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Research Article

Variability of the Minor Season Rainfall over Southern Ghana (1981–2018)

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The monitoring of rainfall variability over recent decades has become a necessity due to its devastating effects such as floods and droughts, which render humans vulnerable across different parts of the West African region. The current study seeks to provide a good understanding of variability within the minor rainfall season over southern Ghana by employing statistical tools to quantify variability in rainfall. Daily rainfall data from 1981 to 2018 for seventeen (17) synoptic weather stations across southern Ghana are used for this analysis. We perform trend and descriptive statistics of rainfall amount and extreme indices intending to identify the areas with the greatest variability in rainfall. Further, for five recent years (2014–2018), we do an interpolation of the ground station rainfall data and compute anomalies. We find increasing trends of rainfall in the minor rainy season for 16 out of the 17 stations, with rainfall increasing between 0.10 mm and 4.30 mm each season. For extreme rainfall indices, the 17 stations show nonsignificant trends of very wet and extremely wet days. We also find that the middle parts of Ghana have the highest rainfall amounts (262.7 mm/season–400.2 mm/season), while the East Coast has the lowest (125.2 mm/season–181.8 mm/season). Over the whole of southern Ghana, we find high variability in rainfall amount with the coefficient of variations (CV) between 25.3% and 70.8% and moderate to high variability in rainfall frequency (CV = 14.0%–48.8%). The results of rainfall anomalies show that the middle parts had an above-normal rainfall amount. In the same period, the transition areas experienced below-normal rainfall. Our finding of high variability in the minor rainfall season has implications for agricultural productivity in Ghana and countries in the West African region, which rely heavily on rain-fed agriculture. Hence, this study recommends more research to understand the causes of variability in the West African monsoon and how this will change in the region.

1. Introduction

Rainfall variability monitoring over West Africa is essential for various activities such as forecasting for early warning systems, hydroelectric power generation, agriculture, and food security. Literature has shown that the past five decades provide evidence of increasing rainfall extremes and frequency over West Africa [1–3]. The increase in the rainfall extremes raises much concern about whether high-impact weather events will worsen soon. However, the scarcity of water resources in some parts of the West African subregion has made it necessary for a good understanding of the rainfall regimes and variability.

The variability observed in rainfall events has resulted in extreme events like devastating floods and droughts in the history of West Africa. For instance, the Sahel region of West Africa experienced severe drought and famine during the early 1970s as a result of rainfall irregularities [4]. Floods are the main environmental challenge affecting people in West Africa. Examples of such disastrous cases of flood due to extreme precipitation over West Africa include 39 deaths in Abidjan (Côte d'Ivoire) in 2014, damage due to runoff of the Bagre Dam in Burkina Faso in 1994 and 2009 [5], death of

154 people in Accra (Ghana) in 2015 [6], and two-stage rainfall-triggered landslide which claimed 1100 lives, destroyed hundreds of buildings, and left more than 5000 people homeless in Freetown Peninsula, Sierra Leone, in 2017 [7]. In Ghana, rainfall-related floods economically displaced 3.81 million people and killed 298 people from 1968 to 2011 [8, 9].

Many studies have contributed to the understanding of rainfall regimes over West Africa and more specifically the southern portions of the subregion [1–3, 10–13]. Ta et al. [1] analyzed rainfall trends and variability and found out that the penetration of monsoon flows into the land influences extreme rainfall over West Africa. Many of the previous studies give a general trend of rainfall over the African continent. Therefore, it was necessary to zoom into Ghana and conduct an analysis of the rainfall seasons [13, 14]. In Ghana, major studies have been carried out on annual and seasonal scale rainfall trends and variability. For example, Baidu et al. [10] analyzed rainfall trends over Ghana and found decreasing trends of seasonal rainfall amounts over agro-Ecological zones between 1901 and 2010. Nyatuame et al. (2014) [11] as well indicated that annual rainfall over the Volta region of Ghana shows oscillatory rainfall trends for different months. In studying the rainfall trends in Ghana, Owusu and Waylen (2013) [12] concluded that rainfall during the minor (September-October-November) rainfall season and the beginning of the major (April-May-June-July) season encountered a reduction between 1951 and 2000. A noteworthy feature of most of the above previous studies is that they explained the spatial and temporal variations in rainfall and further highlighted the impacts on the socioeconomic activities of the country. Another interesting outcome concerning rainfall patterns over southwestern Africa is a hint of increasing rainfall amounts in some parts of the subregion during the September-October-November (SON) season [2, 13]. Notwithstanding the greatest successes in understanding the trends of rainfall in Ghana, limited studies have been conducted for specific rainfall seasons. As a result, detailed statistical studies were conducted with more emphasis on minor rainfall seasons.

Aside from the rainfall trends and variations, many attempts have been made to understand different aspects of the climate system in Ghana. The aspects include the onset, cessation, length of the rainfall seasons, dry spell predictions, and temperature trend analysis [15–19]. Interestingly, the above studies have successfully explained the behaviors of temperature, rainfall, and dry spells on seasonal and subseasonal scales and their link with major meteorological parameters like sea surface temperature (SST) and intertropical discontinuity. Kouadio et al. [14] studied the relationship between SST and rainfall variability and established that a warm ocean is associated with an increase in rainfall over southern portions of West Africa. Moreover, other exciting works have also examined the dynamics of the various meteorological factors which make up the weather and climate in West Africa [20–22].

There are two main rainfall seasons in Ghana, and these are the major rainfall season which starts in April and ends in July and the minor season from September to November. Extreme rainfall events and frequent events usually occur during the major rainfall season in Ghana [6]. Yet, between 2016 and 2018, the press in Ghana reported the rising concerns by policymakers and the public about the increasing rainfall cases and its related extreme events in the minor season [23–25]. As a result, it warrants the need for further studies to understand the dynamics of the minor seasons and to determine recent rainfall trends and extremes. This work aims to provide a quantifiable understanding and to provide enough scientific evidence regarding rainfall variability in the minor seasons over southern Ghana. This work will provide answers to the following questions: What are the current trends of rainfall in the minor season over southern Ghana? Did southern Ghana experience extraordinary rainfall amounts in the minor seasons from 2014 to 2018? In the current study, we analyze the descriptive statistics parameters, perform linear regression, and further employ the Mann-Kendall test to establish the trends of rainfall amounts, frequency of rainfall occurrence, and extreme rain days from 1981 to 2018. We further analyze rainfall anomalies for the minor seasons from 2014 to 2018.

2. Materials and Methods

2.1. Study Area. Ghana is located between latitudes 4°N to 12°N and longitudes 1.5°E to 3.5°W. The study area (Figure 1), southern Ghana (4°N–8°N), has a bimodal rainfall regime known as the major and minor seasons [14, 15]. The major season starts in April and ends in July. This is followed by the little dry season in August, and the minor season continues from September to November, which is also followed by the main dry season in December.

Monthly rainfall totals during the major season are the highest in June, while the minor rainy season peaks in October [15]. Southern Ghana is characterized by forest and/or coastal areas. Southern Ghana was selected for this study due to its unique minor season, which makes it different from the north with only one continuous rainfall season. In this work, the minor season and September–November (SON) season have been used interchangeably.

2.2. Description of Data. In situ rainfall observations from 1981 to 2018 for seventeen stations (Figure 1) over southern Ghana were obtained from the Ghana Meteorological Agency (GMet). Rainfall data used in this work has been verified at the quality control unit of GMet. Less than 2% of missing data were found in each of the 17 stations over the study period. A normality test was performed using the Shapiro–Wilk tests for the distribution type at a 5% significance level. Data were observed to be approximately normally distributed. A homogeneity test was then carried out to ensure that variation in the data used is due to climatic factors only [26]. Two methods were considered for testing for homogeneity: standard normal homogeneity test (SNHT) and Buishand's test at a 5% significant level. The null hypothesis was that the data were homogenous. A more detailed discussion about the homogeneity test can be

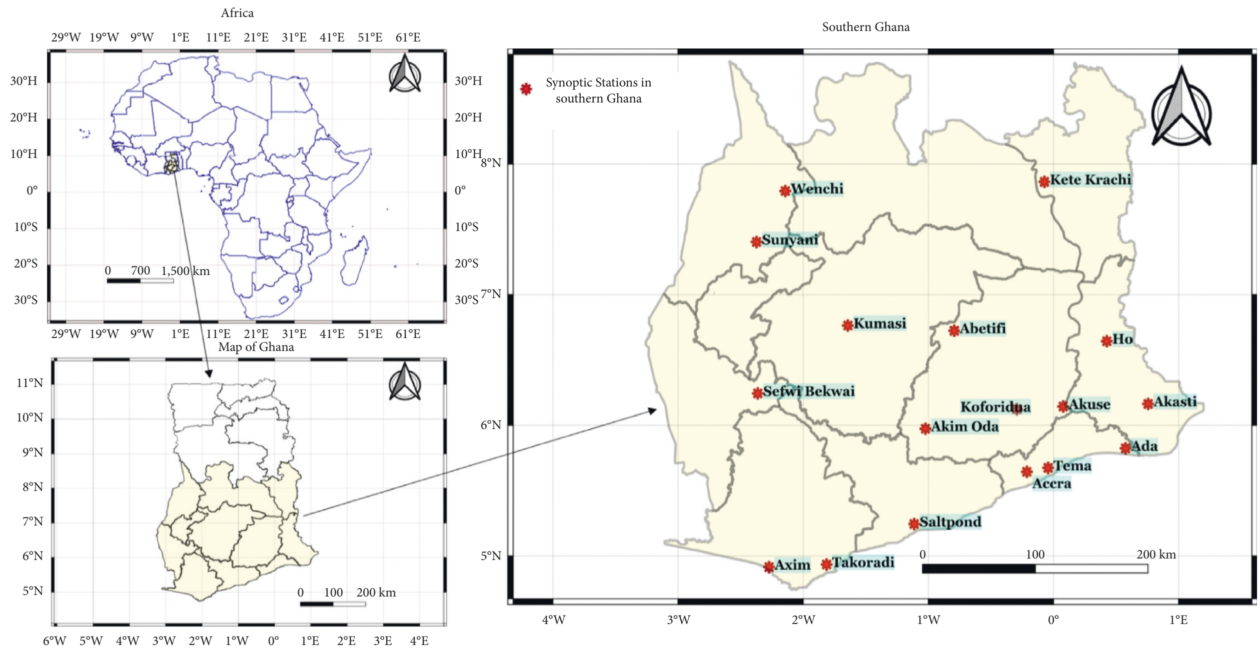

Figure 1: Map showing the various synoptic stations over southern Ghana. The map was created using QGIS software. The coordinates of the Ghana Meteorological Agency's synoptic stations were used.

Table 1: Rainfall station group.

Sections	Latitude	Longitude	Stations
East Coast	5.5°N–6.0°N	0.5°W–1.0°E	Accra, Tema, and Ada
West Coast	4.5°N–5.0°N	3.0°W–0.5°W	Takoradi, Saltpond, and Axim
Middle Sector	5.3°N–7.0°N	3°W–1.2°E	Akatsi, Koforidua, Akim Oda, Abetifi, Ho, Akuse, Kumasi, and Sefwi Bekwai
Transition Zone	7.0°N–8.0°N	3°W–1.0°E	Kete Krachi, Wenchi, and Sunyani

obtained from [26, 27]. For this analysis, we grouped the stations into four (4) sectors based on their geographical locations as shown in Table 1.

2.3. Rainfall Amount, Frequency of Occurrence, and Extreme Precipitation Indices. Rainfall totals and frequency of occurrence for September to November (SON) in each year were calculated for each station. Descriptive statistical parameters, which include the maximum, minimum, mean, skewness, kurtosis, and coefficient of variation, were generated for each station. Coefficient of variation (CV) explains the degree of rainfall amount and frequency variability in the minor season, and four CV categories are identified, that is, $CV < 20\%$ (no variability), $20\% < CV < 30\%$ (moderate), $CV > 30\%$ (high), $CV > 40\%$ (very high), and $CV > 70\%$ (extremely high) [28, 29]. For this analysis, we considered a frequency of rainfall occurrence as an event of rainfall amounts measurable by the rain gauge (0.1 mm threshold) [15, 30] and a rainy day as an event greater than or equal to 1.0 mm/day.

Five climate extreme indices from the World Meteorological Organization's Expert Team on Sector-Specific Climate Indices (ET-SCI) were used to describe extreme rainfall for the minor season [31–34]. These are Rain Days (R1), number of days with precipitation greater than or equal to 1 mm, Heavy Precipitation Days (R10), number of days with precipitation greater than or equal to 10 mm, Very Heavy Precipitation Days (R20), number of days with precipitation greater than or equal to 20 mm, Very Wet Days (R95p), number of days with precipitation greater than the 95th percentile, and Extreme Wet Days (R99p), number of days where precipitation is greater than the 99th percentile. For each station, these indices were calculated over the September–November season each year.

2.4. Trends and Standardized Anomaly Indices. Mann-Kendall trend test (M-K test) is a nonparametric test that has been widely used for the analysis of rainfall trends in different parts of the world [35–41]. We used the M-K test to find the trends of rainfall, frequency, and extreme indices for the minor season. In the M-K test, the null hypothesis assumes that there is no trend, and it is tested against the alternative hypothesis (there is a trend). Mathematically, the Mann-Kendell Statistics S, the variance of S V(S), and the standard test statistics Z are stated by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(X_j - X_i\right),$$

$$\operatorname{sgn}\left(X_j - X_i\right) = \begin{cases} +1 \text{ if}\left(X_j - X_i\right) > 0, \\ 0 \text{ if}\left(X_j - X_i\right) = 0, \\ -1 \text{ if}\left(X_j - X_i\right) < 0, \end{cases}$$

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

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{\mathrm{VAR}(S)}} \text{ if } S > 0, \\ 0 \text{ if } S = 0, \\ \dfrac{s+1}{\sqrt{\mathrm{VAR}(S)}} \text{ if } S < 0, \end{cases} \tag{1}$$

where X_i and X_j are the time series of observations in order of chronology, n is the length of time series, t_p is the number of ties for the pth value of observation, and q is the number of tied values. High positive values of Mann-Kendell Statistics S, the variance of S V(S), and standard test statistics Z indicate an increasing trend, while high negative values show decreasing trends. We applied the Sen's Slope Estimator Technique (S Slope) to find the magnitudes of trends in the minor season [42, 43]. Moreover, linear regression was applied to the total precipitation and rainfall frequency time series. In this study, a python programming language package (pyMannKendall) was used for the M-K test with a confidence level of 95%. PyMannKendall returns the trend, h (true if the trend is present and false if there is no trend), p value (p), S, Z, Kendall Tau (Tau), V(S), and S Slope [44]. M-K tests were carried out on total rainfall amount, frequency of occurrence, and the extreme indices (R1, R10, R20, R95p, and R99p).

Further, we used the Standardized Anomaly Index (SAI) [45], a commonly used index for regional climate studies, to calculate minor seasonal rainfall anomalies for 2014–2018. The 5 years were selected to find out the behavior of minor rainfall seasons in recent years. Mathematically, SAI is stated as

$$X_i = \frac{r - r_i}{\sigma} \quad i = 1, 2, 3, 4, 5 \ldots n, \tag{2}$$

where X_i is the SAI, r is the minor seasonal mean rainfall in each year (2014–2018), r_i is the long-term mean (1981–2010), and σ is the standard deviation of the observation (1981–2010). SAI = 0 means normal rainfall, SAI > 0 means above normal, SAI < 0 means below-normal rainfall, SAI ≥ 2 is extreme wetness, and SAI < = −2 is extreme dryness.

3. Results and Discussion

In Section 3.1, we present the results of descriptive statistics of rainfall and frequency of rainfall occurrence. Section 3.2 presents the results of regression analysis. Mann-Kendall test results are presented in Sections 3.3 and 3.4. Section 3.5 presents the Standardized Anomaly Index results for the minor season. In this work, rainfall stations may be presented either as individual stations or as part of a group of stations in a given sector.

3.1. Descriptive Statistics of Rainfall Amount and Frequency. Statistics of the minor season rainfall (Table 2) show a comparatively higher rainfall amount and frequency for stations over the Middle Sector. For instance, Akim Oda has the highest mean rainfall of 451.3 mm with a maximum value of 696.0 mm, a minimum value of 260.8 mm, and moderately skewed data (skewness = 0.6). In Table 3, Akim Oda has the highest mean frequency of rainfall occurrence (45.8 days) with a coefficient of variation of 14.2%, a signal of very low standard deviation concerning the mean. On the other hand, rainfall stations over the East Coast have comparatively lower rainfall amounts and corresponding frequency. Citing Tema as a typical example on the East Coast, the station has the lowest mean rainfall amount of 125.2 mm and the lowest maximum rainfall of 373.5 mm with slightly skewed (skewness of 1.0) data and insignificant outliers (kurtosis of 1.6) (Table 2). It is observed that the statistics of rainfall amount and frequency presented in this section are location-dependent. For example, Akim Oda, Kumasi, Koforidua, Ho, and Abetifi located in the forest and mountainous area show relatively higher mean rainfall amount and frequency as compared to the other sections. Atiah et al. [46] hinted that the rainfall measured by either rain gauge or satellite depends on many factors, including the location. This implies that the relatively lesser amounts and frequency over the East Coast could be a result of the absence of forest or other orographic contributions [47–49]. Assessing vegetation and change, Owusu [48] throws more light on how Accra, the major city on the East Coast, has lost all of its vegetation due to urbanization. This goes a long way to contribute to the lesser rainfall amounts recorded over the area.

Over the study area, rainfall amounts show the coefficient of variation (CV) values between 25.3% and 70.8% (moderate and extremely high variability). The degree of variability in the total frequency of occurrence is between 14.0% and 48.8%, which is moderate to high variability (Table 3). Kurtosis values of rainfall amount fall within the normal range, an indication of no or insignificant outliers in the data [50–52]. The frequency of occurrence also has kurtosis values that fall within the normal value range for all stations except Wenchi with a kurtosis value that is greater than 7.0 and skewness of −2.0, suggesting the presence of few outliers. Moreover, the rainfall amount and frequency for many rainfall stations are fairly symmetrical (skewness between −0.5 and 0.5). The absence of significant outliers portrays the level of certainty in the data. The level of

Table 2: Descriptive statistics for the minor season total rainfall in Ghana.

Station	Maximum (mm)	Minimum (mm)	Mean (mm)	Standard deviation (mm)	Skewness	Kurtosis	Coefficient of variation (%)
Accra	368.1	6.6	150.6	75.1	0.4	0.5	49.2
Ada	646.6	19.2	181.8	130.6	1.7	3.8	70.8
Tema	373.5	26.8	125.2	76.4	1	1.6	60.2
Saltpond	666.7	26.2	204.3	116.7	1.7	5.4	56.3
Takoradi	536.4	96.4	258.1	113.3	0.7	−0.2	43.3
Axim	792.1	153.6	372.1	124.4	1	0.5	32.9
Koforidua	629.8	112.6	375.8	107	−0.3	0.2	28.9
Abetifi	755.8	124.3	376.8	115.3	1	2.2	30.2
Ho	663.8	215.4	377.7	100.4	1	1.2	26.2
Akim Oda	696	260.8	451.3	115.7	0.6	−0.4	25.3
Akatsi	430.3	7.2	262.7	107.7	−0.5	0	40.5
Akuse	486.8	155.6	303.4	89.2	0.4	−0.7	29.0
Sefwi Bekwai	612.4	204.7	400.2	111.1	0	−0.9	27.4
Kumasi	740.2	157.1	375.1	122	0.6	0.9	32.1
Sunyani	587.4	156.5	360.7	106.9	0.3	−0.4	29.2
Wenchi	687.7	53.1	399.3	127.1	−0.3	0.4	31.4
Kete Krachi	729.6	194.3	418.4	111.7	0.9	1.5	26.4

Table 3: Descriptive statistics for the minor season total frequency of rain in Ghana.

Station	Maximum (days)	Minimum (days)	Mean (days)	Standard deviation (days)	Skewness	Kurtosis	Coefficient of variation (%)
Accra	30	4	18.7	6.3	−0.4	−0.1	33.4
Ada	53	6	20	9.9	1.6	3.6	48.8
Tema	26	3	15.6	5.9	−0.1	−0.6	37.5
Saltpond	35	12	24.2	5.9	0.2	−0.6	23.9
Takoradi	50	18	30.7	7	0.4	0.2	22.5
Axim	59	22	39.3	7.5	0.4	0.3	18.8
Koforidua	53	10	38.7	8.5	−1.1	3.2	20.5
Abetifi	49	12	36.4	6.8	−1.3	3.4	18.4
Ho	49	25	35	5.9	0.4	−0.2	16.4
Akim Oda	58	27	45.8	6.6	−0.7	0.7	14.2
Akatsi	39	2	25.3	8.9	−0.9	0.7	34.8
Akuse	40	20	29.8	5.3	−0.2	−0.9	17.5
Sefwi Bekwai	54	24	41.3	7.3	−0.2	−0.1	17.4
Kumasi	51	25	37.8	6.5	0.2	−0.8	17
Sunyani	48	18	34.7	6.1	−0.1	0.5	17.5
Wenchi	51	3	37.6	8.4	−2	7	21.9
Kete Krachi	41	18	31.3	4.4	0.4	1.5	14

certainty of the rain gauge data used in this work at the seasonal scale confirms the findings of more recent work in the region [53] that validates satellite data with rain gauge data and reports relatively higher consistency of seasonal data than annual scale data.

3.2. Regression Analysis of Minor Seasonal Total Rainfall Amount and Frequency. Many of the rainfall stations have positive slopes, which portray at least small increasing trends of rainfall amount. As indicated by positive slopes, sixteen (16) out of the 17 stations studied show slight increasing trends in the frequency of rainfall occurrence. Ho is the only station that shows a decreasing trend in rainfall frequency (0.066 days/season) (Figure S3) but an increasing trend in rainfall amount (1.491 mm/season) (Figure 2). Interestingly, Ho is the capital city of the Volta Region of Ghana, where Nyatuame et al. [11] reported oscillatory trends of annual rainfall.

Giving some highlights of the results of this regression analysis, slopes between 0.897 and 3.314 mm/season and an r-squared value range between 0.7% and 8.8% (Figure 3) are explained by the regression models on rainfall amount for stations situated on the West Coast of Ghana. The regression model explains variability between 3.0% and 6.0% over the East Coast (Figure 4). The Middle Sector has slopes from 0.350 to 4.331 mm/season, which is greater than the Coast, and up to 15.6% variability (Figures 2 and 5). Like all other sections, the Transition Zone stations generate positive slopes and r-squared values as indicated in Figure 5. The regression model explains the variability of up to 27% in the frequency of occurrence. The Middle Sector and the Western Coast exhibit relatively greater variability (Figures S1–S4).

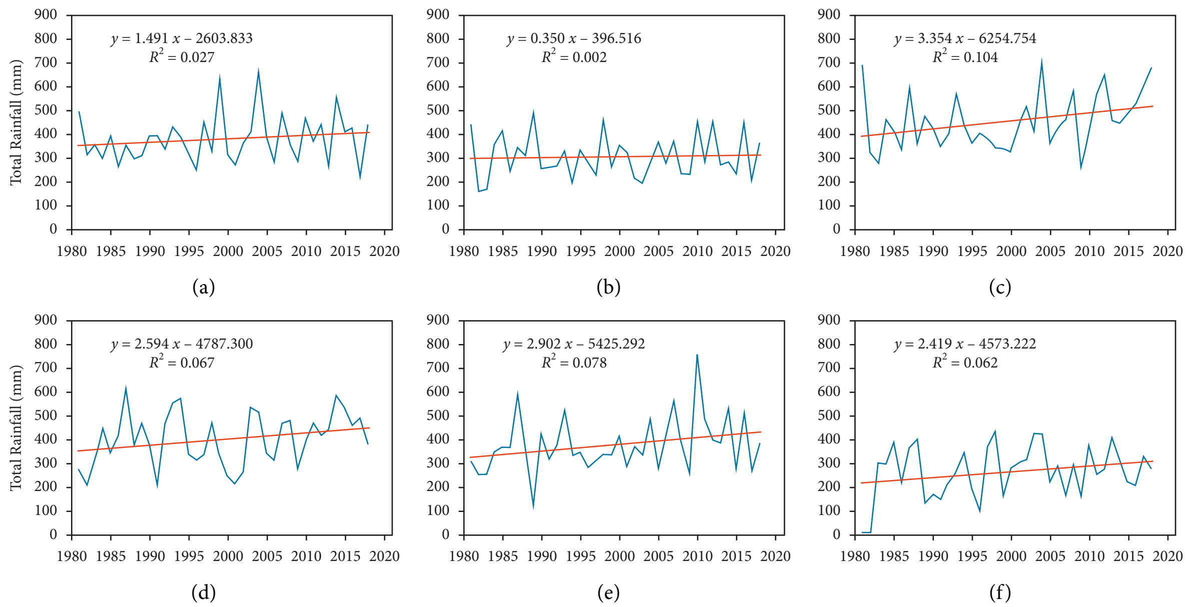

FIGURE 2: Linear plots of minor seasonal total rainfall amount over stations in the Middle Sector of Ghana: (a) Ho, (b) Akuse, (c) Akim Oda, (d) Sefwi Bekwai, (e) Abetifi, and (f) Akatsi. Data used: in situ rainfall data from the Ghana Meteorological Agency.

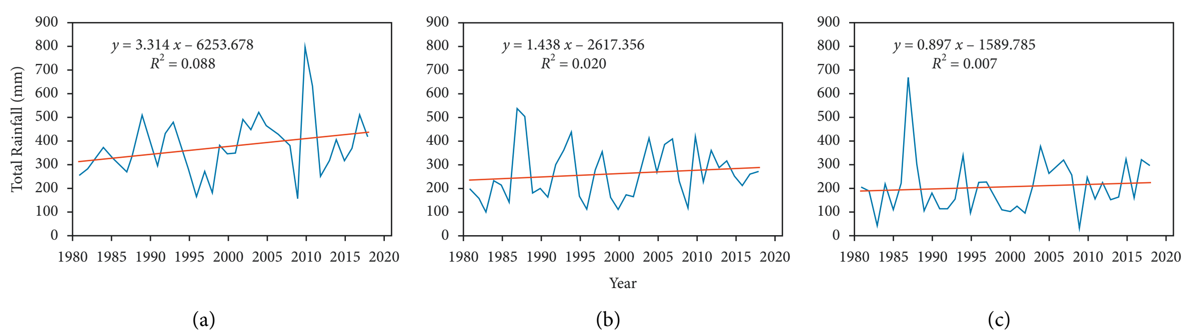

FIGURE 3: Linear plots of minor seasonal total rainfall amount over stations on the West Coast of Ghana: (a) Axim, (b) Takoradi, and (c) Saltpond. Data used: in situ rainfall data from the Ghana Meteorological Agency.

The increasing trends of rainfall in the minor season mimic the results of recent work [19] that presented increasing trends of annual rainfall in Accra and Kumasi [19]. This implies that the behavior of rainfall amount and extremes in the minor season could provide a clue on how the annual rainfall might behave.

3.3. Mann-Kendall Trend Analysis Results for Total Rainfall Amount and Frequency of Rainfall Occurrences. In the Mann-Kendall trend test, if $p < 0.05$, the trend is significant, but if $p > 0.05$, the trend is considered insignificant or simply no trend [54–56]. As evidence of increasing trends, all the stations have positive values for Z, Tau, S, and V(S) concerning rainfall amount. Moreover, for rainfall amount, S Slope between 0.433 and 4.410 mm/season is generated (Table 4). Kumasi and Akim Oda in the Middle Sector are the only two stations that exhibit a statistically significant trend with appreciable slopes ($p < 0.05$, S Slope = 4.410, and 4.000 mm/season) of rainfall amount. Kumasi and Akim Oda are located in thick forest areas surrounded by rivers and special forest reserves [57, 58]. Therefore, the greening of the vegetative cover that increases the surface moisture is likely to enhance the increasing rainfall amounts [59]. Regardless of the positive slopes, the remaining 15 stations show no significant trend (from $p = 0.060$ to $p = 0.820$) of rainfall amount.

For frequency of occurrence, all stations except Ho show either zero or positive values for Z, Tau, S, Var(S), and S Slope. The frequency of rainfall occurrence shows positive but lesser values of Sen's Slope values (S Slope = 0.000–0.333 days/season). Mann-Kendall test reveals that 8 out of the 17 stations studied show significant trends of frequency. The remaining stations have no significant trends of rainfall frequency (Table 5). Out of the 8 stations, 4 are in the Middle Sector (Kumasi, Sefwi Bekwai, Akim Oda, and Koforidua), 2 are in the East Coast (Ada and Tema), 1 is in the West Coast (Axim), and 1 is in the Transition Zone (Kete Krachi).

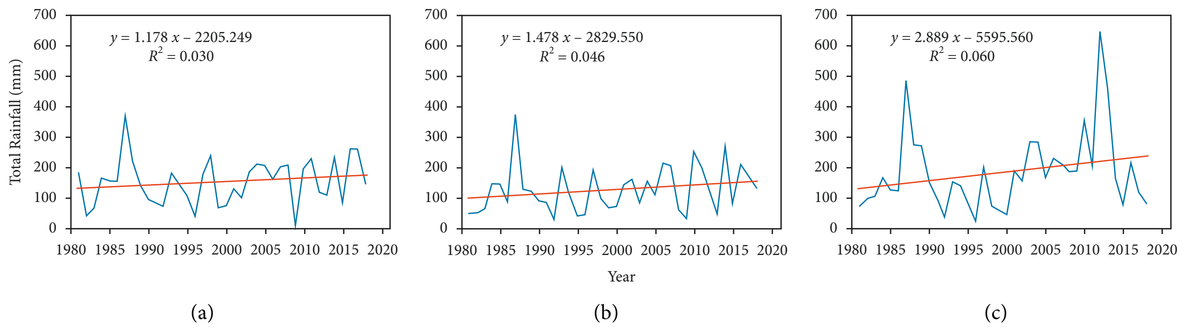

FIGURE 4: Linear plots of minor seasonal total rainfall amount over stations on the East Coast of Ghana: (a) Accra, (b) Tema, and (c) Ada. Data used: in situ rainfall data from the Ghana Meteorological Agency.

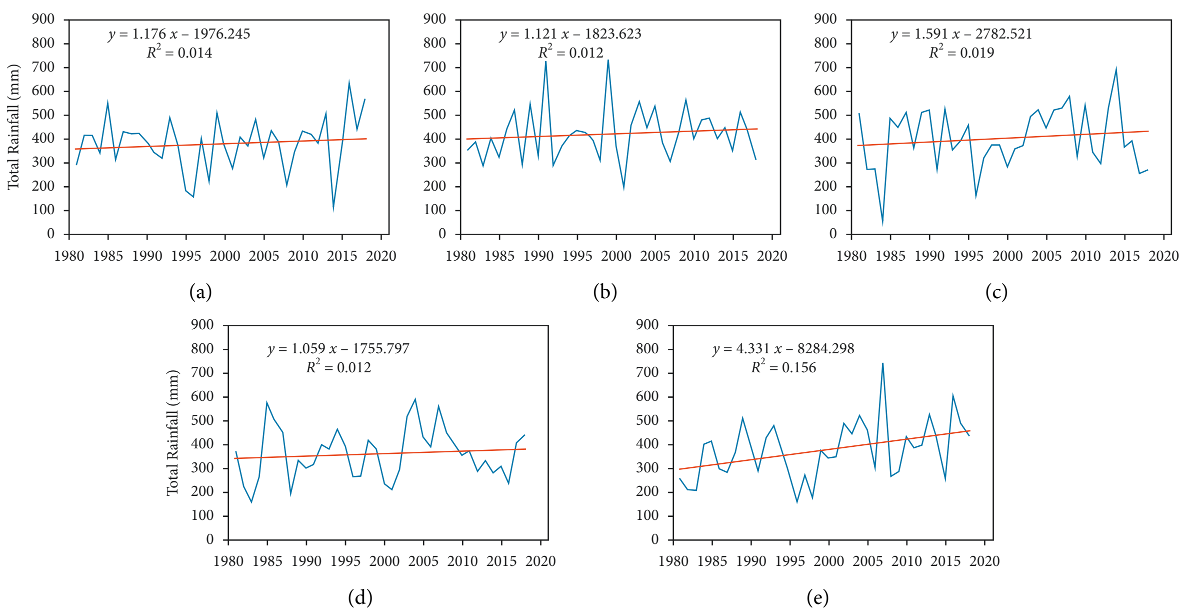

FIGURE 5: Linear plots of minor seasonal total rainfall amount over the Middle Sector (a and e) and Transition Zone (b-d). (a) Koforidua, (b) Kete Krachi, (c) Wenchi, (d) Sunyani, and (e) Kumasi. Data Used: in situ rainfall data from the Ghana Meteorological Agency.

TABLE 4: Mann-Kendall trend analysis of minor seasonal total rainfall.

Stations	Trend	h	p	Z	Tau	S	V(S)	S Slope (mm/season)
Accra	No trend	False	0.120	1.57	0.18	126	6326	1.780
Ada	No trend	False	0.089	1.69	0.19	136	6326	2.516
Tema	No trend	False	0.102	1.63	0.18	131	6327	1.866
Saltpond	No trend	False	0.240	1.18	0.14	95	6327	1.950
Takoradi	No trend	False	0.182	1.33	0.15	131	6327	2.082
Axim	No trend	False	0.060	1.91	0.22	153	6327	3.410
Koforidua	No trend	False	0.314	1.00	0.11	81	6327	1.143
Abetifi	No trend	False	0.097	1.65	0.18	133	6327	2.428
Ho	No trend	False	0.257	1.13	0.12	91	6327	1.838
Akim Oda	Increasing	True	**0.022**	**2.28**	**0.26**	**183**	**6327**	**4.000**
Akatsi	No trend	False	0.260	1.10	0.12	89	6327	1.937
Akuse	No trend	False	0.820	0.22	0.02	19	6327	0.433
Sefwi Bekwai	No trend	False	0.107	1.60	0.18	129	6327	2.833
Kumasi	Increasing	True	**0.020**	**2.34**	**0.27**	**187**	**6327**	**4.410**
Sunyani	No trend	False	0.620	0.50	0.06	41	6327	0.900
Wenchi	No trend	False	0.406	0.82	0.18	67	6327	0.875
Kete Krachi	No trend	False	0.208	1.25	0.14	101	6327	1.649

Table 5: Mann-Kendall trend analysis of frequency of rainfall occurrences.

Station	Trend	h	*p*	Z	Tau	S	V(S)	S Slope (days/season)
Accra	No trend	False	0.137	1.48	0.16	119	6291	0.148
Ada	Increasing	True	**0.004**	**2.87**	**0.32**	**229**	**6281**	**0.333**
Tema	Increasing	True	**0.008**	**2.66**	**0.3**	**212**	**6281**	**0.222**
Saltpond	No trend	False	0.161	1.4	0.15	112	6264	0.133
Takoradi	No trend	False	0.19	1.31	0.14	105	6298	0.167
Axim	Increasing	True	**0.005**	**2.82**	**0.32**	**225**	**6278**	**0.333**
Koforidua	Increasing	True	**0.008**	**2.66**	**0.3**	**212**	**6276**	**0.23**
Abetifi	No trend	False	0.528	0.63	0.07	51	6274	0.062
Ho	No trend	False	0.743	−0.32	−0.03	−27	6290	0.002
Akim Oda	Increasing	True	**0.005**	**2.82**	**0.32**	**225**	**6287**	**0.25**
Akatsi	No trend	False	0.06	1.9	0.21	152	6286	0.259
Akuse	No trend	False	0.86	0.17	0.02	15	6286	0
Sefwi Bekwai	Increasing	True	**0.001**	**3.16**	**0.35**	**252**	**6284**	**0.33**
Kumasi	Increasing	True	**0.008**	**2.66**	**0.3**	**212**	**6276**	**0.231**
Sunyani	No trend	False	1	0	0	0	6278	0
Wenchi	No trend	False	0.14	1.45	1.45	116	6273	0.153
Kete Krachi	Increasing	True	**0.025**	**2.24**	**2.23**	**178**	**6251**	**0.136**

Table 6: Mann-Kendall trend analysis of Heavy Precipitation Days (R10).

Stations	Trend	h	*p*	Z	Tau	S	V(S)	S Slope (days/season)
Accra	No trend	False	0.394	0.85	0.09	68	6182	0
Ada	No trend	False	0.067	1.829	0.21	145	6198	0.071
Tema	No trend	False	0.303	1.03	0.12	82	6176	0.030
Saltpond	No trend	False	0.969	−0.04	−0.01	−4	6272	0
Takoradi	No trend	False	0.368	0.89	0.1	72	6238	0.038
Axim	No trend	False	0.350	0.94	0.11	75	6229	0.047
Koforidua	No trend	False	0.929	−0.08	0.01	−8	6253	0
Abetifi	No trend	False	0.239	1.17	0.13	94	6257	0.08
Ho	No trend	False	0.432	0.78	0.08	63	6243	0.037
Akim Oda	Increasing	True	**0.046**	**1.99**	**0.22**	**158**	**6218**	**0.111**
Akatsi	No trend	False	0.21	1.22	0.13	98	6244	0.071
Akuse	No trend	False	0.72	0.35	0.04	29	6199	0
Sefwi Bekwai	No trend	False	0.97	1.65	0.18	132	6255	0.10
Kumasi	No trend	False	0.095	1.66	0.18	133	6254	0.091
Sunyani	No trend	False	0.657	0.44	0.05	36	6246	0
Wenchi	No trend	False	0.704	0.37	−0.04	−31	6247	0
Kete Krachi	No trend	False	0.5	0.66	0.075	53	6184	0

Therefore, at least a station in each sector generates a significant trend of frequency of rainfall occurrence. Location dependence of rainfall as reported in [46] is evident in the trends of rainfall presented in this work. It is observed that Kumasi and Akim Oda present a significant increase in both rainfall amount and frequency. As reported by Ayivor et al. [57] and Acheampong et al. [58], these stations are situated over the thick forest areas in the Middle Sector. Therefore, the greening of the vegetation in the area could account for the increasing trends.

The significant increasing trends of rainfall frequency in the eight (8) stations support previous studies [3] in the region that report increasing trends of rainfall frequency. It is observed that 6 of the 8 stations with significant increasing trends of frequency have no significant trend of rainfall amount. The results of trend analysis of rainfall amount and frequency imply that rainfall frequency could be increasing but with lesser amounts. These results could relate to previous studies in the region [12] that report the presence of relatively lesser rainfall amounts at the beginning of the minor season.

3.4. Mann-Kendall Trend Analysis of Extreme ET-SCI. Here, we present the M-K test results of the five extreme ET-SCI. Five (5) out of the 17 stations have significant increasing trends in the number of rainy days (R1). It can be observed that, out of the 5 stations, 3 are in the Middle Sector (Akim Oda, Sefwi Bekwai, and Kumasi), and 2 are located over the East Coast (Ada and Tema) (Table S1). Just one station (Akim Oda) has a significant increasing trend of R10 (Table 6). Four stations (Abetifi, Akim Oda, Sefwi Bekwai, and Kumasi) located over the Middle Sector show significant trends of R20 (Table 7). The other rainfall stations have no

Table 7: Mann-Kendall trend analysis of Extremely Heavy Precipitation Days (R20).

Stations	Trend	h	p	Z	Tau	S	V(S)	S Slope (days/season)
Accra	No trend	False	0.271	1.09	0.12	86	5972	0
Ada	No trend	False	0.372	0.898	0.10	70	5991	0
Tema	No trend	False	0.185	1.32	0.15	103	5944	0
Saltpond	No trend	False	0.109	1.6	0.17	126	6102	0.041
Takoradi	No trend	False	0.256	1.13	0.12	90	6141	0.028
Axim	No trend	False	0.684	0.41	0.05	33	6183	0.120
Koforidua	No trend	False	0.908	0.12	0.01	10	6110	0
Abetifi	Increasing	True	**0.046**	**1.98**	**0.22**	**158**	**6225**	**0.096**
Ho	No trend	False	0.161	1.37	0.15	109	6141	0.038
Akim Oda	Increasing	True	**0.034**	**2.11**	**0.23**	**168**	**6212**	**0.1**
Akatsi	No trend	False	0.168	1.37	0.15	109	6141	0.038
Akuse	No trend	False	0.939	−0.07	−0.01	−7	6152	0
Sefwi Bekwai	Increasing	True	**0.018**	**2.34**	**0.26**	**186**	**6217**	**0.1**
Kumasi	Increasing	True	**0.012**	**2.49**	**0.28**	**198**	**6210**	**0.1**
Sunyani	No trend	False	0.328	0.97	0.11	78	6206	0.034
Wenchi	No trend	False	0.848	0.19	−0.02	−16	6188	0
Kete Krachi	No trend	False	0.413	0.81	0.09	65	6120	0

Table 8: Mann-Kendall trend results for the number of Very Wet Days (R95p).

Station	Trend	h	p	Z	Tau	S	V(S)	S Slope (days/season)
Accra	No trend	False	0.411	−0.82	−0.03	−19	481	0
Ada	No trend	False	0.61	0.071	0.03	−22	1768	0
Tema	No trend	False	0.67	0.42	0.02	14	936	0
Saltpond	No trend	False	0.053	−1.92	−0.08	−60	936	0
Takoradi	No trend	False	1	0	0	0	0	0
Axim	No trend	False	0.41	−0.82	0.02	−19	481	0
Koforidua	No trend	False	1	0	0	0	0	0
Abetifi	No trend	False	0.365	0.9	0.06	43	2153	0
Ho	No trend	False	0.235	1.19	0.04	27	481	0
Akim Oda	No trend	False	1	0	0	0	0	0
Akatsi	No trend	False	1	0	0	0	0	0
Akuse	No trend	False	0.719	−0.35	0.02	−12	936	0
Sefwi Bekwai	No trend	False	0.973	−0.032	−0.03	−2	936	0
Kumasi	No trend	False	1	0	0	0	0	0
Sunyani	No trend	False	0.361	0.91	0.03	21	481	0
Wenchi	No trend	False	0.089	1.69	0.07	53	937	0
Kete Krachi	No trend	False	0.365	0.91	0.06	43	2153	0

significant trends for R10 and R20 ($p > 0.05$). The stations in the Middle Sector with increasing trends of R20 compliment the trend of R1 and rainfall frequency in the studied period. The stations located over the thick forests areas experienced a significant increasing trend of rainfall indices (R1, R10, and R20). Therefore, it is not surprising that some areas like Kumasi have experience hailstones and flooding in recent times [60, 61]. All the 17 stations studied have no significant trends of R95p and R99p during the 37 year-period (Tables S2 and 8). Atiah et al. [32] reported decreasing trends of wet indices over areas around the Volta Lake (7.0°N–9.5°N). It is worth mentioning that Volta Lake passes through some areas in the Transition Zone. Therefore, over the Transition Zone (7.0°N–8.0°N), the no significant trends of 4 of the 5 indices (R10, R20, R95p, and R99p) could relate to the decreasing trends of annual wet indices in the area.

In a nutshell, most of the stations over southern Ghana present no significant trend of rainfall amount and extremes. The stations with significant increasing trends of R10 and R20 represent a smaller fraction of the total number of stations over the Middle Sector. However, as reported by the press [25, 60–62], extreme weather events in the minor season are on the rise. Perhaps, the increase in flood cases during the minor season could be a result of other factors such as poor urban planning and inadequate drainage systems [9]. The behavior of rainfall trends and extremes in Kumasi and Akim Oda makes these stations unique among the 17 stations used in the study. The uniqueness of these two stations could be a subject of discussion for further studies. Accessing flood risk perception, Ahazie et al. [63] reported that Kumasi, the second-largest city in Ghana, is at a higher risk of flooding during the rainy season. Although poor

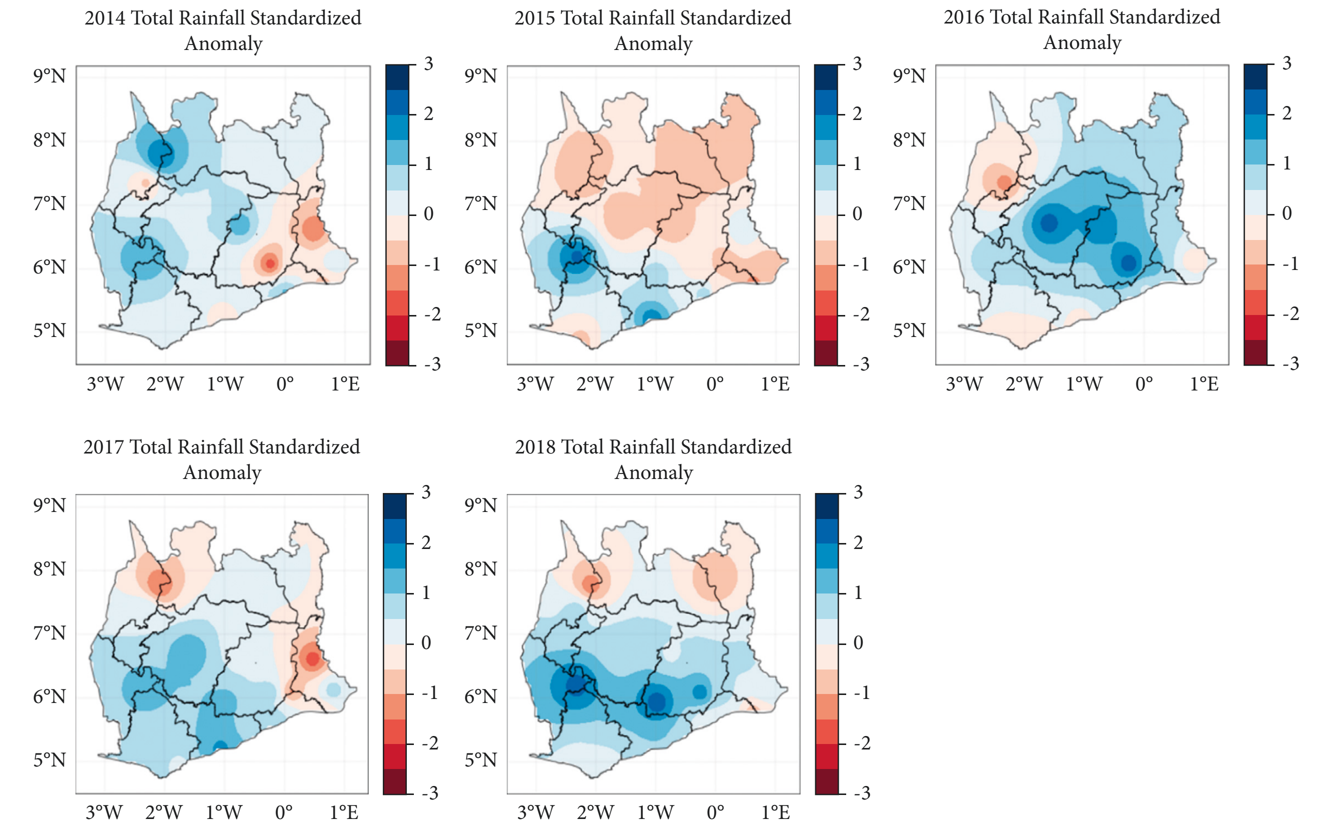

Figure 6: Spatial standardized rainfall anomaly indices for the minor season. Data used: in situ rainfall data from the Ghana Meteorological Agency.

planning and inadequate drainage systems enhance flood disasters, the higher flood risk in Kumasi, in particular, could be a result of the increasing trends of rainfall, its frequency, and extreme rainfall indices.

3.5. Standardized Anomaly Index for Minor Seasonal Rainfall Amount. We compute the Standardized Anomaly Index (SAI) during the minor season for five (5) recent consecutive years (2015–2018). The motivation behind selecting the five year-period is to understand the recent behavior of rainfall in the minor season. Station rainfall data are used to generate SAI for each of the 17 stations. We further compute the spatial interpolation of the SAI. We generate station and spatial plots for SAI.

The minor season in 2015 stands out as extremely dry with many areas having SAI less than zero (Figure 6). Notwithstanding the extreme dryness in 2015, few places in the West Coast and Middle Sector were relatively wet. On the other hand, the minor season in 2016 and 2018 stands out as extreme wet seasons. 2016 presents SAI between 1.0 and 3.0 indicating extreme wetness. In 2018, except the Transition Zone, southern Ghana experienced greater improvements in rainfall amount with SAI between 0.5 and 2.5. However, the study area experienced near-normal rainfall in the minor season of 2014 and 2017. Petrova et al. [64] described 2016 and 2018 as El Nino years. Perhaps, the climate variability driver, EL Nino, could cause wetness in 2016 and 2018.

Over the five year-period, below-normal rainfall ($SAI < 0.0$) was a dominant condition in the Transition Zone (7.0°N–8.0°N). This is evident in both the spatial and station anomaly plots (Figures 6 and 7). Like the extreme trends of ET-SCI, the minor seasonal anomalies for the Transition Zone in this work are direct confirmations of Atiah et al.'s [32] report of decreasing trend of annual wet indices in the area. In the Transition Zone, the below-normal rainfall and the no significant trend of rainfall amount could be a warning sign of longer dryness in the future.

It is observed that stations in the Middle Sector show lots of higher positive SAI ($0.0 < SAI < 3.0$) from 2014 to 2018. The above-normal rainfall in the Middle Sector could contribute to the recent extreme events in the sector. In particular, Sefwi Bekwai and Akim Oda were outstanding for higher values of rainfall anomaly indices. Further, out of the 17 stations, Akim Oda stands out in both extreme indicators and rainfall anomalies.

Ho is the only station in the Middle Sector with lots of negative SAI, and this makes the station unique in the Middle Sector. From Figure 7, it can be observed that the stations Akuse, Akatsi, and Kete Krachi present nonuniform rainfall anomalies. These stations are located in the Volta region (0.0°E–0.5°E), where Nyatuame et al. [11] reported oscillatory rainfall trends. In many of the years studied, the

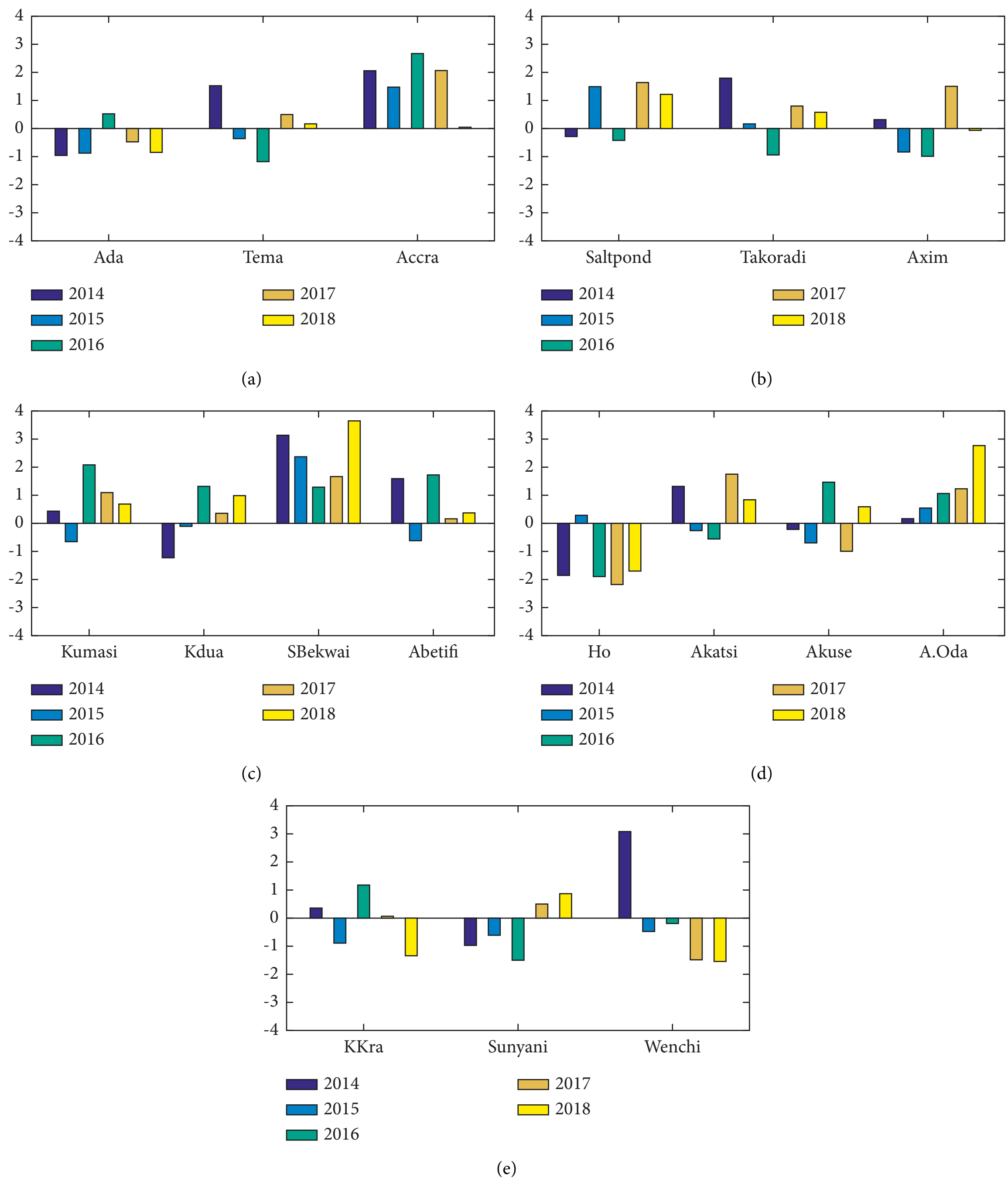

FIGURE 7: Standardized rainfall anomaly indices for the minor season. (a) East Coast, (b) West Coast, (c) Middle Sector, (d) Middle Sector, and (e) Transition Zone. Data used: in situ rainfall data from the Ghana Meteorological Agency.

West Coast experienced wetness. However, areas over the East Coast had near-normal rainfall.

4. Conclusion

In this study, we perform statistical analysis that provides a better understanding of rainfall in the minor season of Ghana. We use daily rainfall data from 1981 to 2018 in 17 rainfall stations. Rainfall amount, frequency of rainfall occurrence, and five (5) of the ET-SCI indicators are analyzed. We find out high variability in rainfall amount and frequency of occurrence. Many places show nonsignificant trends of rainfall amounts and ET-SCI (R10, R20, R95p, and R99p).

Firstly, we generate a qualitative analysis of the dataset. Rainfall amounts are highest over the Middle Sector (262.7 mm/season–400.2 mm/season) but lowest over the East Coast (125.2 mm/season–181.8 mm/season). We find moderate to an extremely high degree of variation in rainfall amount (CV between 25.3% and 70.8%). Moderate to high variation (CV between 14.0% and 48.8%) in rainfall frequency is found. For rainfall amount and frequency, results of skewness and kurtosis analysis of the dataset generate fairly symmetrical and no significant outliers.

We carry out trend analysis of rainfall amount and ET-SCI. Linear regression equations show dominantly positive slopes for rainfall amount and frequency. Positive Sen's Slopes are generated for rainfall amounts (S Slope = 0.433–4.410 mm/season) and frequency of occurrence (S Slope = 0.000–0.333 days/season). Applying the M-K test, at a significant level of 95%, we carry out the statistical significance of the trends. Fifteen (15) out of the 17 stations have no significant trends ($p > 0.05$) in total rainfall amounts. Eight (8) stations generate significant increasing trends ($p < 0.05$) in rainfall frequency. A fraction of stations in the Middle Sector presents increasing trends in two of the ET-SCI. We find significant increasing trends of R1 and R20 for 4 stations over the Middle Sector. For all rainfall stations, we find no significant trends of R95p and R99p.

Finally, to understand the recent behavior of rainfall, we perform a Standardized Anomaly Index (SAI) analysis of the 2014–2018 rainfall amount. We find out that the minor season of 2015 was relatively dry. September–November of 2016 and 2018 stand out as wet seasons. From 2014 to 2018, the Middle Sector shows the highest number of stations with above-normal rainfall. In the same period of 2014–2018, the Transition Zone shows a relative dryness. The West Coast experienced wetness, but the East Coast had near-normal rainfall.

Data Availability

All data used in this work are available upon request by contacting the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

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Supplementary Materials

Figure S1: minor seasonal rainfall frequency over the East Coast of Ghana: plots are shown on the first line (a) Accra, (b) Tema, and (c) Ada. Data used: in situ rainfall data from the Ghana Meteorological Agency. Figure S2: minor seasonal rainfall frequency over the West Coast of Ghana: plots are shown on the second line (a) Axim, (b) Takoradi, and (c) Saltpond. Data used: in situ rainfall data from the Ghana Meteorological Agency. Figure S3: minor seasonal rainfall frequency over the Middle Sector of Ghana: (a) Ho, (b) Akuse, (c) Akim Oda, (d) Sefwi Bekwai, (e) Abetifi, and (f) Akatsi. Data used: in situ rainfall data from the Ghana Meteorological Agency. Figure S4: minor seasonal rainfall frequency over the Middle Sector (a and e) and Transition Zone (b–d) of Ghana: (a) Koforidua, (b) Kete Krachi, (c) Wenchi, (d) Sunyani, and (e) Kumasi. Data used: in situ rainfall data from the Ghana Meteorological Agency. Table S1: Mann-Kendall trend analysis of Rain Days (R1). Table S2: Mann-Kendall trend analysis of Extremely Very Wet Days (R99p). (*Supplementary Materials*)

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