ISSN: 2639-7455

Research article

Earth & Environmental Science Research & Reviews

Trends and Periodicities in Rainfall, Temperature, and Relative Humidity Datasets Over Ghana

[a]Francisca Martey and [b]Kofi Anane-Fenin

[a]*Research and Applied Meteorology division Ghana Meteorological Agency, Legon*

[b]*Department of Physics, College of Natural Science, University of Cape Coast*

[*]**Corresponding author**
Francisca Martey, Ghana Meteorological Agency, Legon.

Submitted: 04 March 2021; **Accepted**: 15 March 2021; **Published**: 01 Apr 2021

Citation: *Francisca Martey and Kofi Anane-Fenin (2021) Trends and Periodicities in rainfall, temperature, and relative humidity datasets over Ghana. Eart & Envi Scie Res & Rev, 4: 44-54.*

Abstract

This paper analyzed trends and periodicities in annual and seasonal rainfall, temperature, and relative humidity (RH) over Ghana using climatological datasets for twelve (12) synoptic stations spanning the periods of 30 to 52 years (1961–2010), obtained from the Ghana Meteorological Agency (GMet). The datasets were normalized by dividing with the long time mean, and grouped in decades. Findings show that 1961-1970 and 2001-2010 decades recorded significant wetter years, while 1981-1990 recorded relatively drier years within in the zones with bimodal rainfall seasons. However in the zone with mono-modal rainfall seasons wetter years occurred within the decades of 1981-1990 and 2001-2010. Furthermore, it is realised that, there is a cyclic pattern noted in the rainfall time series and a cycle of about 5 to 8 months for the Northern zone, 6 – 8 month for the middle belt and approximately 8 months for the coastal zone in the rainfall, temperature and humidity datasets suggesting a coherence in their relationship.

Key Words: Rainfall, Climate, Ghana, Periodicity

Introduction

Water resources necessary for human existence are largely dependent on local rainfall, and thus understanding the trend and periodicity of rainfall for a particular region is relevant for a sustainable economy. In Ghana, rainfall is a major source of livelihood [1, 2] and crucial for hydroelectric power—the main source of energy in the country [3]. Thus, for the meteorologist, a major task is to develop objective techniques for forecasting seasonal or annual rainfall amounts vis-à-vis prevailing trends. Furthermore, effective forecasting of rainfall near to accurate mainly relies on the technical knowledge of the cyclic nature of rainfall over Ghana. Probabilities of forecast, analysis of rainfall data and the extent of accuracy in forecast of rainfall for sectoral and stakeholders in Ghana is paramount for planning purposes [4].

A number of studies have analyzed rainfall trends in West Africa, and reportedly identified a general downward tendency conspicuous in the period 1970–2000 [5, 6]. [7] While have shown a similar trend for Ghana in specific for the period 1980-2000 (as compared to 1950-1970), especially significant in the south. Notwithstanding, other studies have equally reported seasonal and local varying results within the same region, thus pointing to the difficulty in effectively analyzing rainfall trends particularly in Ghana, owing to different precipitation regimes coexisting from the coast in the south to the Sahelian region in the north, resulting in a complex spatial climate variability [2]. [3] For example, found that total annual rainfall in the Volta river area generally increased by 5 % but extremely decreased (up to 70 %) in April, while [8]. Observed no significant trends for annual rainfall in the period 1960-2005, but local varying results for spells and onset of the wet season. Meanwhile, the use of different gauges in their studies is a major setback for a fair analysis of the results. Therefore, a detailed seasonal analysis of rainfall variability and trends from quality-controlled gauge data is still needed in Ghana.

In this paper the inter-annual trends and periodicities within the total annual/seasonal rainfall, temperature, and RH datasets in Ghana during the last fifty years (1961–2010) were analyzed, using a quality-controlled network of twelve (12) gauges from the Ghana Meteorological Agency (GMet). The motivation was to identify prominent trends and cycles within the datasets relevant for informed and accurate forecasting.

Methodology

Study area

Ghana is the study area situated on the coastal edge of tropical West African, bounded in latitude 4.5˚N and 11.5˚N and longitude 3.5˚W and 1.5˚E, and characterised by a typical tropical monsoon-al climate system [9, 10]. The country shares boundaries with Cote d'Ivoire, Togo, Burkina Fasso and the Gulf of Guinea in the West, East, North and South of the country respectively, with a total land cover of approximately 240,000 Km2 [11]. Spatio-temporal rainfall variability in the region is mainly regulated by the oscillatory migration of the Inter-Tropical Discontinuity (ITD), accounting for the West African Monsoon (WAM) [8]. [12] Thus, the country is characterised by two main rainfall seasons, the wet and dry. The dominance of the dry North-easterlies in the region brings about the dry season whereas the wet season is as a result of the dominance of South-westerlies in the region [11, 10]. Furthermore, owing to the highly variable spatio-temporal distribution of rainfall and the resulting climatic conditions in different parts of the region, the country is partitioned by the Ghana Meteorological Agency (GMet) into four main agro-ecological zones namely, the Savannah, Transition, Forest and Coastal zones as shown in Figure 1 [10].

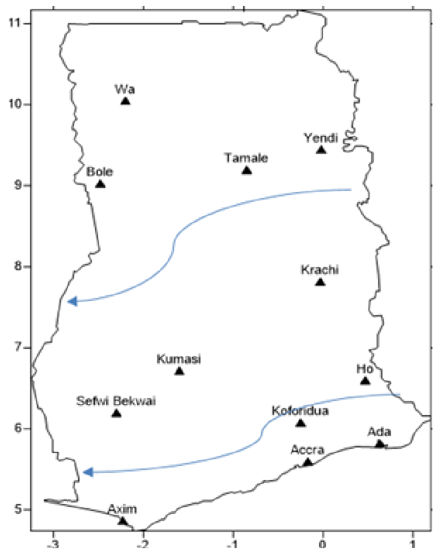


Figure 1: Map of the study area showing the selected 12-gauge stations distributed in the four agro-ecological zones (Savannah, Transition, Forest and Coastal)

Figure 1: Map of the study area showing the selected 12-gauge stations distributed in the four agro-ecological zones (Savannah, Transition, Forest and Coastal)

The Savannah zone covers the largest climatic area approximately, 63% of the total area (see Figure 1), relatively dry with warm temperatures all year round compared to other zones and receives a mean annual rainfall of about 1100 mm. Owing to this peculiar climatic condition of the zone, it is considered a home for dispersed trees and grasses. The dominant food crops well supported and grown in this zone are sorghum, millet and maize [11]. Meanwhile, the Transition zone separates the dry Savannah from the Forest zone (see Figure 1), and thus shares the climate of both zones, thereby known to experience a mixed weather condition. The Transition zone covers approximately 28% of the land surface of the country and receives an annual mean rainfall of about 1300 mm per year, thus supports annual food crops like plantain, peas, corn and others [11, 9]. The Forest zone on the other hand stretches from the east to the Southwestern parts of the country (see Figure 1), characterised by all year-round wetness with a high annual mean rainfall amount of approximately 2200 mm per year. The Coastal zone as shown in Figure 1 has a rainfall type modulated by a sea-land breeze circulation accounting for a mean annual rainfall of about 900 mm and has sandy beaches and thus attracts tourist attention. In effect, the rainfall patterns of the Forest, Coastal and Transition zones are typically bi-modal whereas that of the Savannah zone is mono-modal [9,10].

Data

Daily collage of rainfall, temperature, and humidity datasets from twelve (12) gauges acquired from the Ghana Meteorological Agency (hereafter GMet) were considered for the period of study 1961–2010. These stations have not suffered changes in location and present less than 2 % of missing data in the whole period. Gauges are spread across country and cover the different existing rainfall regimes [2]. To account for this in the next sections, we grouped the fourteen gauges into the same four main agro-ecological zones that have been used in previous studies [7]. Which are homogeneous in terms of rainfall regimes. Gauges forming these zones —referred hereafter to as North, Transition, South and Coast— are marked in Fig. 1 in black, blue, green and red color, respectively.

Synoptic stations were mostly used but stations that did have missing data was filled up with nearest stations. Rainfall data was used to do line graphs, time series and normal distributions. Temperature data which were no full and had gaps were filled with data from nearby stations. Wenchi was used to fill up the gaps in Bole, Salaga was used to fill up Tamale, Ejura was used for Kumasi, Tarkwa was used for Axim and Akim Oda for Sefwi Bekwai

Fourier Series Evaluation

It is possible to form any function f(x) as a summation of a series of sine and cosine, terms of increasing frequency. Also any space or time varying data can be transformed into a different domain called frequency space, which offers some attractive advantages like making large filtering operations much faster, collects information together in different ways and allows measurements that would be very difficult in spatial domain [13].

For f(x) representing the continuous function of a real variable (x), for example rainfall, varying with time (t), the Fourier transform f(t) is defined as:

$$\left(F(u)\right) = \int_{-\infty}^{\infty} f(t)e^{i2\pi t}dt$$

Where u is the frequency variable and F(u) is the data in the frequency space. Given F(u) we can go backwards and get f(t) by using inverse Fourier:

$$\left(f(t)\right) = \int_{-\infty}^{\infty} f(u)e^{i2\pi t}dt$$

Representing the exponential in terms of sine and cosine,

$$\left(f(t)\right) = \int_{-\infty}^{\infty} f(u)e^{i2\pi t}dt$$

And considering the Euler's formula:

$$e^{i\theta t}=\cos\theta+i\sin\theta \qquad (4)$$

$$e^{i\theta t} = \cos\theta - i \sin\theta \quad (5)$$

Equation 1 and 2 are called the Fourier transform pairs, and they exist if f(t) is continuous and integrable and F(u) is also integrable, these conditions are usually satisfied in practice [12].

Results and Discussion

Mean Rainfall Variabilities

The monthly mean total rainfall variabilities for different decades over the entire study area for the individual stations distributed within the four climatic zones depicted in figure 2 is discussed in this section. In a brief, the general rainfall pattern depicted in figures 2 - 5 show that the lower southern half stations located in the Coastal and Forest climatic zones show a typical bimodal rainfall type and thus has the highest rainfall season occurring mainly in June and the minor season peaking in October as also observed by [14] and [15]. While the upper northern half stations in the Transition and Savannah climatic zones show a typical mono-modal rainfall type peaking generally in the month of September agreeing with [16]. The datasets thus agrees with the characteristic West African Monsoon (WAM) regulated by the Inter-Tropical Discontinuity (ITD) mentioned by other studies in section 2.1

Mean rainfall variabilities over the Savannah

As indicated in section 3.1, figure 2 shows the monthly mean rainfall for the Savannah climatic zone at Wa, Bole, Tamale, and Yendi in sequence. All four stations follow the mono-modal rainfall type typical of the prevailing climate. The rainfall at Wa (figure 2a) starts from April and peaks in September ending in November. The decade with the highest rainfall is was 1981-1990, followed by 1961-1971, 1991-2000 and finally 1971-1980.

Again, the rainfall at Bole (figure 2b) follows a similar pattern commencing in April and peaks in September ending in November 1961-1970, with 1981-1990 and 1991-2000 showing the wettest decades followed by 2001-2010 and then 1971-1980.

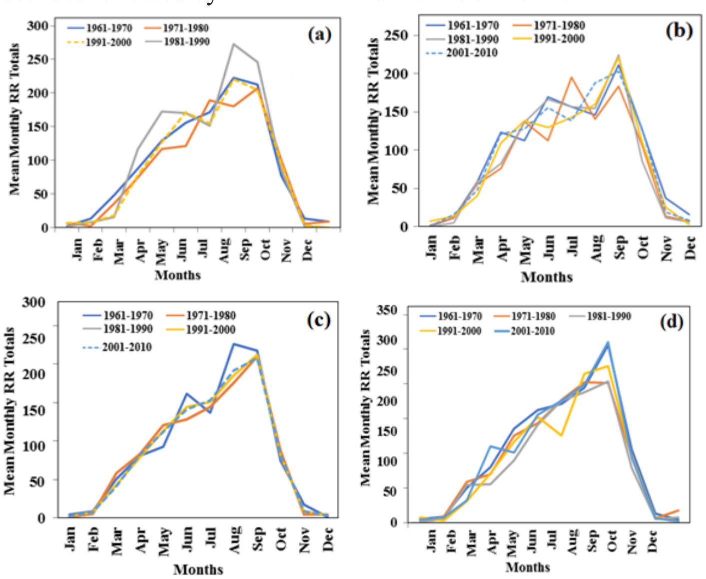


Figure 2: Monthly mean rainfall variabilities over the Savannah climatic zone in the past five decades at (a) Wa (b) Bole (c) Tamale (d) Yendi

The rainfall at Tamale (Figure 2c) starts from April and peaks in September ending in November. The data at this stations shows that, apart from 1981-1990 which is the highest decade of rainfall values, all the other decades measured almost the same rainfall amount and totals. Finally, at Yendi (figure 2d), rainfall begins from April ending in October. Yendi (Figure 8) rainfall values showed that 1961-1970 and 2001-2010 had equal rainfall values followed by 1991-2000, 1981-1990 and finally 1971-1980. Have also reported similar decadal variability trends [7].

Mean rainfall variabilities over the Transition zone

Figure 3 shows the rainfall variability for a Transition climatic zone at Kete-Krachi station. The pattern shows a similar mono-modal rainfall regime as with the Savannah zone, peaking in September. 1981-1990 was the decade with the highest rainfall values followed by 2001-2010, then 1991-200 and then 1971 -1980.

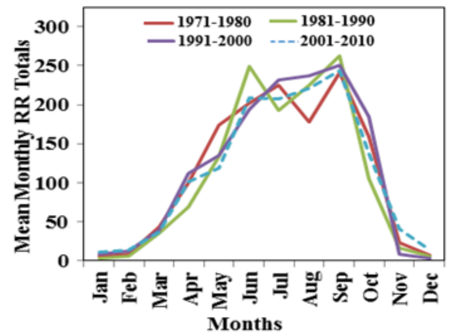
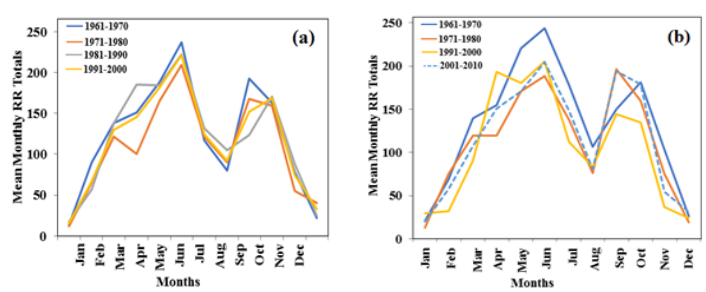


Figure 3: Monthly mean rainfall variabilities over the Transition climatic zone in the past five decades at Kete Krachi

Mean Rainfall Variabilities Over the Forest Zone

Figure 4 shows the monthly mean rainfall variabilities over the Forest climatic zone in the past five decades at Sefwi Bekwai, Kumasi, Koforidua, Ho, and Axim. Typical of the Forest zone, all the stations in this zone show two main rainfall seasons, generally a major one in the early half of the year and a minor one in the latter half of the year as also indicated by [14]. However, it is worth mentioning that, the commencement date varies for both seasons at each station; the major rainfall seasons for Sefwi Bekwai (figure 4a) and Ho (figure 4d) occurs mainly between March-June, when for Kumasi (figure 4b), Koforidua (figure 4c), and Axim (figure 4e) occurs mainly between February-June.



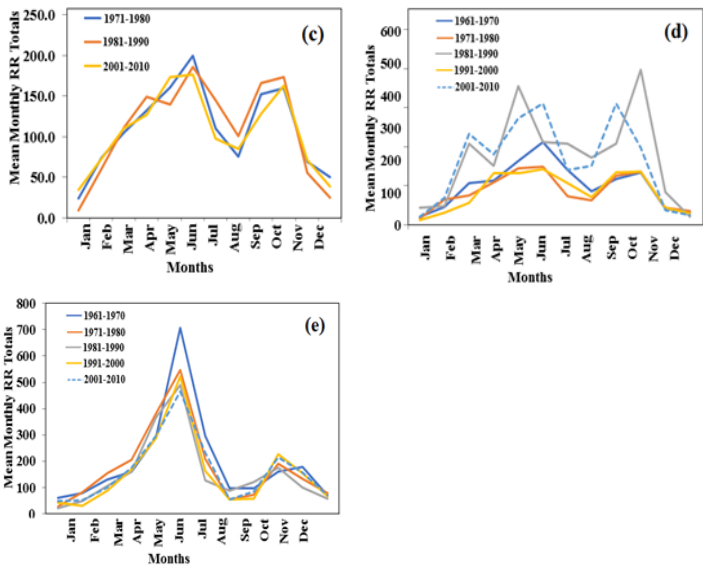


Figure 4: Monthly mean rainfall variabilities over the Forest climatic zone in the past five decades at (a)Sefwi Bekwai (b) Kumasi (c) Koforidua (d) Ho and (e) Axim

Meanwhile, the minor rainfall seasons is between September-November for Sefwi Bekwai (figure 4a), Kumasi (figure 4b), and Ho (figure 4d), and between August-November for Koforidua (figure 4c) and Axim (figure 4e). Furthermore, the monthly mean decadal variation for Sefwi Bekwai (figure 4a) follows the order 1971-1980 > 2000-2001 > 1991-2000 > 1981-1990. For Kumasi (figure 4b) 1961-1970 > 2001-2010 > 1991-2000 > 1971-1980, although the minor season in 1980 was higher than 2001.

For Koforidua (figure 4c), 1971-1980 had the highest rainfall peak in the major rainfall season but the lower minor rainfall season compared to 1981-1990. Meanwhile, 2001-2010 had the least decadal rainfall season. Again, for Ho (figure 4d), 1981 to 1990 had the highest decadal rainfall amount followed by 1961-1970, whilst 1971-1980, 1991-2000 and 2001-2010 had almost the same rainfall amount together. And finally for Axim (figure 4e), the decadal rainfall amounts follow the peak order 1971-1980 > 1991-2000 > 1981-1990 > 2001-2010.

Mean Rainfall Variabilities Over the Coastal Zone

Figure 5 shows the monthly mean rainfall variabilities over the Coastal climatic zone for the past five decades at Accra and Ada. As with the Forest climatic zone, the rainfall type here is bimodal showing two main rainfall seasons, a major one in the early half of the year and a minor one in the latter half of the year.

The total monthly mean rainfall datasets together with selected literature confirm this regime [17,14]. For both stations, Accra (Figure 5a) and Ada (figure 5b), the first and major rains commences from February through to June whilst the second minor season commences from August through to November, while the cumulative decadal rainfall for both show the highest rainfall recorded during 1961-1970, followed by 1971-1980, 2001-2010, 1991-2000 and then 1981-1990.

As realised from the above discussions, there exist a periodicity in the rainfall regime over the study area which can be analysed in order to established safe guidelines for accurate rainfall forecasting.

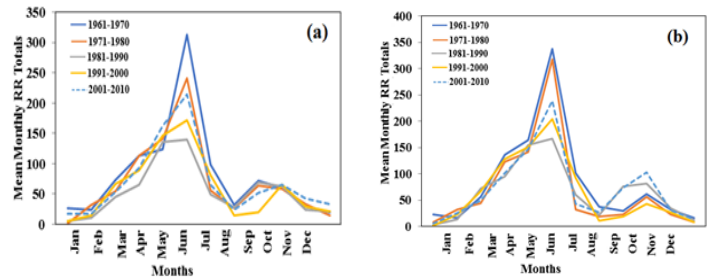


Figure 5: Monthly mean rainfall variabilities over the Coastal climatic zone in the past five decades at (a) Accra (b) Ada

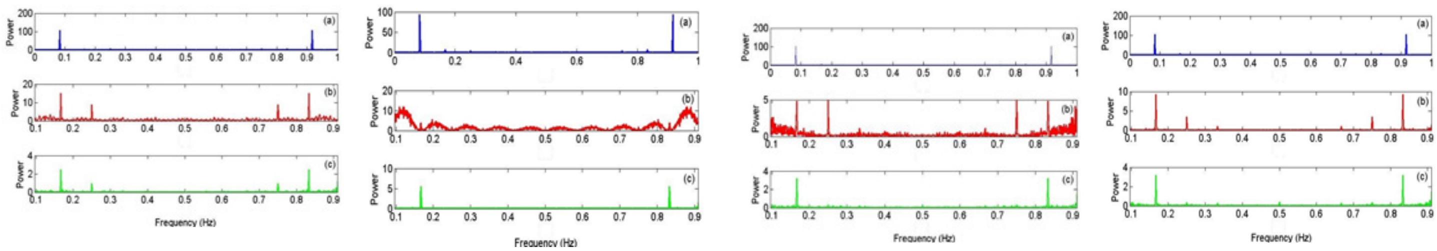
Rainfall Periodograms

This section discusses the variabilities in the rainfall datasets using periodogram technique to show the periods responsible for the variable pattern within the rainfall data as well as establish technical guidelines to forecast accurate rainfall over the region.

Savannah Climatic zone Periodogram

Figure 6 shows the periodogram for the Savannah Climatic zone of the study area for rainfall, temperature, and RH for Wa, Bole, Tamale, and Yendi. As seen from tables 1 and 2, the first, second, and third harmonics for Wa are 0.07324, 0.06934, 0.06641, 0.05469 and 0.04688 cycles, with respective periodicities of 1.1, 1.2, 1.3. 1.5 and 1.8 years and respective percent variance as 36.07%, 14.78%, 11.57%. Apparently, the dominant cycle of rainfall series at Wa for the 36.07% variance shows periodicity of 1.1 years, indicating a repeating cycle of approximately every year and associated with highest amount of rainfall. Again, the second dominant cycle of rainfall series in the area with 14.78% variance could also indicate a repeating cycle of every 1.2 years which is roughly every 6 months with the second highest rainfall. Finally, the third dominant cycle of rainfall series in the area with 11.57% of variance (%V) is shows periodicity of three times every 1.8 years, which indicate a repeating cycle of approximately 6months.

At Bole, the rainfall dataset shows first, second, and third harmonics of 0.082 and 0.05078, 0.043 cycles and respective periodicities of 1, 1.7 and 2 years and respective %V as 46.28%, 42.22% and 13.6%. As seen from tables 1 and 2, the dominant cycle of rainfall series at Bole and one that explain 64.10% of the variance is with periodicity of 0.9 year. This means that, the cycle repeats itself every year and associated with highest amount of rainfall. The second dominant cycle of rainfall series in the area and one that explain 9.90% of the variance is with periodicity of 1 year, interpreted to mean that the cycle repeats itself two times every one year which is roughly every one year with the second highest rainfall.



Wa Bole Tamale Yendi

Figure 6: Savannah Climatic zone Periodogram for (a) rainfall, (b) temperature, and (c) RH

Table 1: Frequencies obtained by spectral analysis for the Savannah climatic zone

f (cycle/ month)				Time, T (month)				Time, T (year)			
S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
0.073	0.086	0.089	0.083	13.654	11.641	11.254	12.047	1.1	0.9	0.9	1
0.069	0.079	0.086	0.079	14.421	12.642	11.636	12.642	1.2	1	0.9	1.1
0.066	0.076	0.079	0.076	15.057	13.123	12.642	13.129	1.3	1.1	1.1	1.1
0.055	0.074	0.073	0.069	18.285	13.477	13.654	14.380	1.5	1.1	1.1	1.2
0.047	0.069	0.069	0.069	21.331	14.422	14.491	15.284	1.8	1.2	1.2	1.3
0.041				24.378				2			
S1 – Wa S2 – Bole					S2 – Tamale S2 – Yendi						

Then finally third dominant cycle of rainfall series in the area and one that explain 5.6% and shows that it has periodicity of three times in 1.2 years. This means approximately 4 months with the third highest rainfall.

Table 2: Percentage variances obtained by spectral analysis for the Savannah Climatic zone

Order of importance		Harmon-ics	Periodicities (cycles/year)	% V explained
First	Wa	0.073	1.1	36.07
	Bole	0.086	0.9	64.10
	Tamale	0. 073	1.1	49.5
	Yendi	0.073	1.1	36.07
Second	Wa	0.069	1.2	14.78
	Bole	0.086	0.9	64.10
	Tamale	0. 069	1.2	20.14
	Yendi	0.069	1.2	14.78
Third	Wa	0.047	1.8	11.57
	Bole	0.086	0.9	64.10
	Tamale	0. 041	12	13.59
	Yendi	0.047	1.8	11.57

At Tamale, the rainfall dataset shows first, second, and third harmonics of 0.073 and 0.06901, 0.04102 cycles and respective periodicities and percent variance of 1, 1.2 and 2 years and 49.49%, 20.14% and 13.6%. It is thus apparent that the dominant cycle of rainfall series at Tamale with 49.50% of the variance is with periodicity of 1 year. This means that this cycle repeats itself every year and associated with highest amount of rainfall. The second dominant cycle of rainfall series in the area and one that explain 20.15% of the variance is with periodicity of 1.2 year for example could be interpreted to mean that the cycle repeats itself 2 times every 1.2 years which is roughly every 6 months with the second highest rainfall. Finally, the third dominant cycle of rainfall series in the area and one that explain 13.61% and shows that it has periodicity of 3 times in 2.0 years for example. This means approximately 8 months with the third highest rainfall.

At Yendi, the rainfall dataset shows first, second, and third harmonics of 0.07324, 0.06934, 0.06641, 0.05469 and 0.04688 cycles and respective periodicities of 1.1, 1.2, 1.3. 1.5 and 1.8 years and respective %V explained as 36.07%, 22.56% and 14.78%. The spectrum of monthly rainfall variation is from Fig. 95 which was normalized between 0 and 1, the peaks frequencies fp for Yendi were 36.0727, 22.5574,14.7846 and 11.5723 (which are between 11months to 3 years) are around the 11 months and more, other smaller peaks were also obtained from the spectrum (but not shown in the tables) which speculates almost every year there are peaks rainfall events. Then it would appear that the dominant cycle of rainfall series at Yendi from the table below and one that explain 36.07% of the variance is with periodicity of 1.1 year. This means that this cycle repeats itself approximately every year and associated with highest amount of rainfall. Then the second dominant cycle of rainfall series in the area and one that explain 14.78% of the variance could be interpreted to mean that the cycle repeats itself times every 1.2 years which is roughly every 6 months with the second highest rainfall. Then finally third dominant cycle of rainfall series in the area and one that explain 11.57% of the variance is with periodicity of 3 times every 1.8 years for. This is translated to means that this cycle repeats itself approximately 6months.

Transition Climatic zone Periodogram

Figure 7 shows the periodogram for the Transition Climatic zone of the study area for rainfall, temperature, and RH at Kete Krachi. From tables 3 and 4, the rainfall dataset at Kete Krachi shows first, second, and third harmonics of 0.082 and 0.05078, 0.043 cycles and respective periodicities of 1, 1.7 and 2 years and respective %V explained as 46.28%, 42.22% and 13.6%. Then it would appear that the dominant cycle of rainfall series at Kete Krachi and one that explain 44.06% of the variance is with periodicity of 0.8 months for example. This means that this cycle repeats itself every 8months and associated with highest amount of rainfall.

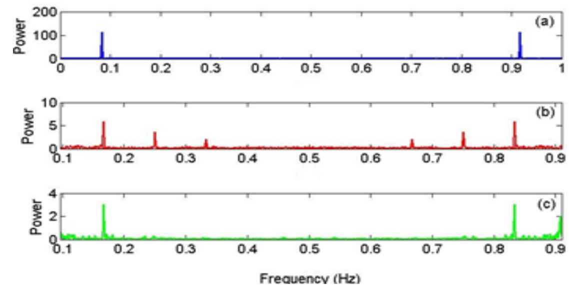


Figure 7: Kete Krachi Periodogram for (a) rainfall, (b) temperature, and (c) RH

Table 3: Kete Krachi frequencies obtained by spectral analysis

f (cycle/ month)	Time, T (month)	Time, T (year)
0.09766	10.2396	10 months
0.0791	12.6422	1.1
0.07422	13.4734	1.1
0.06924	14.44	1.3

Table 4: Kete Krachi percentage variances obtained by spectral analysis

Order of importance	Harmonics	Periodicities (cycles/year)	% V explained
First	0.09766	0.8	44.0577
Second	0.0791	1.1	40.9348
Third	0.06924	1.3	0.7

Also the second dominant cycle of rainfall series in the area and one that explain 40.9% of the variance is with periodicity of 1.1 year for example could be interpreted to mean that the cycle repeats itself 2 times every 1.1 years which is roughly every 6 months with the second highest rainfall. Then finally third dominant cycle of rainfall series in the area and one that explain 0.7% and shows that it has periodicity of 3 times in 1.3 years for example. This mean s approximately 4months with the third highest rainfall.

Forest Climatic zone Periodogram

Figure 8 shows the periodogram for the Forest Climatic zone of the study area for rainfall, temperature, and RH for Sefwi Bekwai, Kumasi, Koforidua, Ho, and Axim.

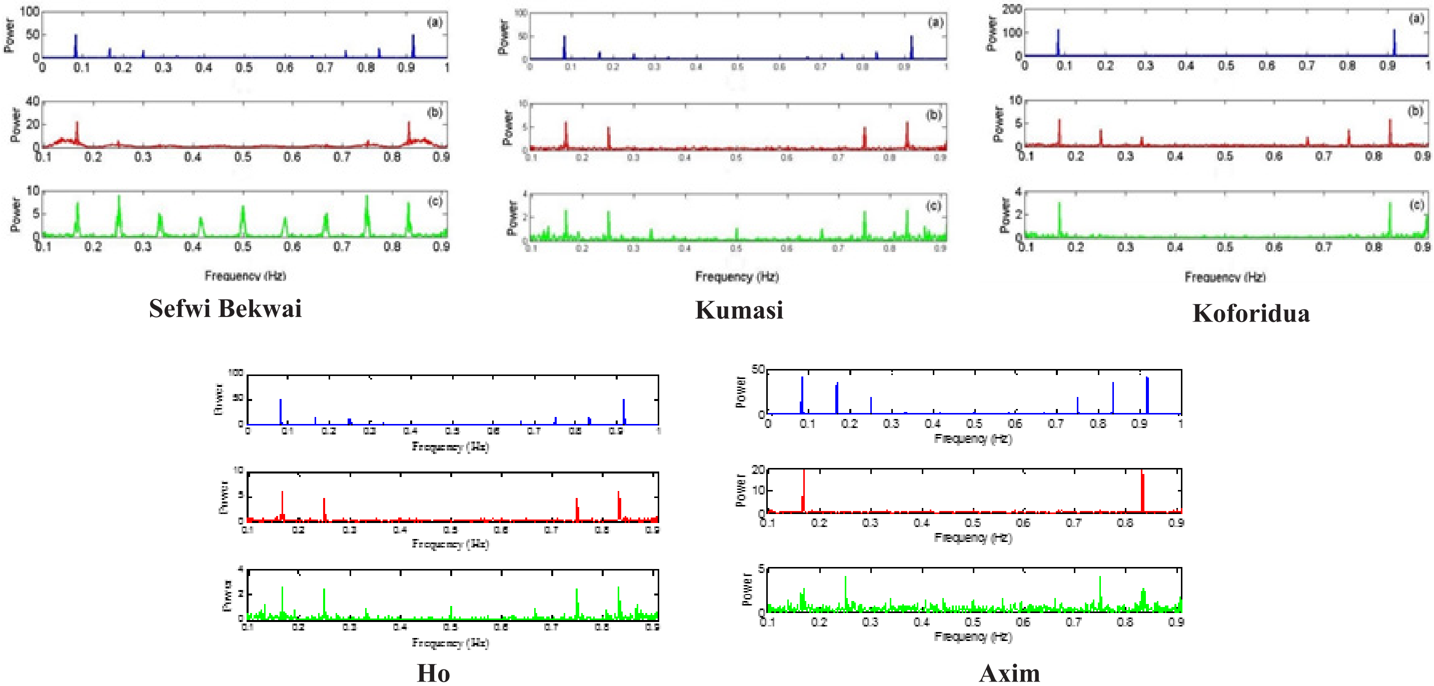


Figure 8: Forest Climatic zone Periodogram for (a) rainfall, (b) temperature, and (c) RH

As seen from tables 5 and 6, the first, second, and third harmonics for Sefwi Bekwai have 0.082 and 0.05078, 0.043 cycles and respective periodicities of 1, 1.7 and 2 years and respective %V explained as 46.28%, 42.22% and 13.6%. Then it would appear that the dominant cycle of rainfall series at Sefwi Bekwai and one that explain 22.25% of the variance is with periodicity of 1 year for example. This means that this cycle repeats itself every year and associated with highest amount of rainfall. The second dominant cycle of rainfall series in the area and one that explain 18.14% of the variance is with periodicity of 1.3year for example could be interpreted to mean that the cycle repeats itself 2 times every1. 3years which is roughly every 7 months with the second highest rainfall. Then finally third dominant cycle of rainfall series in the area and one that explain 15.48% and shows that it has periodicity of 3 times in 3.5 years for example. This means approximately 1.3 years with the third highest rainfall.

Table 5: Frequencies obtained by spectral analysis for the Forest climatic zone

f (cycle/ month)					Time, T (month)					Time, T (year)				
S1	**S2**	**S3**	**S4**	**S5**	**S1**	**S2**	**S3**	**S4**	**S5**	**S1**	**S2**	**S3**	**S4**	**S5**
0.08	0.08	0.1	0.07	0.07	12.34	12.64	10.24	14.422	14.42	1	1	10	1	1.2
0.08	0.08	0.08	0.06	0.06	13.13	13.12	12.64	16.515	16.79	1.1	1.1	1.1	1	1.4
0.07	0.07	0.07	0.06	0.04	15.06	15.06	13.47	18.285	22.75	1.3	1.3	1.1	1	1.8
0.06	0.06	0.07	0.04	0.04	16.79	17.69	14.44	22.753	23.27	1.4	1.5	1.3	1	1.9
0.05	0.05		0.03	0.04	18.96	19.69		32.000	24.98	1.6	1.7		2.7	2.1
0.029	0.03				34.13	31.03				2.8	2.6			
0.02	0.03				42.66	36.58				3.5	3			

S1 – Sefwi Bekwai
S2 – Kumasi
S3 – Koforidua
S4 – Ho
S5 – Axim

Table 6: Percentage variances obtained by spectral analysis for the Forest Climatic zone

Order of importance		Harmonics	Periodicities (cycles/year)	% V explained
First	Sefwi Bekwai	0.081	1	22.25
	Kumasi	0.079	1	22.74
	Koforidua	0.098	0.8	44.06
	Ho	0.08	1.0	74.97
	Axim	0.069	1.2	33.72
Second	Sefwi Bekwai	0.066	1.3	18.14
	Kumasi	0.056	1.5	19.42
	Koforidua	0.079	1.1	40.93
	Ho	0.059	1.5	11.31
	Axim	0.059	1.4	18.94
Third	Sefwi Bekwai	0.023	3.5	15.48
	Kumasi	0.027	3.0	17.29
	Koforidua	0.069	1.3	0.729
	Ho	0.043	2.8	0.15
	Axim	0.04	2.1	14.87

The first, second, and third harmonics for Kumasi (see tables 5 and 6) have 0.082 and 0.05078, 0.043 cycles and respective periodicities of 1, 1.5 and 3.0 years and respective %V explained as 22.74%, 19.42% and 17.29%. Then it would appear that the dominant cycle of rainfall series at Kumasi and one that explain 22.74% of the variance is with periodicity of 1 year for example. This means that this cycle repeats itself every year and associated with highest amount of rainfall. The second dominant cycle of rainfall series in the area and one that explain 19.42% of the variance is with periodicity of 1.5 year for example could be interpreted to mean that the cycle repeats itself 2 times every 1.5 years which is roughly every 1.5year with the second highest rainfall. Then finally third dominant cycle of rainfall series in the area and one that explain 17.29% and shows that it has periodicity of 3 times in 2.0 years for example. This means approximately 8 months with the third highest rainfall highest rainfall.

The first, second, and third harmonics for Koforidua (see tables 5 and 6) have 0.082 and 0.05078, 0.043 cycles and respective periodicities of 1, 1.7 and 2 years and respective %V explained as 46.28%, 42.22% and 13.6%. Then it would appear that the dominant cycle of rainfall series at Koforidua and one that explain 44.06% of the variance is with periodicity of 0.8 months for example. This means that this cycle repeats itself every 8months and associated with highest amount of rainfall. Also the second dominant cycle of rainfall series in the area and one that explain 40.9% of the variance is with periodicity of 1.1 year for example could be interpreted to mean that the cycle repeats itself 2 times every 1.1 years which is roughly every 6 months with the second highest rainfall. Then finally third dominant cycle of rainfall series in the area and one that explain 0.7% and shows that it has periodicity of 3 times in 1.3 years for example. This mean s approximately 4months with the third highest rainfall.

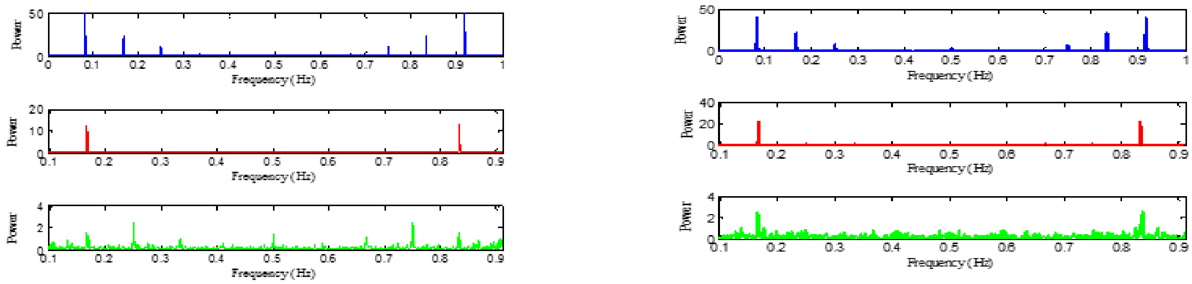
At Ho (see tables 5 and 6), the first, second, and third harmonics are 0.082 and 0.05078, 0.043 cycles and respective periodicities of 1, 1.7 and 2 years and respective %V explained as 46.28%, 42.22% and 13.6%. It would then appear that the dominant cycle of rainfall series at Ho and one that explain 74.97% of the variance is with periodicity of 1 year for example. This means that this cycle repeats itself every year and associated with higher amount of rainfall. Also the second dominant cycle of rainfall series in the area and one that explain 11.31% of the variance is with periodicity of 1.5 years for example. This means that this cycle repeats itself 2 times every 1.5 years which is roughly every 8 months. Then finally third dominant cycle of rainfall series in the area and one that explain 0.15% of the variance is with periodicity of 2.8 years (almost 3 years) for example. This means that this cycle repeats itself 3 times in every 2.8 years, which is approximately every 18.7 years with the third.

Again, first, second, and third harmonics for Axim (see tables 5 and 6) have 0.0762, 0.043 and 0.0250 cycles and respective periodicities of 1, 2 and 3 years and respective percentage variances obtained by spectral analysis as 43.73%, 24.53% and 11.38%. Then it would appear that the dominant cycle of rainfall series at Axim and one that explain 33.71% of the variance is with periodicity of 1.2 year for example. This means that this cycle repeats itself every year and associated with highest amount of rainfall. Also the second dominant cycle of rainfall series in the area and one that explain 18.94% of the variance is with periodicity of 1.4 year for example could be interpreted to mean that the cycle repeats itself 2 times every 1.4 years which is roughly every 7 months with the second highest rainfall. Then finally third dominant cycle of rainfall series in the area and one that explain 14.67% and shows that it has periodicity of 3 times in 2.1 years for example. This means approximately 7 months with the third highest rainfall.

Coastal Climatic zone Periodogram

Figure 9 shows the periodogram for the Coastal Climatic zone of the study area for rainfall, temperature, and RH for Accra and Ada. As seen from tables 7 and 8, the first, second, and third harmonics for Accra have 0.082 and 0.05957, 0.043 cycles and respective periodicities of 1, 1.7 and 2 years and respective %V explained as 46.28%, 42.22% and 13.6%. Then it would appear that the dominant cycle of rainfall series at Accra and one that explain 72.59% of the variance is with periodicity of 1 year for example. This means that this cycle repeats itself every year and associated with highest amount of rainfall. Also the second dominant cycle of rainfall series in the area and one that explain 12.58% of the variance is with periodicity of 1.4 year for example could be interpreted to mean that the cycle repeats itself 2 times every 1.4 years which is roughly every 7 months with the second highest rainfall. Then finally third dominant cycle of rainfall series in the area and one that explain 2.46% and shows that it has periodicity of 3 times in 1.6 years for example. This means approximately 5 months with the third highest rainfall.

The first, second, and third harmonics for Ada (see tables 7 and 8) have 0.06641 and 0.05566, 0.04395 cycles and respective periodicities of 1.3, 1.5 and 1.8 years and respective %V explained as 34.89%, 27.34% and 23.89%. Then it would appear that the dominant cycle of rainfall series at Ada and one that explain 34.87% of the variance is with periodicity of 1 year for example.



Accra Ada

Figure 9: Coastal Climatic zone Periodogram for (a) rainfall, (b) temperature, and (c) RH

This means that this cycle repeats itself every year and associated with highest amount of rainfall. Also the second dominant cycle of rainfall series in the area and one that explain 27.34% of the variance is with periodicity of 1.5 year for example could be interpreted to mean that the cycle repeats itself 2 times every 1.5 years which is roughly every 8 months with the second highest rainfall. Then finally third dominant cycle of rainfall series in the area and one that explain 23.89% and shows that it has periodicity of 3 times in 1.8years for example. This means approximately 6 months with the third highest rainfall.

Table 7: Frequencies obtained by spectral analysis for the Forest climatic zone

f (cycle/ month)		Time, T (month)		Time, T (year)	
S1	S2	S1	S2	S1	S2
0.092	0.09668	10.89	10.34	0.9	0.8
0.082	0.09277	12.20	10.78	1.0	0.9
0.069	0.06641	14.49	15.06	1.2	1.3
0.059	0.05566	16.787	17.97	1.4	1.5
0.056	0.04395	17.86	22.75	1.5	1.8
0.053	0.02344	18.86	42.66	1.6	3.5
S1 – Accra S2 – Ada					

Table 8: Percentage variances obtained by spectral analysis for the Coastal Climatic zone

Order of importance		**Harmonics**	**Periodicities (cycles/year)**	**% V explained**
First	Accra	0.082	1	72.58623
	Ada	0.066	1.3	34.8684
Second	Accra	0.059	1.4	12.57775
	Ada	0.056	1.5	27.3355
Third	Accra	0.043	1.6	2.460188
	Ada	0.044	1.8	23.8899

The analyses of annual monthly rainfall and the coefficient of variation within the period 1961-2012 (Table 9) shows lower values for Bole. Wa, Tamale, Yendi, Ho, Kete-Krachi, Koforidua and Kumasi had lower values form march to October. Accra, Ada and Axim had lower values from March to June. These can be interpreted as the most reliable months for these stations. These tend to coincide with the rainfall seasons experienced by these stations.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wa	R̄	4.53	6.97	30.31	82.36	123.51	140.29	161.20	208.01	196.29	79.69	7.01	4.96
	Cv	3.12	1.85	0.56	0.50	0.38	0.42	0.28	0.39	0.34	0.51	1.03	1.43
Yendi	R̄	3.27	7.35	50.98	87.03	130.92	174.14	190.18	228.47	260.09	105.79	7.91	5.68
	Cv	3.03	1.78	0.92	0.51	0.39	0.33	0.32	0.39	0.36	0.55	1.93	3.17
Kete Krachi	R̄	7.71	10.79	42.46	98.83	141.98	205.03	214.00	214.96	241.54	146.86	25.32	8.92
	Cv	2.06	1.68	0.96	0.58	0.51	0.41	0.45	0.40	0.33	0.57	1.29	1.96
Ho	R̄	19.95	58.46	105.84	135.34	165.55	197.36	130.29	91.88	157.19	163.83	49.72	33.41
	Cv	1.17	0.83	0.55	0.41	0.46	0.42	0.56	0.74	0.49	0.36	0.64	0.99
Koforidua	R̄	26.52	64.54	111.75	140.49	162.60	199.35	123.01	89.05	150.63	161.87	67.25	34.29
	Cv	1.13	0.58	0.43	0.41	0.37	0.38	0.63	0.76	0.50	0.37	0.52	0.95
Sefwi Bekwai	R̄	18.47	68.68	126.53	154.98	184.35	231.45	128.32	97.23	156.77	171.73	80.22	30.06
	Cv	1.11	0.64	0.41	0.46	0.35	0.34	0.54	0.91	0.53	0.38	0.55	1.34
Ada	R̄	8.9	25.4	55.7	115.2	151.2	249.5	65.0	22.9	44.6	71.5	28.6	11.7
	Cv	2.0	1.2	0.7	0.5	0.4	0.7	1.4	2.0	1.3	0.8	0.9	1.6
Accra	R̄	11.31	22.45	56.88	94.87	142.93	212.46	70.00	24.42	54.81	64.80	31.26	21.65
	Cv	1.80	1.43	0.79	0.68	0.52	0.61	1.04	1.11	1.03	0.71	0.83	1.27
Axim	R̄	39.68	59.03	112.71	170.24	325.50	543.75	201.74	69.38	85.88	199.59	144.74	68.55
	Cv	0.98	0.80	0.55	0.53	0.44	0.43	1.03	1.30	0.98	0.63	0.52	0.73
Bole	R̄	1.85	11.59	51.45	101.65	130.29	146.93	156.42	158.68	209.14	111.74	20.81	8.03
	Cv	4.03	1.62	0.73	0.44	0.43	0.42	0.46	0.35	0.31	0.59	1.31	2.12
Tamale	R̄	3.08	8.98	42.22	87.16	117.02	151.65	165.37	204.86	219.64	89.62	9.25	3.89
	Cv	3.18	1.79	0.81	0.60	0.44	0.41	0.41	0.40	0.33	0.63	1.99	2.29
Kumasi	R̄	20.34	59.26	120.74	144.84	175.20	215.56	146.11	85.56	167.71	158.40	64.26	26.45
	Cv	1.30	0.73	0.45	0.44	0.37	0.39	0.66	0.81	0.51	0.40	0.72	1.01

Conclusion

This work studied the trend and variabilities in rainfall datasets for the last fifty years at twelve meteorological stations distributed in the four Climatic zones of the study area, herein Ghana. The primary aim was to find the cyclic occurrence of flooding with temperature, humidity and rainfall across the country. From the graphical and tabular analysis, it is noted that there were significant wetter years which were 1961-1970 and 2001-2010 and drier years occurred within 1981-1990 in the zones with bimodal rainfall seasons. However, in the zone with mono-modal rainfall seasons wetter years occurred within the decade 1981-1990 and 2001-2010. Furthermore, it is realised that, there is a cyclic pattern noted in the rainfall time series and a cycle of about 5 to 8 months for the Northern zone, 6 – 8 month for the middle belt and approximately 8 months for the coastal zone in the rainfall, temperature and humidity datasets suggesting a coherence in their relationship. The findings are relevant as a useful tool in monitoring excessive rainfall across the country. Spectral techniques and time series are useful techniques which are very effective in studying variation of temperature, humidity and rainfall data in that a cyclic nature of the measures were found easily. Whereas the climate data analysis is valuable particularly to understand the complexity of the variations associated with global climate change.

References

1. Ofori-Sarpong E (2001) Impact of climate change on agriculture and farmers coping strategies in the upper east region of Ghana. West African Journal of Applied Ecology 2: 21-35.
2. Cooper P J M, Dimes J, Rao K P C, Shapiro B, Shiferaw B, et al. (2008) Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? Agriculture, ecosystems & environment 126: 24-35.
3. Kunstmann H, Jung G (2005) Impact of regional climate change on water availability in the Volta basin of West Africa. IAHS publication 295: 75-85.
4. Boyetey D B, Darkwah K F, Osei-Frimpong E, Acheampomg E, Agyemang E, et al. (2012) Least square determination of spectral time series with trend: Application to rainfall patterns in Ghana. International Scientific Research Journal 1: 50-61.
5. Nicholson S E, Some B, Kone B (2000) An analysis of recent rainfall conditions in West Africa, including the rainy seasons of the 1997 El Niño and the 1998 La Niña years. Journal of climate 13: 2628-2640.
6. Yepdo Djomou Z, Monkam D, Lenouo A (2009) Spatial variability of rainfall regions in West Africa during the 20th century. Atmospheric Science Letters 10: 9-13.
7. Owusu K, Waylen P (2009) Trends in spatio-temporal vari-

ability in annual rainfall in Ghana (1951-2000) Weather 64: 115-120.
8. Lacombe G, McCartney M, Forkuor G (2012) Drying climate in Ghana over the period 1960–2005: evidence from the resampling-based Mann-Kendall test at local and regional levels. Hydrological Sciences Journal 57: 1594-1609.
9. Manzanas R, Amekudzi L K, Preko K, Herrera S, Gutiérrez J M, et al. (2014) Precipitation variability and trends in Ghana: An intercomparison of observational and reanalysis products. Climatic change 124: 805-819.
10. Amekudzi L K, Yamba E I, Preko K, Asare E O, Aryee J, et al. (2015) Variabilities in rainfall onset, cessation and length of rainy season for the various agro-ecological zones of Ghana. Climate 3: 416-434.
11. Baidu M, Amekudzi L K, Aryee J N, Annor T (2017) Assessment of long-term spatio-temporal rainfall variability over Ghana using wavelet analysis. Climate 5: 30.
12. Asante F A, Amuakwa-Mensah F (2015) Climate change and variability in Ghana: Stocktaking. Climate 3: 78-99.
13. Yoo Y (2001) Tutorial on Fourier theory. Retrieved June 17, 2007.
14. Aryee J N A, Amekudzi L K, Quansah E, Klutse N A B, Atiah W A, et al. (2018) Development of high spatial resolution rainfall data for Ghana. International Journal of Climatology 38: 1201-1215.
15. Asare-Nuamah P, Botchway E (2019) Understanding climate variability and change: analysis of temperature and rainfall across agroecological zones in Ghana. Heliyon 5: e02654.
16. Ndamani F, Watanabe T (2014) Rainfall variability and crop production in Northern Ghana: The case of Lawra District.
17. Knoben W J, Woods R A, Freer J E (2019) Global bimodal precipitation seasonality: A systematic overview. International Journal of Climatology 39: 558-567.