Article

Seasonal Rainfall Variability over Southern Ghana

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Abstract: Rainfall variability has resulted in extreme events like devastating floods and droughts which is the main cause of human vulnerability to precipitation in West Africa. Attempts have been made by previous studies to understand rainfall variability over Ghana but these have mostly focused on the major rainy season of April-July, leaving a gap in our understanding of the variability in the September-November season which is a very important aspect of the Ghanaian climate system. The current study seeks to close this knowledge gap by employing statistical tools to quantify variabilities in rainfall amounts, rain days and extreme precipitation indices in the minor rainfall season over Ghana. We find extremely high variability in rainfall with Coefficient of variation (CV) between 25.3% and 70.8%, and moderate to high variability in rain days (CV=14.0% - 48.8%). Rainfall amount was found to be higher over the middle sector (262.7 mm – 400.2 mm) but lowest over the east coast (125.2 mm – 181.8 mm). Analysis of the second rainfall season using Mankandell Test presents a non- significant trend of rainfall amount, and extreme indices (R10, R20, R95p and R99p) for many places in southern Ghana. Rainfall Anomaly Indices show that the middle sector recorded above normal precipitation which is the opposite for areas in the transition zone. The result of this work provides a good understanding of rainfall in the minor rainfall season and may be used for planning purposes.

Keywords: rainfall trend, extreme precipitation indicators, Mann Kendall's test, Sen's slope estimator, rainfall variability, climate statistics, seasonal rainfall, standardized anomaly index, southern Ghana

1. Introduction

Rainfall variability 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 provides 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 in the near future. However, the scarcity of water resources in some parts of the West African sub-region has made it necessary for a good understanding of the rainfall regimes and variability.

Rainfall variability 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. Example of such disastrous cases of flood due to extreme precipitation over West Africa includes 39 deaths in Abidjan (Côte d'Ivoire) in 2014, damages 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 and two-stage rainfall-triggered landslide which claimed 1100 lives and affected 5000 people in Freetown peninsula, Sierra Leone in 2017 [7] . In Ghana, rainfall-related floods affected 3.81 million 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 sub-region [1,3,10-13]. Ta et al. (2016) [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 and therefore necessary to zoom into Ghana and conduct an analysis of the rainfall seasons[13,14]. In Ghana, major studies have been done on annual and seasonal scale rainfall trends and variability. For example, Baidu et al. (2017) [10] analyzed rainfall trends over Ghana and found out a decreasing trend in 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. Studying the rainfall trends in Ghana, Owusu and Waylen (2013) [12] concluded that rainfall during the minor rainfall season and the beginning of the major season encountered a reduction between 1951 and 2000. An exciting feature about most of the above previous studies is that they explained spatial and temporal variations in rainfall and further highlighted the impacts on socio-economic activities of the country. Another interesting revelation concerning rainfall patterns over southwestern Africa is a hint of increasing rainfall amounts in some parts of the sub-region 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, it is necessary for detailed statistical studies to be conducted with more emphasis on particular rainfall seasons.

Aside from the rainfall trends and variations, many attempts have been made to understand different aspects of the climate system in Ghana which include the onset, cessation, and length of the rainfall seasons, rainfall and dry spell predictions, and temperature trend analysis [15-19]. Interestingly, the above studies have successfully explained the behaviors of temperatures, rainfall, dry spells at seasonal and sub-seasonal scales and their link to major meteorological parameters like seas surface temperatures (SST) and intertropical discontinuity. Kouadio et al. (2011) [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 looked into the dynamics of the various meteorological factors which make up 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 which is fromSeptember to November. Conventionally, extreme rainfall events and frequent events usually occurred around April-July which doubles as the major rainfall season in Ghana [6]. On the contrary, the electronic and print media in Ghana is flooded by rising concerns by policymakers and the public of increasing rainfall cases and its related extreme events between September and November[23 - 25]. As a result, it warrants the need for further studies into the minor season to find out recent rainfall trends and extremes. This work aims to provide improved understanding of rainfall regimes, frequency, and extremes in the minor season. This work will provide answers to the following questions; Are rainfall amounts, rain days or wet indices in the second rainfall season increasing? Is the rainfall amount recorded over the past few years during the minor season above average ?

In the current study, we analyze the descriptive statistics parameters, perform linear regression, and further employ Mann Kendall test, to establish trends of rainfall amounts, rain days and extreme rain days. We further analyze rainfall anomalies for the minor season. Section 2 describes the methods, study area, data and the Mann Kendall test and other statistics used. In section 3 the results of descriptive statistics of rainfall and rainy days were presented.. The conclusion of this study is discussed in the final section.

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, southern Ghana (4° N - 8 ° N) has a bimodal rainfall regime known as the major and minor seasons [14,15]. The major season starts from April to July which 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 highest in June whilst the minor rainy season peaks in October [15]. Southern Ghana is characterized by forest (6 ° N - 8° N) and/or coastal areas (4 ° N - 6 ° N). 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.

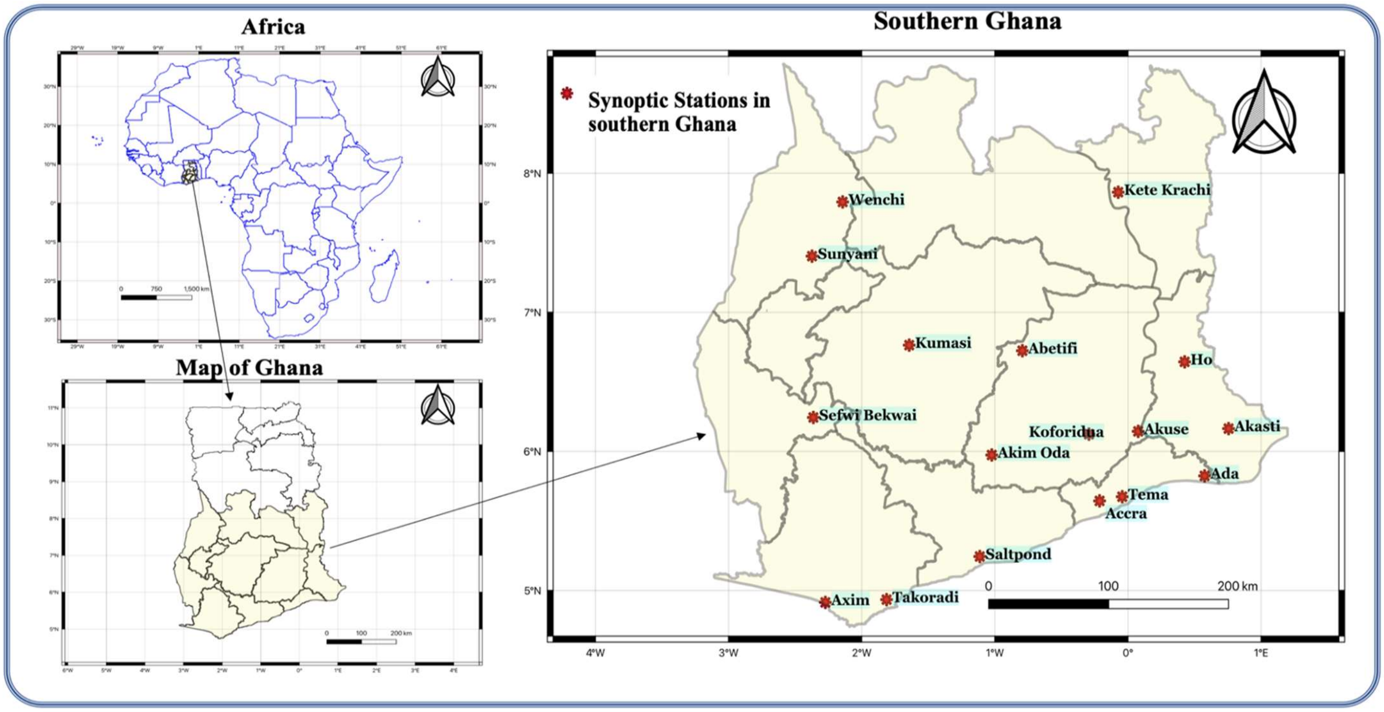

Figure 1: Map showing the various rainfall stations over southern Ghana

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. For this analysis, we group stations into four (4) sections based on their geographical locations as shown in Table 1. Data gaps in Akatsi were filled with data from a rainfall station which is situated about 10km away from Akatsi synoptic station.

Table 1: Rainfall station groups

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, Axim
Middle Sector	5.3 °N - 7.0 °N	3 °W -1.2 °E	Akatsi, Koforidua, Akim Oda, Abetifi, Ho, Akuse, Kumasi, Sefwi Bekwai
Transition Zone	7.0 °N - 8.0 °N	3 °W - 1.0 °E	Kete Krachi, Wenchi, Sunyani

2.3. Rainfall Amount, Rain Days and Extreme Precipitation

Rainfall totals and total rain days for September to November in each year were calculated for each station. For this analysis, we consider a rainy day as an event of rainfall amount greater or equal to 0.1 mm [15, 26]. Descriptive statistical parameters which include the maximum, minimum, mean, skewness, kurtosis, and coefficient of variation generated for each station were calculated. Coefficient of variation (CV) explains the degree of rainfall amount and frequency variability in the minor season and its stated as less (CV < 20%), moderate (20% < CV < 30%), high (CV > 30%), very high (CV > 40%), and extremely high (CV > 70%) [27,28].

We use four indices (R10, R20, R95p, and R99p) from the World Meteorological Organization's list of Experts Team on Climate Change Detection Indices (ETCCDI) for our analysis [29-32]. Heavy Precipitation Days (R10) - precipitation greater or equal to 10 mm, and Very Heavy Precipitation Days (R20) – number of days with precipitation greater or equal to 20 mm, were calculated for each year in each station. Very Wet Days (R95p), -

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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 were also calculated for each station.

2.4. *Trend Analysis*

Mann Kendall Trend Test (M-K test) is a non-parametric test which has been widely used for analysis of rainfall trends in different parts of the world, and we use this test to find trends of rainfall, rain days and extreme indices for the minor season [33 - 39]. In the M-K test the null hypothesis assumes there is no trend and it's tested against the alternative hypothesis (there is trend). The Mann Kendell Statistics S, the Variance of S V(S) and the standard test statistics Z are stated mathematically by

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

$$sgn\left(X_j - X_i\right) = \begin{cases} +1 \; if\left(X_j - X_i\right) > 0 \\ 0 \; if\left(X_j - X_i\right) = 0 \\ -1 \; if\left(X_j - X_i\right) < 0 \end{cases} \tag{2}$$

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_{p(t_p-1)(2t_p+5)}\right] \tag{3}$$

$$Z = \begin{cases} \frac{s-1}{\sqrt{VAR(S)}} \; if \; S > 0 \\ 0 if S = 0 \\ \frac{s+1}{\sqrt{VAR(S)}} \; if \; S < 0 \end{cases} \tag{4}$$

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, q is the number of tied values.

High positive values of Mann Kendell Statistics S, Variance of S V(S) and standard test statistics Z indicates an increasing trend whilst high negative values show decreasing trends.

Sen's Slope Estimator Technique is a non parametric method of estimating the magnitude of a trend based on the method of least squares [40 - 41] and we apply this method to find magnitudes of trends in the minor season.

$$T_i = \frac{X_j - X_k}{2} \tag{5}$$

$$i = 1, 2, 3, 4, 5, \ldots.. n, j > k$$

Where T is the slope, X_j and X_k are the data values at the time of j and k respectively . For

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} \quad N \; is \; odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) \quad N \; is \; Even \end{cases} \tag{6}$$

Where Q_i is the median of the n values of T_i and its symbolized as the Sen's Slope Estimator. Positive values of Qi show an increasing trend, and negative Qi values represent decreasing trends.

In this study python programming language package (pyMannKendall) was used for the M-K test at a confidence limit of 95% which returns the trend, h (True if the trend is present and False if there is no trend), p-value (p), normalized test statistics (z), Kendall Tau (Tau), Mann-Kendall's Score (s), variance S (var_s) and the Sen's slope (S Slope) [42]. Mann- Kendall Trend test (M-K test) were carried out on total rainfall amount, rain days, R10, R20, R95p and R99p.

An equation of a linear regression is given mathematically by

$$y = mx + c \tag{7}$$

where y is the dependent variable, x is the independent variable, c is the intercept and m is the slope of the line. Positive values of m indicate increase in trend, and negative m values indicate decreasing trend [39].

For this analysis we plot rainfall amounts, and rain days against the years and a slope is generated which tell us whether there are decreasing or increasing trends.

2.5. *Standardized Anomaly Index Estimation Model*

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Standardized Anomaly Index (SAI), a commonly used index for regional climate studies was used here to calculate minor seasonal rainfall anomalies for 2014 – 2018, using the average rainfall from 1981 to 2010 as the long-term mean (equation 8). SAI is stated mathematically as

$$X_i = \frac{r - r_i}{\sigma} \quad (8)$$

i= 1, 2,3, 4, 5,…..n

Where X_i is the SAI, r is the mean of observations, r_i is the long-term mean, and σ is the standard deviation of the observation. Positive values of X_i is considered above long-term mean, and negative values of X_i depicts below the long-term mean [39]. SAI = 0 means normal rainfall, SAI > 0 means above normal and SAI < 0 below normal rainfall, SAI >= 2 is an extreme wetness, and SAI< = - 2 is an extreme dryness

3. Results and Discussion

In section 3. 1 We present the results of descriptive statistics of rainfall and rain days. Section 3.2 presents results of regression analysis which include linear regression equations. Mann Kendall test results are presented in Section 3.3 and 3.4. Section 3.5 presents standardized anomaly index results for the minor season. For this work, rainfall stations may be presented either as individual stations or as part of a group of stations in a given section.

3.1 Descriptive Statistics of Rainfall Amount and Rain Days

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

Station	Maximum (mm)	Minimum (mm)	Mean (mm)	Standard Deviation	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

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Table 3: : Descriptive statistics for the minor season total number of rainy days in Ghana

Station	Maximum (mm)	Minimum (mm)	Mean (mm)	Standard Deviation	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

Statistics of the minor season rainfall (1981 - 2018) show a comparatively higher rainfall amount and rain days for stations over the middle sector. From table 2, the middle sector has mean rainfall values between 262.7 mm and 451.3 mm, and maximum rainfall ranging between 430.3 and 755.8 mm. For instance, Akim Oda in the middle sector has the highest mean rainfall of 451.3 mm with a maximum value of 696.0 mm, and a minimum value of 260.8 mm with moderately skewed data (skewness = 0.6)]. Akim Oda has the highest mean number of rain days (45.8 days), and the second-highest maximum of 58 rainy days with a coefficient of variation of 14.2%, a signal of very low standard deviation with respect to the mean. Rainfall stations over the east coast (5.5 °N 0.5 °W - 5.5 °N 1 °E) have comparatively lower rainfall amounts and corresponding rainy days. Citing Tema as a typical example in the east coast, the station has the lowest mean rainfall amount of 125.2mm and lowest maximum rainfall of 373.5 mm with a slightly skewed (skewness of 1.095) data, and insignificant outliers (kurtosis of 1.5). Tema doubles as having a symmetrical number of rain days (skewness= -0.1), with the lowest number of mean rainy days (15.6 days), the lowest maximum of 26 rain days with no outliers (kurtosis of -0.6), and having 37% variability. From our analysis, the west coast has higher rainfall amount and rain days as compared with the eastern side of the coast with Axim known to experience the highest rainfall in Ghana per climatology being a typical example.

Rainfall amounts show coefficient of variation (CV) values between 25.3% and 70.8% (moderate and extremely high variability). The degree of variability in the total number of rainy days 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 [43-45]. The number of rain days also have kurtosis values which fall within the normal value range for all stations except Wenchi. Wenchi, a station located over the transition zone, has mean rain days of 37.6 which is among the stations with the highest mean rain days. However, Wenchi has Kurtosis value which is greater than 7.0 and skewness of -2.0 which makes us suggest the presence of few outliers and non-symmetrical respectively for the dataset. Moreover, the rainfall amount and number of rainy days 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 set which was used in this work. For a clearer overview of rainfall amount and frequency during the minor season, we can say that rainfall amounts in the minor season are highest over the middle sector and lowest over the east coast. Perhaps, green

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vegetation and the topography of the middle sector can be a contributing factor that influences higher rainfall amounts and rain days.

3.2. Regression Analysis of Minor Seasonal Total Rainfall Amount and Rain Days

The results of regression analysis for both rainfall amount and number of rain days were analysed with a time series plot generated for each synoptic station.

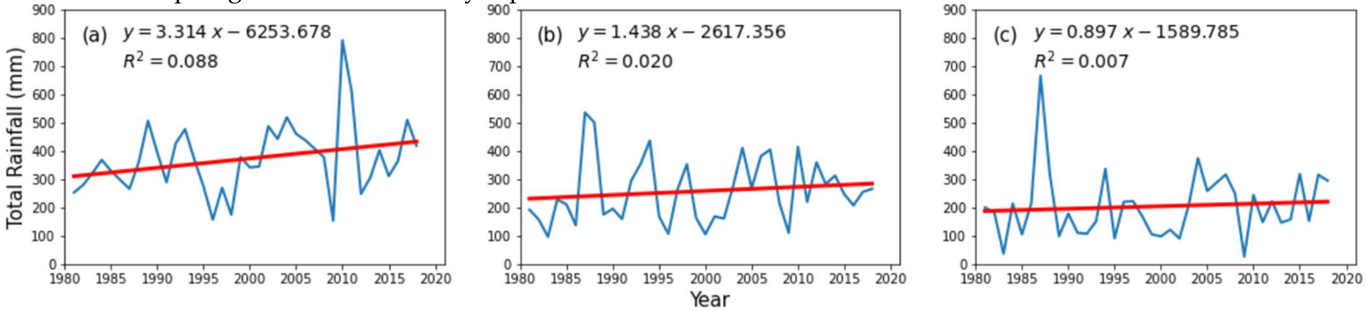

Figure 2: Minor Seasonal Total Rainfall amount over Stations in the West Coast of Ghana (a) Axim (b) Takoradi (c) Saltpond

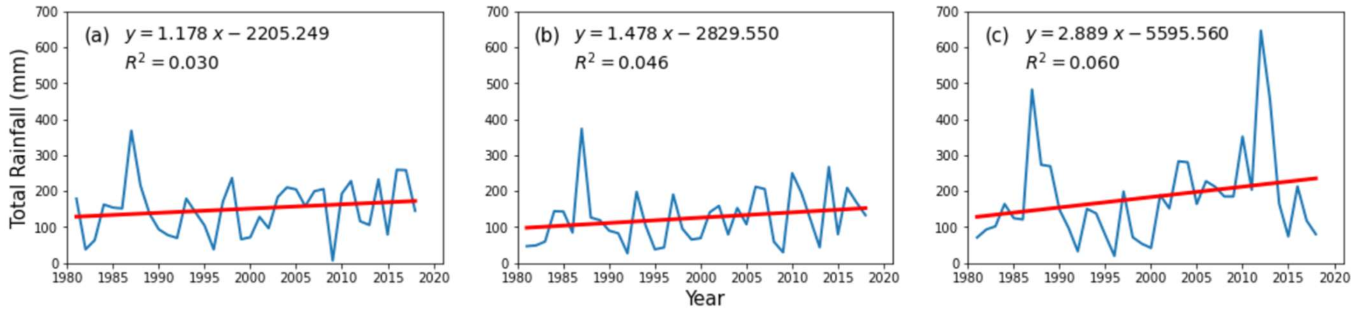

Figure 3: Minor Seasonal Total Rainfall amount over stations in the East Coast of Ghana (a) Accra (b) Tema (c)Ada

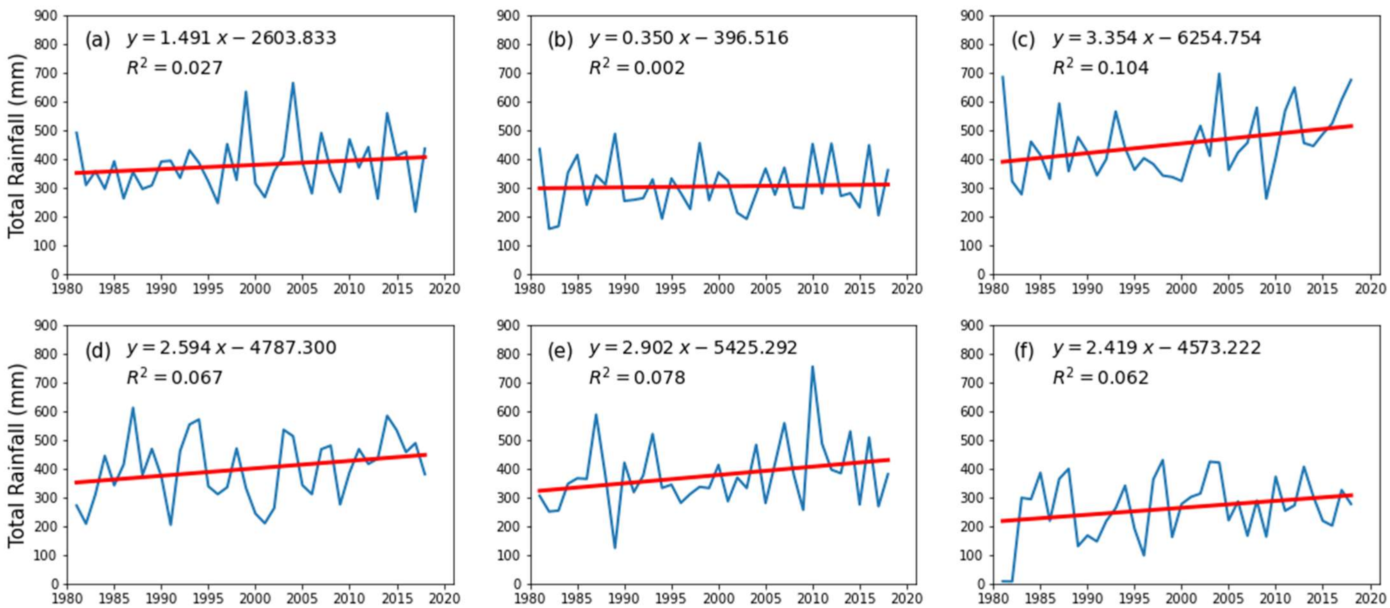

Figure 4: Minor Seasonal Total Rainfall amount over stations in the middle sector of Ghana (a) Ho (b) Akuse (c) Akim Oda (d) Sefwi Bekwai (e) Abetifi (f) Akatsi

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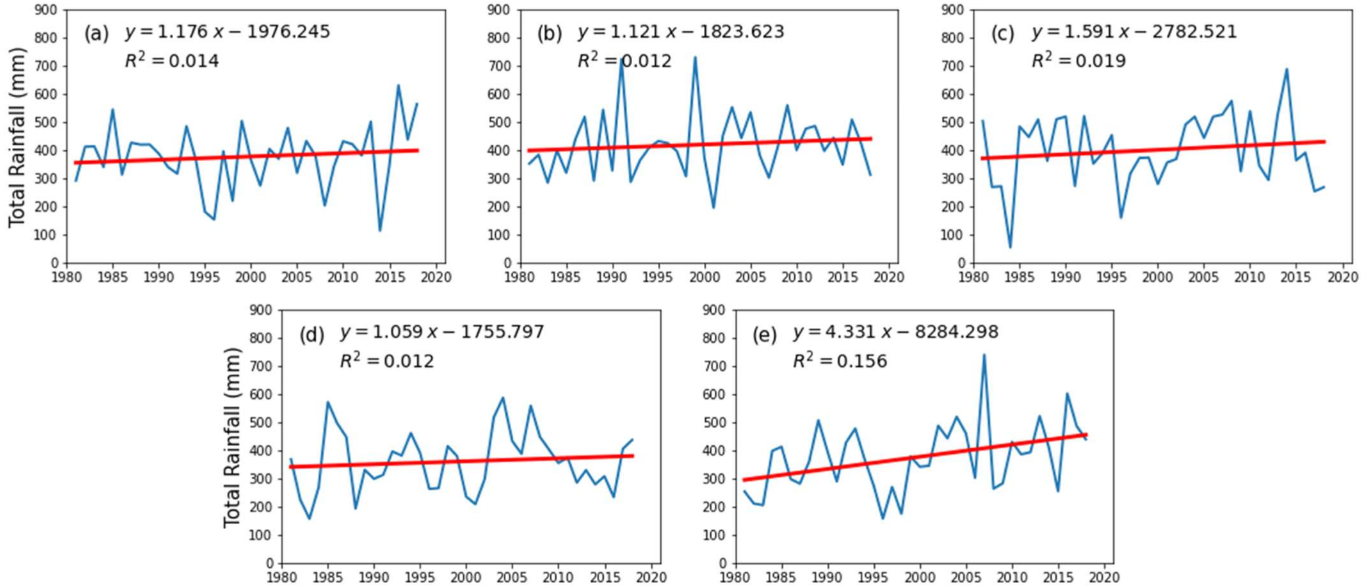

Figure 5: Minor Seasonal Total Rainfall amount over the middle sector (a and e) and Transition Zone (b-d). (a) Koforidua (b) Kete Krachi (c) Wenchi (d) Sunyani (e) Kumasi

Even though some stations show little or no significant slope (E.g., Akuse and Saltpond), many of the rainfall stations have positive slopes which portrays at least a small increasing trend of total rainfall amounts. Giving some highlights of the results of this regression analysis, slopes between 0.097 and 3.314 mm/year, and r-squared value range between 0.7% and 8.8% (Figure 2) are explained by the regression models on rainfall amount for stations situated in the west coast of Ghana. The middle sector has slopes from 0.350 to 4.331 mm/year which are greater than the coast, and up 15.6% variability as explained by the regression models (Figure 3 and 4). Like all other stations, the transition zone stations generate positive slopes and r-squared values as indicated in Figure 5. 16 out of the 17 stations studied show slight increasing trends in the number of rainy days as indicated by positive slopes. Ho is the only station which shows a slight decreasing trend of rain days as explained by the regression model. It is interesting to know that Ho in the middle sector, is located in the Volta region of Ghana where previous study [11] found oscillatory trends rainfall at annual scales. The regression model explains variability of up to 27% in the number of rain days with the middle sector and the western coast exhibiting greater variability (Figure S1, S2, S3 and S4). Result of regression in this work this work coincides clearly with results of most recent study [19] within the study area which found an increasing trend of annual rainfall totals for Accra and Kumasi

3.3 Mann-Kendall's Trend Analysis Results for Total Rainfall Amount and Number of Rain Days

Table 4: Mann Kendall Trend Analysis of Minor Seasonal Total Rainfall

Stations	trend	h	p	z	Tau	s	Var (s)	S Slope
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

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 [46-47]. In general, all the stations showed a positive Sen's Slope (between S Slope= 0.40 and 4.41) for rainfall indicating at least an increasing trend (Table 4). Kumasi and Akim Oda in the middle sector are the only two stations which exhibit a statistically significant trend (p < 0.05), and quite good positive Sen's slope values (S_slope = 4.41 and 4.0). The other stations show p values between p=.060 and p=.820 (p >0.05) which makes the trends statistically non-significant or simply no trend of total rainfall amount. All the stations show either zero or positive values for Z- score, Tau, Mann Kendall parameter (s), Variance of s and this is a good sign of the increasing trend of rainfall amount. Kumasi and Akim Oda in the middles sector are situated in the forest area of Ghana and probably greening of the vegetation is likely to cause this significant increase in rainfall amount during the minor season. With these results, we can say that there is an increasing trend of rainfall amounts over southern Ghana, but this increase is not significant at a 95% confidence limit over most places.

Table 5: Mann Kendall Trend Analysis of Rain Days

Station	trend	h	p	z	Tau	s	Var (s)	S Slope
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

Rain days have Sen's slope between S Slope= 0.000 and 0.333 meaning there is either no trend or increasing trend of rain days (Table 5). Mann Kendall test reveals that 8 out of 17 stations studied show a significant trend whilst the rest of the stations have a non-significant trend of rain days. Mann-Kendall's test results for rain days generate p values less than 0.05 (p=.004 and .025) for 8 stations which means that the trends are significant. Ada, Tema,

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Axim, Koforidua, Akim Oda, Sefwi Bekwai, Kumasi, and Kete Krachi are the stations showing a significant trend of rain days. 2 out of 3 stations over the east coast (Ada and Tema), 1 station in the west coast (Axim), and 4 stations over the middle and transition zone (Koforidua, Akim Oda, Sefwi Bekwai, Kumasi and Kete Krachi) show the significant trend of rain days between the 37-year period. A non-significant trend ($p>0.05$) was found for the other stations (Table 4). All the stations show either zero or positive values for Z- score, Tau, Mann Kendall parameter (s), Variance of s, and the Sens slope except Ho which has negative values of z, Tau, and s for rain days. Mann Kendall test results for Kumasi and Akim Oda in the middle generates a significant increase ($p<0.05$) for rainfall both rainfall amount and rain days. Ada, Tema, Axim, Koforidua, Sefwi Bekwai, and Kete Krachi have a significant increase in rain days and non-significant trends in rainfall amounts. However, Accra, Saltpond, Takoradi, Abetifi, Ho, Akuse, Akatsi, Sunyani, and Wenchi show non-significant trends for both rainfall amounts and rain days. The significant increase in rainfall frequency and non-significant increase in rainfall amounts from 1981 to 2018 over many stations in southern Ghana could be a result of lesser rainfall amounts which are recorded at the beginning of the rainfall season as reported by [12]

3.4 Mann-Kendall's Trend Analysis of Extreme Precipitation

Table 6: Mann Kendall Trend Analysis of Heavy Precipitation Days (R10)

Stations	trend	h	p	z	Tau	S	Var (S)	S Slope
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

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Table 7: Mann Kendall Trend Analysis of Extremely Heavy Precipitation Days (R20)

Stations	trend	h	p	Z	Tau	s	Var S	S Slope
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	0.014	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

Akim Oda is the only station having an increasing trend of R10 (Table 6). Abetifi, Akim Oda,Sefwi Bekwai, and Kumasi located over the middle sector (5.5 °N - 7.0 °N) show significant trends of R 20 (Table 7). The other rainfall stations have no significant trends for R10 and R20 since their p-values are greater than 0.05 ($p > 0.05$). Concerning R95p and from Table 8, we can see that Akatsi, located over the middle sector has increasing trends (($p<0.05$) of very wet days. All the 17 stations studied have no significant trends ($p>0.05$) of extreme wet days (R99p) during the 37-year period (Table S1). R95p and R99p show Sen's Slopes values of zero (0) or p-value greater than 0.05 for rainfall stations which is an indication of no trends.
From the above analysis, 4 stations in the middle sector have increasing trends for R20 and this compliment the trends of rain days which was revealed earlier in this work. It is worth knowing that all these stations in the middle sector are located in forest areas of Ghana, and it is therefore not surprising to find out increasing trends. Therefore, at a confidence level of 95%, we can explain that some areas in the middle sector have experienced significant increase of extreme rain days.

Table 8: Mann Kendall Trend Results for Number of Very Wet Days (R95p)

Station	trend	h	p	Z	Tau	s	Var S	S Slope
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	increasing	True	0.02	2.32	0.102	72	936	0
Akuse	no trend	False	0.719	-0.35	0.017	-12	936	0

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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

It is worth reminding that Kumasi and Akim Oda are the two stations which showed significant increase in rainfall amount and at the same time showing increasing trends of R20. It is therefore not surprising that some areas like Kumasi, Koforidua etc. experienced recent cases of extreme weather events such as floods and hail stones [48-50] It can be observed that stations in the transition zone (7.0 °N - 8.0 °N) is captured with non- increasing trends of R10, R20, R95p and R99p which slightly differs from the findings of [30] which found decreasing trends of wet indices over areas between on the volta lake (7.0 °N - 9.5 °N) on annual scales.

3.5 Standardized Anomaly Index for Minor Seasonal Rainfall Amount

To further understand the recent variabilities, a spatial map of the minor season rainfall standardized anomaly indices for 2014 – 2018 were generated. This 5-year period was used to show whether rainfall recorded in recent years are above or below the long term mean

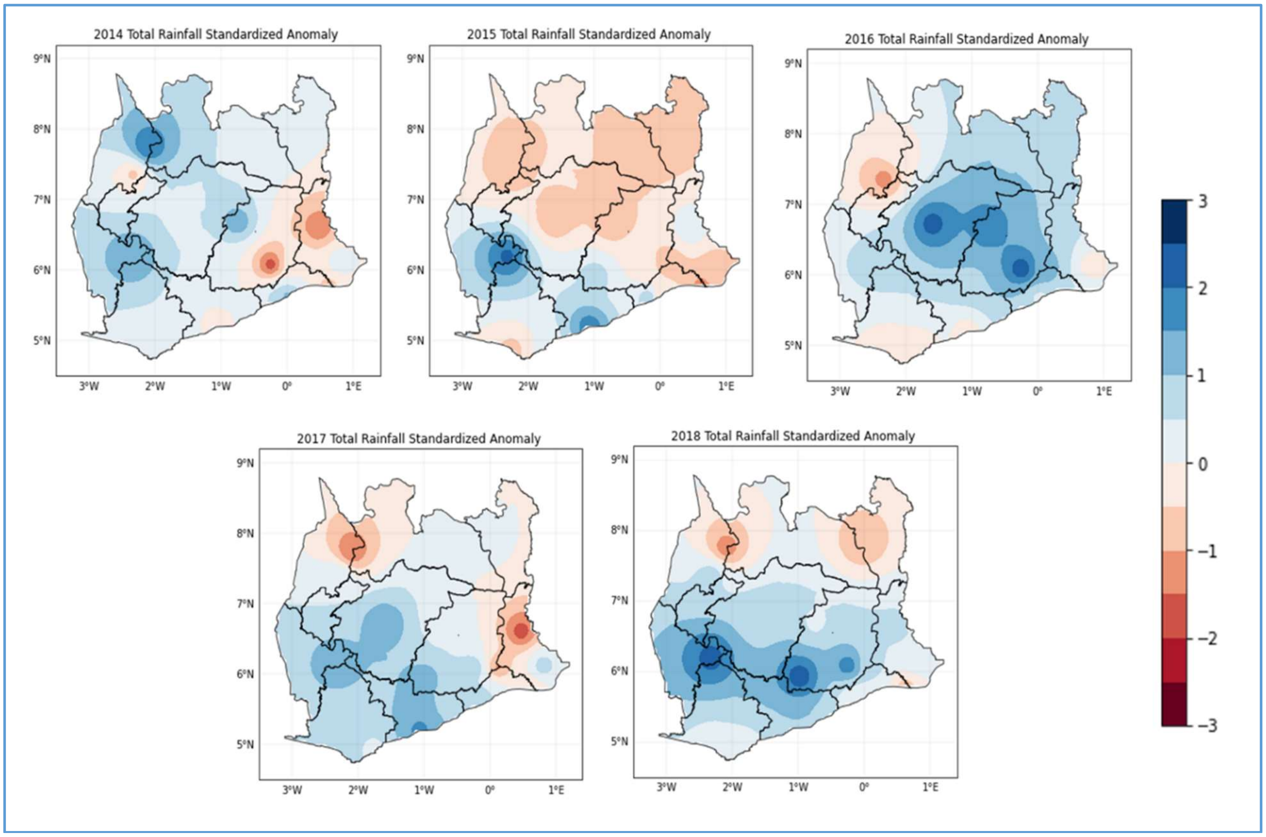

Figure 6: Spatial standardized rainfall anomaly indices for the minor season

In this analysis, the mean standardized index is zero which is the benchmark for comparison. Indices greater than zero are wet and those less than zero are dry. Generally, 2015 stands out as the dry year while 2016 stands out as the wet year. In 2015, Ghana experienced a general decline in rainfall with many areas having SAI less than zero. Notwithstanding the extreme dryness in 2015, few places in the west coast and middle sector (6.5 ° N 2 ° W - 6 ° N 0 °E) were wet with SAI greater than 1.0. In addition to a few areas, 2016 is a wet year over most places with SAI between 1.0 and 3.0 which are extreme high rainfall anomalies. In 2018, the coastal and middle sectors experienced greater improvements in annual rainfall with standardized index between 0.5 and 2.5. Many places located in the transition zone (7.0 °N - 8.0 °N) experienced rainfall deficits in 2015.

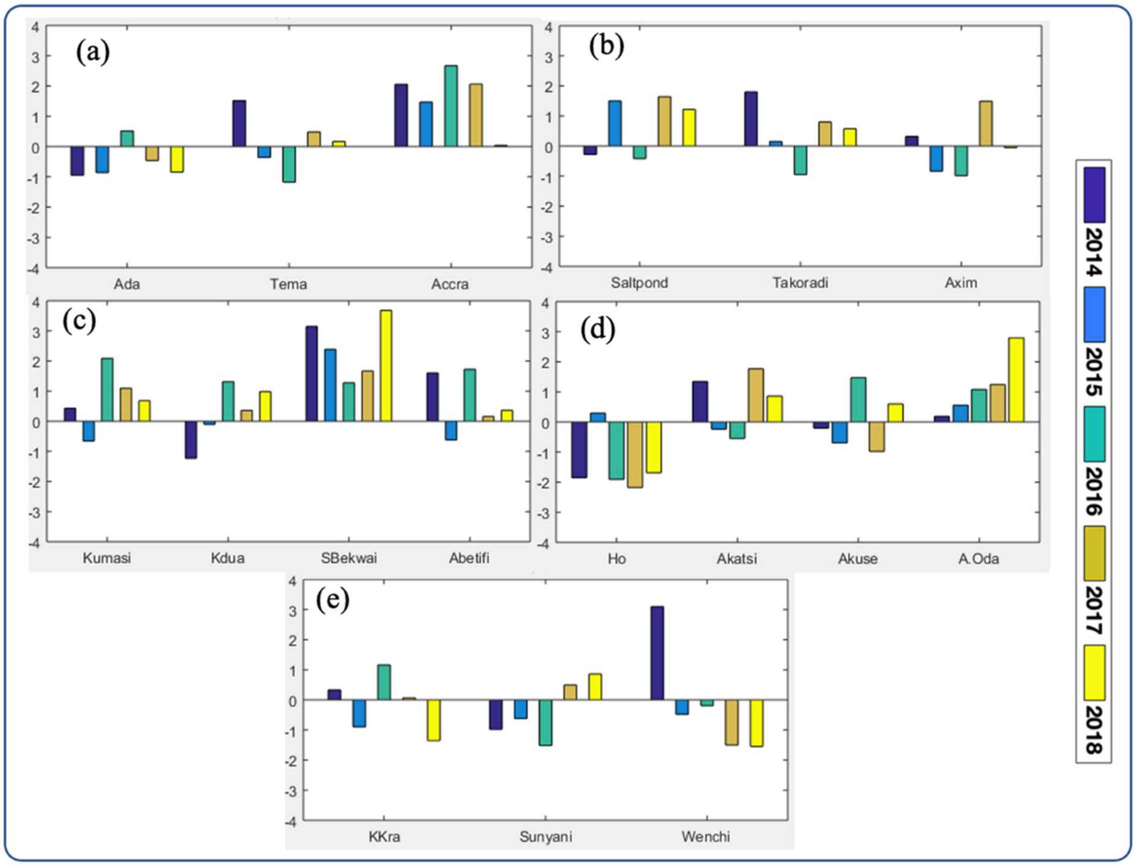

Figure 7: Standardized rainfall anomaly indices for the minor Season. (a) East Coast (b) West Coast (c) Middle Sector (d) Middle Sector (e) Transition Zone

However, it is interesting to see that areas along the coastal strip of Ghana where the capital town is located experienced near- normal rainfall for 2017 . Perhaps climate drivers such as the EL-Nino effect may be the cause of general dryness in 2015 and wetness in 2016. We can therefore deduce that apart from 2015 and 2016, rainfall over the five year period was within normal indices except the transition zone of Ghana which experienced rainfall deficits for the other years.

Now, we continue by looking at specific station SAI for the minor season. Except for Accra which experienced positive rainfall anomalies (SAI >0) for all years, all the stations in the east coast have near-normal rainfall anomalies (-1.0 < SAI < 1.0). Apart from 2016 when the west coast experienced a deficit in all stations, the area experienced wetness in many of the years over all stations and the details can be found in Figure 7 (b). The middle sector shows lots of higher standardized index (0.0 < SAI <3.0) indicating above-average rainfall or wetness for the five year-period. Sefwi Bekwai and Akim Oda in the middle sector were outstanding for higher rainfall anomalies from 2014 to 2018 (Figure 7 (c) and (d)). Ho is the only station in the middle sector with lots of negative SAI (Figure 7(d)) and this makes the station unique in the middle sector. SAI < 0.0 dominates in the transition zone which confirms the poor rainfall performance over the five-year period.

Previous studies [30] reported that annual rainfall extreme indices over areas along the Volta Lake (From 7.0 N Northwards) have decreasing trends of wet indices and the anomaly plots in this work for the transition zone is a clear confirmation. Ho, Akuse, Akatsi, and Kete Krachi are in the Volta region, (0.0 °E - 0.5 °E) and their oscillatory anomalies in the minor seasonal rainfall confirm the findings of [11] which reveals that rainfall trends within all zones of the volta region are oscillatory. Again, throughout this work, we observe the uniqueness of Akim Oda in terms of higher rainfall amounts, higher rain days, increasing R20 and the presence of positive standardized rainfall anomalies.

4. Conclusion

In this study we perform analysis of the minor rainfall season with the aim of finding recent trends and extremes in rainfall. We perform descriptive statistics, and find trends of rainfall amount, rain days, and some extreme indicator Even though variation in rainfall amount and rain days were found to be high, trends of rainfall amounts, and extreme indicators were generally non-significant for the 37 year-period.

The results of descriptive statistics of the area show that rainfall amounts are highest over the middle sector and lowest over the eastern coast. Moderate to an extremely high degree of variation in rainfall amount (between CV=25.3% and 70.8%), and moderate to high variation (between CV=14.0% and 48.8%) in rain days were shown by the coefficient of variation. Information on skewness and kurtosis of rainfall amount and its frequency in the minor season illustrate the existence of a fairly symmetrical data set with the presence of no significant outliers.

Trends of total rainfall amounts and rain days in the minor season from 1981 to 2018 were studied using linear regression and Mann-Kendall's trend test. Apart from Ho which has shown decreasing trends of rain days, linear regression equations show positive slopes for both total rainfall amount and number of rainy days (most of the slopes were very small). Variability in total rainfall amounts between 0.2% and 15.6% for rainfall amount, and between 0.3% and 21.9% were explained by the linear regression analysis (R-square values). Like the regression analysis, positive Sens slopes were generated for rainfall amounts (S Slope= 0.40 -4.41) and rain days (S slope= 0.000-0.333) in all the 17 stations studied and this is a sign of at least an increasing trend.

Even though positive slopes were found in the regression analysis, Mann Kendall test which was conducted at a 95% confidence limit indicated non-significant trends ($p > 0.05$) of total rainfall amounts for 15 out of 17 stations. In terms of rainfall frequency, 7 out of 17 stations generated a statistically significant increase in rain days ($p < 0.05$). Man Kendall test results for Kumasi and Akim Oda in the middle produce significant increasing trends ($p < 0.05$) for rainfall both rainfall amount and rain days. The significant increase in rain days (7 stations) in the minor season over southern Ghana is in line with a previous study conducted over southern West Africa [3] that reported increasing trends of rainfall frequency. Man-kendell tests conducted on wet indices show significant increasing trends of R20 for 4 stations situated over the middle sector. Generally, non-significant trends of R95p and R99p, and R10 were found. The transition zone however, show no trends for all the indices (R10, R20, R95 and R99). Rainfall standardized anomalies which were computed and plotted at spatial and station levels, show that 2015 is a dry year and 2016 is a wet year. The middle sector experienced lots of positive rainfall anomalies over the 5-year period. Anomaly indices generated over the transition zone were comparatively below normal.

From this analysis, it can be deduced that at a significant level of 95%, trends of rainfall amounts, and extreme rain days in the minor season were found to be non-significant for the second rainfall season in many places of southern Ghana. However, some stations over the middle sector experienced significant increasing trends of rain days and R20 during the 37 – year period. If the current trend of increasing rainfall continues in the coming years for the middle sector, the minor rainfall season may experience more frequent rainfall.

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Supplementary Materials

Figure S1: Minor Seasonal Rainy Days over rainfall stations over East Coast of Ghana Accra (b) Tema (c) Ada

Figure S2: Minor Seasonal Rainy Days over rainfall stations in the West Coast of Ghana (a) Axim (b) Takoradi (c) Saltpond

Figure S3: Minor Seasonal Rainy Days over the Middle Sector of Ghana (a) Ho (b) Akuse (c) Akim Oda (d) Sefwi Bekwai (e) Abetifi (f) Akatsi

Figure S4: Minor Seasonal Rainy Days over stations in the Middle Sector (a and e), and the Transition Zone (b-d) of Ghana (a) Koforidua (b) Kete Krachi (c) Wenchi (d) Sunyani (e) Kumasi

Table S1: Mann Kendall Trend Analysis of Extremely Very Wet Days (R99p)

References

1. Ta, S. & Kouadio, Yves & Ali, K. & Toualy, Elisee & Aman, A. & Yoroba, Fidèle. (2016). West Africa Extreme Rainfall Events and Large-Scale Ocean Surface and Atmospheric Conditions in the Tropical Atlantic. Advances in Meteorology. 2016. 1-14. 10.1155/2016/1940456
2. Taylor, C.; Belusic, D.; Guichard, F.; Parker, D.; Vischel, T.; Bock, O.; Harris, P.; Janicot, S.; Klein, C.; Panthou, G. Frequency of extreme Sahelian storms tripled since 1982 in satellite observations. Nature 2017, 544, 475–478.
3. Nkrumah, Francis & Vischel, Theo & Panthou, Gérémy & Ama, Nana & Klutse, Nana Ama Browne & Adukpo, David & Diedhiou, Arona. (2019). Recent Trends in the Daily Rainfall Regime in Southern West Africa. Atmosphere. 10. 10.3390/atmos10120741.
4. J. P. Lhomme, 1981. "Evolution de la pluviométrie annuelle en Côte d'Ivoire au cours des soixante dernières années," La Météorologie, 6, 135–140,
5. E. Mine and J. M. Bocquet, Safety Rehabilitation Works for the Bagré Dam, Colloque CFBR-SHF: Dimensionnement et Fonctionnement des Évacuateurs de Crues, Lyon, France, 2009.
6. Asumadu-Sarkodie, Samuel & Owusu, Phebe & Jayaweera, Herath. (2015). Flood risk management in Ghana: A case study in Accra. Advances in Applied Science Research. 6. 196-201. 10.6084/M9.FIGSHARE. 3381484.V1.
7. Redshaw, P., Boon, D., Campbell, G., Willis, M., Mattai, J.,Free, M., Jordan, C., Kemp, S. J., Morley, A., and Thomas, M. (2019). The 2017 Regent Landslide, Freetown Peninsula, Sierra Leone}, Quarterly Journal of Engineering Geology and Hydrogeology,52(4),435—444.
8. Okyere, C. Y., Yacouba, Y., & Gilgenbach, D. (2013). The problem of annual occurrences of floods in Accra: an integration of hydrological, economic and political perspectives. *Theoretical and Empirical Researches in Urban Management*, *8*(2), 45-79.
9. Tengan, C. & Aigbavboa, C. O. (2016). Addressing Flood Challenges in Ghana: A Case of the Accra Metropolis. *International Conference on Infrastructure Development in Africa (ICIDA-2016). South Africa.*
10. Baidu, Michael & Amekudzi, Leonard & Aryee, Jeffrey & Annor, Thompson. (2017). Assessment of Long-Term Spatio-Temporal Rainfall Variability over Ghana Using Wavelet Analysis. Climate. 5. 30.
11. Nyatuame, Mexoese & Owusu-Gyimah, V. & Ampiaw, F. (2014). Statistical Analysis of Rainfall Trend for Volta Region in Ghana. International Journal of Atmospheric Sciences. 2014. 10.1155/2014/203245
12. Owusu, Kwadwo & Waylen, Peter. (2013). The changing rainy season climatology of mid-Ghana. Theoretical and Applied Climatology **112**, 419–430. https://doi.org/10.1007/s00704-012-0736-5
13. Sanogo, S.; Fink, A.H.; Omotosho, J.A.; Ba, A.; Redl, R.; Ermert, V. Spatio-temporal characteristics of the recent rainfall recovery in West Africa. Int. J. Climatol. 2015, 35, 4589–4605.
14. Kouadio, Yves & Aman, A & Ochou, A & Ali, K & Assamoi, P. (2011). Rainfall Variability Patterns in West Africa: Case of Cote d'Ivoire and Ghana. Journal of Environmental Science and Engineering. 5. 1229-1238.
15. Amekudzi L.K., Yamba E.I., Preko K., Asare E. O., Aryee J., Baidu M., Codjoe S. N.A (2015). Variabilities in Rainfall Onset, Cessation and Length of Rainy Season for the Various Agro-Ecological Zones of Ghana. Climate 3:416-434. doi:10.3390/cli3020416

16. Gbangou, Talardia & Ludwig, Fulco & Slobbe, E. & Greuell, Wouter & Kranjac-Berisavljevic, Gordana. (2020). Rainfall and dry spell occurrence in Ghana: trends and seasonal predictions with a dynamical and a statistical model. Theoretical and Applied Climatology. **141**, 371–387. 10.1007/s00704-020-03212-5.
17. Larbi, I.; Hountondji, F.C.C.; Annor, T.; Agyare, W.A.; Mwangi Gathenya, J.; Amuzu, J. Spatio-Temporal Trend Analysis of Rainfall and Temperature Extremes in the Vea Catchment, Ghana. *Climate* 2018, *6*, 87.
18. Asamoah, Yaw & Ansah-Mensah, Kow. (2020). Temporal Description of Annual Temperature and Rainfall in the Bawku Area of Ghana. Advances in Meteorology. 2020. 1-18. 10.1155/2020/3402178.
19. Ansah, S. & Ahiataku, Maureen & Yorke, C. & Otu-Larbi, F. & Bashiru, Yahaya & Lamptey, P. & Tanu, M.. (2020). Meteorological Analysis of Floods in Ghana. Advances in Meteorology. 2020. 1-14. 10.1155/2020/4230627.
20. Lele, Issa & Lamb, Peter. (2010). Variability of the Intertropical Front (ITF) and Rainfall over the West African Sudan-Sahel Zone. Journal of Climate 23. 3984-4004. 10.1175/2010JCLI3277
21. Parker, D.J. & Diop-Kane, M. (2016). Meteorology of tropical West Africa: The forecasters' handbook. 10.1002/9781118391297
22. Lavaysse, Christophe & Flamant, Cyrille & Janicot, Serge & Parker, Douglas & Lafore, J.-P & Sultan, Benjamin & Pelon, Jacques. (2009). Seasonal evolution of the West African Heat Low: A climatological perspective. Climate Dynamics. 33. 313-330. 10.1007/s00382-009-0553-4.
23. BBC News. (2019). Available Online: https://www.bbc.com/pidgin/tori-50217890 (accessed on 5 June 2021)
24. Flood List. (2020). Available Online: http://floodlist.com/africa/ghana-flash-floods-cause-traffic-chaos-in-accra (accessed on 5 June 2021)
25. Garda World. (2019). Available Online https://www.garda.com/crisis24/news-alerts/278116/ghana-heavy-rain-and-flooding-kill-at-least-28-in-upper-east-region (accessed on 5 June 2021)
26. Stern RD, Denett MD, Garbutt DJ (1981). The start of the rains in West Africa. J Clim1:59 -68
27. (2008) Coefficient of Determination. In: The Concise Encyclopedia of Statistics. Springer, New York, NY. https://doi.org/10.1007/978-0-387-32833-1_62
28. Panda, Arpita & Sahu, Netrananda. (2019). Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. Atmospheric Science Letters. 20. 10.1002/asl.932.
29. Zhang, X.; Alexander, L.; Hegerl, G.C.; Jones, P.; Tank, A.K.; Peterson, T.C.; Trewin, B.; Zwiers, F.W. Indices for monitoring changes in extremes based on daily temperature and precipitation data. *Wiley Interdiscip. Rev. Clim. Chang.* **2011**, *2*, 851–870.
30. Atiah, W.A., Mengistu Tsidu, G., Amekudzi, L.K. *et al.* Trends and interannual variability of extreme rainfall indices over Ghana, West Africa. *Theor Appl Climatol* **140,** 1393–1407 (2020). https://doi.org/10.1007/s00704-020-03114-6
31. Bhatti, A.S.; Wang, G.; Ullah, W.; Ullah, S.; Fiifi Tawia Hagan, D.; Kwesi Nooni, I.; Lou, D.; Ullah, I. Trend in Extreme Precipitation Indices Based on Long Term in Situ Precipitation Records over Pakistan. *Water* **2020**, *12*, 797. https://doi.org/10.3390/w1203079
32. Ibn Musah, A.-A.; Du, J.; Bilaliib Udimal, T.; Abubakari Sadick, M. The Nexus of Weather Extremes to Agriculture Production Indexes and the Future Risk in Ghana. *Climate* **2018**, *6*, 86. https://doi.org/10.3390/cli6040086
33. Kendall, M.G. (1975) Rank Correlation Methods. 4th Edition, Charles Griffin, London.
34. Mann, H.B. (1945) Non-Parametric Test against Trend. Econometrica, 13, 245-259
35. Lacombe, G.; MacCartney, M.; Forkuor, G. Dry climate in Ghana over the period 1960–2005: evidence from resampling-based Man-Kendall test at local and regional levels. Hydrol. Sci. J. 2012, 57, 1594–1602.
36. Hussain, Fiaz & Nabi, Ghulam & Boota, Muhammad. (2015). Rainfall trend analysis by using the mann-kendall test & sen's slope estimates: A case study of district chakwal rain gauge, Barani area, northern Punjab province, Pakistan. 27(4). 3159-3165.
37. Ahmad, Ijaz & Tang, Deshan & Wang, TianFang & Wang, Mei & Wagan, Bakhtawar. (2015). Precipitation Trends over Time Using Mann-Kendall and Spearman's rho Tests in Swat River Basin, Pakistan. Advances in Meteorology. 2015. 1-15. 10.1155/2015/431860.

 doi:10.20944/preprints202108.0150.v1

38. Saini, Atul & Sahu, Netrananda & Kumar, Pankaj & Nayak, Sridhara & Duan, Weili & Avtar, Ram & Behera, Swadhin. (2020). Advanced Rainfall Trend Analysis of 117 Years over West Coast Plain and Hill Agro-Climatic Region of India. Atmosphere. 11. 1-25. 10.3390/atmos11111225.
39. Trend in Standardized Precipitation Index and Standardized anomaly index in context of climate change in southern. Togo. Atmospheric and Climate Sciences. 7. 20. 10.4236/acs.2017.74030
40. Sen, P.K. (1968) Estimates of the Regression Coefficient Based on Kendall's TAU. Journal of the American Statistical Association, 63, 1379-1389. https://doi.org/10.1080/01621459.1968.10480934
41. Theil, H. (1950) A Rank-Invariant Method of Linear and Polynomial Regression Analysis. Nederlandse Akademie Wetenchappen Series A, 53, 386-392.
42. Hussain et al., (2019). pyMannKendall: a python package for non-parametric Mann Kendall family of trend tests. Journal of Open-Source Software, 4(39), 1556, 1. https://doi.org/10.2307/1907187
43. Hair, J., Black, W. C., Babin, B. J. & Anderson, R. E. (2010) Multivariate data analysis (7th ed.). Upper Saddle River, New Jersey: Pearson Educational International. p.61
44. Byrne, B. M. (2010). Structural equation modelling with AMOS: Basic concepts, applications, and programming. New York: Routledge.
45. George, D. & Mallery, M. (2010). SPSS for Windows Step by Step: A Simple Guide and Reference, 17.0 update (10a ed.) Boston: Pearson.
46. Di Leo, G., Sardanelli, F. Statistical significance: *p* value, 0.05 threshold, and applications to radiomics—reasons for a conservative approach. *Eur Radiol Exp* **4,** 18 (2020). https://doi.org/10.1186/s41747-020-0145-y Amrhein V, Greenland S, McShane B (2019) Scientists rise up against statistical significance. Nature 567:305–307 https://doi.org/10.1038/d41586-019-00857-9
47. Dahiru T. P - value, a true test of statistical significance? A cautionary note. *Ann Ib Postgrad Med*. 2008;6(1):21-26. doi:10.4314/aipm. v6i1.64038
48. My Joy Online (2021). Available Online: https://www.myjoyonline.com/icy-kumasi-a-hailstone-joke/ (accessed on 2 August 2021)
49. Modern Ghana (2018). Available Online: https://www.modernghana.com/news/882285/koforidua-flood-submerge-homes.html (accessed on 2 August 2021)
50. Flood List Available Online: https://floodlist.com/africa/ghana-floods-ashanti-june-2021 (accessed on 2 August 2021).