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Rising Temperature and Declining Rainfall – a Threat to Water Security in Northern Region of Ghana

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

This research provides an insight into the threat of water resources in the northern region due to rising temperature and declining rainfall with the broad objective of analysing temperature and rainfall trends and their significance. A 50-year climate data from 1961-2010 on temperature and rainfall was analysed to determine the trends using temperature and rainfall anomalies (deviation from the mean) as suggested by the World Meteorological Organization (WMO). The data series was further subjected to Mann-Kendal test to confirm the trends and their significance. The data was analysed using Microsoft excel and XLSTAT software. The results showed an increasing temperature and declining rainfall trends of the anormalized data and this was confirmed by the Mann-Kendal's test. The Mann-Kendal's test shows that there is no trend in the rainfall data series even though rainfall is declining which means that the evidence is not sufficient to conclude at 95% level of confidence that a trend exist. However, there exist increasing

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temperature trends of the data series. Additionally, the trend in declining rainfall was found to be statistically insignificant while the temperature trend was statistically significant. The research which was concluded with suggested strategies to avert water scarcity in the mist of climate change will be relevant to decision and policy makers, water users and providers as well as NGOs and other stakeholders.

Keywords: Rising temperature; declining rainfall; water security; climate change; drought.

1. INTRODUCTION

Water is an indispensable commodity and a basic right but its regular supply and accessibility have been a matter of concern in Ghana most especially those in the north. The lack of adequate water sources, rising population, poor piping and infrastructural systems, water mismanagement and illegal connections coupled with drought and pollution have resulted in the intermittent supply of water in the region. According to UNICEF [1] one- third of urban water supply in Africa, Latin America and the Caribbean and more than ½ in Asia are operating intermittently during periods of drought. In 1990 about 1.1 billion people lacked access to safe drinking water [2] and this figure has risen exponentially. UNESCO also estimated that 1.7 billion or a third of the world population lives in areas where there is water scarcity and this figure is projected to grow to 5 billion by 2025 due to population growth [3]. According to Boko et al. [4] about 25% of the population in Africa are presently having extreme water stress and a projected 75-250 million and 350-600 million people in Africa will experience water stress by 2020 and 2050 respectively possibly due to drought. Considering the current trend of water usage in many countries, it is estimated that at least 3.5 billion or 48% of the world projected population will live under water-stressed with 2.4 billion living under high water stressed conditions [5]. For this reason, there is the need for developing nations to build a climate resilient economy, consider adaptation and mitigation strategies, and adopt integrated water development management and application approach to cope with the increasing population and climate variability (ibid).

Despite the growing challenges in the water sector, climate change has become another threat to the people in the region. It is estimated that shrinking surface and underground water resources will expose 90-220 million people to water stress in Africa due to climate change. Rainfall will decline by 20-30% and groundwater recharge will also reduce by 5-22% by 2020 [6]. Climate change will affect water flow and extent dry season spells in arid and semi-arid regions which will affect the reliability of reservoirs or deep groundwater wells [7]. According to Sanders et al. [8] climate change is expected to cause decline in future average water availability and an increase in the frequency of extreme events such as drought especially in Sub-Saharan Africa. Giansante et al. [9] and Galaz [10] therefore stressed on the need for both infrastructural investment and institutional change to address drought related stresses, flood events, water quality issues and growing demands.

Water demand will increase even without climate change due to high population growth rates and this will cause decline in per capita water availability especially in Africa [11]. High population and poor water management coupled with climate variation will cause water stress and affect the ecosystems on which life depends. It is estimated that ¼ of the global population lives in coastal regions with rapid population growth and water scarcity [12]. Population growth and economic development over the next few decades will probably outweigh climate change in terms of per capita water availability despite the effect of climate change on the elements of the hydrologic cycle [13]. These revelations of dwindling water resources and climate change require a research into the water and climate situations in the region to inform policy makers and opinion leaders on the need for integrated water resource management in the region. The northern region is plagued with poverty and under development coupled with very harsh weather condition and these challenges are already a disadvantage to the well-being of the people. The region also lies in the Sudan Savannah belt closed to the dry Sahel and suffers from water related stresses. According to Srivastava et al. [14] dry-land ecosystem such as the northern region has most of the rainwater lost through direct evaporation from the soil, runoff and drainage. This research is therefore to provide insight into the threat of water resources in the northern region due to rising temperatures and declining rainfall with the broad objective of analysing temperature and rainfall trend and their significance in the northern region and how this situation could affect water resources in the region.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The northern region is the largest region closed to 1/3 of the total land area of Ghana. It is bordered by the Upper East and Upper West to the north, Brong Ahafo and Volta to the south. The region consists of 13 districts with Tamale being the regional capital. The region is semi-arid and has the largest landmass of 70,384km^2 which represents about 29.5% of the total land area of Ghana. It is one of the fastest growing regions in Ghana with a growth rate of 2.9%. The population is 2,479,461 with 750,712 (30.3%) and 1,728,749 (69.7%) living in the urban and rural areas respectively [15]. The region has a single rainy season and the climate is relatively dry. The annual rainfall figures ranges between 750mm to 1050mm with the average temperature ranging between 22℃ in the night and 35℃ during the day with very low relative humidity. The region is characterized by the Guinea Savannah woodland, grassland and drought resistance trees such as shea, dawadawa and neem trees. The main source of energy for cooking is wood fuel and charcoal and it is estimated that about 84% and 11.7% use wood fuel and charcoal as their main source of energy for cooking in the region respectively [16]. There is lack of significant industrial activities in the `region and the economically active population engages in subsistence and rain-fed agriculture with about 73.3% fully engaged in farming, hunting and forestry.

2.2 Temperature and Rainfall Anomalies

Temperature anomalies (deviation from the mean) are used to determine the trend in temperature and rainfall data series. A long-term temperature average of 30 years (1961-1990) is calculated as the expected measurement (reference value) and compared with the observed values as suggested by the World Meteorological Organization (WMO). The anomalies are the differences between the long-term average temperature (reference value) and the temperature that is actually occurring. The anomalies provide the best method to estimate changes in rainfall and temperature over large regions and also serve as a frame of reference for easier analysis of climate data due to lack of adequate weather stations.

2.3 The Mann-Kendall's Test

The Mann-Kendall's test is also used to determine the significant of the trend lines. It is non-parametric and formulated by Mann [17] to identify trends in a data series. It is widely used for the analysis of trends in climatology [18,19,20], hydrology and environmental time series

[21]. The XLSTAT software was used to perform the classical Mann-Kendall's test with the assumption that the observations are independent and identically distributed. The Mann-Kendall test applies the null hypothesis (H_o) and the Alternative hypothesis (H_1) in its analysis. The null hypothesis H_o suggest that there is no trend in the series while the alternative hypothesis (H_1) indicates that there is a trend in the tests. The software uses the normal approximation to the distribution of the average Kendall tau to calculate the p-value of the test.

The Mann-Kendall test follows a standard normal distribution (Z) where a positive value of Z signifies an upward trend and vice versa. A significance level alpha (α) is also used in a two-tailed test to determine the trend and significance of the series. If Z appears greater than $Z_{\alpha/2}$ where α depicts the significance level, then the trend is considered significant. A detailed analysis of the Mann-Kendal equation, however, is out of scope of this paper.

2.4 Data Collection and Analysis

The northern region being the largest region in Ghana has three synoptic stations namely Bole, Tamale and Yendi. Monthly observed maximum and mean temperatures, and average monthly rainfall data from 1961-2010 at the three synoptic weather stations were collected from the Ghana Meteorological Agency (GMET) in Accra.

The climate data were converted into temperature and rainfall anomalies which were used to plot the graphs with the trend lines using Microsoft Excel 2007. The mean temperature (mean T) and average rainfall for each synoptic station were plotted on one graph (Fig. 1). Trend lines were then drawn through the graphs to determine the temperature and rainfall variations. The data was further subjected to Mann-Kendal test to confirm the trends and their significance using Addinsoft's XLSTAT 2012 software. The null hypothesis was tested at 95% confidence level for both temperature and rainfall data series. The interpretation of the output of the test was either to accept H_o or reject H_o (Table 1).

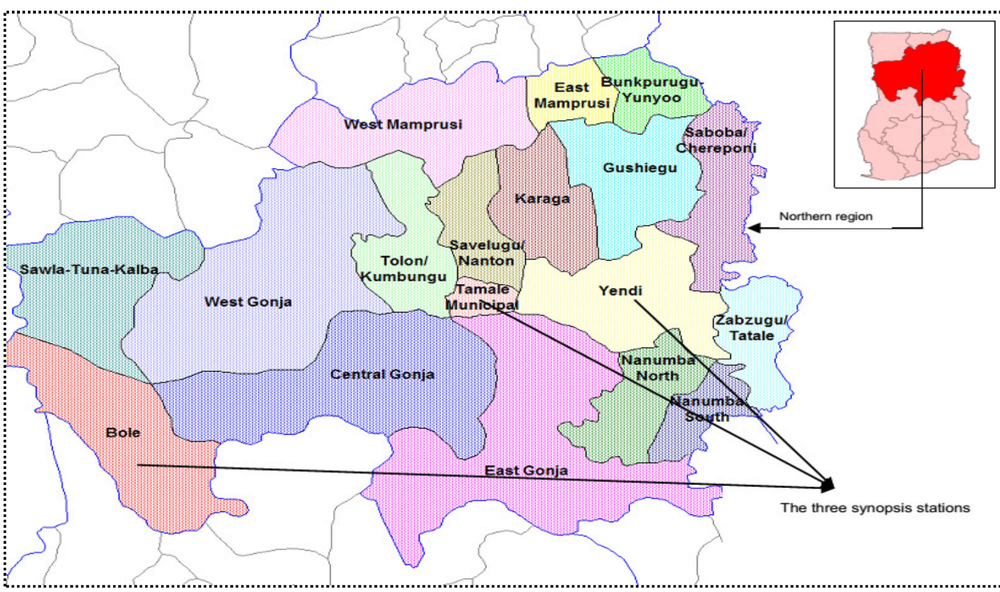


Fig. 1. Map of the study area (Northern region)-Google maps

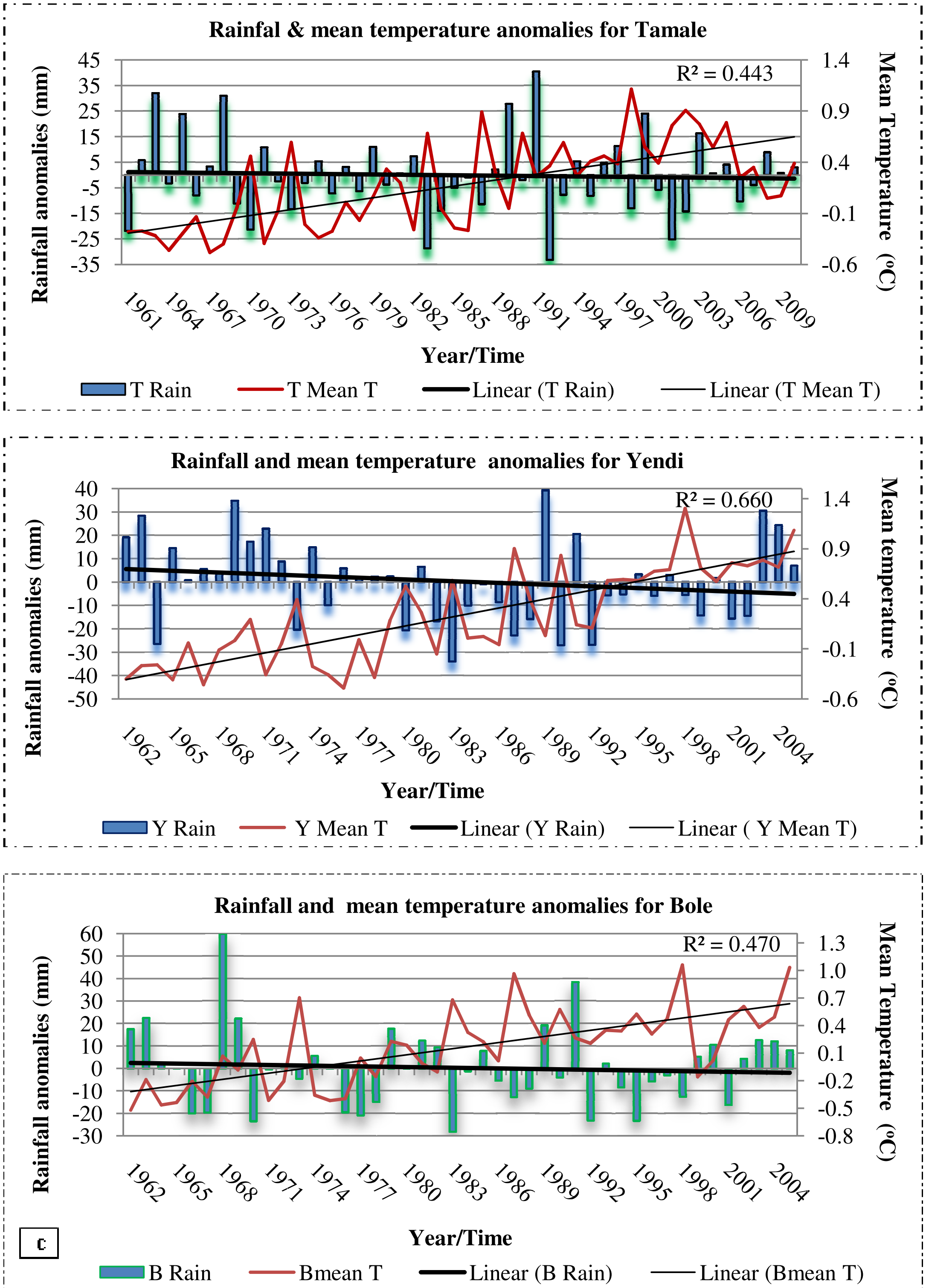
Table 1. Mann-kendall's test results for rainfall and temperature

District	M-K statistics (Z_s)	Kendall' tau (τ)	Var (S)	P-value (2-tailed test)	Sen's slope	Alpha α=5%	Test interpretation
Rainfall output							
Tamale	-54	-0.046	0.000	0.650	-0.059	0.05	Accept H_o
Bole	34	0.029	0.000	0.777	0.033	0.05	Accept H_o
Yendi	-104	-0.088	0.000	0.377	-0.223	0.05	Accept H_o
Temperature output							
Tamale	545	0.464	13457.667	<0.0001	0.019	0.05	Reject H_o
Bole	694	0.591	13456.667	<0.0001	0.026	0.05	Reject H_o
Yendi	641	0.621	11150.333	<0.0001	0.027	0.05	Reject H_o

3. RESULTS AND DISCUSSION

The graphs clearly shows a decline in rainfall for all the three synoptic stations with Yendi having more pronounced reduction in rainfall over the years. The T Rain, Y Rain and B Rain on the graphs indicate the rainfall plotted against time for Tamale, Yendi and Bole respectively while T mean T, Y mean T, and B mean T show the mean temperature of the stations against time. The regression lines indicate a gentle decline of rainfall in the region. The average rainfall observed in Tamale, Bole and Yendi over the period are 1093.4mm, 1104.4mm and 1244.2mm respectively. The regression lines of temperature for the three stations conversely showed an upward trend indicating an increase in temperature over the years (Figs. 2a, b and c). The regression coefficients (R^2) of temperatures in Tamale, Bole and Yendi are 0.443, 0.471 and 0.660 respectively with Yendi showing a moderately strong correlation.

The Mann-Kendall's test output as indicated in (Table 1), however, shows that there is no trend in rainfall at all the three synoptic stations in the Northern region even though the test statistics (Z_s) of Bole is positive the computed probability (p-value) remain greater than the level of significance (alpha (α) =5%). The null hypothesis H_o is therefore accepted indicating that there is no trend in rainfall. The graphs of the test output (Fig. 3) indicated a decrease in the rainfall of the region as in (Figs. 2 a, b and c) but such decline of rainfall is insignificant. The fact that the test shows no trend does not mean that rainfall is not decreasing but rather indicates that the evidence is not sufficient to conclude at 95% level of confidence that a trend exist or the rainfall is decreasing. The declining rainfall is, therefore, not statistically significant. Even though the test shows no trend and statistically insignificant but the decline is worth considering due to the harsh weather condition in the area coupled with the rising temperature. On the other hand, the test clearly shows a rising temperature in all the three synoptic stations of the region. The null hypothesis (H_o) is therefore rejected and the alternative H_1 is accepted indicating a trend in the data series. The output is similar to that of (Figs. 2 a, b and c) with clear indication of rising temperature trend across the three synoptic stations. The rising temperature is also found to be statistically significant. The Mann-Kendall's test has therefore confirmed the rising temperature which may lead to water stress in the region as indicated in (Figs. 2a,b and c).



Figs. 2a, b and c. Rainfall and mean temperature graphs for three synoptic stations

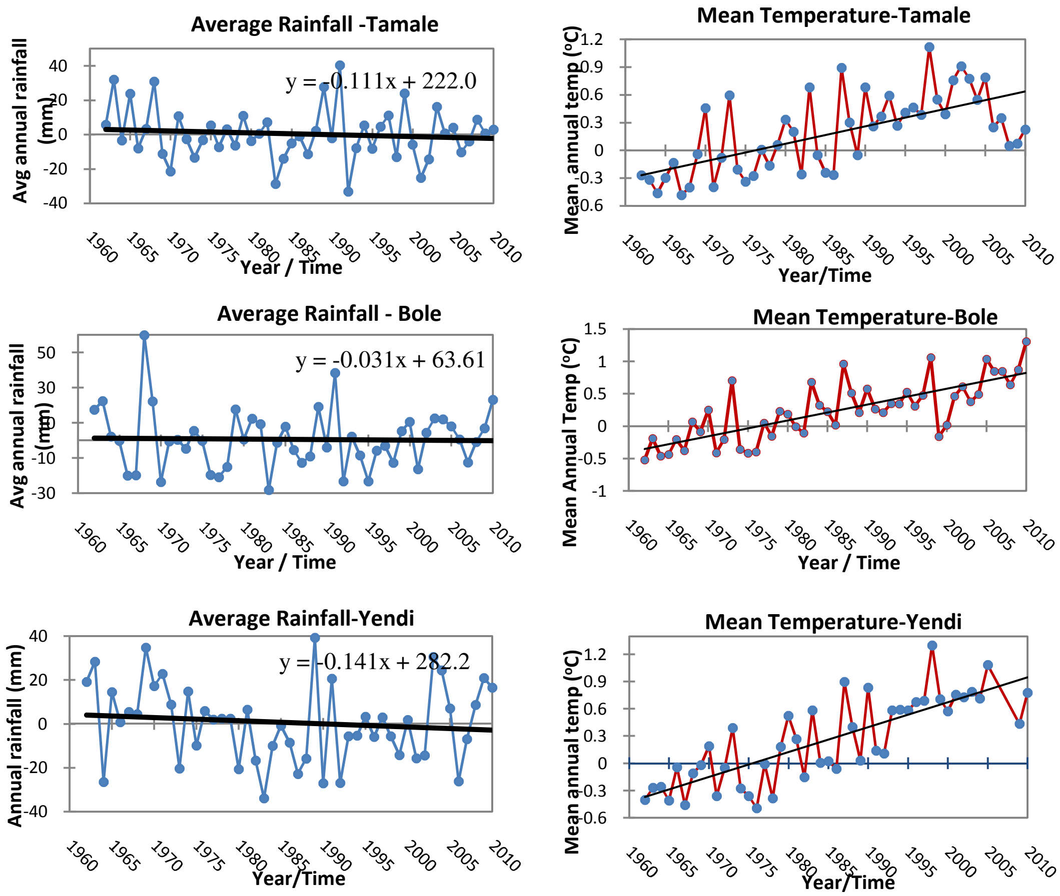


Fig. 3. Graphical output of Mann-Kendall's test for the northern region

The analysis of the climate data has shown an increasing temperature trend in the region which will result in higher evaporation of water bodies but may not be compensated due to declining rainfall trend. Higher evaporation will culminate into water shortages for domestic and irrigation purposes. Research has shown that higher temperature and lower rainfall due to climate variability will influence water flow and extend dry season spells in arid and semi-arid regions which will affect the reliability of reservoirs or deep groundwater wells [7]. The northern region which is one of the poverty endemic regions in Ghana [15] with very harsh weather conditions may experience worse scenario due to climate change. According to Philander [22] water resources in drier climates are more sensitive to climate change due to increasing temperature and this may result in high evaporation, low river flows and decline lakes and groundwater levels. The rise in temperature especially in tropical climate will increase evaporation from water and soil surfaces and transpiration from plants leading to water stress and droughts. Many research findings have already confirmed the impact of rising temperature and declining rainfall on water resources, agricultural yields and incomes of farmers [23,24,25]. Drought conditions have already been experienced in the region resulting in water scarcity. Trenvberth et al. [26] discovered that the rate of evapotranspiration and water-holding capacity increases with an increase in temperatures in the atmosphere which encourages intense rainfall and droughts. This situation may be responsible for the regular drought and occasional floods in the region. Higher temperature is also said to influence groundwater levels where the confining layer is thin [27] and this will affect borehole yields which is one of the major sources of water supply to the people in the north. Increased in temperature and declining rainfall in arid and semi-arid regions is one of the indicators of climate change which is predicted to have significant impact on agriculture, health and hydrology. All these precipitation and temperature variations are likely to cause water problems including floods [28], deterioration of water quality [29,30] among others.

4. CONCLUSION AND RECOMMENDATIONS

The research has confirmed an increasing trend of temperature and declining rainfall in the region which will affect water availability and accessibility. The lack of water in the region will bring untold hardship to the people. It will retard food production and worsen sanitation challenges. Water for domestic application will undoubtedly take precedence over water for irrigation when there is a water crisis and this will result in food insecurity in the region. The rise in temperature is so significant that it will create moisture imbalance due to higher evapotranspiration and rising population leading to water stress and drought. It is sad that the water that falls during the rainy season is allowed to escape without any deliberate attempt to harvest and store, and then start looking for water after the rainy season. 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. Already the continent is prone to drought even without climate change. Africa is the most arid continent in the world and thus will suffer from the effect of climate change leading to severe drought in the continent. It is therefore important that measures are taken to address the water situation in the region especially in the mist of climate change. Among the measures needed to ensure sustainable water availability and prevent the threat to water scarcity are:

4.1 Purposeful Rainwater Harvesting and Storage

The region has a total of over 1100mm of rainfall annually which should have been sufficient all for domestic and agricultural purposes if properly harvested and managed. The need for water harvesting cannot be overemphasized due to high evaporation, population growth and general demand for water for other applications. During the rainy season, water can be harvested and stored for use later and runoffs can also be rechanneled into irrigation dams and underground recharge zones.

4.2 Water Management and Conservation

Effective implementation of an integrated water resource management and conservation is principal to ensuring sustainable water availability in the region. The competition for water in several sectors of the economy may require specific management and conservation techniques for water availability in the future.

4.3 Protection of Water Bodies and Irrigation Dams

Water supply in the region is sourced from the White Volta and other irrigation dams and those who do not have access to direct water supply rely on boreholes which sometimes get dry during the dry season. It is therefore very important that river bodies and irrigation dams are properly managed and protected. Regular dredging and de-siltation of water bodies and dams in addition to the construction of new ones to harvest runoff water during rainy seasons are necessary steps to avoid water stress and drought.

4.4 Establishment of Legal Framework and Policy on Water Management

This is very important to ensure sustainable water management and usage. This will require the integration of water harvesting techniques in all building codes and protection of water resources in the region and the country as a whole. All water related organizations should create synergy for effective water management in the country.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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