Adapting to Climate Change in West Africa

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Abstract

Impacts of climate change vary from region to region. The 4th Assessment Report of the IPCC mentions that drier areas will be affected by more droughts and that 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 suggest that the onset of the rainy season has been shifting forward in time over the past two generations. Recently, detailed atmospheric modeling over the region (Jung and Kunstmann, 2008) shows that also in the near future, the onset of the rainy season will shift to later in the year, roughly from April towards May. The end of the 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 in the dry season. River runoff in West Africa is very sensitive to the rainfall distribution. When the same amount of rain falls within a shorter period, as is suggested by climate projections, runoff will show an important increase. Also the recharge of groundwater will improve under these circumstances. Storage of surface runoff in small reservoirs would be an important part of climate change adaptation. Extensive use of (shallow) groundwater in the 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 in the 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.

Key words: West Africa, rainy season, climate change, climate adaptation

1. Introduction

Although climate change is a global phenomenon, the impacts it may have on a given region are extremely location specific. Also, although media attention often focuses on increased CO_2 and the associated increases in global temperatures, the impact on the hydrological cycle may very well be more urgent. Given the vulnerability of societies in developing countries with respect to changes in the hydrological cycle, research is needed to assess impacts and to design adaptation measures. It is generally recognized that developing countries will be forced to focus on adaptation to climate change, whereby support is needed from the richer countries responsible for increased CO_2 levels.

The geographical focus of this article is West Africa, a region often hit by droughts and, less frequently, floods. Specifically, we will look at climate change and adaptation measures in the Volta Basin. The Volta Basin covers 400,000 km^2 of which more than 80% lies in Ghana and Burkina Faso. Other riparian countries are Côte d'Ivoire, Mali, Benin, and Togo. Many people associate West Africa with the Sahel but it should be understood that the Volta Basin is more representative of the so called Sudan and Guinea Savanna zones, which lie south of the Sahel. Where the Sahel is sparsely populated, the savanna zones contain some of the highest population concentrations of West Africa such as Northern Côte d'Ivoire, Southern Mali, the Mossi plateau in Burkina Faso, the Upper East of Ghana, and the Jos plateau of Nigeria. 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 rainfall). Rainfed agriculture is by far the most important economic activity within the Volta Basin. Also Lake Volta, one of the largest manmade lakes in the world, lies in the Volta Basin and produces over 90% of Ghana's electricity.

This article consists of two parts. The first part covers detected climate change in West Africa and the Volta Basin during the 20th century and climate projections for this century. Specific attention is given to rainfall variability and distribution and to river discharge. The second part covers possible adaptation strategies, whereby we look especially at the extended use of surplus water for irrigation during the dry season.

The material presented here is mainly based on recent research within the framework of the GLOWA Volta Project (GVP, www.glowa-volta.de, see Schiermeier 2003; Rodgers *et al.* 2006). GVP is a large, long-term research project funded in the framework of the GLOWA program by the German Federal Ministry for Research and Education (BMBF). The objective of the GLOWA program is to study the impact of global change on demand and availability of water resources in large river basins. In addition to GVP, which studies the West African Volta Basin, there are GLOWA projects in the Elbe and Danube rivers in Europe, the Jordan river in Asia, and the Drâa and Ouêmé in Africa. The GVP results presented here focus on climate analysis and simulation. Two applied GVP spin-off projects, the Small Reservoirs Project (SRP, www.smallreservoirs.org) and the Shallow Groundwater Irrigation Project (SGI, sgi.alturl.com), provide the material on the adaptation strategies in the Volta Basin. Both SRP and SGI are part of the Challenge Program Water for Food (www.waterforfood.org).

2. Climate change signals in West Africa

2.1. Inter-annual variability

Since the failing rains of the 1970's, West Africa is 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 (Adiku and Stone 1995, Bigot *et al.* 2002, Jung and Kunstmann 2007). This means that also observed changes may be related to changes in global circulation patterns. The story 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 (Kunstmann and Jung 2003). So the mixed patterns of decreasing trends and stability in rainfall is probably the product of the complex interactions between large scale and regional scale changes. If anything, this stresses the need for (further) regional climate models and predictions as GCM's are not designed to reproduce such variability over space. The most important efforts in this respect were undertaken by Jung and Kunstmann (2007) who used the weather model MM5 in a climate simulation mode, using GCM's as boundary conditions. The improvements this brought over the results from GCM's were very significant. Their results showed no major changes in annual precipitation between the time slices 1991-2000 (reference period) and 2030-2039.

Whereas there are no indications of future changes in average precipitation, the 20th century has shown a large variability in precipitation. A good recent review of studies for West Africa can be found in Neumann *et al* (2007). Oguntunde *et al.* (2006) provides a detailed statistical analysis of the hydroclimatology for the Volta Basin, which shows the same major trends as the complete region. The 1930's and 1950's were relatively wet decades, while the 1970's and 1980's were very dry, including the 1983-1984 disaster years during which large parts of the rainforests in Ghana burned down. Since 1990, we see a mixture of above and below average years comparable to that found in the 1940's and before 1930. Statistically, there is a clear and significant jump in 1970. The mean over the period 1901-1969 was 1100 mm/year, whereas over the period 1970-2002, the mean was 987 mm/year. Once this single jump is removed, no clear trend remains. Whether the switches between 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 runoff, although not necessarily simple and straightforward ones. Mahé *et al.* (2002) made the important observation that Sahel and savanna reacted differently to the 1970-1990 drought. In the Sahel, due to a deterioration of land cover, runoff coefficients have increased, even to the extent that reductions in overall rainfall coincided with increases in surface and river runoff. In the savanna, the reduced rainfall has generally resulted in reduced riverflow although also here the decrease is much less than would be expected on the basis of reduction in rainfall alone (Oguntunde *et al.* 2006). The line that divides both types of reaction coincides roughly with the 700 mm/year isohyet. Friesen *et al.* (2005) showed that the distribution of rainfall is very important for the generation of river runoff, which makes that changes in intra-annual patterns, as described below, may partially offset reductions.

2.2. *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 plow 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, losses are major. For this reason, the onset of the rainy season has received extensive attention within GVP (Laux *et al.* 2007, Jung and Kunstmann, 2007). There is anecdotal evidence from farmers that the onset of the rainy season has been shifting forward in the year. Farmers claim to sow 10 to 20 days later than there parents but such claims are difficult to substantiate as new varieties of the 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.* (2007) used Principal Component Analysis to show that there is, indeed, a statistically significant shift forward in several components of 0.4 to 0.8 days/year. The end of the 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

Whereas Jung and Kunstmann (2007) did not project changes in annual rainfall for the period 2030-2039, they do predict that the shift in the onset of the rainy season may continue to move forward. The latitudinal position of the Inner Tropical Discontinuity (ITD) determines the arrival of the rainy season. The ITD follows the position of the sun but is also constrained by the African Easterly Jet (AEJ). The 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° N to 20° N. The sooner the AEJ, and associated ITD, move northwards, and the further, the better the rains in the savanna and Sahel tend to be. For the period 2030-2039, a shift in the position of the ITD for April is predicted with respect to its position in the reference period 1991-2000. As a consequence, also the onset of the rainy season shift from April to May. In all, an additional shift in the onset of the rainy season of almost ten days is predicted from the 1991-2000 to the 2030-2039 period. The end of the rainy season does not seem to change. More rainfall is expected in the peak months August and September, resulting in a slight overall increase in rainfall over the Volta Basin.

Groundwater recharge and river discharge are very sensitive to the exact distribution of rainfall within the year (Friesen *et al.* 2005). Without going into detail, the deep West African soils can store a large amount of water that can be extracted by grasses, crops, and trees. Only when the deep soil profile is close to saturation does water percolate below the rootzone to feed groundwater and thereby river flow (see also Masiyandima (2003) for a further description of the most relevant hydrological processes). If the rainfall is spread out evenly over the season, little to no recharge may occur. A more concentrated rainy season increases recharge and may offset a reduction in overall rainfall. If indeed there is a partial recovery in total rainfall with respect to the 1970's and 1980's, 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 very common in West Africa but 2007 brought extensive flooding in the Volta Basin, especially in 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 in the dry season due to increased recharge.

In addition to the onset of the rainy season, within-season drought spells are also very important. Sultan *et al.* (2005) show that a later sowing date than presently used would lead to better yields because, on average, the impact of within season drought spells would be less. Also Laux *et al.* (2007) showed the occurrence of such dry spells. Whether global and regional change cause the frequency and/or intensity of these dry spells to change is not known at this moment.

3. Adaptation strategies

Both past observations and simulations of the future climate point towards a shortening of the rainy season, probably accompanied with more groundwater recharge and river discharge. This asks for adaptation in both the wet season and the dry season. Adaptation in the wet season focuses on existing rainfed agriculture, the socio-economic mainstay of the region. A better use of the so called green water, the water kept under tension in the unsaturated rootzone that is only available to the plants, is key. Plant breeding programs will need to continue to aim at shortening the growing season. Also improved in situ management of soil moisture and supplementary micro-irrigation will have their roles to play. Here, we focus on adaptation in the dry season through two strategies, namely the use of small reservoirs and the exploitation of shallow groundwater. The idea is that there is already surplus runoff and recharge in the region. Because both are likely to increase, better use can be made of these water resources. Both groundwater and surface water are called blue water, indicating that these sources can be manipulated directly with pumps and canals. So far, irrigation and blue water management have been very limited in West Africa but recent initiatives may change this (see for example the recent "Initiative for Agricultural Water in Africa" by World Bank, African Development Bank, Food and Agriculture Organization, International Fund for Agricultural Development and the International Water Management Institute).

3.1 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 here as reservoirs with a surface area between 1 ha and 100 ha. Typically, such reservoirs are sited 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 (Liebe *et al.* 2005), which has helped to assess the overall hydrological impact of this geographically diffuse development.

Table 1: *Development of small reservoirs in Ghana and Burkina Faso (Van de Giesen et al. 2002)*

	Burkina Faso						Ghana					
	1984/86		1999		Increase (%)		1984/86		1999		Increase (%)	
	Nr.	ha	Nr.	ha	Nr.	ha	Nr.	ha	Nr.	ha	Nr.	ha
<5ha	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%)

Field research within the framework of SRP 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 very 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 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 very small part of the total surface runoff. 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 runoff water spills. 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 leaves room for improvement (Faulkner *et al.* 2008). From a hydrological point of view, there is ample room to expand the number of small reservoirs.

Ecological and socio-economic impacts of large scale development of small reservoirs are not yet as 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 the changes in the physical environment (Henry *et al.* 2003; Briët *et al.* 2003). Water quality is affected through algae blooms (Cecchi *et al.* 2005). 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 cascading 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 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 (Cecchi 2007). Perhaps the most significant positive socio-economic aspect of small reservoir development is that it allows for productive use of labor in the dry season. Without irrigation, there are few economic activities outside the rainy season. This causes a large seasonal migration flux, especially of young men, from the countryside to the larger cities. The economic opportunities in the cities are very limited and 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 one year to the next. 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.

3.2 Shallow groundwater

An alternative to the construction of small reservoirs is the use of groundwater in shallow alluvial aquifers. In northern Ghana, specifically the Upper East Region, shallow groundwater irrigation has started to expand spontaneously over, roughly, the past five years. For a long time, there have been permanently fenced irrigated gardens close to compounds that supplied households with horticultural products for auto-consumption and market. Over the past five years, we see the development of temporary shallow groundwater irrigation along the rivers. These rivers do not carry water during the dry season but the neighboring floodplains do provide groundwater for small scale irrigation. The spontaneous character of this development is very interesting, especially from an adaptation point of view. It is at present not clear if this development is a reaction to (changes in) the socio-economic and/or the natural environment.

The mechanics of this development are relatively simple. At the beginning of the dry season, farmers rent a piece of suitable land, much like they would rent rainfed land during the rainy season. Rent, in this case, mainly consists of asking permission of the local chief to use the land, whereby the request is accompanied by a small, token-like gift. This renting mechanism makes access to this type of irrigation even easier than access to land irrigated with small reservoirs, the latter often being surrounded by an additional organizational layer. Shallow wells (2-6m) are then dug by hand and water is brought up with hand buckets. Fields are small, typically less than 0.1 ha. Farmers form complexes of fields to facilitate fencing and guarding against roaming cattle. At the end of the season, the wells are closed again so the field can be used for the rainy season, often by a different farmer.

Total development of shallow groundwater irrigation is still modest. The wells are dug and exploited through trial and error. Expansion through the development of new fields sometimes fails completely due to the fact that wells fall dry towards the end of the irrigation season. The location of good wells, that produce water throughout the growth cycle, are remembered and opened again the next season. The 2007-2008 season showed a high level of water availability, following the extensive floods in the area.

Just as for the development of small reservoirs, there is a need to improve agricultural extension because the same crops are grown under both types of irrigation, leading to market fluctuations and spreading of plant diseases. From a physical point of view, also this type of irrigation can be extended further as most floodplains are not yet used. There may even be important synergies between small reservoirs and shallow groundwater irrigation as the reservoirs increase groundwater recharge. Knowledge of shallow groundwater irrigation as potential adaptation strategy is still limited. The recently initiated Shallow Groundwater Irrigation research project will help to fill this gap.

4. Summary and conclusions

The main impact of changes in global circulation patterns in precipitation in the Volta Basin, West Africa, is likely to be the (continued) forward shift of the onset of the rainy season. Annual rainfall will probably not change much in the coming decades. Because the end of the rainy season is fixed as well, this implies that the rains will fall over a shorter period. Given the sensitivity of riverflow and groundwater recharge to the distribution of rainfall, concentrated rains will result in more ground- and surface water availability.

From an adaptation point of view, farmers in the region will need to be able to grow crops during a shorter rainy season. Short-duration varieties and better use of in situ rainfall would need to be part of the adaptation strategy. In this article, we point to the possibilities for extension of irrigated agriculture during the dry season. Increased levels of riverflow and groundwater recharge can be used to this end. Diffuse development of water resources is suggested here based on the construction of small, village level reservoirs and of better exploitation of groundwater in shallow aquifers.

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