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Rainfall and temperature changes and variability in the Upper East Region of Ghana

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Key Points:
- Day temperature is increasing in the Upper East Region
- Night temperature is increasing in the Upper East Region
- Rainfall is decreasing in the Upper East Region

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Abstract The aim of the research was to assess the current trend and variation in rainfall and temperature in the Upper East Region, Ghana, using time series moving average analysis and decomposition methods. Meteorological data obtained from the Ghana Meteorological Agency in Accra, Ghana, from 1954 to 2014 were used in the models. The additive decomposition model was used to analyze the rainfall because the seasonal variation was relatively constant over time, while the multiplicative model was used for both the daytime and nighttime temperatures because their seasonal variations increase over time. The monthly maximum and the minimum values for the entire period were as follows: rainfall 455.50 and 0.00 mm, nighttime temperature 29.10°C and 13.25°C and daytime temperature 41.10°C and 26.10°C, respectively. Also, while rainfall was decreasing, nighttime and daytime temperatures were increasing in decadal times. Since both the daytime and nighttime temperatures were increasing and rainfall was decreasing, climate extreme events such as droughts could result and affect agriculture in the region, which is predominantly rain fed. Also, rivers, dams, and dugouts are likely to dry up in the region. It was also observed that there was much variation in rainfall making prediction difficult. Day temperatures were generally high with the months of March and April have been the highest. The months of December recorded the lowest night temperature. Inhabitants are therefore advised to sleep in well-ventilated rooms during the warmest months and wear protective clothing during the cold months to avoid contracting climate-related diseases.

1. Introduction

Climate is a statistically significant variation in climate that persists for decades [*Intergovernmental Panel on Climate Change* (*IPCC*), 2001a]. The classical period used in modern measures of climate is 30 years [*IPCC*, 2001b]. Globally climate change induces redistribution of precipitation [*Stolberg et al.*, 2003] and threatens human life. The IPCC has noted that the average land surface temperature data as calculated by a linear trend show a warming of 0.65 to 1.06°C, over the period 1880–2012, and maximum and minimum temperatures over land have both increased in excess of 0.1°C per decade since 1950. These increases have led to sea level rise, soil moisture changes, changes in land and water conditions, changes in the frequency of fires, and changes in the distribution of vector borne diseases [*IPCC*, 2001a]

It is projected that summer precipitation would decrease in northern Europe and the Mediterranean and some parts of central and eastern Europe would experience increased drought [*Döll*, 2002; *Donevska and Dodeva*, 2004]. According to *Batima et al.* [2005], the increased frequency and intensity of droughts in Asia are due to temperature rise. Regions which experience severe drying are likely to have a larger decrease in the number of rainy days but with greater intensity of rainfall [*McDonald et al.*, 2005]. Climate variability has varied impacts on communities or regions. With these variations, the IPCC projects that, an increase of 2°C in temperature poses a risk to both fauna and flora and an increase in annual economic losses due to flood and drought [*Intergovernmental Panel on Climate Change* (*IPCC*), 2014].

The manifestation of the change and effects of climate varies from place to place. In eastern Africa, temperatures of areas close to the coasts and major inland lakes have fallen [*Kruger and Shongwe*, 2004]. In general, the tendency is for the drier subtropical regions to warm more than the moister tropics [*Christensen et al.*, 2007]. Already, the Sahel region of West Africa has experienced a multidecadal variability in rainfall [*Dai et al.*, 2004]. Rainfall is predicted to become more seasonal, with prolonged dry periods between rainfall events [*Kundzewicz et al.*, 2007]. For example, *Holmes et al.* [1997] reported that the African Sahel region has experienced a persistent drought since the late 1960s. The long-term change in surface water availability is very much related to rainfall patterns and increased evaporation [*Kundzewicz et al*., 2007]. The vulnerability of Ghana's agriculture to climate change is largely due to its over dependence on rainfall [*Yaro*, 2010]. Subsistence farming is predominant (nearly 90%) which relies on rainfall with little mechanized farming. Temperature continues to get warmer, whereas rainfall remains uncertain [*U.S. Environment Protection Agency* (*EPA*), 2015a]. In the analysis of historical records of Ghana, the observed rate of change in minimum temperature for the period 1960 to 2010 was 37% for the northern part (Guinea and Sudan Savannah Zones). Mean minimum temperature over the Savannah Zone is projected to increase by 1.10°C by 2040 and mean monthly maximum temperature is expected to increase by 1.2°C and 2.1°C by 2040 and 2060, respectively. It was also projected that decadal rainfall would be 3.3% for northern Ghana [*EPA*, 2015b]. *Laux et al*. [2008], *Armah et al*. [2011], and *Laube et al*. [2012] attributed the reduction in river flow and reduced groundwater availability to climate variability rather than change as a result of decreases in rainfall and increases in temperature for the Guinea Savannah agroecological zones of northern Ghana. The northern regions of Ghana are vulnerable to climate change and variability because of its location in the savannah climate zone as compared to regions in southern Ghana. The region is relatively hotter and has lower annual rainfall figures, higher rainfall variability, and a single maxima rainfall regime with high intensity which results in perennial flooding. This variability in climate variables has necessitated studies in to the future of climate in northern Ghana.

An attempt by *Jung and Kunstmann* [2007] to make a projection of climate variables concluded that a shorter rainy season and increased temperature was anticipated for the northern regions of Ghana. *McSweeney et al*. [2015] predicted an increase in the number of hot days and a decrease in the number of cold nights. *Wiredu et al*. [2013] proposed seasonal autoregressive integrated moving average model as the best model for forecasting rainfall in the Upper East Region. The gap in these studies was that little effort was made to identify the months or periods the Upper East Region would be hot or cold. Therefore, the main objective of this study was to contribute to the existing discourse on climate change in the Upper East Region and in particular to describe the characteristics and investigate whether or not there is a change in rainfall and temperature of the Upper East Region of Ghana. The results of this could explain the current state of reservoirs and dugouts in the Upper East Region and help in regional planning.

2. Specific Objectives

The specific objectives are as follows: (1) to examine the trends in rainfall and temperature in the Upper East Region (1954–2014), (2) to investigate the variation in rainfall and temperature in the Upper East Region (1954–2014), and (3) to make 30 year projections of rainfall and temperature in the Upper East Region.

In order to achieve the objectives, the hypothesis that there is no change in temperature and rainfall variability in the Upper East Region of Ghana was tested.

3. Research Methodology

3.1. Study Area

The Upper East Region (Figure 1) is located on the northeastern corner of Ghana between latitudes 10°30′ to 11°00′ north and longitudes 0° to 1°30′ west.

The region covers a land surface area of 8842 km^2 with a population density of 103 persons/km^2. It has two international boundaries with the Republics of Burkina Faso to the north and Togo to the east. The other boundaries are Northern Region and Upper West Region to the south and west, respectively [*Ghana Statistical Service* (*GDP*), 2010]. The regions' soil is shallow and low in soil fertility, weak with low organic matter content, and predominantly coarse textured. The region has a tropical continental or interior savanna climate, mostly influenced by the tropical continental air mass [*Intergovernmental Panel on Climate Change* (*IPCC*), 2010]. While the movement of the air masses results in two rainy seasons in the southern part of the country, the Upper East Region experiences only one, lasting from May to October. Annual average precipitation is about 1000 mm [*Dickson and Benneh*, 1988]. About 85% of the region falls within the White Volta Basin, with a network of tributaries, mainly, the White, Red, and Black Voltas and the Sissile River. Also, the Kulpawn River which has its catchment to the southwest of the region is joined by the Sissile just before its confluence with the White Volta. About 80% of the economically active population engages in

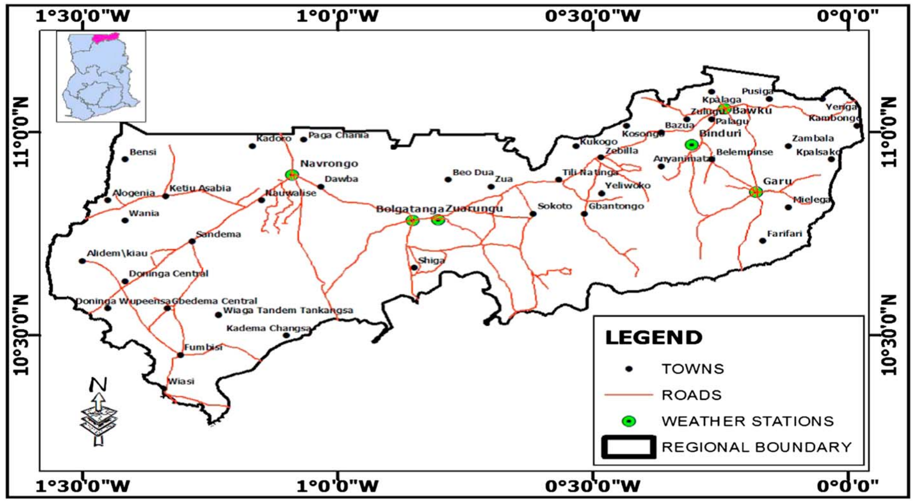

Figure 1. Map of Upper East Region Showing locations of Meteorological Stations used for this study.

agriculture. The main produce is millet, guinea corn, maize, groundnut, beans, sorghum, and dry season tomatoes and onions. Livestock and poultry production are also important. There are two main irrigation projects, the Vea Project in Bolgatanga covering 850 ha and the Tono Project in Navrongo covering 2490 ha. Altogether they provide employment to about 6000 small-scale farmers. Also, dotted in many parts of the region are dams and dugouts which provide water for both domestic and agricultural purposes [*Ghana Statistical Service*, 2010].

3.2. Research Method

Meteorological data of all weather stations in Upper East Region from 1954 to 2014 were taken from the office of the Ghana Meteorological Agency in Accra, Ghana. Missing data were estimated by linear interpolation of the data of the same months of the adjacent years on either side of the missing value [*World Meteorological Organization* (*WMO*), 1983]. Monthly average temperature and average annual rainfall data were used in the models. Rainfall and temperature data were tested for normality using probability and residual plots because parametric data are valid for normally distributed data. Minitab and Statistical Package for Social Sciences were the statistical packages whose tools were used to analyze the data. Since the response variables were more than one and there was the need to explore their relationship, multiple linear regressions were used instead of simple linear regression.

To ensure that internal variation of outliers would not affect the absolute values of means and totals, the moving average process of time series was used [*Anderson*, 1975]. Decomposition procedures were used to make predictions of temperature and rainfall. The model describes the trend and seasonal factors in a series. In this study, the maximum absolute percentage error (MAPE), mean absolute deviation (MAD), and mean squared deviation (MSD) were used to select the best model. The model with the least of these values was selected as the best. The equations below show the decomposition models:

$$\text{Additive model}: \; Y_t = \text{Trend} + \text{Seasonal} + \text{Random}$$
$$\text{Multiplicative model}: \; Y_t = \text{Trend} \times \text{Seasonal} \times \text{Random}.$$

The additive model is useful when the seasonal variation is relatively constant over time, while the multiplicative model is useful when the seasonal variation increases over time [*Douglas et al*., 2008].

4. Results

4.1. Preliminary Analysis

The maximum and the minimum rainfall for the study period (1954–2014) were 455.50 and 0.00 mm, for nighttime temperature data, the maximum and the minimum for the entire period were 29.10°C and 13.25°C, while those of the daytime temperature data were 41.10°C and 26.10°C, respectively. Also, the monthly rainfall for the entire period was positively skewed to the right and platikurtic in nature with mean

Table 1. Descriptive Statistics of Monthly Daytime Temperature (°C)

Variable	Mean	Minimum	Maximum	CV	Skewness	Kurtosis
January	35.543	32.800	40.700	3.670	0.920	2.860
February	37.868	35.600	40.000	2.530	−0.100	−0.420
March	38.843	26.100	41.100	5.520	−4.150	22.100
April	38.163	33.000	40.600	3.590	−1.050	2.350
May	35.838	32.200	39.000	3.410	−0.250	0.950
June	33.101	31.300	35.700	3.190	0.600	−0.190
July	31.310	29.600	34.100	2.640	0.420	1.100
August	30.480	29.000	32.800	2.560	0.480	0.440
September	31.357	29.600	35.800	3.430	2.270	7.640
October	34.127	32.000	36.600	2.650	0.510	0.970
November	36.363	27.550	38.200	4.170	−3.420	18.490
December	35.507	33.600	38.100	2.980	0.450	−0.180

and coefficient of variation of 82.02 and 117.71, respectively. The nighttime temperature was negatively skewed to the left and leptokurtic in nature with its mean and coefficient of variation being 22.54 and 10.95, respectively. The daytime temperature was also negatively skewed to the left and leptokurtic in nature with mean and coefficient of variation of 34.83 and 8.51, respectively. The skewness of rainfall (1.25) revealed that rainfall data were not normally distributed. August recorded the highest mean rainfall with a value of 455.00 mm followed by September, July, June, May, October, April, and March with recorded values of 447.70 mm, 330.20 mm, 274.30 mm, 267.80 mm, 207.70 mm, 148.00 mm, and 136.00 mm, respectively, while January, December, November, and February recorded the lowest values of maximum rainfall with values of 25.70 mm, 33.60 mm, 60.20 mm, and 70.60 mm, respectively. The highest daytime temperature occurred in the months of January, February, March, and April, while the lowest occurred in the months of March, November, and July–September ranging from 32.8 to 41.1°C (Table 1). For the nighttime temperature, the highest temperatures were recorded in the months of December and April with values of 29.10°C and 28.30°C, respectively, while the lowest temperatures were recorded in the months of November–January with values ranging from 13.4 to 18.3°C (Table 2).

4.2. Trend Analysis of Rainfall and Temperature

The general linear model analysis was used to investigate the trends in rainfall, daytime temperature, and nighttime temperature. The results indicated that the parameters were highly significant at 5% level ($p < 0.05$). The model revealed that the adjusted R-squared was about 85.3% showing that the model was well fitted. The model had F statistics of 327.359 and P value of 0.0013.

The change in rainfall was significant ($F = 205.157$; $p = 0.0004$). Homogeneity test of variance was carried out and Levene's test of equality of error variance rejected the null hypothesis of an existence of homogeneity across groups ($F = 4.184$; $p = 0.00002$). Also, the plots of the moving average points indicated that there was wide variation in the points, and therefore, the trends were insignificant (Figures 2a and 2b).

Table 2. Descriptive Statistics of Monthly Nighttime Temperature (°C)

Variable	Mean	Minimum	Maximum	CV	Skewness	Kurtosis
January	19.870	13.380	27.700	8.580	0.790	9.460
February	22.270	15.370	25.500	6.720	−1.510	6.340
March	15.197	17.590	27.500	5.760	−2.330	11.440
April	26.106	18.330	28.300	4.990	−3.480	20.780
May	25.054	17.890	27.300	4.690	−3.710	22.900
June	23.465	16.670	24.800	4.500	−4.500	28.760
July	22.590	16.110	24.200	4.700	−4.460	24.900
August	22.410	15.810	24.400	4.430	−4.890	33.210
September	22.198	15.640	23.300	4.540	−4.730	30.180
October	22.480	15.760	23.500	4.820	−3.950	22.320
November	20.185	13.250	26.400	8.710	−0.780	6.580
December	19.297	13.250	29.100	10.24	1.810	11.410

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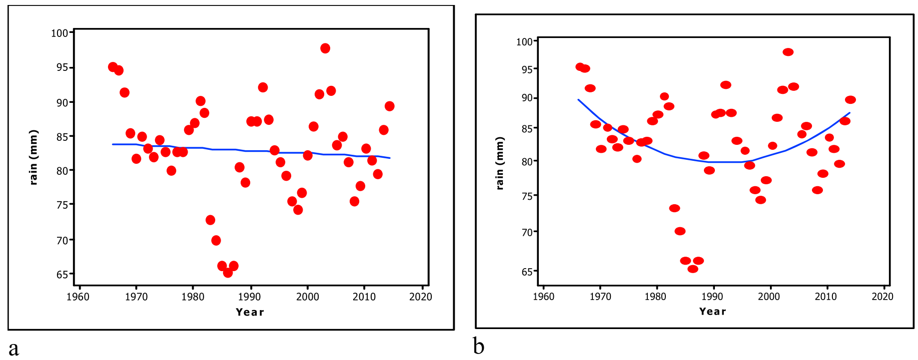

Figure 2. Trends in rainfall of the Upper East Region of Ghana ((a) linear and (b) quadratic).

Table 3. R^2 and R^2-Adjusted Values of Rainfall in the Upper East Region of Ghana

Equation	*R*-Squared	*R*-Squared Adjusted
Linear = 83.91 − 0.04152 t	0.7	0.0
Quadratic = 90.09 − 0.769 t + 0.01455 t^2	13.7	10.0

All the *R*-squared and *R*-squared adjusted values were less than 50% and suggested that the linear and quadratic trends (Table 3) were not significant.

To determine the trend in minimum temperature, trend lines were drawn through scatterplots using moving average points. The best trend line was selected based on the values of their *R*-squared and R^2 adjusted values (Figures 3a and 3b).

It was noticed that unlike the rainfall which had a decreasing trend, both minimum and maximum temperatures were increasing. The level of increase in temperature was significant ($R^2 > 50\%$). The increase in minimum temperature (0.00065) was higher than the increase in maximum temperature (0.000496) and showed that the number of cool nights is reducing.

The quadratic trend had the highest R^2 values (Table 4) and was therefore selected as the trend for minimum temperature. The trend was an increasing temperature at a rate of 0.065% per decade. The regression equation in minimum temperature was minimum temperature = $1.343 + 0.00065\,t - 0.000004\,t^2$. Both linear and quadratic were suitable for the trend lines. However, the R^2 value of the quadratic was greater and makes it more suitable for the trend analysis (Table 4).

In the case of the maximum temperature the highest R^2 values were the quadratic function (Table 5) and so the quadratic trend was selected for the maximum temperature. Regression equation of the trend in

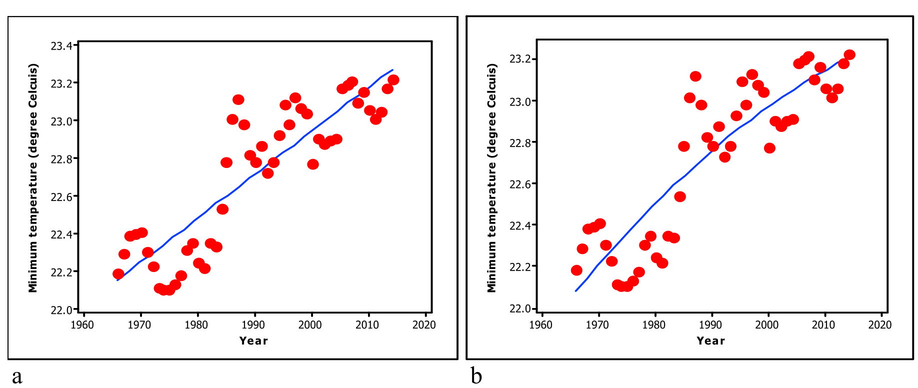

Figure 3. Trends in minimum temperature of the Upper East Region, Ghana ((a) linear and (b) quadratic).

Table 4. R^2 and R^2-Adjusted Values for Minimum Temperature in the Upper East Region, Ghana[a]

Parameter	R^2 (%)	R^2 Adjusted (%)	Standard Deviation
Linear	77.1	76.6	0.18
Quadratic	78.0	77.0	0.18

[a]Source: Field Survey 2015.

Table 5. R^2 of Maximum Temperature of the Upper East Region, Ghana

Equation	R^2	R^2 Adjusted
Linear = 34.22 + 0.02676 t	83.3	82.9
Quadratic = 34.11 + 0.03942 t − 000253 t^2	84.5	83.8

maximum temperature is maxtemp = 1.533 + 0.000496 t − 0.000003 t^2, where S = 0.00208284, R-Sq = 84.7%, and R-Sq(adj) = 84.0%.

Figure 4 shows that daytime temperatures were increasing. That is, daytime temperature will continue to be hotter and this would result to increase hot days into the future. Surface water bodies such as dams and rivers are most likely to dry up and those that are meant to support livelihoods would not be able to perform satisfactorily. Evapotranspiration would increase as a result and some plant and animal species would scorch because they cannot cope. New diseases are likely to emerge and the incidence of already known climate-related disease will become severe.

4.3. Selection of Models for Predicting Temperature and Rainfall

In time series analysis and forecasting, two or more models compete, and because of that, the most appropriate model needs to be used in for the analysis. Comparing the two decomposition models the additive model was having the least values of MAPE, MAD, and MSD for rainfall and best fit the data, except that MAPE was greater than the value in the multiplicative model due to outliers (Table 6).

From the additive modeling of rainfall, the result depicted that the trend in the data was linear and moving downward but the trend was not significant because of too many outliers. The multiplicative model was then used for the rest of the variables. The quadratic model best fits the trend for nighttime temperature, rainfall, and the daytime temperature (Table 7).

4.4. Variation in Rainfall and Temperature

The Upper East Region has a unimodal rainy season usually from April to October. This study indicates that there were variations in rainfall between the months. The variations in monthly rainfall and in both night and day temperatures determine the rainy and dry seasons in the Upper East Region. Table 8 shows that

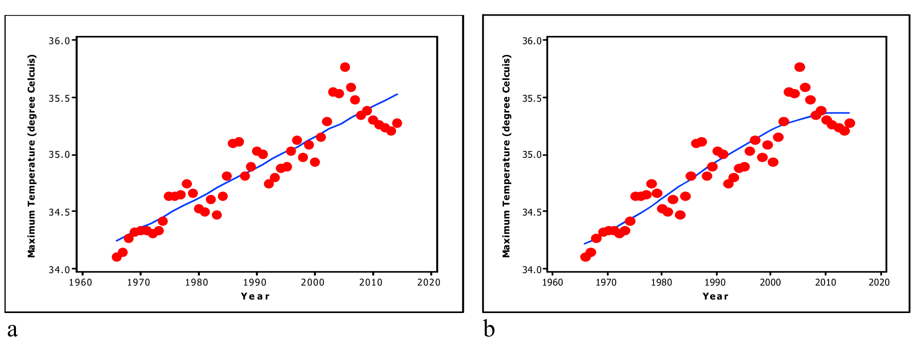

Figure 4. Trends in day temperature of the Upper East Region, Ghana ((a) linear and (b) quadratic).

Table 6. Linear and Quadratic Models for the Residuals

Model	Variable	MAPE	MAD	MSD
Additive	Rainfall	347.04	30.95	2472.28
	Nighttime temperature	3.4595	0.7442	1.8189
	Daytime temperature	2.1869	0.7442	1.3102
Multiplicative	Rainfall	342.40*	30.87*	2469.12*
	Nighttime temperature	3.4570*	0.7435*	1.8187*
	Daytime temperature	2.1728*	0.7450*	1.3056*

*The least values show the most significant model.

Table 7. Decomposition Additive and Multiplicative Models of the Residual

Model	Variable	MAPE	MAD	MSD
Additive	Rainfall	208.94	31.04*	2478.05*
	Nighttime temperature	3.84589	0.81088	1.86478
	Daytime temperature	2.44066	0.84482	1.53784
Multiplicative	Rainfall	188.94*	32.20	2819.29
	Nighttime temperature	3.84273*	0.81016*	1.86449*
	Daytime temperature	2.43928*	0.84419*	1.53335*

*The least values show the most significant model.

there was a fall in the rainfall in some months as shown by the negative indices and a rise in rainfall amount as shown by the positive indices of the months of the rainy season. From the indices, rainy season in the Upper East is between May and September (months with positive indices) and the dry season is from October to April (months with negative indices). During the period of negative indices, rainfall is either reduced or no record of rain will be obtained in the Upper East Region. The highest positive index is August (185.632) and indicates the peak of the rainy season, while the lowest index was recorded in January (−77.447) and indicates the peak of the dry season.

In the months of March–July, nighttime temperatures are high in the Upper East Region (positive indices), while in the months of August–February nighttime temperatures drop (negative indices). It was also observed that the indices of the month of April had the highest positive index (3.5372) and show that it is near impossible to sleep in unventilated room. This period also marks the onset of the rainy season (local indicator of the beginning of rains). The lowest index was recorded in December (−3.4316) and indicates that December is the coldest month in the Upper East Region (Table 8). The Harmattan which is associated with very low temperatures is recorded in this month. Residents in the region must therefore wear protective clothing to avoid getting cold and other diseases which are triggered by low temperatures.

Table 8. Monthly Indices of Rainfall (mm) and Night and Day Temperatures of the Upper East Region

Month	Rainfall	Nighttime Temperature (°C)	Daytime Temperature (°C)
January	−77.447	−2.6774	1.018
February	−76.505	−0.2691	1.088
March	−64.843	2.7101	1.121
April	−17.213	3.5372	1.102
May	12.174	2.4843	1.028
June	48.957	0.9122	0.948
July	89.895	0.0591	0.893
August	185.632	−0.1741	0.87
September	75.741	−0.3774	0.892
October	−24.484	−0.2961	0.896
November	−75.578	−2.4774	1.048
December	−76.33	−3.4316	1.016

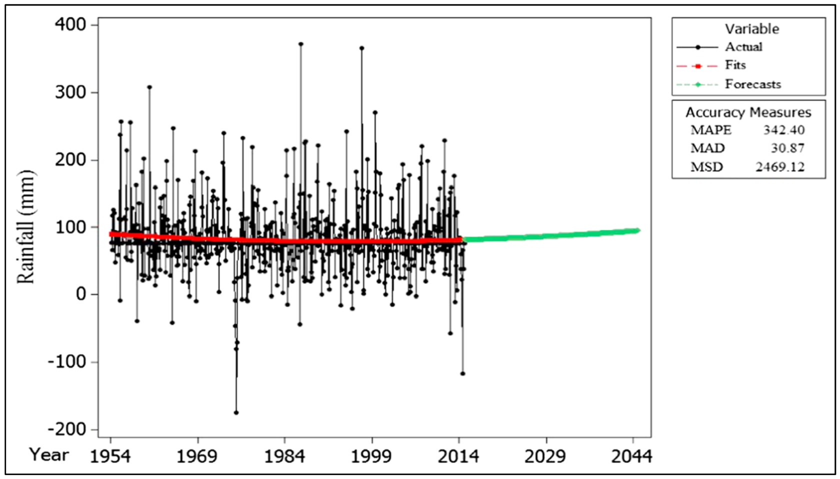

Figure 5. Long-term forecast of Rainfall in the Upper East Region of Ghana.

From the seasonal indices (Table 8), the daytime temperature had a sinusoidal pattern with the time periods. Temperatures were relatively higher February–April as shown by their indices. There was a decline in temperature in June–October which was due to the heavy rainfall in those months.

4.5. Long-Term Projections of Rainfall and Night and Day Temperatures in the Upper East Region

Rainfall data were well fitted by the quadratic trend model (Figure 4). It was seen that, from 1954 to 1994, the rate of change in rainfall was negative at a rate of 4.4% per decade. The rainfall can be described by the linear model equation: Rainfall $= 90.29 - 0.0440\,t + 0.000044\,t^2$.

The case of nighttime temperature was not different. The quadratic trend analysis of nighttime temperature revealed that the change was upward and is likely to continue to increase into the future. The forecast trend showed an increasing rate of change of nighttime and daytime temperature (Figures 5 and 6).

The estimated parameters of the linear regression model revealed that both nighttime and daytime temperatures were linear and trending upward by the model equations: Nighttime temperature $= 21.730 + 0.002494\,t - 0.000000\,t^2$ and that of daytime temperature $= 34.078 + 0.003037\,t - 000002\,t^2$. The indication is that while rainfall was decreasing at 4.4% per decade, nighttime temperature was increasing at 0.2494%

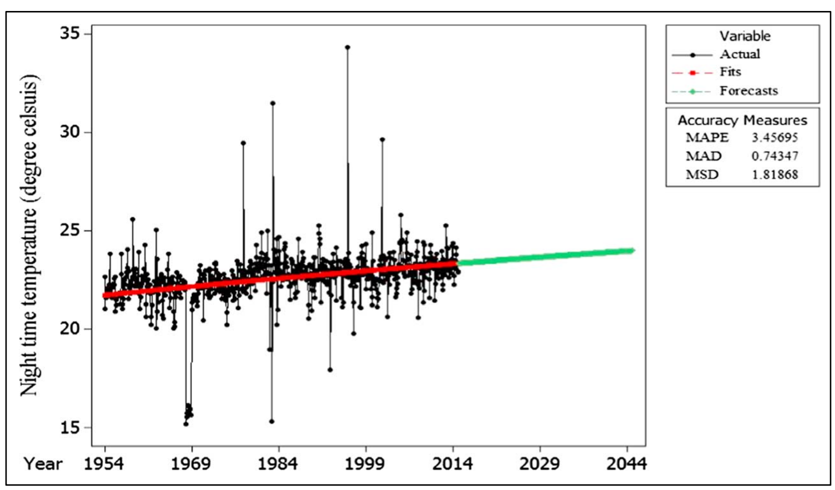

Figure 6. Long-term forecast of nighttime temperature in the Upper East Region of Ghana.

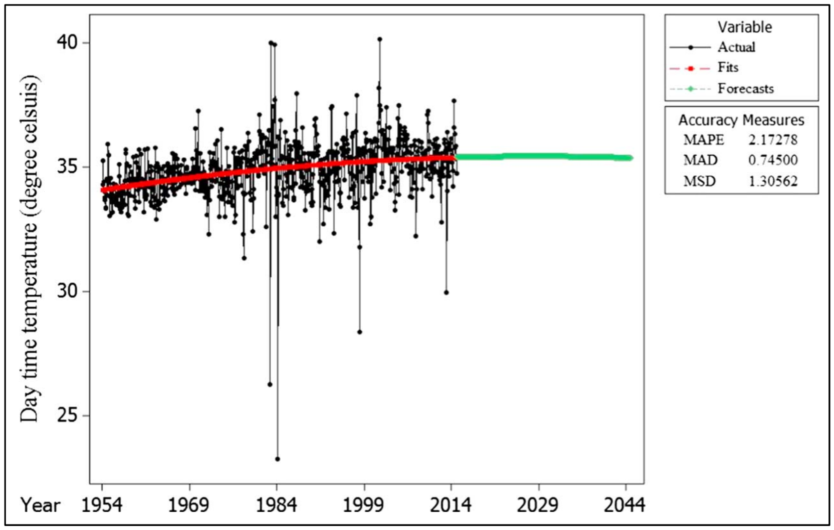

Figure 7. Long-term forecast of daytime temperature of the Upper East Region, Ghana.

per decade and daytime temperature was also increasing at 0.3037% per decade (Figure 7). Since both the daytime and nighttime temperatures were increasing and rainfall was decreasing dams and dug outs are likely to dry up in the Upper East Region. The projections here are that by 2045 (in three decades), rainfall would have decreased by 13.2%, nighttime temperature by 7.482%, and daytime temperature would increase by 9.111%.

5. Discussion

This study assumes rainfall and temperature as the main determinants of climate of the Upper East Region. The study revealed a downward trend of rainfall in the Upper East Region. There was also a seasonal and decadal variation in rainfall as a result of too many outliers. The variation in rainfall agrees with analysis of Ghana Environmental Protection Agency [*EPA*, 2015b] which projected a reduction in rainfall on average between 2.8% and 10.9% by 2050 in the Savannah agroecological zone over the coming decades but contravenes the findings of *Jung and Kunstmann* [2007] that a moderate increase in rainfall was anticipated in the northern regions of Ghana.

The decrease in rainfall could accelerate the incidence of drought in the Upper East Region. Rivers, dams, and dugouts would dry up and dry season farming would be hampered. Also, crop yield could reduce in the region because farming is rain dependent. However, low crop yield could be averted if storm water is harvested in controlled dams for irrigation because rain amount does not necessarily mean uniform distribution of water. Incidence of climate-related diseases such as cerebrospinal meningitis would increase, and the cost of drugs and food needed for mitigation would increase. This is because global temperature increases combined with increasing food demand as population grows and would pose large risks and increase cost to food security globally, regionally, and locally.

Daytime and nighttime temperatures were all increasing both annually and in decadal times and agreed with [*McSweeney et al*., 2015] that the mean annual temperature was expected to increase with changes expected to be more pronounced in the northern regions of Ghana based on a review of 15 different models. Empirical analysis performed at the local scale in some selected towns in the Upper East Region of Ghana indicated that temperature will increase with a reduction in the number of cool nights and an increase in the number of hot days [*Tachie-Obeng et al*., 2010]. Other contributing factors that would increase the severity of decreasing rainfall amount and increasing temperatures are deforestation [*Walther et al*., 2005] and desertification as a result in change in land use and increase fuel wood consumption.

6. Conclusions

Over the study period 1954 to 2014, the study finds that the climatic factors, rainfall, and temperature of the Upper East Region are changing. Rainfall in the Upper East Region is most likely to start from the month of

April to the month of August each year when it would be heavier and starts to decline again in September. The projections into the future revealed that rainfall was trending downward with the linear model equation: Rainfall = $90.29 - 0.0440\,t + 0.000044\,t^2$. The estimated parameters of the linear regression model revealed that both nighttime and daytime temperatures were linear and trending upward by the model equations: Nighttime temperature = $21.730 + 0.002494\,t - 0.000000\,t^2$ and that of daytime temperature = $34.078 + 0.003037\,t - 000002\,t^2$. The study revealed a decreasing trend in rainfall at a rate of 4.4% per decade. Daytime temperature was increasing at a rate of 0.30% per decade and nighttime temperature was increasing at 0.25% per decade. The annual and decadal trends in rainfall were decreasing but not significant ($R^2 < 50$). There were also several outliers suggest that many factors such as temperature, humidity, evaporation, and vegetation contribute to the amount of rainfall recorded in a locality. Day and night temperatures were increasing ($R^2 > 50$) with the night temperatures increasing more than the day temperatures. The higher increase in night temperature would reduce the number of cold nights in the Upper East Region.

There was variation in rainfall throughout the months. The seasonal analysis indicated that rainfall reduces from October to April as shown by the negative signs, but the amount of decrease varies in terms of magnitude. The variation show 7 months of low rainfall in the region. The months of May–September have positive indices and indicate that those months are ideal for rain-fed agriculture. The highest rainy month is August where the rain intensity is high and flooding could result. Nighttime temperature is highest in March–July. The variation in day temperature in the Upper East Region was similar throughout the months of the year. The projections in to the future show that the decreasing trends in rainfall though not significant would continue in to the future. Also, the increasing trends in temperature would not see any decrease in the shortest possible time. The increase trend in both night and day temperatures would continue into the future.

It is therefore recommended that climate change policies are actively incorporated in all their developmental plans. For example, water harvesting can be promoted for irrigation to supplement rain-fed agriculture in the region.

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