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Rainfall Distribution in the Upper East Region of Ghana, 1976 – 2016

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Abstract

The knowledge and understanding of rainfall distribution of a region are very essential and useful in determining the overall impacts of climate change, especially to the agricultural sector. Monthly rainfall data from 1976-2016 for five selected stations were acquired and subjected to various statistical techniques namely coefficient of variation, 5-year moving average and departure from the mean to obtain the variability and trends in the data. The results showed that the selected stations have uni-modal rainfall distribution and that the rain mostly starts in May and ends in September. High precipitation occurs in July, August and September, with August recording the highest amount with a low variability, indicating the reliable occurrence of precipitation within this period of the year. This is of high importance to farmers and the recharging of aquifers. The wettest station was Zuarungu, with a mean total monthly rainfall of 89.55 mm followed by Navrongo, Bolgatanga, Garu and Manga-Bawku with their respective mean total monthly rainfall as 81.08 mm, 80.59 mm, 79.64 mm and 78.86 mm. High annual variability was found in all the stations and long dry spells were observed from November to March. The rainfall season wet period is between July and September at all the stations and it is recommended that farmers should cultivate early-maturing crops and adopt irrigation farming practices as well as practices which utilize water efficiently.

Keywords: *Rainfall variability, rainfall distribution, Upper East Region, Ghana*

INTRODUCTION

One of the greatest challenges this century has faced is the issue of climate change because of its enormous stress on the environment and humans, such as changes in weather patterns, rising sea level and more extreme weather events (IPCC, 2015). These events threaten our food production, increase catastrophic flooding and global warming (FAO, 2008).

To mitigate and combat climate change, several agreements have been reached by various countries as a step in addressing climate change in order to reduce greenhouse gas (GHG) emissions, which

is primarily influenced by anthropogenic activities such as burning of fossil fuels, clear-felling of forests, urbanization and certain farming methods (United Nations, 2015).
The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 and the ultimate aim was "*to prevent 'dangerous' human interference with the climate system*". Some of the treaties under the general framework of the UNFCCC are the Kyoto Protocol, the Montreal Protocol and the Paris Agreement. The Paris Agreement is one of the latest that came to effect on November 16th, 2016 (United Nations, 2015) and pinion members to limit global temperature rise.

Rainfall distribution and variability is one of the key areas which are used to determine the overall impacts of climate change since its variation has consequential impacts on food production and availability of freshwater (Dore, 2005; Cruz *et al*., 2007). Rainfall is directly related to the economic growth and development (Ekwe *et al*., 2014) of Ghana at large and the Upper East Region in particular, where a greater number of the inhabitants engage in rain-fed agriculture.

Understanding the variability and trends in rainfall in the Upper East Region, and for that matter, Ghana as a whole is crucial for different socio-economic activities especially agriculture (Ofori-Sarpong, 2001). Due to the relevance of understanding rainfall patterns, various studies on the analysis of rainfall distribution and variation in Ghana have been previously carried out. These include: studies on Atlantic sea surface temperatures and rainfall variability in Ghana (Opoku-Ankomah and Cordery, 1994), trends in Spatio-temporal rainfall variability in Ghana (Owusu and Waylen, 2009), simulation of the rainfall regime over Ghana from CORDEX (Lacombe *et al*., 2012), analysis of rainfall variability in Ghana (Logah *et al*., 2013), rainfall variability over Ghana: model versus gauge observation (Nkrumah *et al*., 2014), climate change and variability in Ghana: stocktaking (Asante and Amuakwa-Mensah, 2015) and rainfall and temperature changes and variability in the Upper East Region of Ghana (Issahaku, *et al*., 2016).

According to McSweeney *et al*. (2010), rainfall in Ghana is now highly variable, which means it is difficult to determine the long term trends as compared to the early 1970s to 1980s where the rainfall was timely. This led to efficient planning and management of water resources and the meeting of food production targets by farmers, which in turn increased the country's economic development. Hence, it is expedient to carefully monitor the behaviour in the rainfall pattern in this area where there is a single rainy season and the rainfall is erratic and agriculture is predominantly rain-fed and still the primary source of food and employment for the general population. Rainfall is also the source of water for the recharging of aquifers and to the drainage system for the supply of water for livestock and irrigation. Thus, this paper seeks to examine the behaviour in the rainfall pattern of the Upper East Region that is the distribution and variability across the region. This would enable policymakers to make better decisions which will encourage better farming practices leading to the economic growth of the region and increase in the standard of living of the people. Monthly rain gauge data of five selected stations were obtained from the Ghana Meteorological Agency (GMet) from 1976-2016 purposely, to determine the trend in the rainfall data, temporal variability within and spatial variability across the study areas.

MATERIALS AND METHODS

This study was conducted in the Upper East region of Ghana, which is located in the north-eastern part of Ghana between Longitude 0^0 and 1^0 West and Latitudes 10^0 30'N and 11^0N (Figure 1). Upper East region shares boundaries with Burkina Faso, Togo, Upper West and North East Region to the North, East, West and South, respectively. The region occupies a land area of 8,842 km^2, with a population estimated to be 1,046,545, which is equivalent to 4.2% of the total population of the country (GSS, 2010).

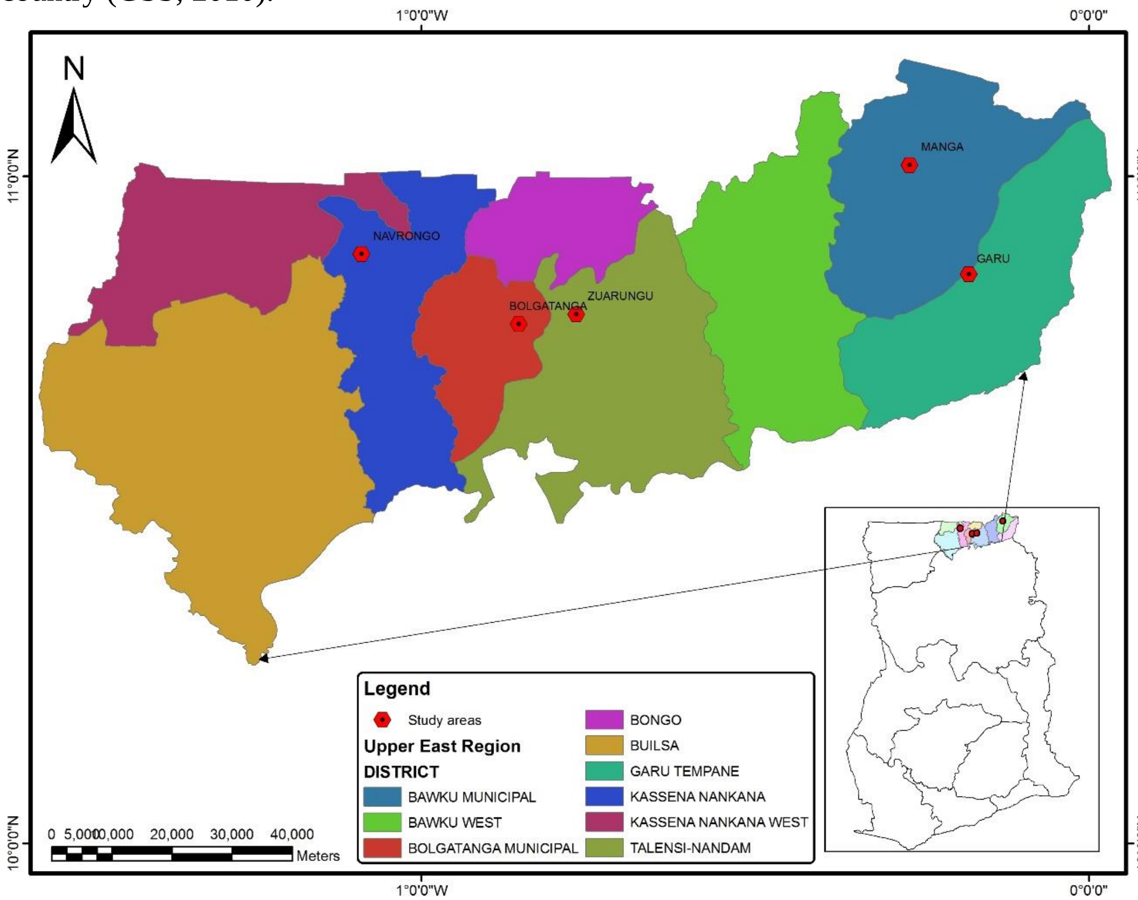

Figure 1. A map of Upper East Region showing the location of the selected stations.

The soil in this region is developed from granite, which is generally low in fertility. The annual mean rainfall falls between 800 mm and 1100 mm. The Region is characterized by uni-modal rainfall regime, which usually begins in May and ends in September. The predominant occupation of the people is agriculture employing over 80% of the population, and the main crops they cultivate are millet, groundnut, maize, beans, rice, onions and sorghum.

The drainage is mainly by the White and Red Volta and Sissili Rivers. There are two main irrigation projects in the entire region, that is, the Vea Project in Bongo District covering 850 hectares and the Tono Project in the Kassena-Nankana East District covering 2,490 hectares (MoFA, 2016). The two projects together employ about 6,000 smallholder farmers (MoFA, 2016; GSS, 2010). Other waterretaining structures (dams and dugouts) provide water for both domestic and agricultural purposes. The dry season possesses a major challenge for farmers to cultivate horticultural crops like tomatoes, pepper, onions, watermelons, okra and livestock farmers who rear cattle, guinea fowls, sheep, goats and pigs because most of the dams and dugouts completely dry off. The Tono and Vea dams have increased the economic status of the people and revenues generated from the area are used to carry out developmental projects because of their potential to retain water for farmers to farm throughout the year including the dry season (MoFA, 2016).

Data Collection and Analysis

Monthly rainfall data for five rain-gauge stations (Bolgatanga, Garu, Manga-Bawku, Navrongo and Zuarungu) for 41 years (1976-2016) were obtained from the Ghana Metrological Services Department at Bolgatanga in the Upper East Region of Ghana. The data were used for the computation of monthly and annual values for descriptive statistical analysis such as mean (x), standard deviation (SD) and coefficient of variation (CV) (which is the ratio of the standard deviation to the mean). According to Cherkos (2001) CV values < 20% indicate less variable, between 20% and 30% indicate moderately variable and > 30% indicate highly variable. Microsoft Excel statistical tool was used to determine the descriptive statistics and the trend behaviour of the rainfall, such as rainfall departures and five-year moving average. Hutchinson (1985) showed that Microsoft Excel is simple and efficient for predicting trends on climate parameters.

RESULTS AND DISCUSSION

Rainfall Characteristics

The study area is characterized by uni-modal rainfall distribution, which usually starts from April and ends in October, with August recording the highest amount of rainfall (Figure 2). The mean total monthly rainfall amount for the forty-one-year period, that is, 1976 to 2016, ranged between 78.86 mm and 86.55 mm (Table 1). The maximum total monthly rainfall for the period was 601.30 mm, and this was recorded at Zuarungu (Table 1) in August (Table 6), while a minimum of zero was recorded at all the stations (Table 1). The highest mean total monthly rainfall was recorded in Zuarungu (86.55 mm) and the lowest was at Manga-Bawku (78.86 mm) (Table 1). The CVs ranged from 114% to 144% for all the stations (Table 1), with Zuarungu recording the highest CV whilst Garu recorded the least, which indicate that the entire area is characterized by high rainfall variability (Cherkos, 2001). The statistical parameters of the seasonal rainfall characteristics of the individual stations are presented in Table 2 - 6.

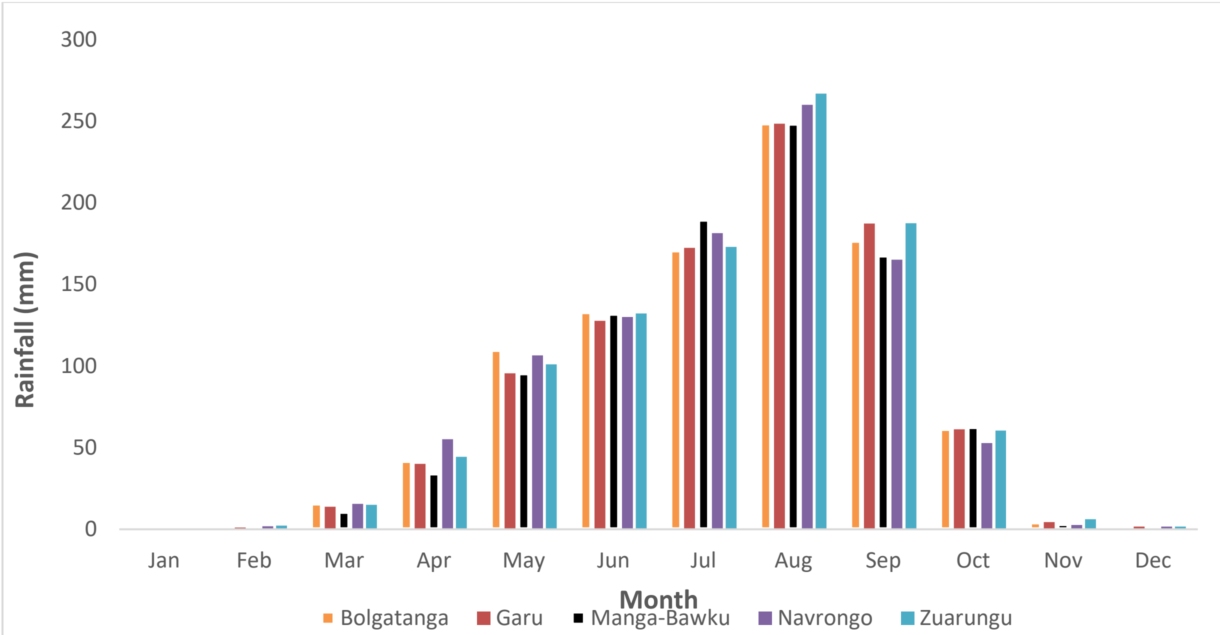

Figure 2: Mean monthly total rainfall of selected rainfall stations in the UER (1976-2016)

Table 1**:** Total monthly rainfall of the selected stations in Upper East Region from 1976-2016

Station	MIN (mm)	MAX (mm)	Mean (mm)	Standard deviation	Coefficient of Variation (%)
Bolgatanga	0	476.90	80.59	93.03	115.44
Garu	0	439.40	79.64	91.55	114.95
Manga	0	574.60	78.86	95.87	121.57
Navrongo	0	455.50	81.08	95.88	118.25
Zuarungu	0	601.30	86.55	99.16	144.57

Table 2**:** Basic statistics of seasonal (monthly) rainfall at Bolgatanga (1976-2016)

Season (Month)	MIN (mm)	MAX (mm)	Mean (mm)	Standard Deviation	Coefficient of Variation (%)
JAN	0	4.8	0.19	0.77	405.26
FEB	0	22.7	2.06	4.72	229.13
MAR	0	79.5	15.86	21.44	135.18
APR	3.7	141.5	41.76	30.52	73.08
MAY	28.8	249.9	109.87	46.83	42.62
JUN	32.9	235	132.89	43.57	32.79
JUL	81	349.4	170.80	49.23	28.82
AUG	99.7	476.9	248.71	88.39	35.54
SEP	49.5	312.1	176.77	61.48	34.78
OCT	0	183.5	61.35	44.89	73.17
NOV	0	47.2	4.24	9.21	217.22
DEC	0	53.1	2.52	10.55	418.65

Table 3**:** Basic statistics of seasonal (monthly) rainfall at Garu (1976-2016)

Season (Month)	**MIN (mm)**	**MAX (mm)**	**Mean (mm)**	**Standard Deviation**	**Coefficient of Variation (%)**
JAN	0	4.5	0.22	0.85	386.36
FEB	0	13.3	1.12	2.73	243.75
MAR	0	90.2	13.82	20.11	145.51
APR	0	123.2	40.03	26.76	66.85
MAY	18	206.6	95.61	42.17	44.11
JUN	39.4	237.6	127.78	41.72	32.65
JUL	72.9	330.3	172.42	63.50	36.83
AUG	100.4	439.4	248.37	63.45	25.55
SEP	75.5	362.3	187.26	64.88	34.65
OCT	0	190.7	61.17	42.21	69.00
NOV	0	40.9	4.33	9.36	216.17
DEC	0	29.6	1.60	5.50	344.75

Table 4: Basic statistics of seasonal rainfall at Manga-Bawku (1976-2016)

Season (Month)	**MIN (mm)**	**MAX (mmm)**	**Mean (mm)**	**Standard Deviation**	**Coefficient of Variation (%)**
JAN	0	5.3	0.13	0.82	630.77
FEB	0	12.2	1.06	2.93	276.42
MAR	0	73.9	10.63	16.51	155.32
APR	0	108.3	34.10	28.10	82.40
MAY	27.2	215.3	95.56	44.33	46.39
JUN	57.8	236.1	132.08	38.77	29.35
JUL	71.3	574.6	189.53	95.88	50.59
AUG	99.7	569.0	248.49	83.57	33.63
SEP	66.8	362.6	167.65	66.86	39.88
OCT	0	232.8	62.60	45.79	73.17
NOV	0	39.1	3.18	7.20	226.42
DEC	0	26.9	1.32	5.35	405.30

Table 5: Basic statistics of seasonal (monthly) rainfall at Navrongo (1976-2016)

Season (Month)	**MIN (mm)**	**MAX (mm)**	**Mean (mm)**	**Standard Deviation**	**Coefficient of Variation (%)**
JAN	0	4.2	0.14	0.66	471.43
FEB	0	22	1.90	5.02	264.21
MAR	0	105.2	15.55	24.17	155.43
APR	2.6	176.6	55.10	44.42	80.62
MAY	13.7	231.2	106.51	51.52	48.37
JUN	38.7	274.3	130.09	55.20	42.43
JUL	91.3	354.9	181.39	63.02	34.74
AUG	69.1	455.5	260.08	86.36	33.21
SEP	55.7	447.7	165.03	74.98	45.43
OCT	0.7	207.7	52.91	40.40	76.36
NOV	0	29.5	2.67	6.87	257.30
DEC	0	33.6	1.62	7.04	434.57

Table 6**:** Basic statistics of seasonal (monthly) rainfall at Zuarungu (1976-2016)

Season (Month)	**MIN (mm)**	**MAX (mm)**	**Mean (mm)**	**Standard Deviation**	**Coefficient of Variation (%)**
JAN	0	1.2	0.05	0.20	400.00
FEB	0	23.1	2.30	5.71	248.26
MAR	0	97.8	14.94	23.22	155.42
APR	0	176.5	44.44	34.53	77.70
MAY	32.6	199.8	101.04	42.56	42.12
JUN	36.8	275.5	132.26	52.55	39.73
JUL	74.8	446.5	172.95	69.30	40.07
AUG	130.1	601.3	266.82	108.39	40.62
SEP	23.8	322.4	187.56	71.76	38.26
OCT	0	196.1	60.51	40.28	66.57
NOV	0	46.5	6.25	10.41	166.56
DEC	0	44.6	1.74	7.84	450.57

Seasonal Rainfall Distribution

Figure 2 illustrates the seasonal distribution of rainfall in the selected stations. Rainfall gradually starts in April, which symbolizes the beginning of the rainy season and peaks mostly in the month of August, and finally declines gradually until there is apparently no rain. The stations were punctuated by long dry spells (successive days without rain) from November to March (the dry season period), thereby making rainfall unevenly distributed in all the areas.

Significant high coefficient of variation was experienced by all the stations from the month of November to March, between 135 % and 630 % (Table 2 – 6) indicating that rainfall in the region is highly variable. Low rainfall variability was observed from April to October (Table 2 – 6).

In general, all the stations under review have high CVs and are highly variable in terms of rainfall according to the scale set by Cherkos (2001). Since the region is characterized by a single rainfall regime as compared to the southern part of the country which experiences a double-maxima rainfall regime, the percentage contribution to the annual rainfall was dependent on July to September rains. During this season, mean total monthly rainfall ranged from 165 to 267 mm (Figure 2 and Table 2-6). This period is the main wet season, and farmers take advantage of this time to engage in serious agricultural activities, and also most of the dams, river bodies and aquifers are recharged within this period. This short wet period might be due to the impact of climate change which has affected the entire Sub-Saharan Africa (SSA) and accounts for only 1.59 per cent of its contribution resulting in severe flooding and droughts which have destroyed most farms as reported by Ekwe *et al*. (2014) and Urama and Ozor (2015). The remaining months contributed far less to the total annual rainfall, and usually, it is during this season that the area also experiences harmattan and high temperatures, leading to high evapotranspiration and severe drought. Droughts have both direct and indirect consequences for human livelihoods (Pavel, 2003). A direct consequence is crop loss, which can cause starvation if alternative food sources are not available. Indirectly, water shortages contribute to the spread of diseases, because people lack water for basic hygiene purposes (Urama and Ozor, 2015).

Rainfall Departure from Annual Mean

Rainfall departure plots define when rainfall of a year departs from the annual mean (Nkrumah *et al*., 2014; Sushant *et al*., 2015). There were successive positive and negative departures from the annual mean rainfall over the past four decades in all the stations. The numbers of years of negative rainfall departures from the annual mean for the study areas in 41 years were as follows: 20 years for Bolgatanga; 23 years for Garu; 21 years for Manga; 18 years for Navrongo, and 25 years for Zuarungu.

These negative departures in the study areas can be attributed to the aggravation of ENSO on West Africa, which was recorded to be the strongest El-Nino event as reported by Dore (2005) and Mawunya *et al*. (2011). The negative trend is important since is an indication of droughts experienced during the study period (Nkrumah *et al*., 2014), whiles the positive departures also has implications on the rainy days and induces floods (Sushant *et al*., 2015). The variability in the year-to-year rainfall in the departure graphs, particularly towards the negative, is an indication of the stress conditions the vulnerable communities in this area are experiencing over the years as reported in Kasei *et al*. (2014).

The studies of Owusu *et al*. (2008) and Nkrumah *et al*. (2014) indicated that the dry season is prolonging and declining in trend over the last five decades. This was observed in the periods of 1980-1987 and 2002-2006 for Bolgatanga (Figure 3); 1976-1978, 1983-1985 and 2011-2015 for Garu (Figure 4); 1983-1988 for Manga-Bawku (Figure 5); 2013-2015 for Navrongo (Figure 6); and; 1976-1978 and 2002-2006 for Zuarungu (Figure 7).

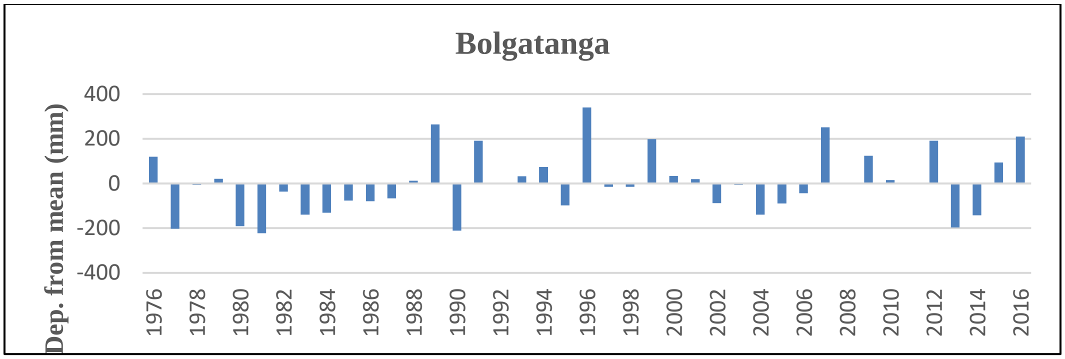

Figure 3: Rainfall departure from mean at Bolgatanga (1976-2016)

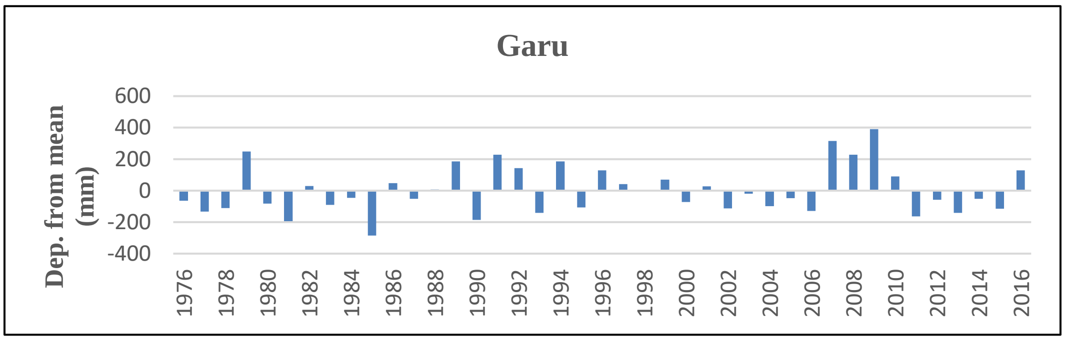

Figure 4: *Rainfall departure from mean at Garu (1976-2016)*

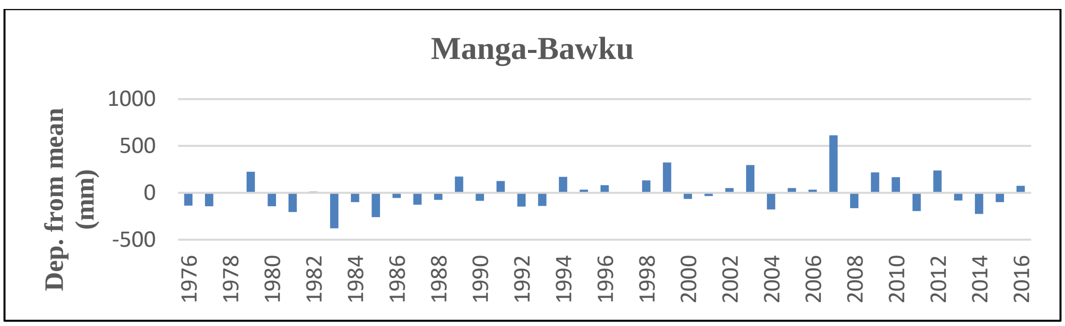

Figure 5: *Rainfall departure from mean at Manga-Bawku (1976-2016)*

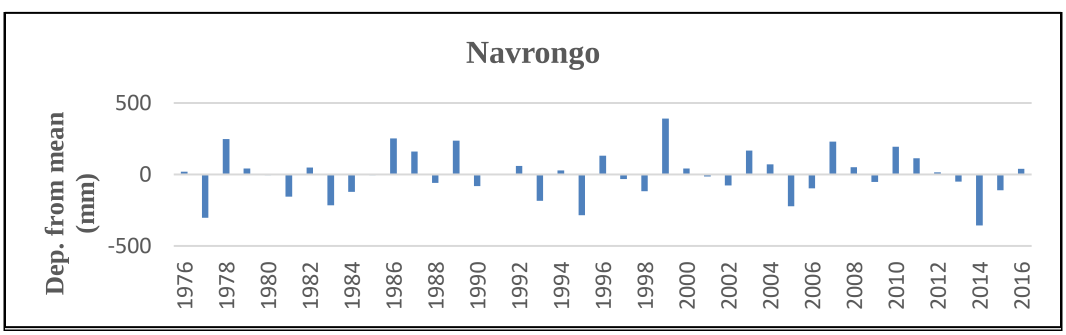

Figure 6: *Rainfall departure from mean at Navrongo (1976-2016)*

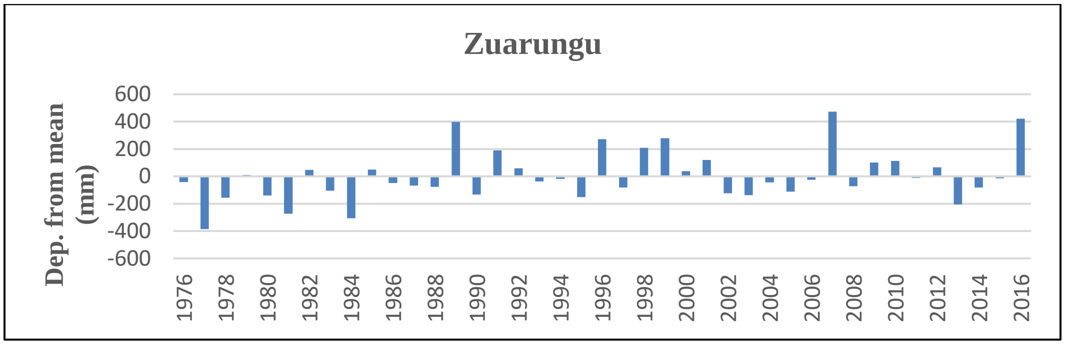

Figure 7: *Rainfall departure from mean at Zuarungu (1976-2016)*

Annual Rainfall Trends

Figure 8-12 shows the annual rainfall time series with 5-year moving average line and trend line fitted to the annual rainfall data of the five selected stations from 1976 - 2016. The most obvious decrease in rainfall amount in Bolgatanga occurred during 1983-1988 and 2002-2006 (Figure 8). There was general fluctuation in the rains in Garu, but the consistent reductions occurred in 2001-2006 (Figure 9). In Manga-Bawku, the consistent reductions occurred from 1983-1990 while the year 2010 showed the highest rise (Figure 10). There were general rise and fall in Navrongo (Figure 11), whiles at Zuarungu, the observable trends occurred from 2002-2006 and 2012-2015 (Figure 12). All the study areas portrayed increasing trends, except Navrongo which showed no visible changes. The trends suggest a fluctuating and general decline in rainfall values in the last four decades for the study area which also confirms the report of Logah *et al*. (2013). They surveyed 77 stations in Ghana from 1981-2010 and their analysis proved that there has been a general decline in the distribution of rainfall in the entire country which is attributed to anthropogenic activities such as deforestation, bad farming practices, overgrazing and burning of fossils and wood for energy. Along the coast of Ghana, in the south of the country, and along with that of Ivory Coast, Koranteng and Pezennec (1998) report of a significant decreasing trend in the rainfall. Asante and Amuakwa-Mensah (2015) report on the climate and variability in the country and suggested low rainfall occurrence in 2020, 2050 and 2080. Ampadu (2008), using the Dynamic Harmonic Regression Modelling approach found declining rainfall in the Upper East Region and attributed it to dust in the atmosphere as a result of desertification due to poor land management. Recently, Rahman (2016) using modelling projections also found a decreasing trend in the rainfall in the area. This clearly communicates to us the changes in rainfall pattern in the Upper East Region, therefore critical steps such as adapting and mitigating to declining rainfall (climate change) should be at the heart of all major decisions for the smallholder farmers and other individuals who depend on water for their livelihoods.

However, the coefficient of determination (R^2) for all the areas were less than 11 percent ($R^2 < 11\%$) suggesting that the dependent variable (annual rainfall) cannot be predicted from the independent variable (for all the stations under review).

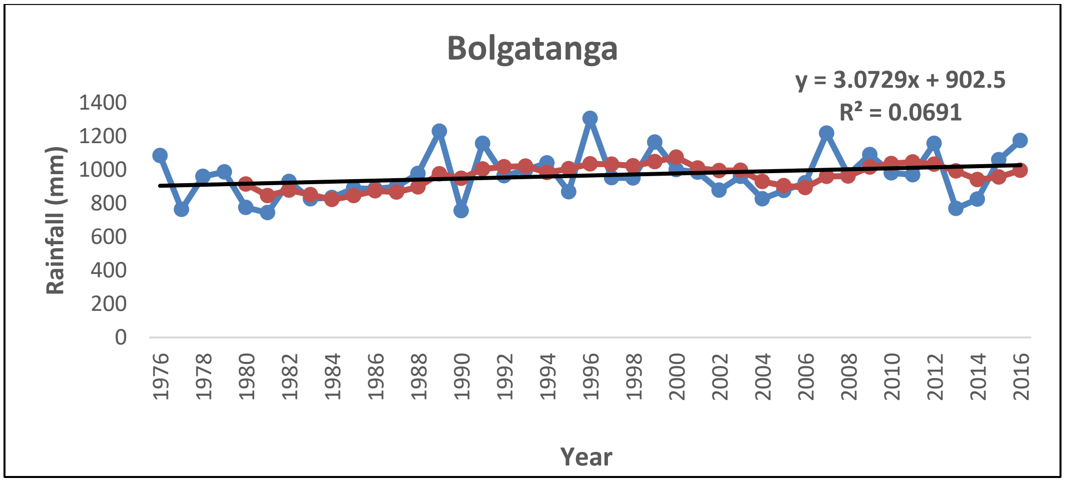

Figure 8: Annual rainfall time series (blue) with 5-year moving average line (red) and trend line fit (black) of Bolgatanga (1976-2016)

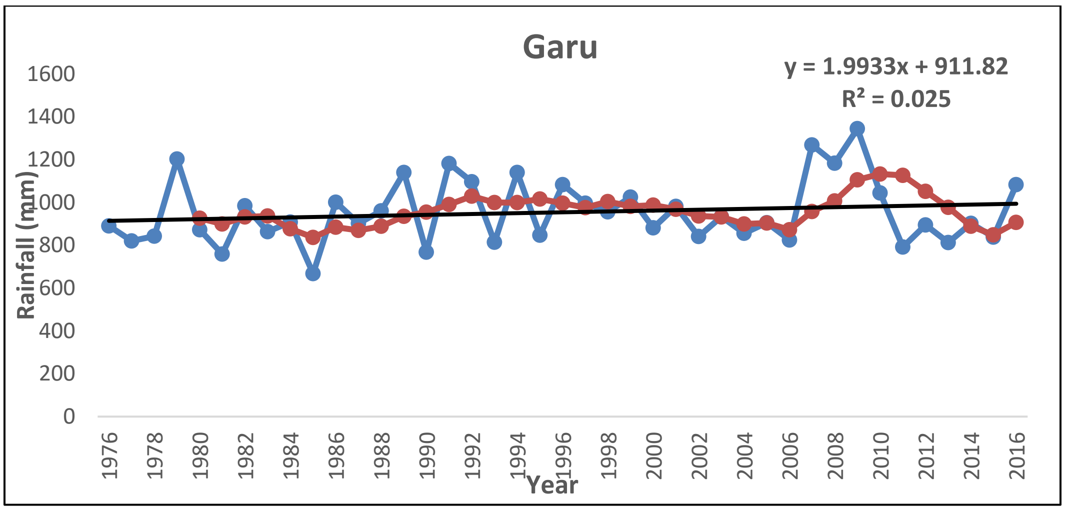

Figure 9: Annual rainfall time series (blue) with 5-year moving average line (red) and trend line fit (black) of Garu (1976-2016)

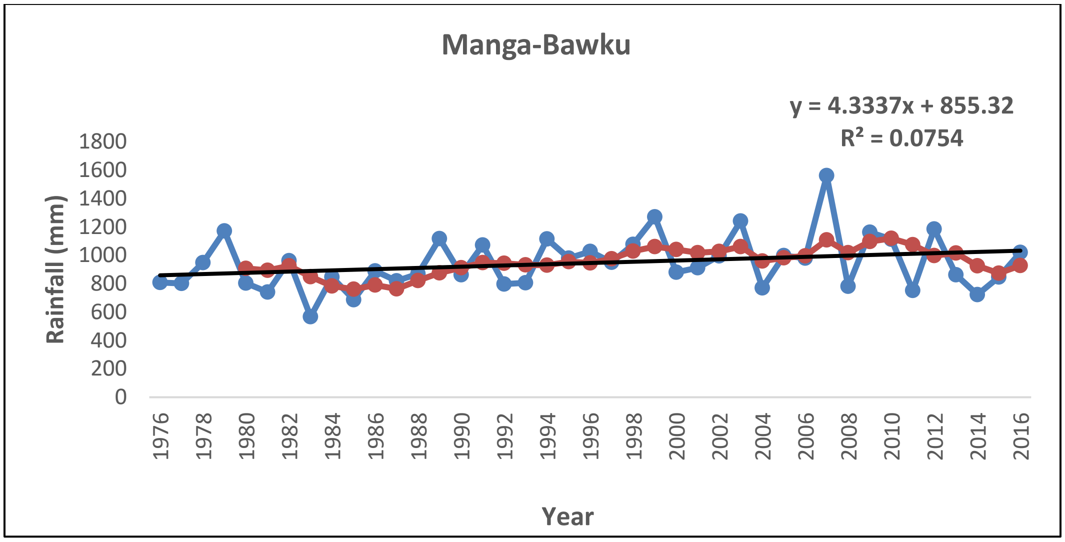

Figure 10: Annual rainfall time series (blue) with 5-year moving average line (red) and trend line fit (black) of Manga-Bawku (1976-2016)

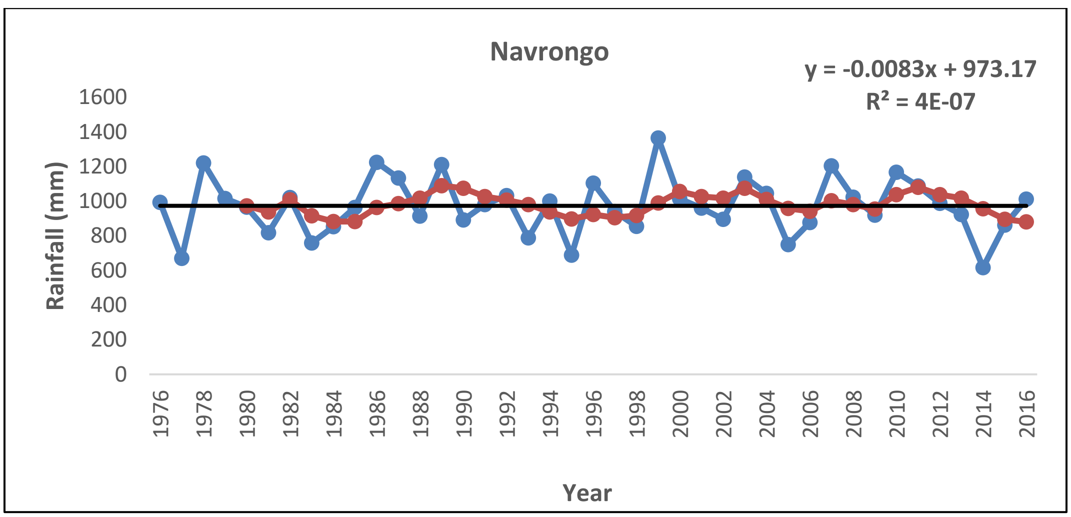

Figure 11: Annual rainfall time series (blue) with 5-year moving average line (red) and trend line fit (black) of Navrongo (1976-2016)

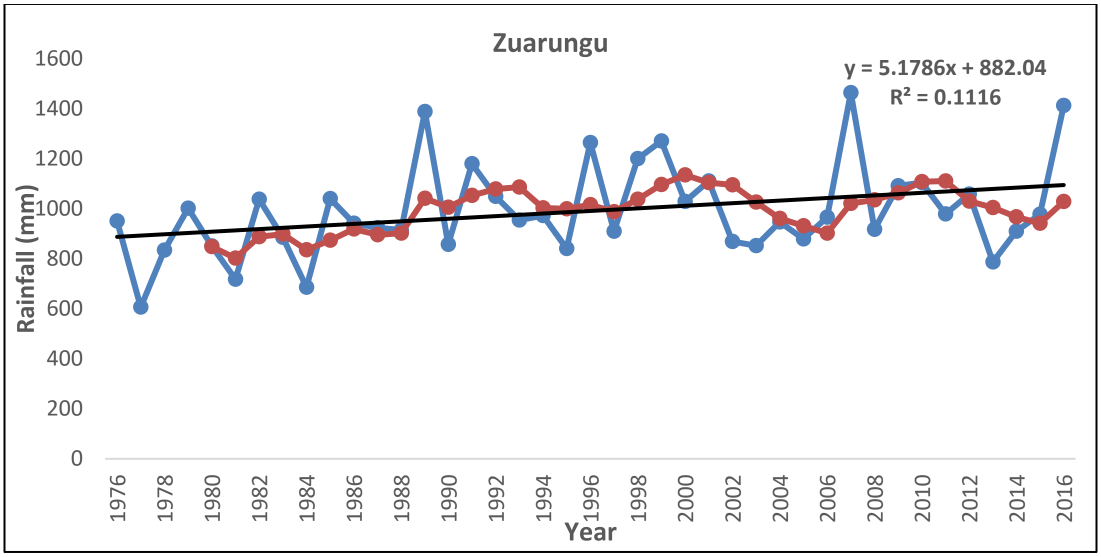

Figure 12: Annual rainfall time series (blue) with 5-year moving average line (red) and trend line fit (black) of Zuarungu (1976-2016)

CONCLUSIONS AND RECOMMENDATION

Rainfall data for five stations in the Upper East Region of Ghana from 1976-2016 were analysed and different statistical parameters were calculated. The analyses revealed that the area is characterized by a uni-modal rainfall regime, where mostly rainfall starts in May and ends in September spanning a period of 5 months. The highest amount of rainfall was recorded in August for all the stations. The dry season spans a period of 7 months from April to October.
The total monthly and annual mean rainfall indicates that Zuarungu receives the highest rainfall and Manga-Bawku receives the least in the study area. There was variation in rainfall amounts throughout the months in all the stations. Consistent negative departures (downward trend) from the mean were observed in all the stations predominantly in 1976-1990s, which resulted in dry spells in the area. High annual variability was seen in all the stations thereby making it difficult to identify and accurately predict long term trends.

We recommend that farmers in the Region should adopt irrigation practices as a supplementary measure and also cultivate early-maturing crops since the rainfall season wet period is between July and September at all the stations. In addition, farmers should adopt farming practices which utilize water efficiently.

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