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Variabilities in Rainfall Onset, Cessation and Length of Rainy Season for the Various Agro-Ecological Zones of Ghana

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Abstract: This paper examines the onset and cessation dates of the rainy season over Ghana
using rain gauge data from the Ghana Meteorological Agency (GMet) over the period of
1970–2012. The onset and cessation dates were determined from cumulative curves using
the number of rainy days and rainfall amount. In addition, the inter-annual variability of
the onset and cessation dates for each climatic zone was assessed using wavelet analysis.
A clear distinction between the rainfall characteristics and the length of the rainy season in
the various climatic zones is discussed. The forest and coastal zones in the south had their
rainfall onset from the second and third dekads of March. The onset dates of the transition
zone were from the second dekad of March to the third dekad of April. Late onset, which
starts from the second dekad of April to the first dekad of May, was associated with the
savannah zone. The rainfall cessation dates in the forest zone were in the third dekad of
October to the first dekad of November, and the length of the rainy season was within
225–240 days. The cessation dates of the coastal zone were within the second and third
dekad of October, and the length of rainy season was within 210–220 days. Furthermore, the
transition zone had cessation dates in the second to third dekad of October, and the length

of the rainy season was within 170–225 days. Lastly, the savannah zone had cessation dates within the third dekad of September to the first dekad of October, and the length of rainy season was within 140–180 days. The bias in the rainfall onset, cessation and length of the rainy season was less than 10 days across the entire country, and the root mean square error (RMSE) was in the range of 5–25 days. These findings demonstrate that the onset derived from the cumulative rainfall amount and the rainy days are in consistent agreement. The wavelet power spectrum and its significant peaks showed evidence of variability in the rainfall onset and cessation dates across the country. The coastal and forest zones showed 2–8- and 2–4-year band variability in the onsets and cessations, whereas the onset and cessation variability of the transition and savannah zones were within 2–4 and 4–8 years. This result has adverse effects on rain-fed agricultural practices, disease control, water resource management, socio-economic activities and food security in Ghana.

1. Introduction

The schedule of agricultural activities, right from land preparation, through crop selection and planting, to the time of harvesting for a developing country like Ghana, is rainfall dependent [1–4]. The assessment and prediction of the onset and cessation dates of the rainy season is therefore crucial to the success of agricultural activities in Ghana [5,6]. The variability in the rainy season onset and cessation could pose socio-economic and developmental challenges as they threaten food security and induce poverty [2,4]. This is so because erratic and significant delays in rainfall affect the country's overall production of food and, in particular, cereals (maize, millet, soya bean and rice), which form the main staple food in the country. In addition, rainy season onset and cessation dates affect the transmission of vector-borne diseases, as the life cycle of the disease transmission vectors is sensitive to the variability and changes in temperature and rainfall. For example, the mosquito population is likely to increase rapidly during the warmer humid conditions [7].

The methods for determining rainy season onset and cessation dates fall under two main categories, namely: those taking into account atmospheric dynamics and those based on water balance, such as rainfall distribution or number of rainy days, among others [6]. Several studies (e.g., [8–11]) have employed models that take into account atmospheric dynamics to identify rainy season onset and cessation dates. Researchers, like [12,13], employed a model that used the relationship between rainfall and evapotranspiration to determine the onset and cessation of the rainy season. Others [1,6,14–19] determined the onset and cessation of the rainy season by using rainfall data alone; this method derives onset and cessation dates by calculating the percentage of cumulative mean rainfall.

Studies conducted in semi-arid parts of West Africa indicated that there is a significant relationship between the start of rains and the length of the rainy season [20]; thus, earlier onset most often leads to longer rainy season. This is an indication that the length of the rainy season is more dependent on

the rainfall onset than its cessation [21,22]. Odekunle [19,23] showed that, even at a single synoptic station, the annual variation in the onset dates could be up to 70 days (10 weeks). Therefore, defining the onset date of the rainy season can sometimes be very challenging, as the onset characteristics can vary drastically with isolated showers or heavy rainfall of varying intensity being accompanied by extended dry spells [24].

The problems associated with poor agricultural practices, food security and human health in a developing country like Ghana could be attributed to the high variability in the onset and cessation of the rainy season. The goal of this paper therefore is to determine the dates for rainfall onset and cessation, the length of the rainy season and their variability. The paper is structured as follows: a briefing of the study area and data source is given in Section 2. In Section 3, the methodology employed is given. The results and discussions are presented in Section 4, and finally, conclusions are given in Section 5.

2. Study Area and Data Source

2.1. The Study Area

The climate of Ghana is characterized by dry and wet seasons, a typical tropical monsoonal climate. Rainfall in this region is mainly associated with mesoscale convective systems and controlled by the advection of moisture from the Gulf of Guinea in the low level atmosphere [25]. This system is usually referred to as the West African Monsoon (WAM), and it is driven by the energy and temperature gradient between the Gulf of Guinea and the Sahara. The maritime tropical air mass, which originates from the Atlantic Ocean, is moisture laden and converges with the dry northeast continental tropical air mass, usually along the Inter-Tropical Discontinuity (ITD) [26,27]. Therefore, the spatial pattern of annual rainfall is closely related to the north- and south-ward migration of the ITD, resulting in changes in the rainfall regime from the south to north of the country [28–30]. This gives rise to two rainfall regimes: bi-modal in the south, consisting mainly of coastal and the forest zones, and uni-modal in the northern part of the country, consisting of part of the transition and savannah zones [30].

2.2. Data Source

In this study, rainfall data from 23 Ghana Meteorological Agency (GMet) stations across the four agro-ecological zones of Ghana covering the period of 1970–2012 were used. The locations of these stations across the country are shown in Figure 1.

GMet uses the World Meteorological Organisation (WMO) standards in its rainfall and other weather parameter measurements. However, these measurements may have some minor errors. These error sources include, but are not limited to, evaporation and wetting loss and wind-induced errors. This could lead to problems of data inhomogeneity [31]. Errors due to evaporation and wetting loss were less than 0.45 mm per day. All the rain gauges were wind shielded; hence, wind-induced errors were infinitesimally small.
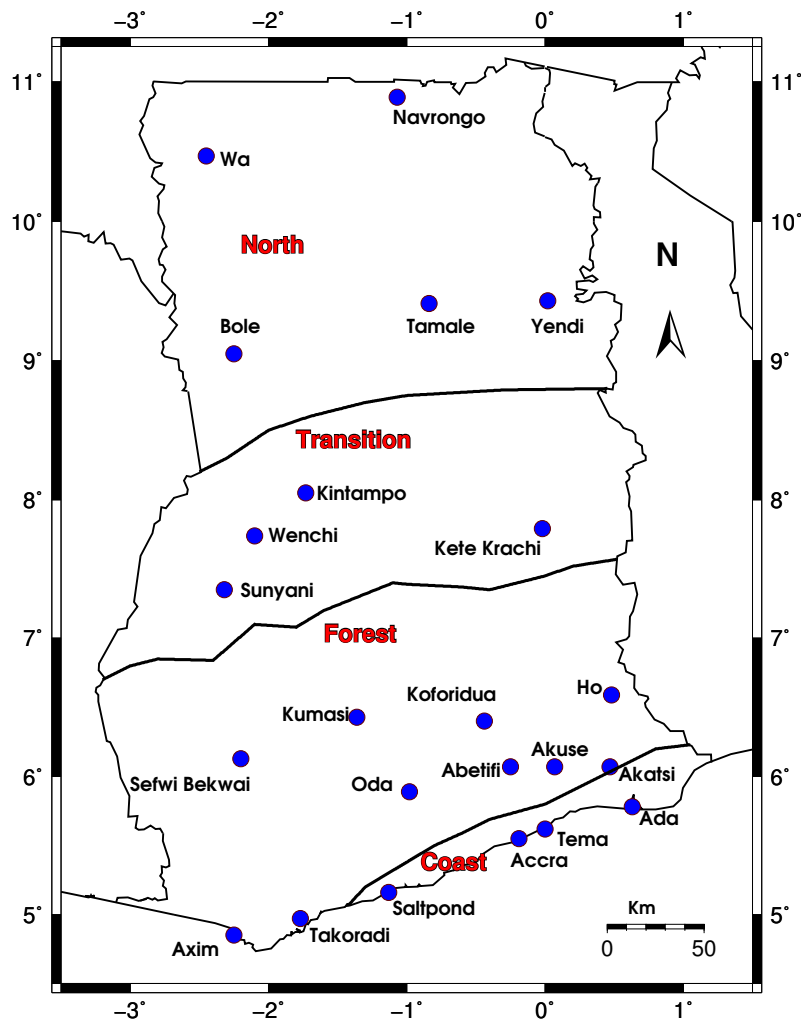
Figure 1. Map of the Ghana Meteorological Agency (GMet) stations covering the four agro-ecological zones of Ghana used for this study.

One of the biggest drawbacks in the long time series record of the meteorological dataset is the availability of data gaps. These data gaps had to be appropriately filled and quality-controlled to provide reliable, continuous and homogeneous reference time series in which divergences are only caused by weather and climate variability [32]. The missing rainfall amount in the data time series was estimated using the inverse distance weighting (IDW) method described in [33]. The rainfall data from the neighboring stations within a distance of less than 50 km were used to estimate the missing data gaps in the reference series using the relation:

$$\hat{R}_p = \sum_{i=1}^{N} w_i R_i \tag{1}$$

and w_i is given by:

$$w_i = \frac{d_i^{-\alpha}}{\sum_{i=1}^{N} d_i^{-\alpha}}, \tag{2}$$

where $\hat{R}_p$ is the missing data in the reference series, R_i is the rainfall value of the neighboring stations, N the total number of the neighboring stations, d_i the distance of each station from the reference station, w_i the weighting of each neighboring station and α the optimal power, which takes values between 0–1.5 and 4–5 [33]. For this study, a power of 5 was employed for the missing rainfall value estimation.

3. Methodology

The rainfall onset and cessation dates, as well as the length of the rainy season were determined by adopting the percentage mean cumulative rainfall and/or the rainy days method(s) described in [23,34,35] (also see the references therein). The method has the advantage of directly using the rainfall data or rainy days, rather than inferring the rainfall amount from other related parameters, making it appropriate for this study. Odekunle [19,23] and Olaniran [15] indicate that at any time and location where the method appeared to be less accurate in the determination of the onset and cessation dates of rainfall, the dry spells involved were very short (mostly less than 5 days), and the frequency of those dry spells was very low. According to [23] (also see the references therein), points of maximum curvature, corresponding to the onset and cessation of rainfall, are expected to be 7%–8% and over 90% of the annual rainfall, respectively.

The following steps were taken to determine the onset and cessation dates: Firstly, the daily mean rainfall amount or rainy days from the entire data record (1970–2012) for each meteorological station are calculated. This was followed by the computation of the mean annual rainfall or rainy days that occurred at each 5-day interval throughout the year. Next, the percentage of that mean annual rainfall and rainy days was computed, as well as their cumulative percentages. The temporal variation of the cumulative percentages for the entire year was then determined. In this method, the mean onset date of rainfall was defined as the first point of maximum positive curvature of the graph; the cessation date of rainfall was defined as the last point of maximum negative curvature and the duration of the rainy season was defined as the difference of the onset and cessation dates of rainfall (length = cessation − onset + 1). Figures 2 provides an example of the cumulative curve for two stations in different agro-ecological zones. The top panel of Figure 2 represents the forest zone, and the bottom panel represents the savannah zone.

The inter-annual variability in the rainfall onset and cessation were determined from the cumulative percentage rainfall for each year. The mode of variability in the onset and cessation was assessed using wavelet analysis described in [36]. The wavelet analysis provides a means to assess the most significant frequencies within the time series. Usually, this is done by making reference of the global power wavelet plot to locate a significant peak that crosses the 95% confidence level. Secondly, the corresponding frequency on the vertical axis of the wavelet power plot is identified as the significant band, where the most significant variability in the onset and cessation are located. A variance of the significant band of the power spectrum is indicated by scale-averaged plots. The dotted line represents the 5% significance level, which allows for identification of periods of late and early onsets and cessations. For this study, the parameters of the wavelet analysis are set as $\delta t = 1$ year, which implies $s_0 = 2$ years, since $s = 2\delta t$, $\delta_j = 0.25$, in order to have 4 sub-octaves per octave. j_1 is calculated as $j_1 = 5/\delta_j$ for 5 powers-of-two with δ_j sub-octaves each.
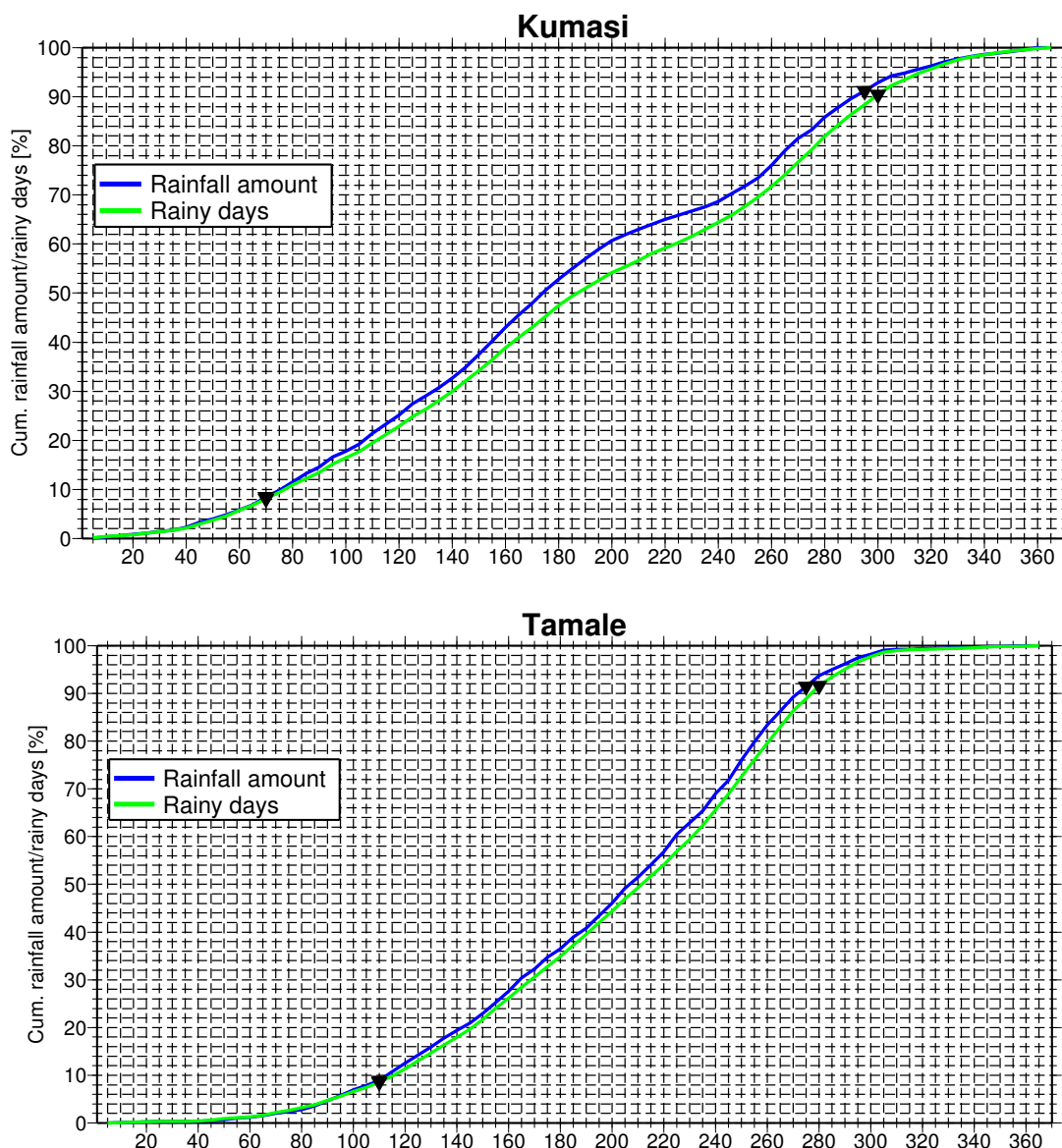
Figure 2. Example of the cumulative curve used to determine rainfall onset, cessation and length of the rainy season; bi-modal rainfall regime (**top**) and uni-modal rainfall regime (**bottom**). Rainy days method (**green**) and the rainfall amount method (**blue**).

4. Results and Discussion

4.1. Onset, Cessation and Length of Rainy Season Climatology

Figure 3 shows the map of the rainfall onset, the cessation and the length of the rainy season using the two different methods, namely: the cumulative rainfall amount and cumulative rainy days. Figure 3a,b indicates the rainfall onset using the rainfall amount and the rainy days, respectively, whereas Figure 3c,d and Figure 3e,f show the cessation and the length of the rainy season derived from the cumulative rainfall amount and cumulative rainy days, respectively.

These results show a clear distinction in the onset from the coastal zone through the forest and transition to the savannah zone, and there are slight differences in some stations for the two methods.

Stations in coastal and forest zones had earlier rainfall onset dates, which are within the second and third dekads of March; whereas the onset dates of the transition zone were variable, starting from second dekad of March in Sunyani through to second dekad of April in Kete Krachi. Late onset were observed in the savannah zone of the country; thus, the onset of this zone was found between the second dekad of April and the first dekad of May. The summary of the onset and cessation days/dates is given in Tables 1 and 2 for all stations within the four agro-ecological zones.
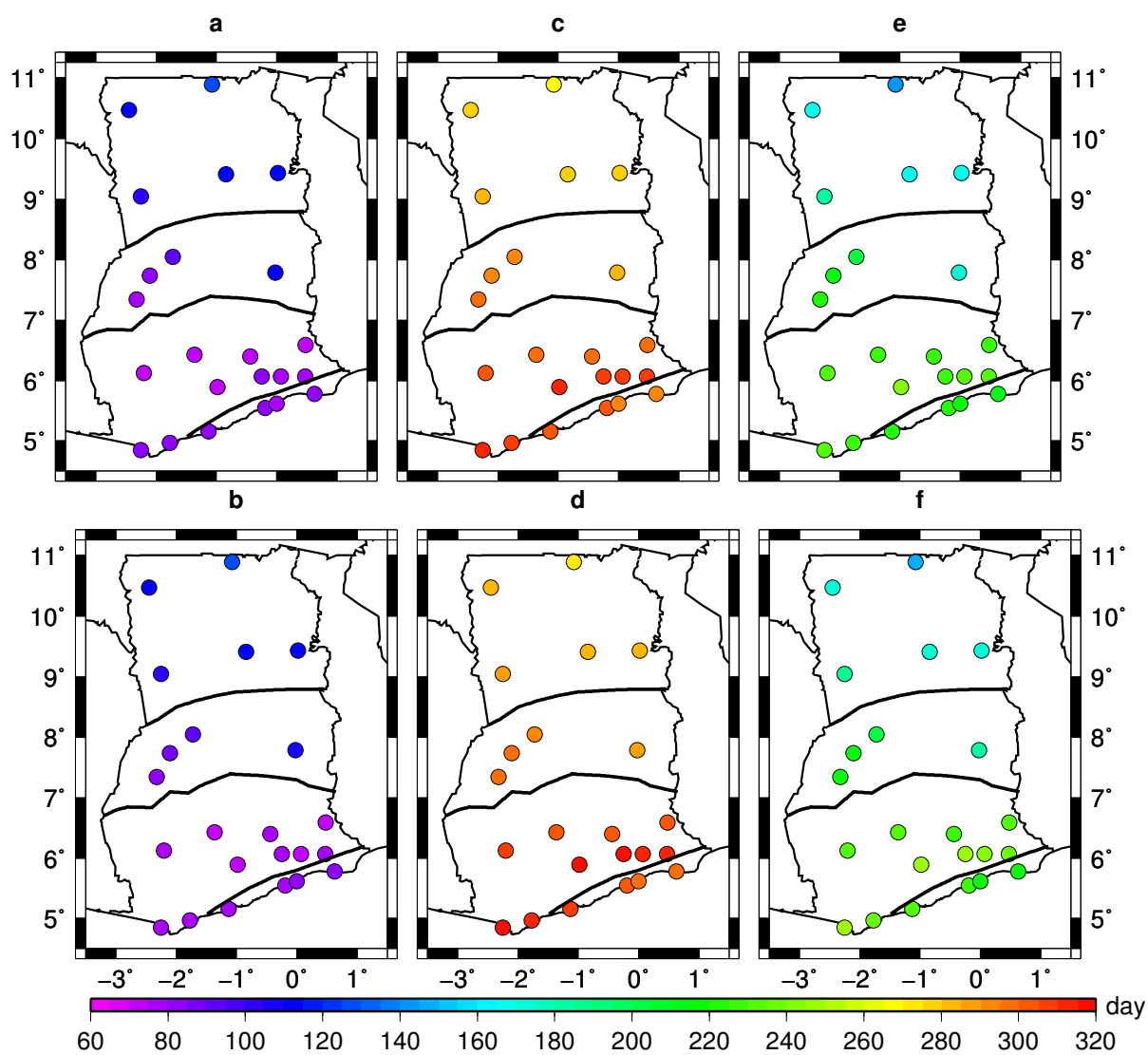

Figure 3. Map of rainfall onset days, cessation days and the length of the rainy season for the 23 GMet stations in Ghana. (**a**) Onset days using rainfall amount; (**b**) onset days using number of rainy days; (**c**) cessation days using rainfall amount; and (**d**) cessation days using number of rainy days. (**e**,**f**) The length of the rainy season using rainfall amount and the number of rainy days, respectively.

Table 1. Summary of rainfall onset days/dates for the GMet stations.

Station	Onset (Rainy Days)		Onset (Rainfall Amount)	
	Days	**Date**	**Days**	**Date**
Sunyani	80 ± 5	21 March	75 ± 5	16 March
Abetifi	75 ± 5	16 March	70 ± 5	11 March
Akuse	70 ± 5	11 March	75 ± 5	21 March
Axim	75 ± 7	16 March	80 ± 7	21 March
Ho	70 ± 5	11 March	70 ± 5	11 March
Koforidua	75 ± 5	16 March	80 ± 5	21 March
Kumasi	70 ± 5	11 March	70 ± 5	11 March
Akim-Oda	70 ± 5	11 March	70 ± 5	11 March
Sefwi Bekwai	75 ± 5	16 March	70 ± 5	11 March
Takoradi	75 ± 7	16 March	80 ± 7	21 March
Accra	75 ± 7	16 March	80 ± 7	21 March
Ada	80 ± 7	21 March	80 ± 7	21 March
Salt pond	75 ± 7	16 March	80 ± 7	21 March
Akatsi	75 ± 5	16 March	75 ± 5	16 March
Bole	100 ± 5	10 April	100 ± 5	10 April
Kete-Krachi	105 ± 5	15 April	110 ± 5	20 April
Navrongo	125 ± 5	5 May	125 ± 5	5 May
Wa	110 ± 5	20 April	110 ± 5	20 April
Wenchi	85 ± 5	26 March	80 ± 5	21 March
Yendi	110 ± 5	20 April	110 ± 5	20 April
Kintampo	90 ± 5	31 March	90 ± 5	31 March
Tema	80 ± 7	21 March	75 ± 7	16 March
Tamale	110 ± 5	20 April	110 ± 5	20 April

Similarly, cessation dates observed were also different for the various agro-ecological zones. Rainfall in the savannah zone, which is uni-modal, had cessation dates much earlier. In particular, the cessation date in Navrongo was found within the third dekad of September. It was observed that the length of the rainy season in the savannah zone (Bole, Yendi, Wa and Tamale) was in the range 165–190 days. A shorter rainy season was observed in the furthest northern station of Navrongo, with a length of about 140–150 days. The cessation dates of the transition zone were within second to third dekads of October, whereas the length of the rainy season in the transition zone (Kintampo, Wenchi and Sunyani) was in the range of 200–225 days. A shorter rainy season of 170 days was observed in Kete-Krachi (see Table 2).

For stations within the forest zone, the cessation date of the rainy season were consistently observed in the third dekad of October to the first dekad of November. The length of the rainy season in the forest zone was within 225–240 days. In the coastal zone, the cessation date was within the second and third dekad of October, while the length of the rainy season was slightly shorter than the forest zone (210–220 days).

Table 2. Summary of the cessation days/dates and the length of the rainy season for the GMet stations.

Station	Cessation (Rainy Days)			Cessation (Rainfall Amount)		
	Days	Date	Length	Day	Date	Length
Sunyani	295 ± 5	22 October	215	295 ± 5	22 October	220
Abetifi	300 ± 5	27 October	225	295 ± 5	22 October	225
Akuse	310 ± 5	6 November	240	305 ± 5	1 November	230
Axim	320 ± 7	16 November	245	310 ± 7	6 November	230
Ho	300 ± 5	27 October	230	295 ± 5	22 October	225
Koforidua	320 ± 5	16 November	245	305 ± 5	1 November	225
Kumasi	300 ± 5	27 October	230	295 ± 5	22 October	225
Akim-Oda	315 ± 5	11 November	245	310 ± 5	6 November	240
Sefwi Bekwai	305 ± 5	1 November	230	300 ± 5	27 October	230
Takoradi	310 ± 7	6 November	235	305 ± 7	1 November	225
Accra	300 ± 7	27 October	225	300 ± 7	27 October	220
Ada	295 ± 7	22 October	215	290 ± 7	17 October	210
Salt pond	305 ± 7	1 November	230	300 ± 7	27 October	220
Akatsi	310 ± 5	6 November	235	305 ± 5	1 November	230
Bole	285 ± 5	12 October	185	280 ± 5	7 October	180
Kete-Krachi	285 ± 5	12 October	180	280 ± 5	7 October	170
Navrongo	270 ± 5	27 September	145	265 ± 5	22 September	140
Wa	280 ± 5	7 October	170	275 ± 5	2 October	165
Wenchi	295 ± 5	22 October	210	290 ± 5	17 October	210
Yendi	280 ± 5	7 October	170	275 ± 5	2 October	165
Kintampo	290 ± 5	17 October	200	290 ± 5	17 October	200
Tema	295 ± 7	22 October	215	290 ± 7	17 October	215
Tamale	280 ± 5	7 October	170	275 ± 5	2 October	165

The bias in the rainfall onset was consistently less than 10 days across the entire country. Similarly, the bias in the cessation and the length of the rainy season is less than 10 days in most of the stations, with the exception of Axim and Abetifi (see Figure 4). The root mean square error (RMSE) was within 5–25 days (see Figure 5). This result demonstrates that the onset derived from the cumulative rainfall amount and the rainy days are in consistent agreement.

4.2. Variability of Onset and Cessation Dates

To assess the mode of interannual variability in the rainfall onset and cessation, wavelet analysis was carried out, and the results are shown in Figures 6–13. In general, there was variability in the onset and cessation dates in all of the agro-ecological zones. Figures 6–13a show the standardized anomaly of the onset and cessation for the four agro-ecological zones. Figures 6–13b show the wavelet power spectrum of the onset and cessation dates. The global wavelet power spectrum is shown in Figures 6–13c, where the dashed line is the 5% significance level for the global wavelet spectrum.
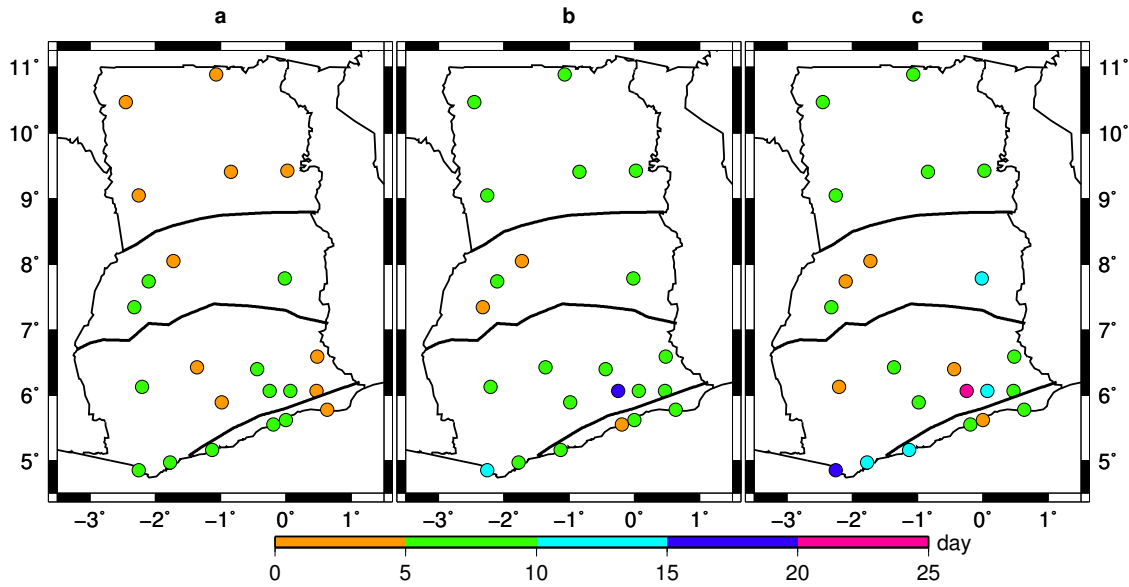
Figure 4. Map showing the bias between number of rainy days and rainfall amount. (**a**) Bias in rainfall onset, (**b**) bias in cessation and (**c**) bias in the length of the rainy season for the 23 GMet stations in Ghana.
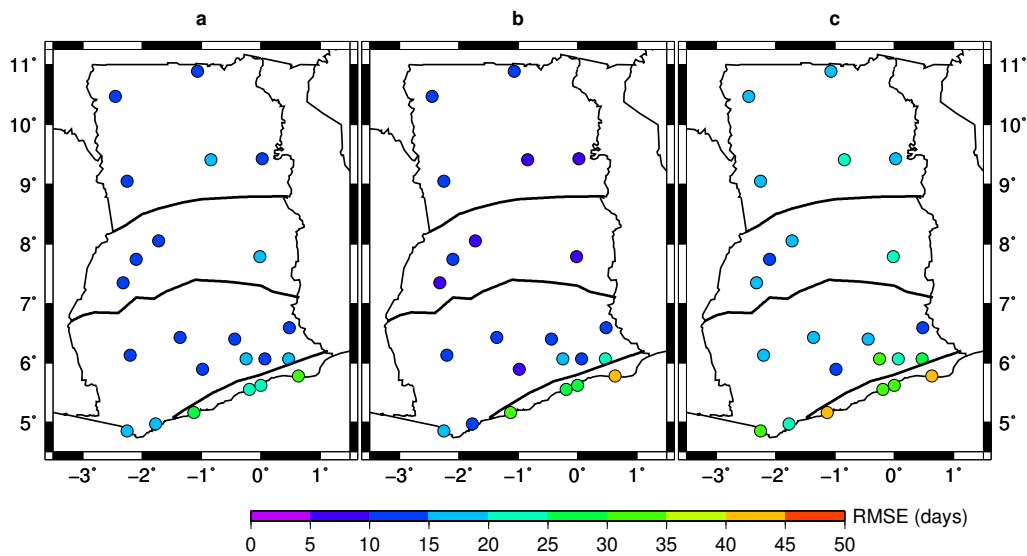

Figure 5. Map showing the RMSE between the number of rainy days and rainfall amount. (**a**) RMSE of rainfall onset, (**b**) RMSE of cessation and (**c**) RMSE of the length of the rainy season for the 23 GMet stations in Ghana.

The savannah and transition zones showed onset variability with the wavelet power spectrum between the 2–4- and 4–8-year scales. This is also shown in the two significant peaks of the global wavelet power spectrum (see Figure 6c and 8c), which is an indication of a strong variability in onset between 2–4 and 4–8 years. Figure 6d and 8d show the variance of the power in the 2–8- and 2–4-year bands for the savannah and transition zones' onset variability, respectively. The early onsets for the Savannah zone are indicated from 1970–1985 and 2003–2010, while late onsets are indicated from 1990–2003. The early onsets for the transition zone are indicated from 1970–1977 and 2007–2012, with late onsets from 1980–1992.
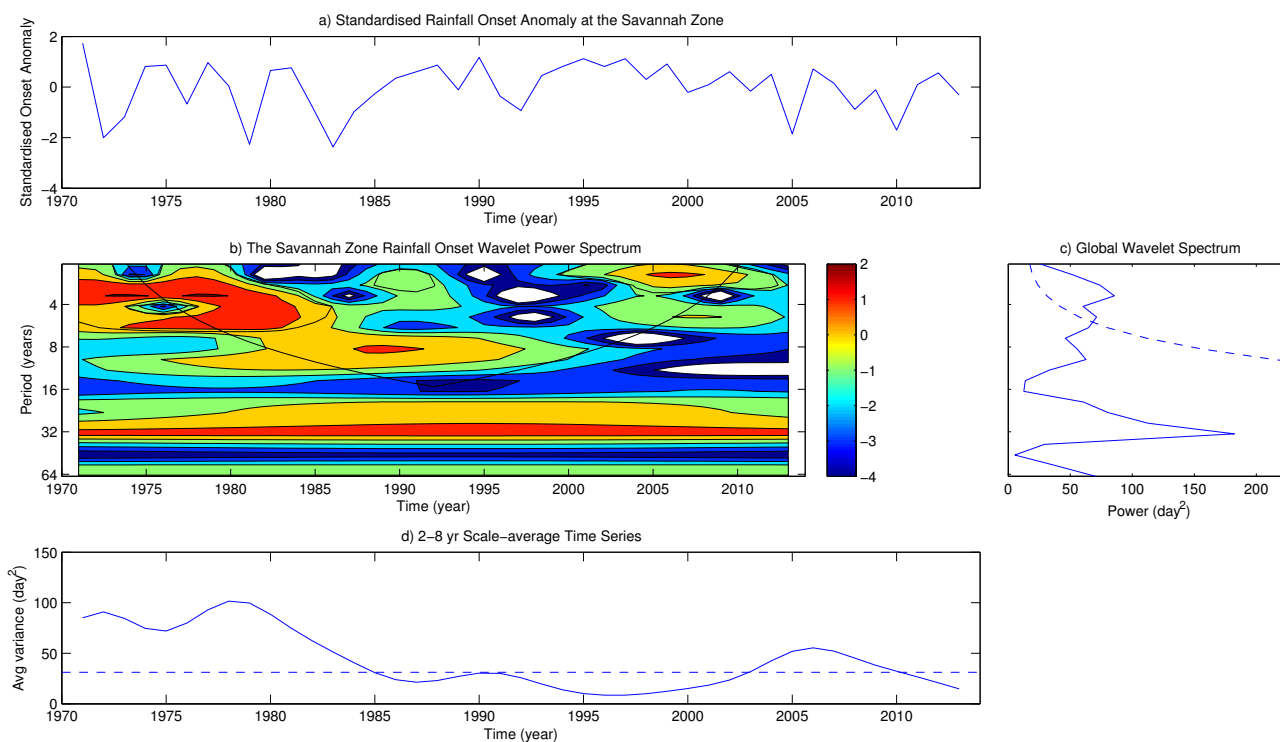
Figure 6. Inter annual variability of rainfall onset dates for the savannah zone using wavelet analysis. (**a**) Standardized anomaly of onset dates; (**b**) wavelet power spectrum; (**c**) the global wavelet power spectrum; the dashed line is the 5% significance level for the global wavelet spectrum; (**d**) the scaled average wavelet power over the 2–8-year band for the onset; the dashed line shows is the 95% confidence level.

The wavelet analyses for the forest and coastal zones are shown in Figures 10 and 12a. From the wavelet power spectrum in Figures 10b and 12b, it can be seen that there is a concentration of power between the 2–4- and 4–8-year bands. These features are also highlighted by the significant peaks shown in Figures 10c and 12c, the global wavelet power spectrum. This further demonstrates that the rainfall onset in the forest zone has variability between 2–4 years and 2–8 years. Figures 10d and 12d show the variance of the power in the 2–8-year band showing late and early onsets. The early onsets of the forest zones are indicated around 1979–1995, while late onsets are indicated around 1970–1978. The early onsets of the coastal zone are indicated from 1986–1993, with late onsets around 1970–1986, 1993–1998 and 2006–2012.

Variability in the cessation for the savannah and transition zones is shown in Figures 7 and 9. The wavelet power spectrum shown in Figures 7b and 9b clearly showed evidence of the concentration of power between the 2–4- and 4–8-year bands. Significant peaks are shown in the global wavelet power spectrum (see Figures 7c and 9c). These results showed that the rainfall onsets in the savannah and transition zones have a strong variation between two and eight years. The variance of the power in the 2–8-year band shows late and early cessations (see Figures 7d and 9d). From Figure 7d, early cessations are indicated around 1972–1988 for the savannah zone. Early onsets for the transition zone are found around 1985–1997, with late cessations from 2005–2012.
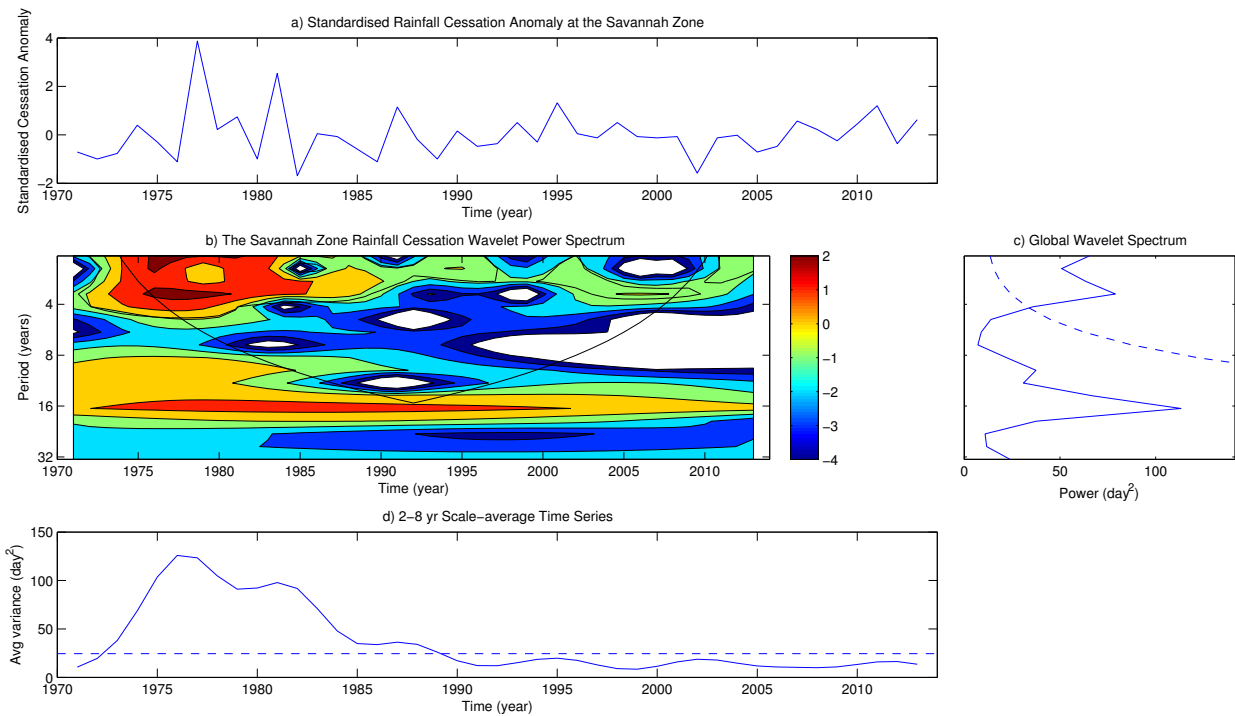
Figure 7. Interannual variability of rainfall cessation dates for the savannah zone using wavelet analysis. (**a**) Standardized anomaly of cessation dates; (**b**) the same as in Figure 6, but for cessation; (**c**) as in Figure 6; (**d**) the same as in Figure 6; the dashed line shows the 95% confidence level.
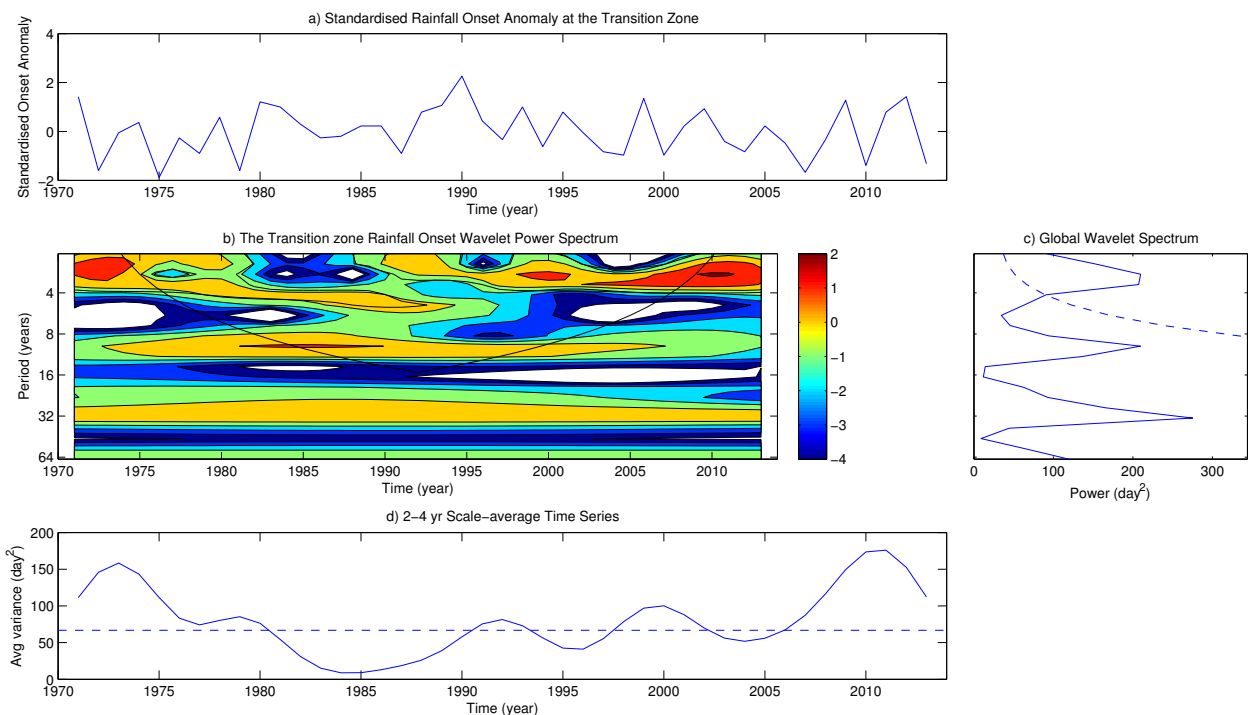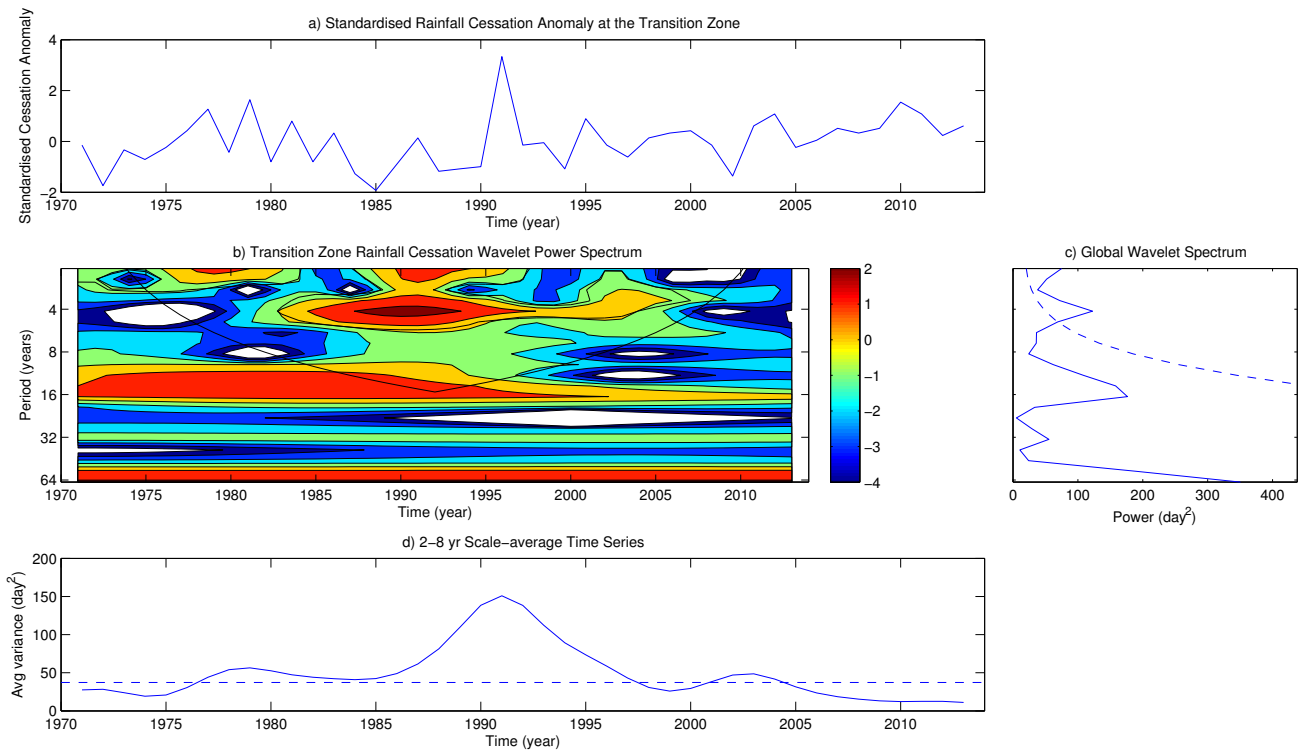

Figure 8. Interannual variability of rainfall onset dates for the transition zone using wavelet analysis. (**a**) Standardized anomaly of onset date; (**b**) as in Figure 6; (**c**) as in Figure 6; (**d**) as in Figure 6; the dashed line shows the 95% confidence level.

Figure 9. Interannual variability of rainfall cessation dates for the transition zone using wavelet analysis. (**a**) Standardized anomaly of cessation; (**b**) as in Figure 6, but for cessation; (**c**) as in Figure 6; (**d**) as in Figure 6; the dashed line shows the 95% confidence level.
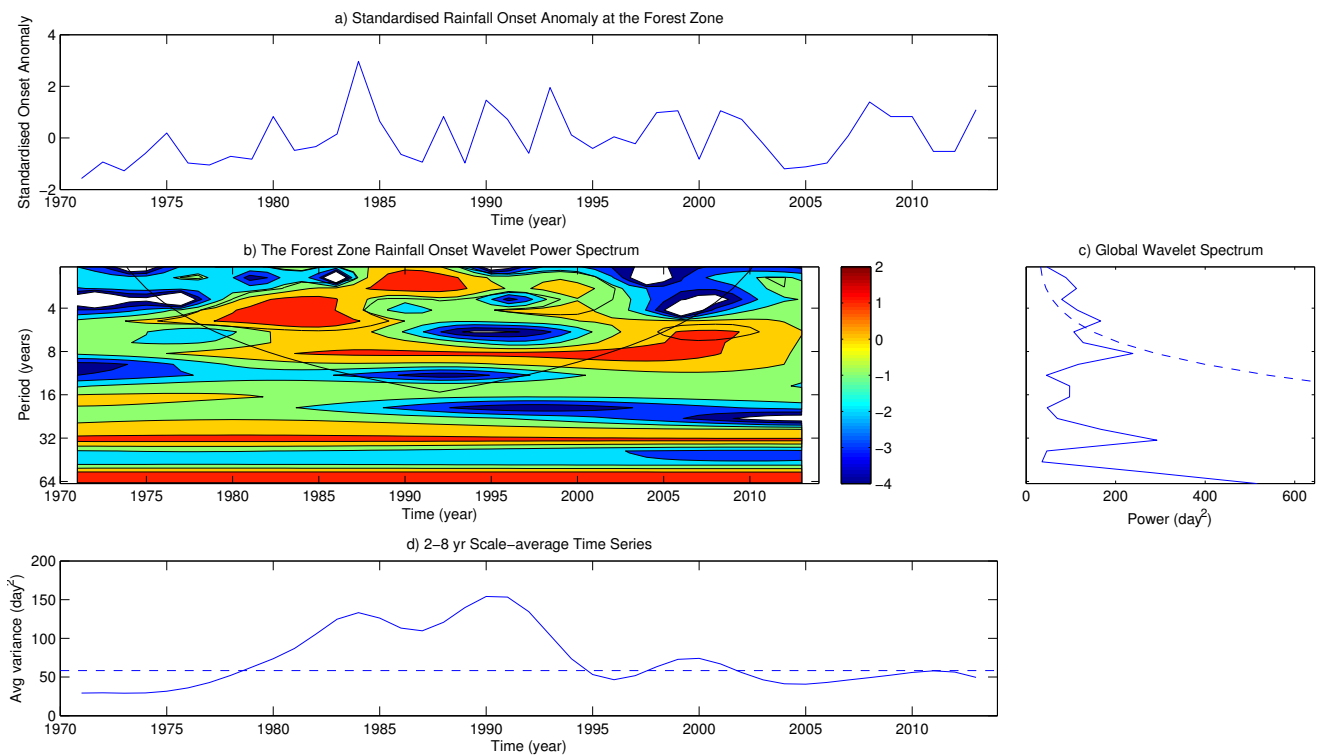

Figure 10. Interannual variability of rainfall onset dates for the forest zone using wavelet analysis. (**a**) Standardized anomaly of onset; (**b**) as in Figure 6; (**c**) the same as in Figure 6; (**d**) as in Figure 6; the dashed line shows the 95% confidence level.
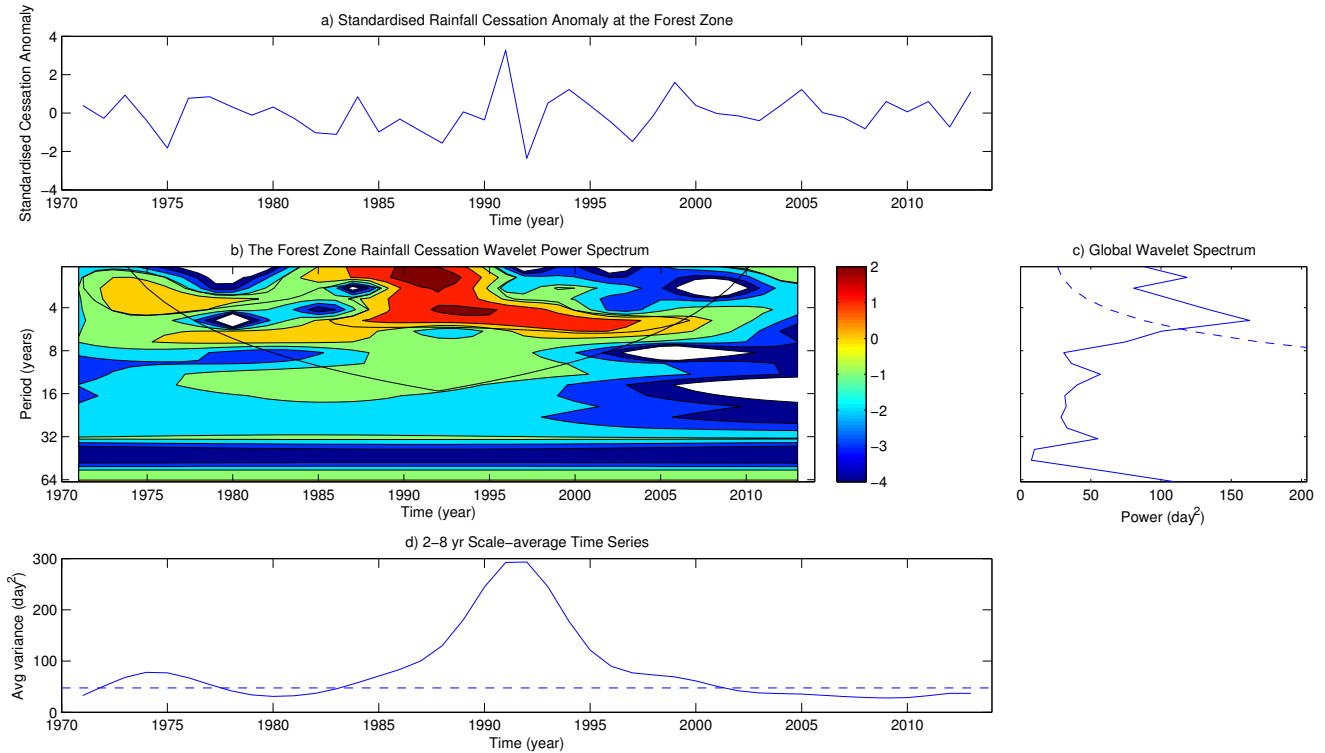
Figure 11. Interannual variability of rainfall cessation dates for the forest zone using wavelet analysis. (**a**) Standardized anomaly of cessation; (**b**) the same as in Figure 6, but for cessation; (**c**) the same as in Figure 6; (**d**) as in Figure 6; the dashed line shows the 95% confidence level.
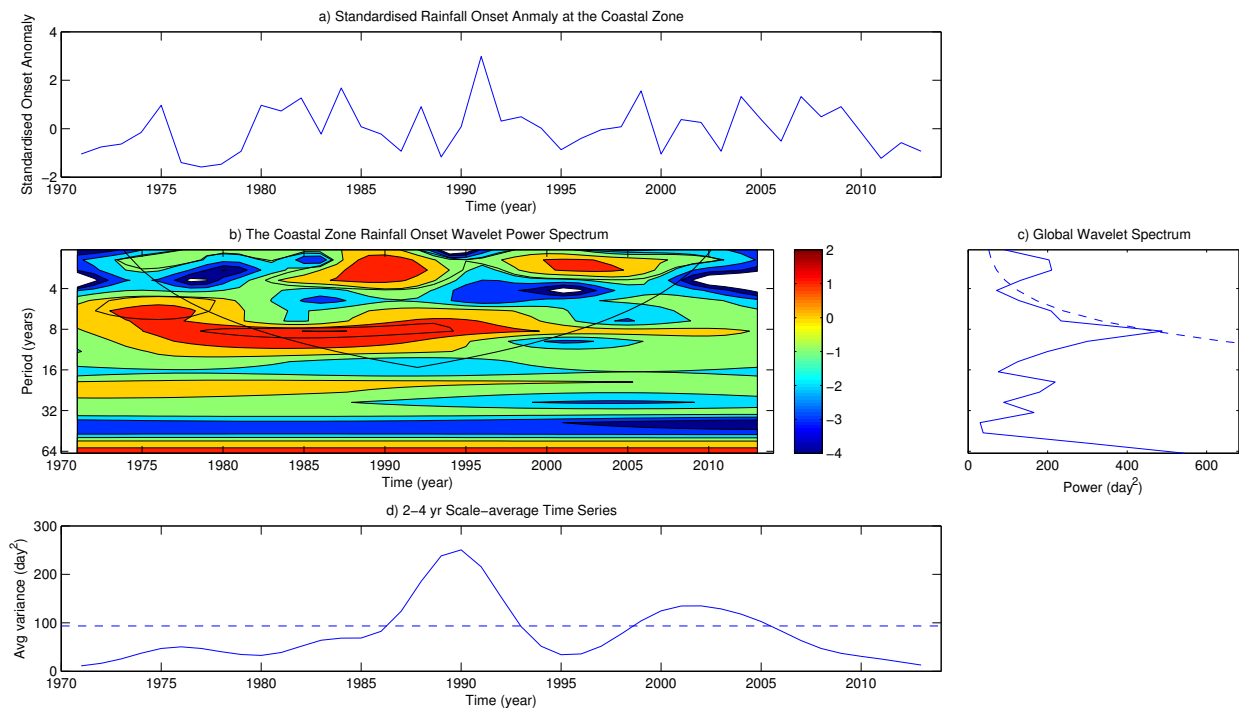

Figure 12. Interannual variability of rainfall onset dates for the coastal zone using wavelet analysis. (**a**) Standardized anomaly of onset; (**b**) as in Figure 6; (**c**) the same as in Figure 6; (**d**) the same as in Figure 6; the dashed line shows the 95% confidence level.
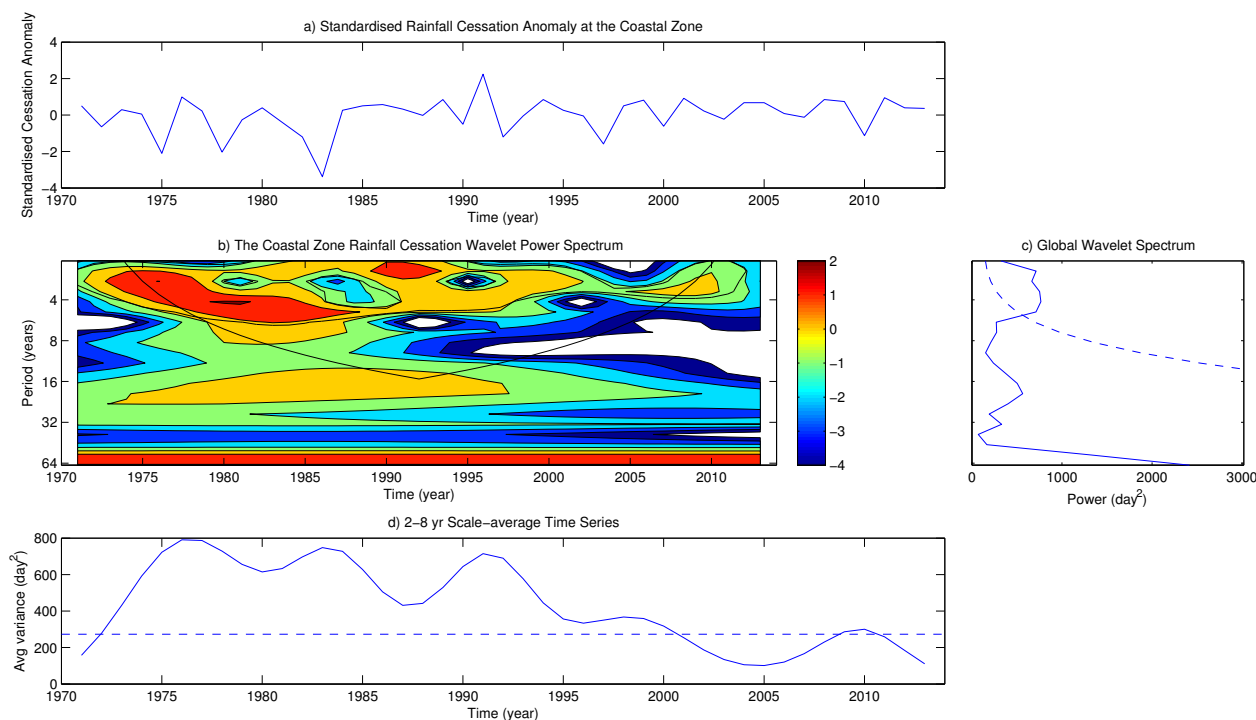
Figure 13. Interannual variability of rainfall cessation dates for the coastal zone using wavelet analysis. (**a**) Standardized anomaly of cessation; (**b**) the same as in Figure 6, but for cessation; (**c**) the same as in Figure 6; (**d**) as in Figure 6; the dashed line shows the 95% confidence level.

The wavelet analyses for the cessation in the forest and coastal zones are shown in Figures 11 and 13. The wavelet power spectrum is shown in Figures 11b and 13b, and the significant peaks of the global wavelet power spectrum are shown in Figures 11c and 13c. It can be seen that there is a strong concentration of power between the 4–8 year band followed by the 2–4 year band. These results show that the rainfall cessation at the forest and coastal zones has strong variation between 2–4 and 4–8 years. The variance of the power in the 2–8-year band showing late and early cessations is shown in Figures 11d and 13d for the forest and coastal zones. The forest zone showed early cessations from 1984–2002. Over the coast, early cessations are observed from 1972–2000, with late cessations from 2001–2008.

5. Conclusions

The rainfall onset and cessation dates, as well as the length of the rainy season over Ghana have been assessed using rain gauge data from GMet covering the period of 1970–2012. Distinct characteristics of the onset, cessation and the length of the rainy season in the various climatic zones in the country were observed. In general, the length of the rainy season decreases from the north of the country to the south and also from the east coast to the west. The longest rainy season of about 240 ± 7 days was found in Axim, and the shortest length of the rainy season of 140 ± 5 days was seen in Navrongo.

In general, rainfall onset occurred from March–May across the country, starting from the west coast through the forest and transition zones to the savannah zone of the country. The rainfall cessation dates

in the forest zone were in the third dekad of October to the first dekad of November, and the length of the rainy season was within 225–240 days. The cessation dates of the coastal zone were within second and third dekad of October, and the length of rainy season was in the range of 210–220 days. Furthermore, the cessation dates of the transition zone were in the second to third dekad of October, and the length of the rainy season was in the range of 170–225 days. Rainfall in the savannah zone had cessation dates within the third dekad of September to the first dekad of October, and the length of the rainy season was within 140–180 days. Biases in the onset, cessation and length of the rainy season were mostly less than 10 days across the entire country, and the root mean square error (RMSE) was in the range of 5–25 days. These findings demonstrate that the onset derived from the cumulative rainfall amount and the rainy days are in consistent agreement.

The wavelet analysis was carried out to assess the inter-annual variability of the onset and cessation for each agro-ecological zone. The wavelet power spectrum, its significant peaks and variances showed evidence of variability in the rainfall onset and cessation dates across the country. The coastal and forest zones showed 2–8- and 2–4-year band variability in the onsets and cessations. Similarly, the transition and the savannah zones showed 2–4- and 4–8-year onset and cessation variability.

These findings support the south to north oscillation of ITD, which modulates the pressure system of West African Monsoon [26,27,37,38]. In addition, local convective activities resulting from the nature of the vegetation and the terrain are known to play a critical role in rainfall onset and cessation [39]. For example, the Togo-Akwapim ranges, which stretch from Togo through to the central part of the forest zone of Ghana, enhance the convective activities of the forest zone, and areas in the windward side of the mountains are strongly affected. This is because, when a moisture-laden airflow encounters a terrain, the air becomes buoyantly unstable and could enhance precipitation, depending on the strength of the cross-barrier component of the upstream airflow, the degree of the thermodynamic stability of the incoming flow and the height of the terrain barrier [39]. Other atmospheric feedback mechanisms, such as the surface feedback, dynamic instability, sea surface temperature (SST) and influence of transient tropical waves [40], could account for the seasonal and the interannual variability in the rainfall onset and cessation of the region. Further study using a dynamic climate model to investigate the contribution of topography, dynamics and thermodynamics processes on the variability of onset and cessation is under consideration. These findings have implications for rain-fed agricultural practices, vector- and water-borne disease control, water resource management, other socio-economic activities and food security in Ghana.

Acknowledgments

Author Contributions

Leonard K. Amekudzi is the first and corresponding author, he conceived, design the study and wrote the manuscript; Edmund I. Yamba and Ernest O. Asare carried out the onset and cessation data analysis; Kwasi Preko supervised the data gap filling, data analysis and proofread the manuscript; Jeffrey Aryee carried out the data gap filling and assisted Michael Baidu in the wavelet analysis; Samuel N. A. Codjoe was the Principal investigator of CCARTCD project and also proofread the manuscript including scientific discussions.

Conflicts of Interest

The authors declare no conflict of interest.

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