

# Adapting to climate change in the Volta Basin, West Africa

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**Impacts of climate change vary from region to region. The 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) mentions that drier areas will be affected by more droughts while the rainfall regime, in general, will become 'rougher'. In West Africa, specifically the area below the Sahel, the climate change signal may be more subtle. Anecdotal evidence from farmers suggests that the onset of rainy season has been shifting forward in time over the past two generations. Recently, detailed atmospheric modelling over the region shows that in the near future too, the onset of rainy season will shift to later periods in the year, roughly from April towards May. The end of rainy season as well as the total amount of rainfall will remain more or less fixed. This implies that adaptation strategies should be twofold. The first part of a comprehensive adaptation strategy would be a continuation of the efforts to produce faster growing rainfed crop cultivars, mainly corn and sorghum. The second part would consist of increased water storage during the wet season for use during dry season.**

**Keywords:** Adaptation, climate change, Volta Basin, water resources, West Africa.

## Introduction

RIVER run-off in West Africa is quite sensitive to rainfall distribution. When the same quantity of rain falls within a shorter period, as is suggested by climate projections, run-off will show a significant increase. Also, the recharge of groundwater will improve under these circumstances. Storage of surface run-off in small reservoirs would be an important part of climate change adaptation. Extensive use of (shallow) groundwater during dry season could be a second, highly complimentary adaptation strategy. The development of large dams would probably be less successful given the flatness of the landscape and the move towards decentralized development in most West African countries. Shortening of the rainy season will reduce rainfed agriculture, which is the dominant mode of food production in the region. Use of surface and

groundwater during dry season may partially offset this negative effect. Success of any of these adaptation strategies will, to a large extent, depend on institutional and socio-economic developments within the region.

## Climate change signals in the Volta Basin

### *Inter-annual variability*

The geographical focus of this article is the Volta Basin in West Africa, a region often hit by droughts and less frequent floods (Figure 1). Specifically, we look at climate change and adaptation measures in the Volta Basin which covers 400,000 km<sup>2</sup> of which over 80% lies in Ghana and Burkina Faso. The average rainfall is 1000 mm/year with distinct dry (October–May) and wet (May–October) seasons. River discharge is about 9% of total rainfall but varies more from year to year than the rainfall (coefficient of variation of 36% vs 7% for



**Figure 1.** Map of the Volta Basin, West Africa, the main tributaries, riparian countries and Lake Volta. The coast line is that of the Gulf of Guinea (source: GLOWA Volta Project, [www.glowa-volta.de](http://www.glowa-volta.de)).

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rainfall). Rainfed agriculture is the most important economic activity within the Volta Basin. Lake Volta, one of the largest manmade lakes in the world, lies in the Volta Basin and produces over 90% of Ghana's electricity.

Ever since rains started failing during 1970s, West Africa has been known as a region plagued by droughts. It should be kept in mind, however, that many studies refer to the Sahel, which was hit most severely. More to the south, which is the region of interest here, the picture seems to be more mixed. Large scale oceanographic and atmospheric patterns are correlated with rainfall patterns within West Africa<sup>1-3</sup>. This means that observed changes may be related to changes in global circulation patterns. The situation is complicated by the fact that, at least for the Volta Basin, a high sensitivity is found of rainfall with respect to land surface properties<sup>4-6</sup>. So a mixed pattern of decreasing trends and stability in rainfall is probably the product of the complex interactions between large scale and regional scale changes. This stresses the need for (further) regional climate models and predictions as GCMs are not designed to reproduce such variability over space. The most important efforts in this respect were undertaken by Jung and Kunstmann<sup>1</sup> who used the weather model MM5 in a climate simulation mode, using GCMs as boundary conditions. The improvements this brought over the results from GCMs were significant. Their results showed no major changes in annual precipitation between the time slices 1991–2000 (reference period) and 2030–2039.

Though there are no indications of future changes in average precipitation, the 20th century has shown a large variability in precipitation. A review of studies in West Africa can be found in Neumann *et al.*<sup>7</sup>. Oguntunde *et al.*<sup>8</sup> provide a detailed statistical analysis of the hydroclimatology for the Volta Basin, which shows the same major trends as the complete region. The 1930s and 1950s were relatively wet decades, while the 1970s and 1980s were very dry, including the 1983–84 disaster years during which large parts of rainforests in Ghana burnt down. Since 1990, we see a mixture of above and below average years comparable to that found in the 1940s and before 1930. Statistically, there is a clear and significant drop in 1970. The mean over the period 1901–69 was 1100 mm/year, whereas over the period 1970–2002, it was 987 mm/year. Once this single jump is removed, no clear trend remains. Whether the changes among wet, mixed and dry regimes are caused by changes in regional landuse and atmospheric circulation or by more global changes in ocean and atmosphere circulation is not clear.

Inter-annual rainfall variability has clear effects on run-off, although not necessarily simple and straightforward. Mahé *et al.*<sup>9</sup> reported that Sahel and savanna reacted differently to the 1970–90 drought. In the Sahel, due to a deterioration of land cover, run-off coefficients increased, even to the extent that reductions in overall rainfall coincided with increases in surface and river run-

off. In the savanna, the reduced rainfall generally resulted in reduced riverflow although the decrease is much less than would be expected on the basis of reduction in rainfall alone<sup>8</sup>. The line that divides both types of reaction coincides roughly with the 700 mm/year isohyet. Friesen *et al.*<sup>10</sup> showed that the distribution of rainfall is important for the generation of river run-off, which means that changes in intra-annual patterns, as described here, may partially offset reductions.

### *Rainfall distribution within hydrological year*

The onset of the rainy season is a major parameter of the in-year rain distribution for the Volta Basin. There are regularly 'false starts', with some spurious early rains inducing farmers to plough and plant without sufficient follow-up rain to sustain the crop. Farmers apply risk management strategies by starting out with less costly seed materials but, still, suffer major losses. For this reason, the onset of rainy season has received extensive attention within GLOWA-Volta Project (GVP)<sup>1,11</sup>. There is anecdotal evidence from farmers that the onset of rainy season has been shifting forward in the year. Farmers claim to sow 10–20 days later than their parents but such claims are difficult to substantiate as new varieties of main crops, sorghum and maize, tend to grow faster as well. An additional problem is the definition of the onset. The best way to define it would be agronomical but this, in turn, depends on crops, varieties and soils. Laux *et al.*<sup>11</sup> used principal component analysis to show that there is, indeed, a statistically significant shift forward in several components of 0.4–0.8 days/year. The end of rainy season remains fixed, however. Because total rainfall does not change as much, or better, seems to change with jumps, rainfall intensity within the rainy season increases. This is an important finding with important implications.

Though Jung and Kunstmann<sup>2</sup> did not project changes in annual rainfall for the period 2030–39, they do predict that the shift in the onset of rainy season may continue to move forward. This signal in projections is not strong and differs geographically. The latitudinal position of the inner tropical discontinuity (ITD) determines the arrival of the rainy season. ITD follows the position of the sun but is also constrained by the African Easterly Jet (AEJ). AEJ does not move smoothly from south to north but often hangs around 5°N for a few weeks in April, after which it jumps relatively quickly to 15°–20°N. The sooner the AEJ and associated ITD move northwards and further, the better the rains tend to be in the savanna and Sahel. For the period 2030–39, a shift in the position of ITD for April is predicted with respect to its position in the reference period 1991–2000. As a consequence, the onset of rainy season also shifts from April to May. In all, an additional shift in the onset of rainy season of almost

10 days is predicted from the 1991–2000 to the 2030–39 period. The end of rainy season does not seem to change. More rainfall is expected during the peak months August and September, resulting in a slight overall increase in rainfall over the Volta Basin.

Groundwater recharge and river discharge are sensitive to the exact distribution of rainfall within the year<sup>10</sup>. The deep West African soils can store a large amount of water that can be utilized by grasses, crops and trees. Only when the deep soil profile is close to saturation does water percolate below the root zone to feed groundwater and thereby river flow<sup>12</sup>. See Masiyandima *et al.*<sup>12</sup> for a further description of the most relevant hydrological processes. If the rainfall is spread out evenly over the season, little or no recharge may occur. A more concentrated rainy season increases recharge and may offset a reduction in overall rainfall. If indeed there is partial recovery in total rainfall with respect to the 1970s and 80s, the summary effect of changes in annual rainfall and in intra-annual rainfall distribution may even be increased recharge of groundwater and river discharge. Floods beyond the established floodplains are not common in West Africa but both 2007 and 2009 brought extensive flooding in the Volta Basin, especially in Central Burkina Faso and Northern Ghana. If the wet season does indeed continue to become more intense, this flooding may become more frequent. Although the 2007 flooding caused widespread crop damage during the rainy season, groundwater was abundant during the dry season due to increased recharge.

In addition to the onset of rainy season, within-season drought spells are also important. Sultan *et al.*<sup>13</sup> show that a delayed sowing date than presently used would lead to better yields because, on an average, the impact of within season drought spells would be less. Also, Laux *et al.*<sup>11</sup> showed the occurrence of such dry spells. Whether global and regional changes cause the frequency and/or intensity of these dry spells to change is not known at this moment.

### Small reservoirs

Small reservoirs supply rural populations locally with water for irrigation, cattle, household, fisheries and recreation. These reservoirs can be found in semi-arid areas around the world. Small reservoirs are defined as reservoirs with a surface area between 1 and 100 ha and a storage capacity of less than  $5 \times 10^6 \text{ m}^3$ . Typically, such reservoirs are located on the headwater of an ephemeral stream where they catch water during the wet season, to be made available during the dry season. Important advantages of small reservoirs over larger irrigation schemes are that they drive a geographically more diffuse development process and that they tend to have less governance problems due to the fact that local institutions

(villages) are already in place. In many semi-arid areas in developing countries, small reservoirs are an integral part of improved rural water management strategies.

In the Volta Basin, we have seen an increase in small reservoirs between 1984 and 1999 (see Table 1). This increase has more or less halted in Ghana although there are some projects concerning rehabilitation. In Burkina Faso, the construction continues and the present number of small reservoirs in this country is presently estimated at 2000. Hydrological monitoring of small reservoirs is possible through the use of remote sensing<sup>14</sup> which has helped to assess the overall hydrological impact of this geographically diffuse development (Figure 2).

Field research has shed light on the total impact of these large numbers of small reservoirs. It is often thought that small reservoirs in a dry environment have high evaporative losses due to advection of energy (hot dry air) from its surroundings. This actually turns out not to be the case with measured evaporation rates being lower than the reference evaporation over land. The stability of the internal boundary layer may be the cause behind this phenomenon.

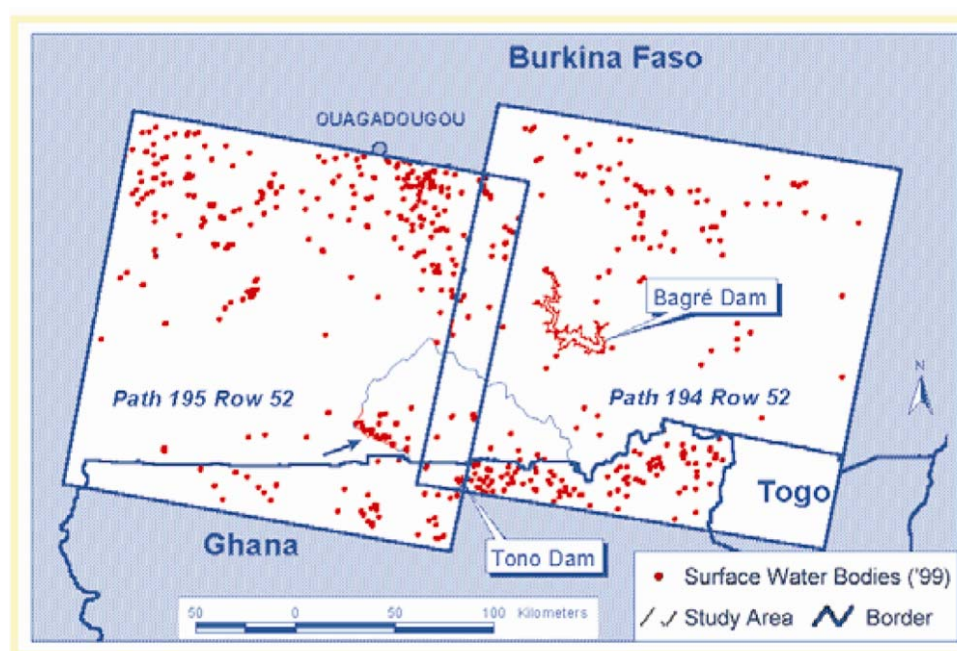
In the Volta Basin, small reservoirs capture only a small part of the total surface run-off. The ephemeral streams carry water only during a few hours following major rainstorms that fall late in the rainy season. Typically, a few rainstorms suffice to fill up a reservoir after which most run-off water spills<sup>15</sup>. At the end of the year, the reservoirs are used to irrigate crops, typically cash crops such as tomatoes and onions. Total irrigated acreage remains low (around 2% of the total area) and also water productivity needs improvement<sup>16</sup>. From a hydrological point of view, there is need to expand the number of small reservoirs. It should be remarked that percolation from reservoirs, which may locally be perceived as losses, should be considered a benefit to the larger groundwater system because percolation feeds aquifers and, thereby, wells.

Ecological and socio-economic impacts of large scale development of small reservoirs are not yet well understood. In a region like West Africa, where most waterborne diseases such as malaria are endemic throughout the year, health impacts of irrigation development are more related to the distribution of extra income than to changes in the physical environment<sup>17,18</sup>. Water quality is affected through algae blooms<sup>19</sup>. The often shallow reservoirs accumulate nutrients that may cause outbreaks of blue-green algae. It is difficult to predict such outbreaks but research so far suggests that a poor environmental condition of the watershed and the presence of reservoirs upstream are conducive to algae blooms.

The socio-economic impact of small reservoirs is also complex. Although in general the reservoirs are managed at village level and, as such, are less prone to conflicts of interest than large scale irrigation schemes, they can become foci of conflict. Conflicts may arise if there are

**Table 1.** Historical development of small reservoirs in the Volta Basin

	Burkina Faso						Ghana					
	1984/86		1999		Increase (%)		1984/86		1999		Increase (%)	
	Nr.	ha	Nr.	ha	Nr.	ha	Nr.	ha	Nr.	ha	Nr.	ha
<5 ha	109	145	377	421	268 (246%)	276 (191%)	96	115	113	170	17 (18%)	56 (48%)
5–100 ha	72	1704	154	3444	82 (114%)	1740 (102%)	18	197	48	534	30 (167%)	338 (172%)
>100 ha	5	789	16	23421	11 (220%)	22632 (2868%)	2	1184	2	2218	–	1034 (87%)
Total	186	2638	547	27286	361 (194%)	24648 (934%)	116	1496	163	2922	47 (41%)	1427 (95%)



**Figure 2.** Map of small reservoirs as detected on two 1999 Landsat scenes (outlined rectangles) (source: GLOWA Volta Project, [www.glowa-volta.de](http://www.glowa-volta.de)).

conflicts within a village or if reservoirs are at the borders between villages. Conflicts may also arise when people from outside the village, such as migrant cattle holders and fishermen, make use of the reservoirs<sup>20</sup>. Perhaps the most significant positive socio-economic aspect of small reservoir development is that it allows productive use of labour during the dry season. Without irrigation, there hardly are any economic activity outside the rainy season. This causes a large seasonal migration flux, especially of young men from the countryside to larger cities. Economic opportunities in cities are limited and the overall returns are minimal at best. Farmers do mention this positive effect when asked about their engagement in irrigated agriculture. The economic returns on irrigation fluctuate largely from year to year. Due to limited experience and agronomic extension, mono-cropping is often observed, which at times leads to destructive plant diseases. Also, bumper harvests may cause problems when market prices collapse. A large expansion of the number

of small reservoirs will have to be accompanied by crop diversification and marketing efforts.

## Conclusions

The impact of global climate change on water resources can only be properly assessed at the local level. Unfortunately, we do not have adequate tools at the global level to assess climate change impact in every region. Specific studies will be needed to address impacts at local and regional scales. This research summarizes some results of such a study for the Volta Basin in West Africa.

There seems to be a climate change signal in the Volta Basin but the exact causes remain unclear. Detailed climate models for the region, together with statistical analysis of the climate over the past decades, show that there seems to be a forward shift of the onset of rainy season. At the same time, the end of rainy season, as well

as the total rainfall, are relatively stable. This implies that rain is more concentrated in time. Because the river flow in the Volta is sensitive to the exact distribution of rainfall over the year, more run-off over shorter times can be expected.

Adaptation is seen as an important complementary activity to climate change mitigation. Local farmers in West Africa will have no choice but to adapt. Adaptation to shortened and intensified rainy season will partially be agronomical through the use of crops and cultivars that are more suitable for this new regime. Part of the adaptation, however, should consist of the capture and retention of the increased run-off. One appropriate strategy would be the increased use of small reservoirs ( $<5 \times 10^6 \text{ m}^3$ ). Such reservoirs have shown to fit better local governance structures than large scale irrigation development. In addition, their multiple use offsets potential reductions in economies of scale.

In all, the rural communities in Volta Basin will be confronted with continual changes in the regional climate. There will be several adaptation options available to them, of which increased local storage will be an important one. Research is needed to aid both local and national decision makers while they evolve strategies.

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