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Competition for water resources of the Volta basin

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Abstract The Volta basin in West Africa is situated mainly in Ghana and Burkina Faso. An overview of the hydrology of the basin and present trends in water demands is presented. The GLOWA-Volta research project is introduced. The scientific challenge of the project is to quantitatively link models from all relevant disciplines to create a decision support system for the Volta basin. The paper concludes by highlighting the institutional links which may favour the acceptance of science-based policies.

Key words integrated basin management; basin hydrology; water competition; cross-boundary issues; water policy

WATER RESOURCES OF THE VOLTA BASIN

The objective of this article is to give an overview of present issues concerning water resources of the Volta basin. This first section quantifies availability and the relatively poor reliability of water resources. The second section describes the increasing demand for irrigation that stands in conflict with the also increasing demand for hydropower. The final section presents a recent initiative to develop a system that will help decision makers in the region to design policies that make optimal use of available water and avoid inter-sectoral conflicts.

The Volta basin covers 398 000 km^2 of the subhumid to semiarid West-African savannah zone (Fig. 1). Forty-two percent of the basin lies in Ghana, 43% in Burkina Faso, and the remaining 15% in Mali, Côte d'Ivoire, Togo, and Benin. Rainfall averages 1025 mm year^{-1} of which 9%, or 36 km^3, becomes riverflow. In 1964, the lower reach of the Volta was dammed at Akosombo for hydropower generation. The resulting Lake Volta has the largest surface area of any manmade lake in the world.

In 1999, about 19.5 million people lived in Ghana and 12.0 million in Burkina Faso (CIA, 2000). The population growth is 2.4% per year, which implies a doubling of the population every 30 years. The average per capita income in Burkina Faso is US$1100 per year. The average income of US$1900 in Ghana is higher, but this is mainly due to the contribution of the more affluent, urbanized areas south of the basin. Poverty and increasing population pressure have led to extensive migration and over-exploitation of the natural resource base in the basin.

Figure 2 shows yearly rainfall and riverflow for the Volta basin from 1936 until completion of the Akosombo dam in 1964 (GRDC, 1998; New *et al.*, 2000; Andreini *et al.*, 2000). In the south, rainfall follows a pseudo-bimodal regime with a humid period during May–October and reduced rainfall in July and August. In the north, we find a monomodal rainfall regime with rainfall from May/June through September.

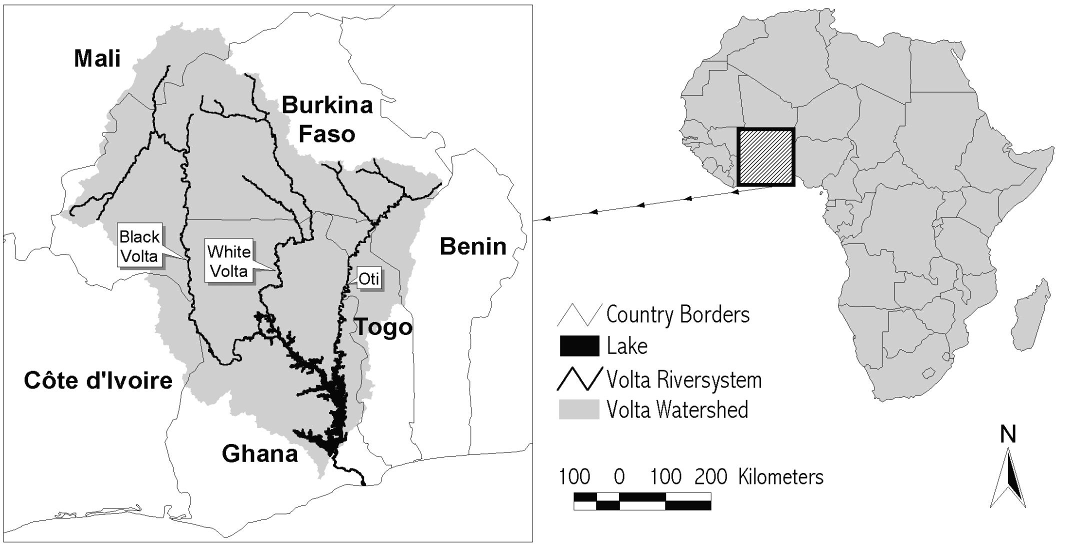

Fig. Map of the Volta basin.

Average rainfall varies from 1250 mm year^{-1} around Lake Volta to 600 mm year^{-1} in the Sahel zone of northern Burkina Faso. Figure 2 suggests a fairly even distribution of rainfall from year to year, but this impression is mainly due to the integration over time and space. For the 1936–1963 period, we find for the basin an average of 1025 mm year^{-1} with a range from –10% to +17% around the mean and a coefficient of variation of 7%. For the same period, but now for the single station of Ouagadougou, we find an average of 870 mm year^{-1} with a large range from –43% to +31% around the mean and a high coefficient of variation of 16% (FEWS, 1998). Also variability within a rainy season is very large due to the convective nature of most rainstorms. The onset of the rainy season is especially unpredictable. From an agronomic point of view, rainfall in the region can only be characterized as unreliable.

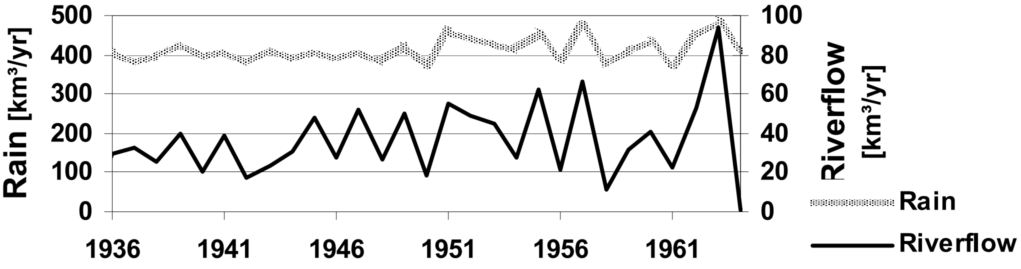

Fig. 2 Yearly rainfall and runoff of the Volta basin.

Figure 2 shows that riverflow varies much more from year to year than rainfall with coefficients of variation of 57% and 7%, respectively. A closer look reveals that there is a surprisingly good correlation between yearly rainfall (P) and riverflow(Q):

$$Q = 0.529(P - 343) \quad [\text{km}^3\ \text{year}^{-1}] \tag{1}$$

with a regression coefficient $r = 0.89$. Once a threshold of 343 km^3 has been filled, more than half of the additional rainfall runs off. The threshold demonstrates the high sensitivity of riverflow to rainfall: relatively small changes in yearly rainfall cause large changes in riverflow. The runoff/rainfall sensitivity also implies sensitivity with respect to the mechanisms that divide rainfall between evapotranspiration and runoff. Changes in land use and land cover may, therefore, have an important impact on water resources.

The basin can be divided into four tributaries: Black Volta (147 000 km^2), White Volta (106 000 km^2), Oti (72 000 km^2), and Lower Volta (73 000 km^2, including Lake Volta). The Black Volta has the lowest average runoff coefficient RC = 4.9%. For the White Volta RC = 7.1% and for the Oti RC = 13.5%. The high runoff coefficient of the Oti is due to the fact that it drains the steep terrain of northeast Ghana and northern Togo, whereas both Black and White Volta drain relatively flat areas.

Along the Lower Volta, total evaporation from Lake Volta has been calculated to amount to 10.2 km^3 per year, which is largely compensated by 7.9 km^3 of rain falling directly on the lake giving net losses of 7.5% of total flow (Andreini *et al.*, 2000). A more important downstream effect of the dam is that there is no longer an annual cycle of extensive flooding followed by drying up and salt intrusion. The change has led to severe environmental problems such as increased schistosomiasis (Derban, 1999), aquatic weeds (De Graft-Johnson, 1999), and collapse of the clamming industry (Gordon, 1999).

PRESENT WATER USE AND TRENDS

Since independence, Ghana has sought economic development through its industrial and mining sectors. Water is used mainly to generate cheap hydropower to fuel industrial growth. In the 1960s, the power generating capacity of 512 MW of the Volta dam exceeded Ghana's demand by far and the majority of the power was to be consumed by the Valco aluminium smelter. Upgrades at Akosombo to 833 MW and building a smaller dam downstream at Kpong with a capacity of 239 MW have doubled hydropower production since 1964. The demand for electricity continues to rise. It is likely that a third hydropower dam will be built in the Bui gorge of the Black Volta.

Figure 3 shows the fluctuations of the water level of Lake Volta. Before 1980, the withdrawal pattern is very regular. In the early 1980s, a severe drought hit Ghana, lowering the water below minimum operating level. After the drought, we see increasing level fluctuations, mainly due to larger withdrawals. In 1998, the lake level dropped again below the minimum, causing major power outages. The reduced rainfall in 1997 was a minor drought but withdrawals in the preceding years left the power

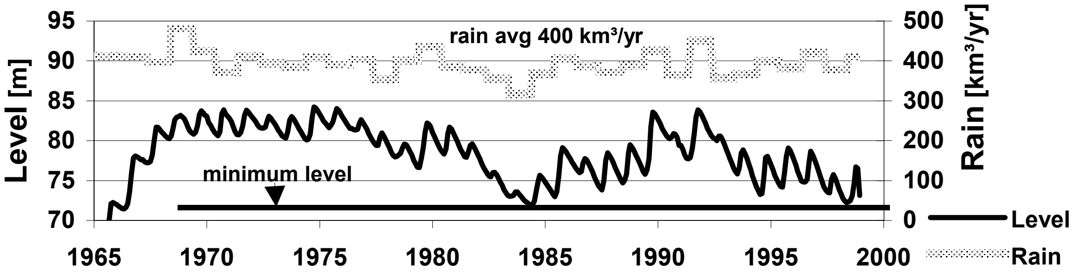

Fig. 3 Water levels of Lake Volta and annual rainfall.

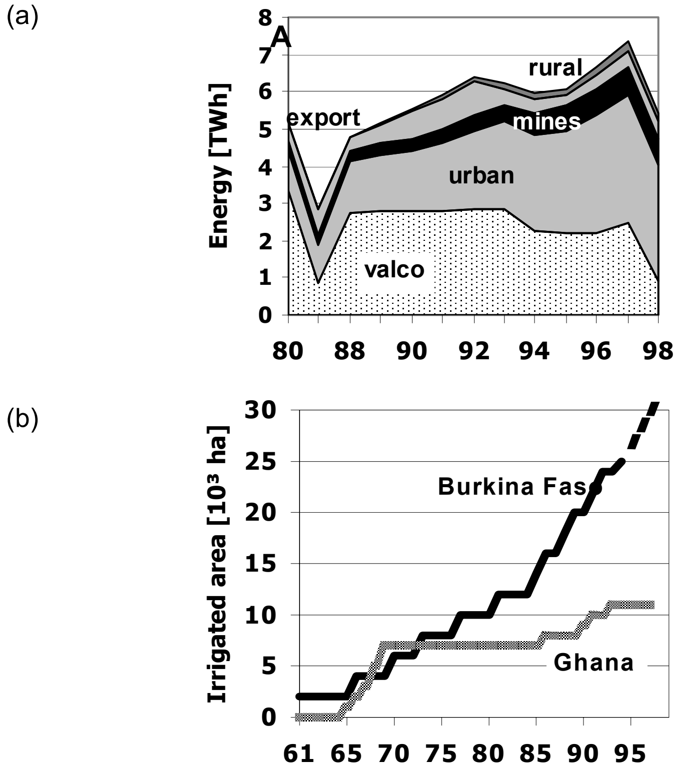

Fig. 4 Competing water uses. (a) Hydropower consumption; (b) irrigation development.

company with inadequate reserves. Figure 4(a) shows the steady rise in the use of electric power in Ghana that lies behind the increased withdrawals. At present, irrigation development is minimal, especially in Ghana, and household water supply, estimated at 20 m^3 per year per household, amounts to less than 1% of the total riverflow. Evidently, power use in urban areas is sustained at the cost of other sectors.

In contrast to Ghana, land-locked Burkina Faso has only minor mining and industrial sectors. Burkina Faso is one of the least urbanized countries in the world and 90% of the population is active in the agricultural sector. Economic development depends on agriculture because no alternatives exist in other sectors. Staple crops are sorghum, millet, and corn, grown under rainfed conditions. Average yield lies between 800 kg and 1000 kg of grain per ha. Farmers would need to invest more labour, improved seed and chemicals to obtain higher yields. Failing rains greatly reduce yields, causing financial losses on investments made. Irrigation is generally seen as necessary to control the risks in order to achieve sustained higher levels of production.

Figure 4(b) shows irrigation development in Burkina Faso and Ghana (FAO, 2000). Irrigated areas in both countries are modest but rapid expansion of irrigation in Burkina Faso and stagnation in Ghana show the different development paths. Most irrigation development in Burkina Faso takes the form of village-level schemes with imperfect hydraulic control. In 1991, 1100 village dams had been built in Burkina Faso, mainly for cattle and drinking water purposes (Sally, 1997). Presently, many dams are built or converted to function also as reservoirs for irrigation water. These activities will affect water availability but the impact is difficult to quantify given the diffuse nature of the irrigation development. To put things in perspective, the total amount of irrigable area in Burkina Faso is estimated at 160 000 ha (Sally, 1997), which is 20% of Lake Volta. Even though potential losses are small compared to those of the lake, anxiety exists in urban Ghana concerning irrigation upstream of Lake Volta in general and in Burkina Faso in particular (Gyau-Boakye & Tumbulto, 2000).

DECISION SUPPORT SYSTEM

We have sketched the sensitivity of water supply and the increasing water demand. To prevent conflicts and mitigate water shortages, policy makers need a decision support system (DSS) to make scientifically sound choices. Here, we describe some key issues concerning the development of such a DSS within a recently initiated project. To address integrated water management, the German Federal government has started an eight-year science programme on Global Change in the Hydrological Cycle (GLOWA) consisting of four projects, one of which is studying the impact of global and regional change on the water resources of the Volta basin. The goal of this GLOWA-Volta project is a DSS for the assessment and sustainable development of water resources. The DSS will simulate water availability and demand under different global change scenarios and help find optimal policies.

The main scientific task is development of the dynamic model underlying the DSS. A multidisciplinary expert panel has defined a set of key variables that embed the most relevant processes: (a) *precipitation*, (b) *evapotranspiration*, (c) *agricultural production*, (d) *land use*, (e) *income*, (f) *population*, (g) *riverflow*, (h) *water use*, (i) *hydropower*, (j) *health*, (k) *technological development*, and (l) *institutional development*. Variables (a)–(i) will be treated as endogenous variables to be solved simultaneously so that all feedback loops among these variables are accounted for. *Health* will be an output variable because the feedback mechanisms are felt to be too difficult to model adequately. *Technological* and *institutional development* are treated as input variables over which the DSS will optimize for given objective functions. The optimal combination of technological and institutional development will be the end product of the DSS.

Models exist to predict all endogenous variables under *ceteris paribus* conditions. The scientific challenge is connecting the variables appropriately. Over-dimensioned complex models in which every variable depends on all other variables tend to produce unrealistically low sensitivities with respect to fitted parameters. Advanced analysis, using graph and information theory, is needed to ensure that the dimensionality of the final model is commensurate with data available for model calibration at the required resolution. In the GLOWA-Volta project, model integration is envisioned from the beginning and each discipline involved is aware of the data needs of other disciplines.

Scale issues tend to compound data exchange difficulties as each discipline has its own units of observation, analysis, and prediction. To facilitate data exchange, a "scale of communication" has been defined as a grid with cells of 9 × 9 km. This is the scale at which both social (villages and associated land use) and physical (first-order basins) patterns start to repeat. It is also the highest resolution for which it is practical to model weather and climate with the MM5 mesoscale model. Any downscaling and upscaling has to take place within disciplinary clusters. For example, one agronomic sub-project disaggregates land-use classes into (distributions of) vegetation elements. A micrometeorological sub-project subsequently develops aggregation schemes for the effect of vegetation on vapour, heat, and impulse exchange between land surface and atmosphere on the 9 × 9 km grid.

West Africa is a relatively data-poor environment with few data sets that are complete and consistent. We have to build upon existing data and select those models that make optimal use of the data. On-site research will focus on model calibration and verification. For example, to predict riverflow, hydraulic routing is necessary. The Onchocercosis Control Project of the World Health Organization has collected a large set of reliable riverflow data in West Africa from 1975 to 1995. We selected the IRAS routing program that needs only limited field measurements to make optimal use of the data available (Loucks *et al.*, 1995).

In Ghana, most water policies still have to be formulated by the new Water Resources Commission (WRC). WRC has supported the GLOWA-Volta project through discussion, exchange of documents and workshop participation and has directly contributed to defining the project goals. In its turn, WRC provides a policy outlet for the research results. For example, one objective of WRC is to develop a DSS for water utilization at the local level. The DSS developed within the GLOWA-Volta project will aid WRC with this task as well as with general policy development. It is important that similar links also be forged with the appropriate institutions in Burkina Faso.

CONCLUSIONS

Although average rain in the Volta basin is ample, the spatial and temporal variability make it an unreliable resource for agricultural purposes. Without a reliable water supply, investments in agriculture are risky or not profitable. The surface water resources needed for irrigation development show a high sensitivity with respect to rainfall and, probably, land surface characteristics. Burkina Faso and northern Ghana stand in competition for water resources with the urbanized society of southern Ghana.

Climatic and social feedbacks tie the region together in a way that only integrated research can assess. In the GLOWA-Volta project, special attention has been given to problems of scale and the general data scarcity in West Africa. In Ghana, a direct link exists between the research project and policy makers through the recently formed Water Resources Commission.

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