

*Research Article*

# Impact of Climate variability and change on agricultural productivity in the three northern regions of Ghana

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**Abstract:**

Agriculture in the three regions of the north is mainly subsistence and rain-fed with very limited irrigation facilities. Traditional approach to agriculture in the region is therefore being threatened by erratic rainfall, high temperature, drought and floods due mainly to a changing climate. This research, therefore, examines the climate in the Upper West, Upper East and Northern regions and its impacts on agriculture productivity. It began with an extensive desktop study and the collection of rainfall and temperature data from 1961-2010 from the three regions. The data was analyzed to determine the rainfall and temperature trends and their significance using XLSTAT software and basic statistical tools and subsequently tested with the Modified Mann-Kendal's test to confirm the increasing or decreasing trends and their significance. The results showed that the climate is changing with an increasing temperature and decreasing rainfall trends across the three regions. The test also confirmed a significant increase in temperature but no trend in rainfall at 95% level of confidence. The change in the climate is also observed to have significant impact on agriculture. The knowledge in the climate variation and change will be relevant to decision and policy makers, farmers, water users, water providers, NGOs and students as a whole. The research was concluded with suggested strategies as policy options to help improve climate change adaptation and agricultural productivity.

**Keywords:** climate change; agriculture productivity; temperature; rainfall; trends

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## 1. Introduction

The issue of climate change has become a global phenomenon and every effort is being made to address the menace. At the Copenhagen Accord, a temperature rise below 2 °C by the end of the century was agreed on and member countries are expected to step up measures to reduce GHG emissions [1]. Already a temperature rise beyond the 2 °C is possible and it's being predicted that a temperature rise of 4 °C by the close of the century is very likely [2]. African countries will mostly be susceptible to a temperature rise beyond 2 °C due to the high sensitivity to more frequent extreme events on the continent [3]. Various studies have confirmed that there is a rising temperature and a declining rainfall in many part of sub-Saharan Africa due to climate change. Climate change is predicted to cause wet areas to get wetter leading to floods while arid and semi-arid areas as in the continent of Africa and Asia becoming dryer resulting in water shortage and scarcity [4]. Research in West Africa also shows that a significant warming between 0.5°C and 0.8°C from 1970 to 2010 had occurred with the last 20 years having high degree of change [5].

Admittedly, temperatures have been increasing significantly across the continent of Africa and it is expected to increase the more if measures are not put in place to address the challenges of Green House Gases (GHGs). Rising temperature is mainly as a results of increased concentration of GHGs most especially carbon dioxide (CO<sub>2</sub>). Carbon dioxide is the most important GHG that is increasing in concentration in the atmosphere due to human activities and has contributed over 70% of the enhanced GHE until now with methane contributing about 24% [6]. Carbon dioxide is a good absorber of infrared radiation, absorbs some of the terrestrial infrared radiation that would normally have escaped to outer space and cause warming in the atmosphere [7]. Its concentration creates a thickening layer of pollution in the atmosphere, trapping in infrared radiation (heat) which eventually causes global warming [8] and warmer atmosphere is able to hold more water vapour thus increasing the rate of evapotranspiration from soils, plants and water surfaces. It is projected that temperature at the end of the 21 century in West Africa will increase between 3°C and 6°C above the 20<sup>th</sup> Century records which is far above the 2°C proposed by Intergovernmental Panel on Climate Change [9, 10]. The African continent is likely to suffer the most from the changing climate due to harsh climatic conditions, high exposure and weak adaptive capacity coupled with inadequate and unreliable observational data set to deal with climate change. This rising temperature will necessitate high potential evapotranspiration and decrease rainfall availability leading to severe droughts in the tropical regions. The temperature is expected to continue to rise due to the continuous release of CO<sub>2</sub> into the atmosphere. IPCC [4] has predicted a temperature rise ranging from 2 to 6 °C by 2100 together with higher CO<sub>2</sub> concentration changes and this will have direct impacts on plant growth and development. In Sudan-Sahel region, increased temperature by 1-3 °C will result in decrease precipitation by 0-5%, and 0-10% decrease in soil moisture content [11]. Rising temperature will precipitate high surface air temperatures, greater evapotranspiration, and lower soil moisture, alter rainfall distribution, affect river flows, and ground water levels which will result in increasing frequency of drought and floods. It will affect water and soil temperatures resulting in thermal habitat of aquatic species, cause changes in species composition, stability and food web dynamics of aquatic ecosystems [12].

The warming of the atmosphere therefore causes a negative repercussion on agriculture and water availability. According to [13] the rate of evapotranspiration and water-holding capacity increases with an increase in temperature in the atmosphere and this encourages intense rainfall and drought. Warmer atmosphere is able to hold more water vapour thus increasing the rate of

evapotranspiration from soils, plants and water surfaces.

The health implication of climate change due to high temperatures is quite damaging as its been observed that the direct effects of increased heat stress and air pollution on human health will probably outweigh impacts resulting from complex changes in the ecosystems and altered patterns of diseases [14]. Storms, wild fires, floods and heat waves are likely to cause death in many countries, mental illness among farmers who lose their livelihood through drought and malnutrition among children due to inadequate food production, [15]. Pearce *et al.* [16] who estimated that with temperature variations between 2-3 °C, the effect on world GDP was going to decline between 1.5-2% in the year 2100. The research is thus to examine temperature and rainfall variations and how they will affect farming activities in the three regions.

### **Climate variability and change scenarios in Ghana**

Ghana is not immune from the challenges of climate change and thus every effort is needed for its mitigation and adaptation. Several climate model projections clearly show signs of climate change and confirm Ghana's vulnerability even though the predictions primarily vary [17]. Temperatures in Ghana are observed to have risen by about significantly since 1970 and within the same period rainfall and runoff were also recorded to have declined by about 20% and 30% respectively [18]. Mean annual temperature changes in Ghana will rise by 0.8, 2.5 and 5.4 and 0.6, 2.0 and 3.9 °C in the semi deciduous and evergreen rainforest zones in 2020, 2050 and 2080 respectively [19]. Climate variability and change will affect the socio-economic conditions of many African countries including Ghana. According to the Global Facility for Disaster Reduction and Recovery [20], Ghana is ranked high among African countries most exposed to climate related risks such as floods, droughts, coastal erosion, pest infestation, urban hazards and landslides especially in the 3 northern regions of Ghana. It is therefore very important that anti-climate change measures are taken to solve the challenges. Adaptation measures such as water harvesting, integrated water resource management could help make water available for consumptive and non-consumptive purposes in Ghana. Research has shown that impoundment of small-scale runoff and improved soil conservation practices could boost agricultural production in Africa in view of the present and future climate variability [21]. Floods waters can also be diverted into ponds, dams, underground recharge zones instead of allowing the floods to cause irreparable damage to properties and human life. Research has already predicted the challenges developing countries are going to face in future due to climate variability and change. In arid, semi-arid and low income countries where rainfall and stream flow are concentrated over a few months with high yearly variations will be more vulnerable to climate variability [22] thus this calls for stringent measures to address the issues of climate change before the situation gets out of hand.

## **2. Materials and Methods**

### **2.1 Description of the study areas**

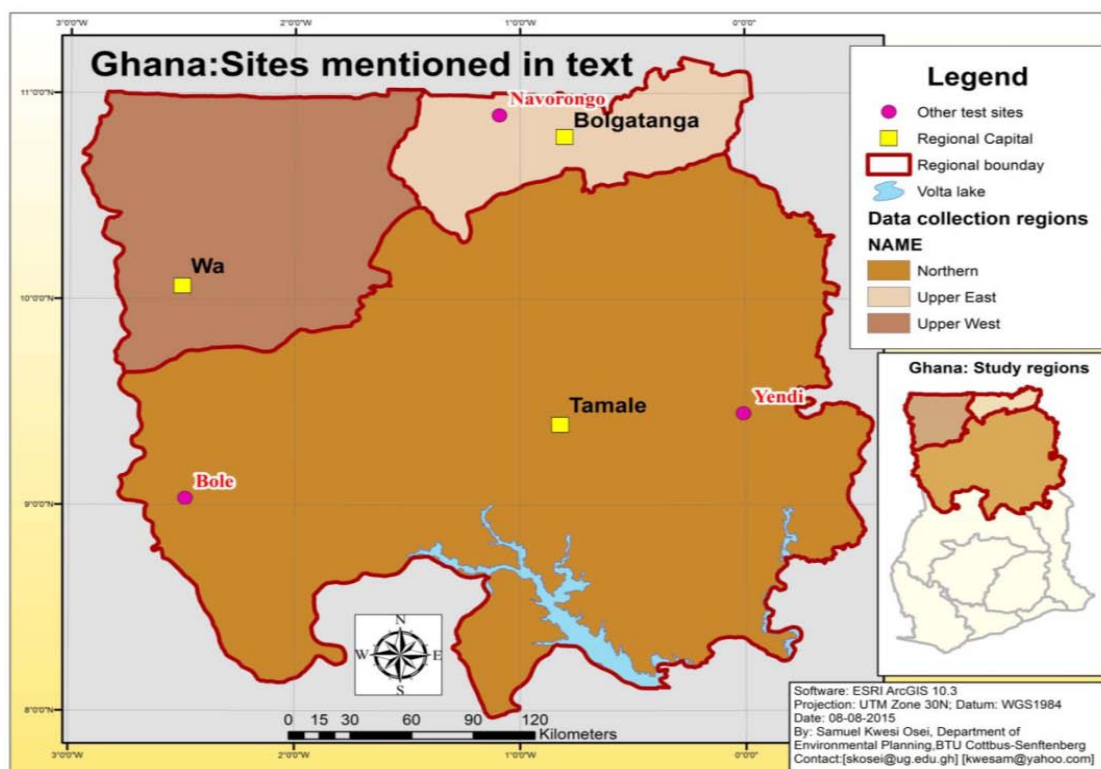
The research was carried out in the three regions of the north. All the three regions were once one region with the capital Tamale. In 1960 the region was divided into Northern and Upper regions and was further divided into Northern, Upper East and Upper West in 1983. In 2019, the region was further divided into five regions but the research will focus on the three earlier regions. The three regions lie in the Sudan-Guinea Savannah stretch with similar cultural and climatic

conditions. The vegetation in the areas is mainly a closed and open savannah woodland, and grassland with scattered trees such as shea, dawadawa, baobab and some mango trees because of their drought resistance nature. The regions are mainly agrarian with about 95.1% of all the agricultural households engage in crop farming [23]. On the average, about 75% of the population live in the rural areas and depend on agriculture for their survival (Table 1). Unfortunately, the three regions are said to hold 53.7% of Ghanaians living in extreme poverty, but only 17.2% of the total population of Ghana with average growth rate of about 2.0% [17]. The regions are most impoverished and disadvantaged with very harsh weather conditions and therefore vulnerable to the changing climate as compared to other regions.

**Table 1** Summary of the characteristics of the three northern regions

Regions	Area (km <sup>2</sup> )	Population	Urban	Rural	Growth rate	Avg. HH size	Agric.
Upper West	18,476	702,110	16.3%	83.7%	1.9%	6.2	72.3%
Upper East	8,842	1,046,545	21%	79%	1.2%	5.8	70.1%
Northern	70,384	2,479,461	30.3%	69.7%	2.9%	7.7	73.3%

Adapted from [23].



**Figure 1** Map showing the study areas, courtesy Mr. Samuel Osei

## 2.2 Data collection and analysis

Data from three synoptic weather stations in the UWR, UER, and NR were gathered from the Ghana Meteorology Agency (GMET) which is mandated to establish, organize and manage surface and upper air observational station networks; collect, process, and disseminate meteorological information nationally and internationally (GMET, ACT 2004). Climate data from 1961 to 2010 with observed mean maximum and minimum monthly temperatures, and average monthly rainfall data were collected from the three regions. The data gathered were analyzed with XLSTAT software and basic statistical tools to determine the temperature and rainfall trends of the data series. The Modified Mann-Kendall test was also used to test and confirm the rainfall and temperature trends of the data series to determine the significance of the decreasing or increasing trends.

### **2.3 Rainfall and temperature anomalies**

The temperature and rainfall anomaly is the difference between a calculated average or reference temperature or rainfall and the actual figures observed. It is the deviation from mean of which an average of 30 year or more data series of temperature and rainfall is calculated. The 30 year average temperature and rainfall from 1961 – 2010 was taken to calculate the baseline value for the measurement of the rainfall and temperature anomalies. The anomaly describes the variations in climate more accurately over a large area than the absolute data measured. When the anomaly is positive, then there is an increase in temperature or rainfall and vice versa. The anomalies for rainfall and temperature were then plotted against the years and the trends determined. This method is mainly used in climate change studies by climatologists and supported by World Meteorological Organization (WMO). It is used because the actual temperature and rainfall measurements are sometimes difficult to gather in order to provide the true reflection of the events due to lack of adequate measurement stations. In Figure 2, 3 and 4, the rainfall and temperature anomalies of the three regions were plotted against the number of years from 1961-2010. A trend line was also employed to determine the trends of the graph.

### **2.4 The Mann-Kendall's test**

The Mann-Kendal's test is also used widely for the analysis of trends in climatology, hydrology and environmental time series [24]. It is also used to identify trends in a data series and to determine the significant of the trend lines and the detection of precipitation and temperature trends [25, 26]. It uses the null hypothesis ( $H_0$ ) and the Alternative hypothesis ( $H_1$ ) where the null hypothesis ( $H_0$ ) suggests that there is no trend in the data series and the alternative hypothesis ( $H_1$ ) shows that there is a negative or positive trend in the tests. The Modified Mann-Kendall's test was performed on rainfall and temperature data from 1961-2010 for each region of the three regions to test the actual trends and their significance.

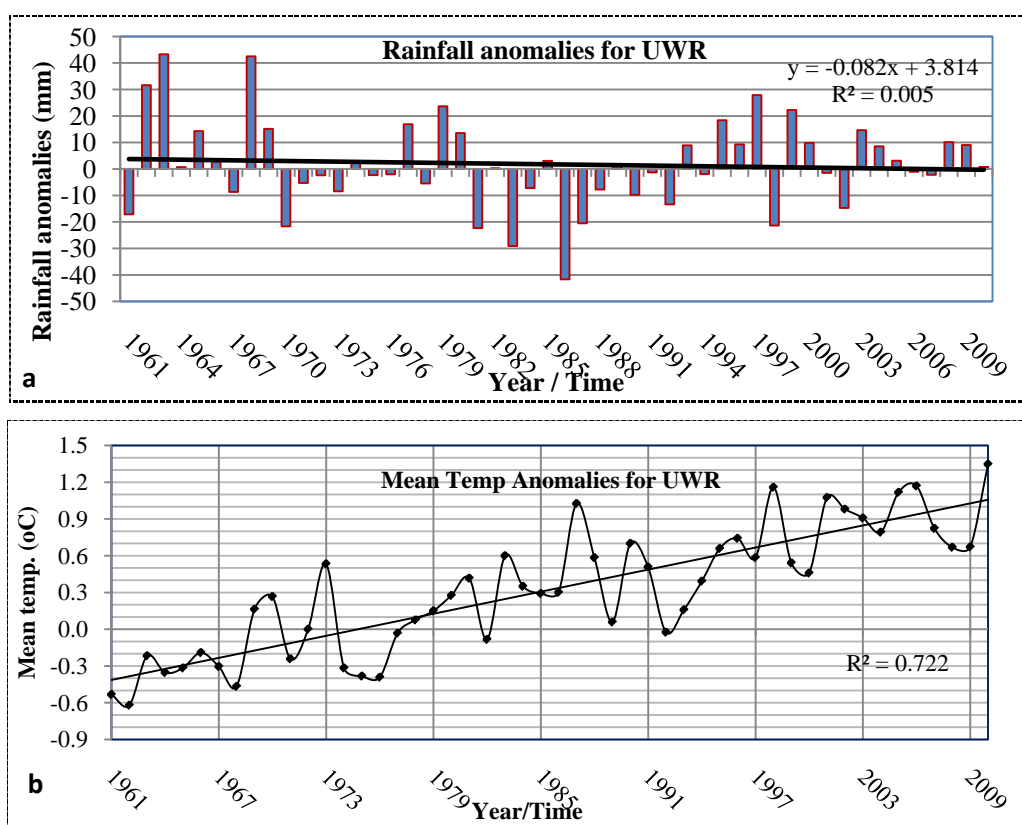
## **3. Results**

### **3.1 Rainfall and temperature trends for the three regions**

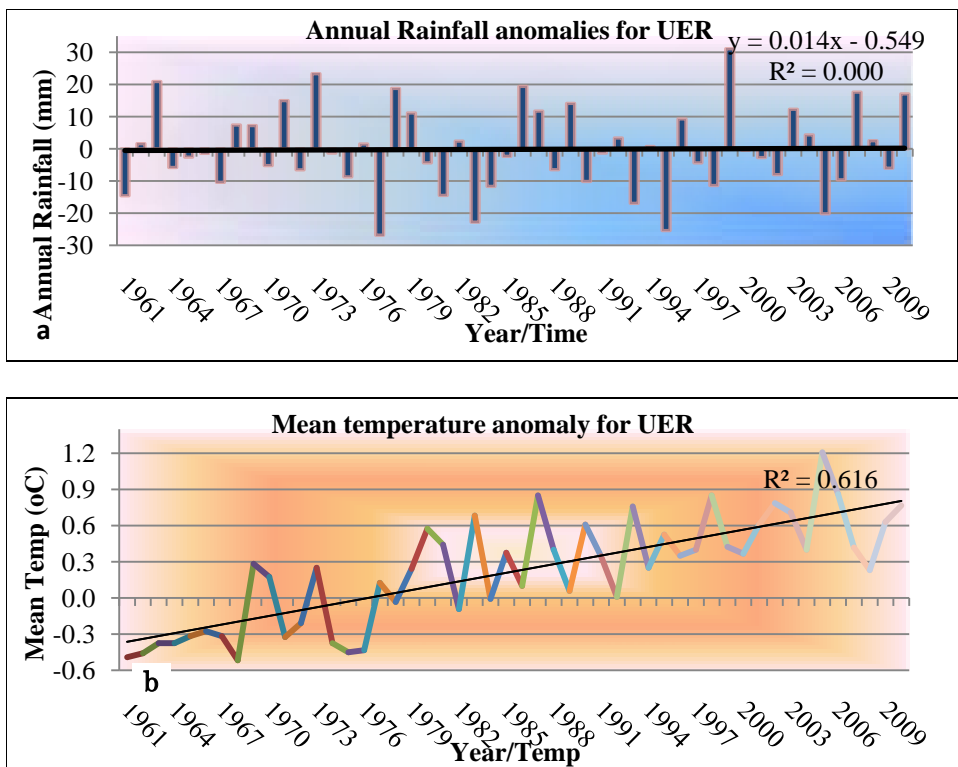
The rainfall anomalies were plotted against the years for each of the three regions. The results indicate a decline of rainfall from 1961-2010 for all the regions. The trend line shows clearly

that there is slight reduction of rainfall across the regions. For the temperature, the trend line shows an increase in temperature over the same periods. To confirm the increasing or decreasing trend of the rainfall and temperature events and their significance, the Mann-Kendall's (M-K) test was performed on the rainfall and temperature data from 1961-2010 using XLSTAT software. The test shows that there is no trend in the rainfall data series at 95% confidence level and the slight decrease in rainfall is not statistically significant (Table 3). However, the test of the temperature shows that there is a positive trend in the data series and the trend is statistically significant and shows evidence of increasing temperature for the three regions (Figure 2a, 3a and 4a). The variations in rainfall and temperature differ from one region to the other. The decline in rainfall is more visible in the UWR followed by the NR with UER being the least. For the temperature, it shows increasing trend across all the regions (Figure 2b, 3b and 4b) and the test indicate a statistically significant evidence of increasing temperature for all the three regions (Table 3).

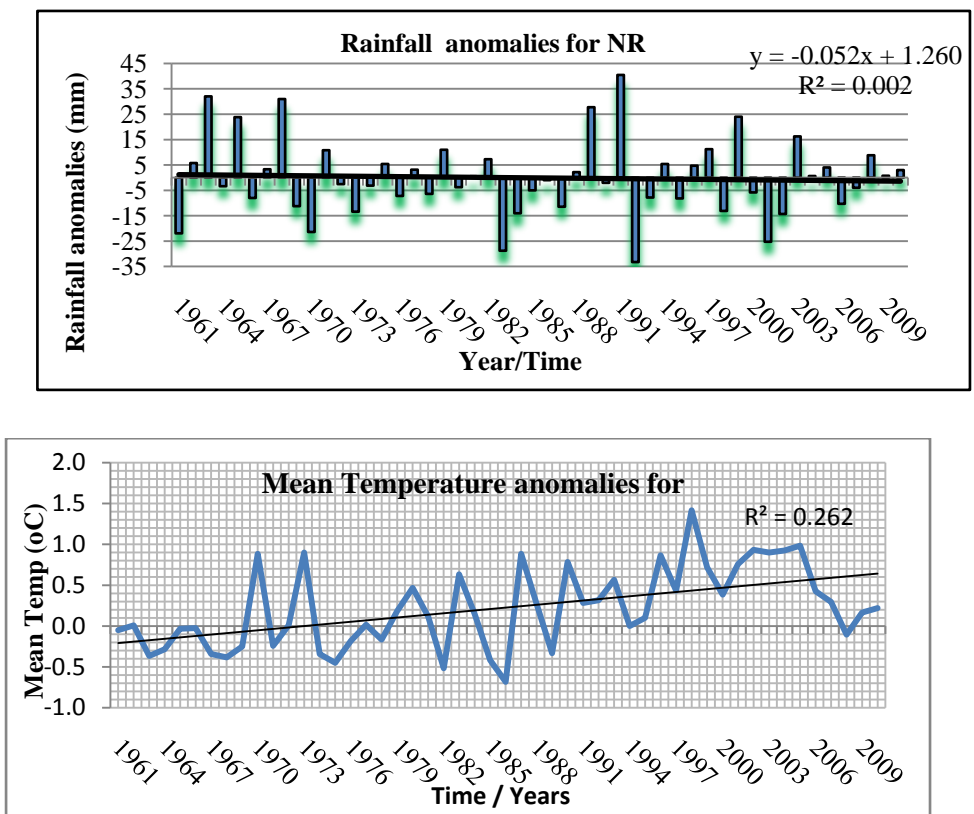
The minimum, maximum and average rainfalls from 1961- 2010 for the three regions are as shown in Table 2.



**Figure 2** Average annual rainfall and temperature anomalies (1961-2010) for UWR



**Figure 3** Average annual rainfall and temperature anomalies for UER (1961-2010)



**Figure 4** Average annual rainfall and temperature anomalies for NR (1961-2010)

**Table 2** Maximum, Minimum and Average rainfalls for the 3 Northern regions for 1961-2010

	Minimum	year	Maximum	year	Average
<b>NR</b>	695.3mm	1992	1579.8mm	1991	1,093.4mm
<b>UWR</b>	523.7mm	1986	1,542.8mm	1963	1,043.0mm
<b>UWR</b>	670.5mm	1977	1,365.3mm	1999	990.2mm

**Table 3** Mann-Kendal's test showing rainfall and temperature trendsMann-Kendall's test results for rainfall

Region	M-K Statistics (Z)	Kendall' tau ( $\tau$ )	Var (S)	P-value (2-tailed test)	Sen's slope	Alpha $\alpha=5\%$	Test Interpretation
UWR	-8	-0.007	0.000	0.952	-0.018	0.05	Accept Ho
UER	-20	-0.017	13456.667	0.870	-0.035	0.05	Accept Ho
NR	-54	-0.046	0.000	0.650	-0.059	0.05	Accept Ho

**Table 4**Mann-Kendal's test results for temperature

Region	M-K Statistics (Z)	Kendall's tau ( $\tau$ )	Var (S)	P-value (2-tailed test)	Sen's slope	Alpha $\alpha=5\%$	Test Interpretation
UWR	761	0.647	13457.667	< 0.0001	0.03	0.05	Reject H <sub>0</sub>
UER	664	0.566	13454.667	< 0.0001	0.023	0.05	Reject H <sub>0</sub>
NR	545	0.464	13457.667	< 0.0001	0.019	0.05	Reject H <sub>0</sub>

## 4. Discussion of results

### 4.1 Rainfall variation

Analysis of the climatic data from 1961-2010 from the three northern regions also showed a decrease in rainfall pattern even though the change is not significant to cause water challenges if water is harvested and managed appropriately. However, erratic and unpredictable rainfall variations have been a major challenge for farmers in Ghana including the three regions. Water is very important for farming activities and without it there will be no agriculture. Fortunately, farmers in Africa have very good knowledge of rainfall and temperature variations through past experience [27, 28] and have developed strategies to continue food production. However, the variations in rainfall coupled with other climatic conditions will surely affect food production and income of small holder farmers. According to [29] there has been a decrease in annual precipitation until the 1960s with a decline of 20% to 40% between 1931 to 1960 and 1968 to 1990 respectively in West Africa which is in line with what has been observed. Such situation will therefore have serious impact on water resources which will intend affect food production and availability. Increase in population and climate change will cause high water stress and drought [22, 30, 31, 32].Drought will essentially affect groundwater recharge and storage and this will have significant impact on those who depend on boreholes and dug-out wells for agriculture and water



supply. Ghana was predicted to become water stress by 2015 and truly, there have been pockets of water shortages across many parts of the countries including water for agriculture. Water stress and drought will impact negatively on water for domestic, irrigation and industrial purposes [33]. Agriculture performance depends directly on the climate and negative changes such as rising temperature and declining rainfall will adversely affect agriculture productivity including processing, transportation, storage, preservation and consumption [34].

These changes in temperature and rainfall will, in no small way, negatively affect irrigation water resources and agricultural output in the regions, Ghana and Africa as a whole [35]. It is estimated that by 2050 demand for food will increase by 2 ½ -3 times the current production [36] which means African countries must really change their agricultural production strategy, water management and adopt new farming systems if they want to avert malnutrition, hunger and poverty. The country therefore requires stringent measures to protect all water bodies and adopt rain water harvesting principles and integrated water resource management as adaptive measures for climate change.

#### **4.2 Temperature variation**

The rising of global temperature leading to global warming which subsequently results in climate variation and change has become more prominent than it used to be. There are several scientific publications that point to the fact that there is rising temperature globally and this has been attributed to the increasing emissions of greenhouse gases into the atmosphere. The analysis of the climate data from 1961-2010 of the three regions (UWR, UER and NR) indicates a significant increase in temperature which agrees with other research findings [2, 4, 31, 37]. The rising temperature, however, differ from region to region. The consistent rise in temperature will affect almost the economy of both temperate and tropical countries in terms of lower productivity as observed by [38] and affect world GDP [39]. High temperature will result in high evapotranspiration which will affect agricultural output with its concomitant challenges such as crop failure and poor yields leading to malnutrition, hunger and poverty as discovered by [13]. Irrigation dams will not also be spared from droughts from surface and groundwater as suggested by [40] and this will further push irrigated farmers out of work. The impact of rising temperature will be more prominent on the African continent with frequent extreme weather related events [2] such as heat waves, drought and floods among others and these conditions will have negative influence on agriculture. The rising temperature in the three northern regions therefore requires an urgent need to adopt measures that will facilitate climate change mitigation and possible adaptation and to ensure sustainable agricultural development in the region and Ghana as a whole.

### **5. Conclusion and Recommendations**

The research has clearly confirmed the rising temperature in the three northern regions and a slight decline in rainfall. Even though the decreasing rainfall is not statistically significant, the slight changes coupled with the increasing temperature will have significant impact on soil environment for plant growth. These variations in rainfall and temperature will affect agricultural productivity and impact negatively on the livelihood of the small holder farmers. Rising temperature will increase evapotranspiration and thus cause water stress and wilting in plants. It will also alter precipitation in time and space; affect both surface and groundwater availability and

trigger floods and droughts. Such situations will threaten sustainable agriculture and eventually lead to food shortages with its attendant hunger, malnutrition and poverty among farmers. Unfortunately, agriculture in Ghana is mainly subsistence and rain-fed dependence thus changes in the climate will affect farming activities from planting, harvesting, processing and storage of farm produce. It is therefore very important that an integrated water resource management approach including water harvesting methods is adopted to warrant continuous crop production all year round. Appropriate measures to mitigate the impact of climate change and strategies for climate change adaptation should be employed to help the farmers cope with the changing climate otherwise such stresses will push small scale farmers into abject poverty. The following measures are further recommended:

- 1) Government should come out with policies that will involve organizations, communities, youth groups and individual citizens to be part of the climate solution. Every individual, in one way or the other, can make a difference.
- 2) Strengthen capacities of universities and research institutions to undertake research for climate change adaptation.
- 3) Education on the need for water harvesting and integrated water resource management should be intensified
- 4) Provision of adequate irrigation facilities to help address water deficit for farmers to continue food production all year round.

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