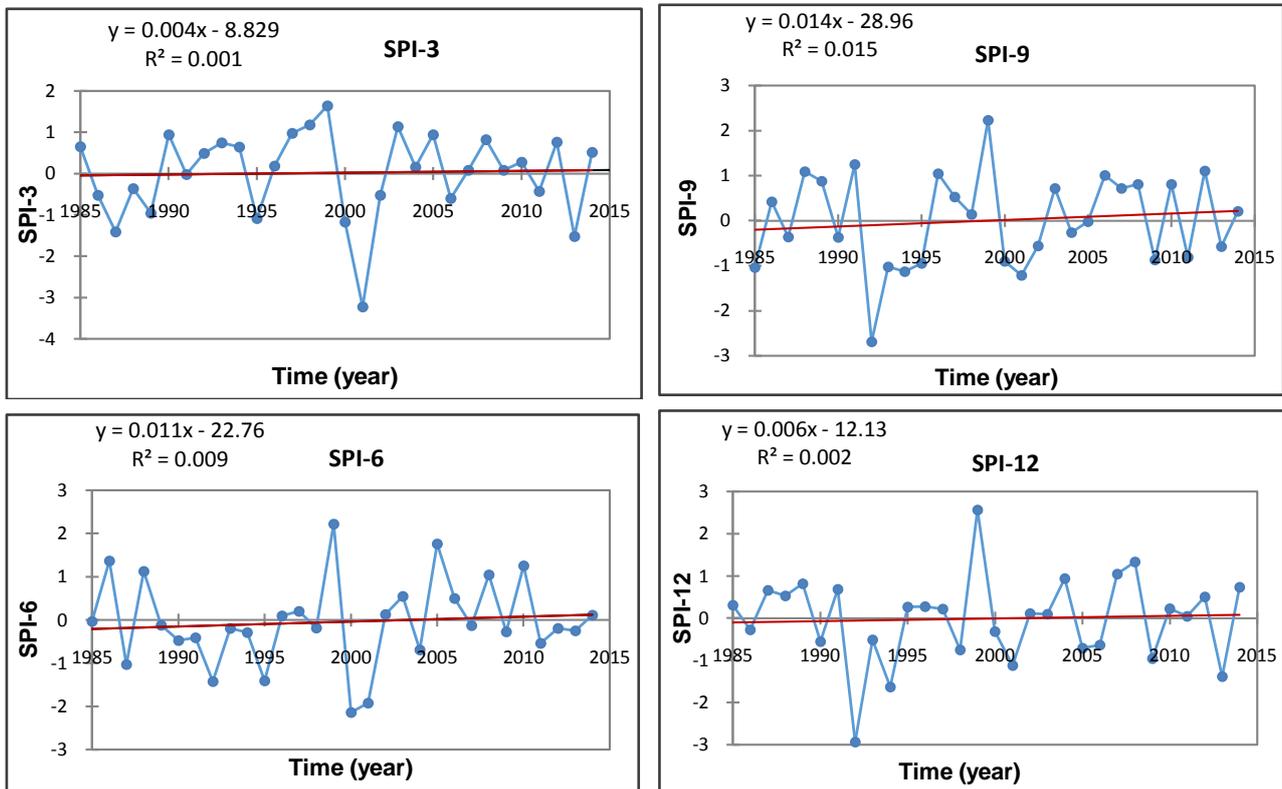


Figure 8. Trend of temporal drought at the time scales of SPI-3, SPI-6, SPI-9 and SPI-12 at Kpetoe.

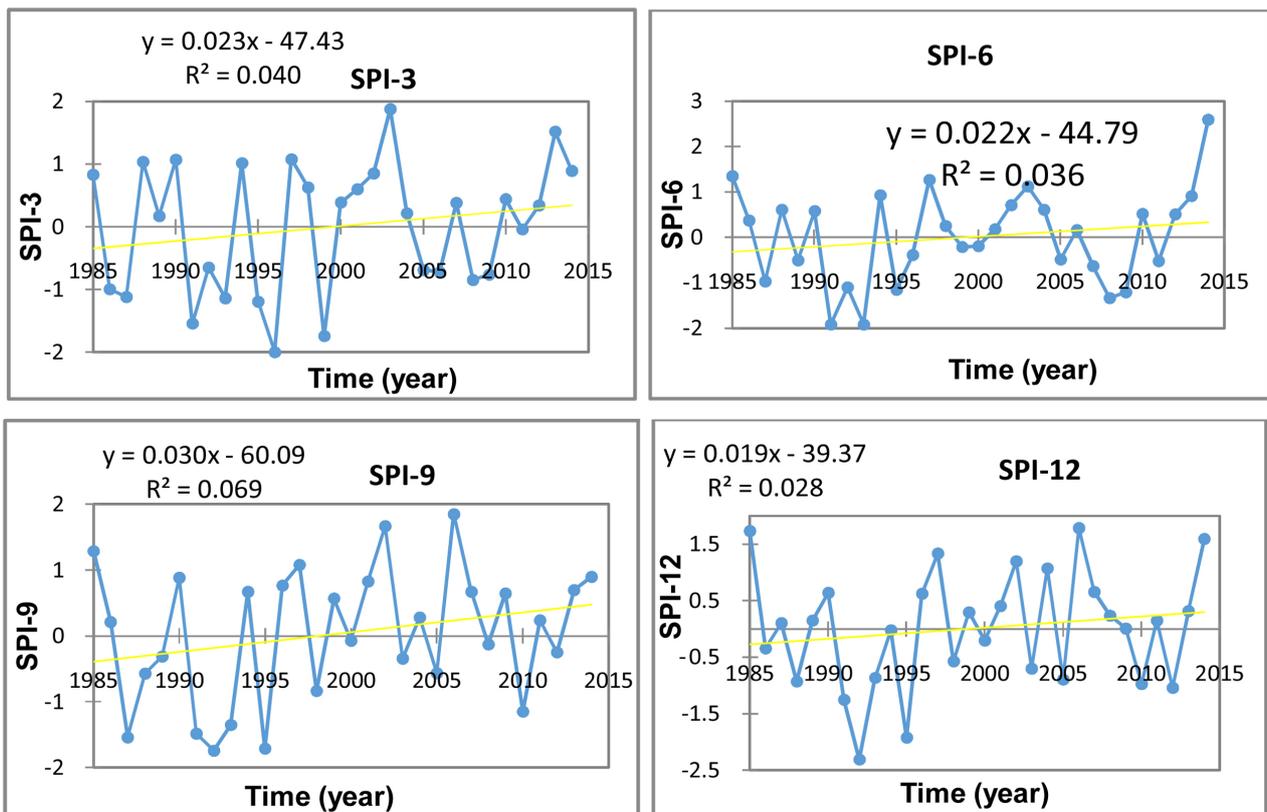


Figure 9. Trend of temporal drought at the time scales of SPI-3, SPI-6, SPI-9 and SPI-12 at Tordzinu.

events had been increasing since the 1970s till now. In that study, the investigators employed the standardised precipitation index for the analysis. Again in a related study by Owusu *et al.* [24] and Nyatuame *et al.* [25], they did not only confirm the declining rainfall and its variability but they also observed the increasing length of the dry season since the half of the twentieth century.

The seasonal temporal drought analysis of the lower reaches (Tordzinu) of the said watershed revealed changes in magnitude of drought in the months of April, May June, September and October as 0.012 mm/year, 0.003 mm/year, -0.007 mm/year, -0.015 mm/year and 0.016 mm/year respectively indicated by the SS estimator. For the same months above the corresponding temporal drought changes as indicated by SS estimator in the middle reaches (Kpetoe) of the watershed were 0.009 mm/year, -0.004 mm/year, 0.028 mm/year, 0.024 mm/year and 0.020 mm/year respectively. Additionally, the change in drought magnitude as estimated by SS is 0.027 mm/year at confidence interval of 95 %. The differences between the SPI and the corresponding trend in the two stations could be due to the variation in temperature. Evidence from the study of Vicente-Serrano *et al.* [26] confirmed that greater atmospheric evaporative demand resulting from temperature increase lead to drought severity increase as a consequence. These changes could have profound implication for agriculture and water resources management in the watershed and by extension engendering food insecurity and poverty among the smallholder farmer especially.

4. Conclusion

The SPI is robust tool for temporal historical drought/flood analysis. The analysis revealed that the watershed is prone to both drought and flood hazards. The changes in drought magnitude have been indicated by SS and the trend by MK at different time scales. Generally, there was a slight upward trend in the drought characteristics, further indicating possible climate change and variability in drought/flood in tandem with the rainfall variability. The study further employed SPI to identify the frequencies of occurrence of dry and wet conditions in the middle and lower reaches of Tordzie watershed for the period under study at different temporal time scales. The tendency towards dryness is higher in magnitude and severity at the lower reaches than the middle reaches of the watershed. The probable explanation could be the difference in the ecological zones and therefore the geomorphology. The middle reaches are located at the middle belt and forest savannah transitional zone with some hilly areas making precipitation more concentrated and the generation of runoff more intense and fast. On the other hand, the lower reaches are found within the coastal savannah with relatively flat terrain, marshes, swamps, strand and low grassland vegetation. It is also clear regarding the identification of dry/wet period, that it is better detected over longer temporal time scales of 6 months and above. It is concluded that, the increasing rainfall variability and rising temperature attributable to anthropogenic activities may not be the only cause for ascendancy in drought/flood

events intensity and frequency over the watershed. It is recommended that a further study be conducted to ascertain the roles played by land use/land cover changes. It is further suggested that spatial analysis of drought be conducted in the future to know the spatial extent of drought phenomena on the Tordzie watershed as data become available with expansion of network stations.

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Author Contributions

This paper is part of the corresponding author's PhD thesis who conducted this research as a part of his PhD thesis and wrote the initial version of the manuscript and the second author is advisor/supervisor. The first author designed the research. The second author advised on the content and analysis. The second author helped in improving the manuscript, proofread and helped in the discussion of the results.

Conflicts of Interest

The authors declare no conflict of interest.

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