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Small Reservoir and Shallow Groundwater -Crucial Inputs for Practical Adaptation of Agriculture to Climate Change in Volta River Basin-West Africa

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Abstract—This study reviews climate change in the Volta basin of West Africa and the practical adaptation of agriculture to climate change in the basin. Historically, the Volta River basin of West Africa has experienced a mixture of decades of drought and above average rainfall which have greatly affected agriculture. Of greater concern is the onset of the rainy season which will shift forward to later periods in the year about a month from April to May, early cessation dates of rainfall and reduction in length of growing periods. Shortening of the rainy season will affect rain-fed agriculture which is the dominant mode of food production in the basin. Future observations from climate models project precipitation and surface runoff in the Volta River basin to increase by 7% and 18% respectively with an increase in streamflow and ground water recharge. With projected increase in both surface and groundwater resources, water storage in the wet season through the use of Small reservoirs and Shallow ground water exploitation for dry season irrigation are two climate change adaptation mechanisms suggested to partially offset this negative effect. These to a large extent would represent essential inputs for accelerating agricultural adaptation to climate change in the Volta River basin of West Africa.

***Keywords*—Volta River Basin, West Africa, Climate Change, Adaptation, Small Reservoir, Shallow Groundwater.**

I. INTRODUCTION

Climate change is expected to impact significantly on global water resources. The degree and extent of climate change impact on socioeconomic development will differ from one region to another. According to the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), developing countries such as those in West Africa will be more vulnerable to climate change. The economies of West Africa in particular are predominantly built on agriculture, which is very sensitive to climate variability and change. Historically, the Volta basin of West Africa has experienced a mixture of decades of drought and above average rainfall which have greatly affected agriculture. Of greater concern is the early cessation date of rainfall and reduction in length of growing periods. Shortening of the rainy season will affect rain-fed agriculture which is the dominant mode of food production in the basin. The objective of this review is to have informed and up-to date knowledge on the present and future climatic trends and propose mechanisms aiming to address the issue of agricultural adaptability to climate change in the Volta River basin of West Africa.

II. STUDY AREA

The Volta river basin (Fig 1) is located in the semi-arid and sub-humid zones of West Africa. It lies between 5^{o}30N-14^{o}30N and 2^{o}00E-5^{o}30W. The Volta basin is about 400,000km^2; it is shared by six West African countries. 80% of the basin lies in Ghana and Burkina Faso and the remaining in Cote d' Ivoire, Mali, Togo and Benin. There are three major tributaries: Black Volta (147,000 km^2), White Volta (106,000 km^2) and Oti (72,000 km^2). The significant feature in the basin is Lake Volta which is one of the largest man-made lakes in the world and provides 90% of Ghana's electricity.

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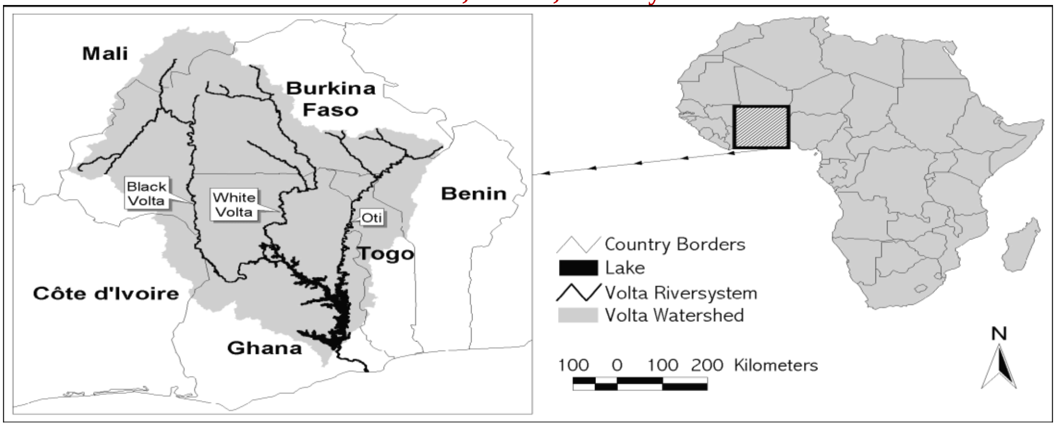

Fig 1. Map of Volta basin [1]

Average rainfall is 1000mm/year with distinct dry season (October-May) and Wet season (May-October). Annual mean temperatures range between 27°C and 30°C respectively with potential evapotranspiration ranging between 1,800mm-2,500 mm [2].

Table 1. Summary of the meteorological characteristics of the four major sub basins

Volta basin	Rainfall (mm)	Rainfall Coefficient of Variation (CV)	Pan Evaporation (mm)	Potential evapotranspiration(mm)
Black Volta	1,023-1,348	0.17-0.23	2,540	1,450-1800
White Volta	930-1,054	0.16-0.20	2,540	1,650-1,968
Oti	1,050-1,500	0.18-0.20	2,540	1,550-1,850
Lower Volta	876-1,565	0.17-0.35	1,778	1,450-1800

Source: Barry et al [3]

River discharge (Table 2) is about 9% of total rainfall but varies from year to year than rainfall with a coefficient of variation of 36% compared to 7% for rainfall.

Table 2. Rainfall and runoff of the Volta basin [4]

Sub-basin	Black Volta	White Volta	Oti
Period of measurement	1955-1975	1954-1980	1960-1973
Mean annual rainfall (mm)	952.4	952.8	1166.7
Coefficient of variation, rainfall	0.09	0.07	0.07
Mean annual runoff (mm)	47.6	66.0	152.8
Coefficient of variation, runoff	0.52	0.33	0.38
Runoff as % of rainfall in sub-basin	5	7	13

The total basin population is estimated at a little over 14 million inhabitants, annual growth rate is estimated at 2.9% [5]. Majority of the communities in the Volta River basin has a rural setting. Small-scale rain-fed agriculture is their main economic activity. Agricultural productivity is low and only a limited size is irrigated.

III. CLIMATE CHANGE IN VOLTA RIVER BASIN

A. Possible Causes of Climate Change in Volta River Basin

Climate variability in West Africa may be due to global climate factors such as El Nino-Southern Oscillation, North-Atlantic Oscillation and regional climate systems such as monsoons, Jet streams etc. [6-8] and secondly by local factors such as vegetation, surface albedo and soil moisture [9, 10]. Kunstmann and Jung [11] revealed that

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for Volta basin, rainfall exhibits a high sensitivity with land surface properties. Thus the possible causative agents of climate change in Volta basin may be complex interactions between large scale and regional scale factors.

B. Present and Projected Future Trend Indications for Rainfall in Volta River Basin

The hydroclimatology of the Volta basin as revealed by Oguntunde et al. [12] shows similar patterns as that of the West African sub-region; with the 1930's and 1950's being very wet decades while the 1970's and 1980's were very dry decades. According to Van de Giesen et al. [13], from the year 1990, a mixture of wet and dry years has prevailed compared to the 1940's and before 1930; 1970 shows clear and significant jump, once this jump is removed, there exist no clear trends. The mean annual rainfall over the periods of 1901-1969 and 1970-2002 were 1100mm/year and 987 mm/year respectively. Thus mixed patterns of increasing, decreasing and stable trends exhibited by rainfall over these decades may be attributed to complex relationships between global and regional scale changes. With respect to the expected future rainfall (Table 3) in the Volta Basin, Andah et al. [14] project increase in precipitation of 8% and 10% for future time slices of 2020-2039 and 6% and 9 % for 2070-2099 respectively. Jung [15] predicts an increase of nearly 5% for the entire Volta Basin for future time periods of (2030-2039). Awotwi et al. [16] project an increase of 8% for 2030-2043 for the White Volta catchment. Nobuhiko et al. [17], project increase of 3% for future time periods of 2075-2099 for Black Volta catchment. Obuobie [18] projects increase of 6% for White Volta catchment. Kuntsmann and Jung [19], project increase of 5% for the entire Volta basin for the future time periods of 2030-2039.

Table 3. Projected future trend in annual mean rainfall for Volta basin and its sub-basins

Paper	River	Target time period	Climate model	Scenario	Increase in rainfall
Andah *et al*.,2003	Volta	2020-2039	HADCM3	A2	8%
Andah *et al*.,2003	Volta	2020-2039	HADCM3	B2	10%
Andah *et al*.,2003	Volta	2070-2099	HADCM3	A2	6%
Andah *et al*.,2003	Volta	2070-2099	HADCM3	B2	9%
Jung,2006	Volta	2030-2039	ECHAM4-MM5	IS92a	5%
Awotwi *et al*.,2015	White Volta	2030-2043	REMO	A1B	8%
Nobuhiko *et al*.,2014	Black Volta	2075-2099	AGCM20	AGCM20 scenarios	3%
Obuobie,2008	White Volta	2030-2039	ECHAM4-MM5	IS92a	6%
Jung,2006	White Volta	2030-2039	ECHAM4-MM5	IS92a	5%
Kuntsmann & Jung,2005	Volta	2030-2039	ECHAM4-MM5	IS92a	5%

In summary, rainfall in the Volta basin is projected to increase by an average of about 7% across climate models and scenarios.

C. Present and future trends of the onset, cessation dates and length of growing period

The vulnerability of agricultural production in West Africa which is mainly rain-fed to the onset of the rains, cessation dates of rainfall and length of growing period variability is very high [20]. The inter-annual variability of the onset of the rains is higher when compared to the cessation dates [21]. More results regarding delayed onset and shortening of the rainy season in West Africa have been revealed by Biasutti and Sobel [22], Conway [23] with similar results being described by Patricola and Cook [24], and McCartney et al. [25]. Onset of the rains in the Volta basin is normally from April to July and it varies from one climatic zone to another. According to Van de

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Giesen et al. [13], farmers have experienced forward shifts in the onset of the rainy season later in the year, from April towards May; farmers now sow 10–20 days later than before. A forward shift in the onset of the rainy season in the Volta basin has also been predicted by Jung and Kuntsmann [8]. They predicted an additional shift in the onset of the rainy season of almost ten days from 1991-2000 to 2030-2039 period. Delay in the onset of the rainy season; and in season dry spells during the wet season has also been reported by Lacombe et al. [26] in the Volta basin. Principal Component Analysis has been used by Laux et al. [27] to show that there is, indeed a significant shift forward in several components of 0.4 to 0.8 days/year with no change in the end of the rainy season. In summary, early cessation date of rainfall, in season dry spells and onset which will shift to later periods in the year about 1 month which will have adverse effects on rain-fed agriculture.

D. Future trend projections for streamflow and Groundwater Recharge

With respect to expected future surface runoff, streamflow (discharge) (Table 4) and groundwater recharge in the Volta Basin, results of Andah et al. [14] reveal an increase in discharge for all future climate change scenarios for the Volta basin. Jung [15] projects increase in future mean annual runoff of 17% for Volta basin for future time periods of (2030-2039). Awotwi et al. [16] project increase in future mean annual surface runoff and discharge of 26% and 20% respectively for the White Volta basin for future time periods of 2030-2043. Obuobie [18] projects increase in mean annual runoff and discharge of 37% and 33% respectively for White Volta catchment for future time periods of (2030-2039). Kuntsmann and Jung [19] project increase in mean annual surface runoff of 18% for the Volta basin for future time periods of 2030-2039 whilst studies by Jung [15] projects increase in mean annual surface runoff of 55% for the White Volta catchment for future time periods of 2030-2039.

Table 4. Projected future trend in mean annual runoff and discharge for Volta basin and its sub-basins

Paper	River	Target time period	Hydrologic model	Scenario	Increase in runoff/discharge
Andah et al.,2003	Volta	2020-2039	WEAP	A2	27%
Andah et al.,2003	Volta	2020-2039	WEAP	B2	34%
Andah et al.,2003	Volta	2070-2099	WEAP	A2	13%
Andah et al.,2003	Volta	2070-2099	WEAP	B2	34%
Jung,2006	Volta	2030-2039	WaSIM	IS92a	17%
Awotwi et al.,2015	White Volta	2030-2043	SWAT	A1B	26%
Obuobie,2008	White Volta	2030-2039	SWAT	IS92a	33%
Jung,2006	White Volta	2030-2039	WaSIM	IS92a	55%
Kuntsmann & Jung,2005	Volta	2030-2039	OSU-LSM	IS92a	18%

Obuobie [18] projects mean annual shallow groundwater recharge to increase by 29% for White Volta catchment for future time periods of 2030-2039 and Jung [15] projects an increase in infiltration of 11% for the White Volta catchment for future time periods of 2030-2039. In summary, future annual surface runoff is projected to increase Averagely by 18% across models and scenarios with an increase in stream flow (discharge) and groundwater in the Volta basin.

IV. AGRICULTURAL ADAPTATION TO CLIMATE CHANGE IN VOLTA RIVER BASIN

Literatures reviewed on climate models in this study, for the Volta basin predict onset of rainy season to shift forward to later periods about a month from April to May and rains to end earlier than anticipated. These may have negative impacts on rain fed agriculture in the basin. On the other hand, precipitation and surface runoff are

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Volume 6, Issue 1, January 2017

projected to increase by 7% and 18% respectively across climate models and scenarios with a corresponding increase in streamflow and ground water recharge. With this projected increase in both surface and groundwater resources, water storage through the use of Small reservoirs and Shallow ground water exploitation for dry season irrigation are two strategies of agricultural climate change adaptation mechanisms which will partially offset this negative effect.

A. Small Reservoirs

Small Reservoirs impound water behind small dams constructed across streams and rivers. They have a size of approximately 0.01 km^3 , built with earth [28] and located on headwaters of ephemeral streams. They store water during the rainy season for irrigating crops typically cash crops such as (cabbage, onions, carrots, tomatoes, okra, and pepper) during the dry season. They get filled up quickly during rainstorms and the surplus runoff spills away. Most of the irrigators are small-scale farmers who produce for the market as well as for home consumption. Total irrigable land is low around 2% of the total area with more ample room available for their expansion [29].
Advantages of Small reservoirs over large irrigation schemes are; they are simpler to construct because of the flat nature of the landscape of the Volta River basin, they are less capital intensive and require simple institutional arrangements to manage them. Water bodies in semi-arid surroundings like the Volta basin of West Africa can be subjected to high evaporation losses due to the oasis effect [30]. According to detailed studies by Liebe [31], in parts of the Volta basin, actual evaporation from these reservoirs was below the potential evaporation rate.
In many parts of Volta basin, small reservoirs make an important contribution to livelihoods through the provision of water for irrigation, livestock and domestic water purposes. Thus the crucial role of small reservoirs in the adaptation of agriculture to climate change in the Volta basin is, it stores water in the rainy season; it allows for productive use of labor in the dry season; bring extra income to farmers to support their families and minimizes rural-urban migration.

B. Shallow Groundwater

Ground water irrigation is where hand-dug wells are used to extract groundwater from alluvial channels along the courses of ephemeral streams for irrigating crops. According to van den Berg [32], farmers practice shallow groundwater during the dry season, mainly in inland valleys where water is retained in the alluvial material close to the river. The farmers use watering cans and buckets tied with ropes to collect water form hand-dug wells to irrigate between 0.04 and 0.1 hectare of vegetable farms [33]. The farms are fenced to guard against roaming cattle and at the end of the rainy season, the wells are closed again so the field can be used for the rainy season. Geophysical surveys of Shallow groundwater by Barry [34] in the Volta basin reveals higher annual aquifer water storage of approximately 3.7 x 108 m^3, which is more than annual irrigation water demand of 8.9 x 104 m^3. Water sample analyses in several studies, Kortatsi [33], Barry [34], Amuzu [35], Andah [36], Ministry of Water Resources Works and Housing, Ghana [37] and Darko and Krasny [38] indicate that the chemical and biological quality of groundwater in the basin is generally good for multi-purpose use.

V. CONCLUSION

Historically, the Volta basin of West Africa has experienced a mixture of decades of drought and above average rainfall which have greatly affected agriculture. Of greater concern is the onset of the rainy season which will shift forward to later periods in the year about a month from April to May, early cessation dates of rainfall and reduction in length of growing periods which are presently locally impacting negatively on rain-fed agriculture. Future observations from climate models project precipitation and surface runoff to increase respectively with an increase in streamflow and ground water recharge. With projected increase in both surface and groundwater resources, water storage in the wet season through the use of Small reservoirs for dry season irrigation and Shallow ground water exploitation for dry season irrigation are two climate change adaptation mechanisms suggested to represent essential input for accelerating agricultural adaptation to climate change.

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