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The River Niger water availability: facing future needs and climate change

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Abstract The River Niger is the third longest river in Africa, with a stream length of 4200 km, a drainage basin of 2 170 500 km^2 (of which 1 500 000km^2 is an active basin), and an average discharge of about 6000 m^3/s. The natural variability of its rainfall and discharge are analysed for several major sub-basins, in the context of the West African drought, which has lasted for nearly 40 years. Two paradoxes are shown: the increase of Sahelian runoff since the beginning of the drought due to land degradation, and the steep decrease of Sudanian runoff over the same period, substantiated by the long-lasting decrease of the groundwater tables. The cooperation between the nine countries sharing the basin is organized through the Niger Basin Authority (NBA), which needs to propose and administer plans to meet objectives for all development projects throughout the basin. Much information about the water resources available in the basin is collected and analysed by the NBA, which is summarized in this paper, including surface and groundwater resources, rainfall and evaporation over the basin, existing and projected dams and water consumption for irrigation. From the standpoint of water resources, the Niger basin can be divided into four zones with different physical and geographical characteristics: (i) the Upper Niger basin, in Mali, Guinea, and Ivory Coast, covering a surface of 257 000 km^2, with only one large dam in Mali (Selingue, 1.7 MMm^3); (ii) the inner delta, in Mali, which seasonally flooded surface can reach 35 000 km^2, and where the water losses vary between 24% and 48%; (iii) the Middle Niger basin, in Mali, Niger and Benin, where local flows from Sahelian and Sudanian areas join the residual outflow from the inner delta; and (iv) the Lower Niger basin, between Cameroon, Nigeria and Chad, where high rainfall increases the River discharge, and where large dams for hydro-electric power production and irrigation are built. The River Niger is deficient in dams to control water, especially in its upper and middle basins. Nigeria has many dams, including large dams, while Burkina-Faso has many small dams, but there are only a few dams upstream of the River Niger in Mali/Guinea/Ivory Coast. It is therefore likely that several dams will be built in the Niger basin in the coming years, and several are in the project phase: among which three are large ones in Guinea (Fomi), Mali (Tossaye) and Niger (Kandadji). All of these will have a large impact on the River Niger regime and the environment, especially the Fomi dam, which will significantly change the river regime upstream of the inner delta, inducing an important reduction of the flooded area, and the Tossaye dam on the Saharan border of Mali, which could promote a very significant level of evaporation, while the Kandadji dam will have less impact downstream. It is very important before building these dams to take into account the past years variability of climate and river regime. It is particularly important to take into account the very large runoff decrease in the tropical humid sub-basins, and the runoff increase in the Sahelian sub-basins.

Key words drought; River Niger; Sahel desert; water resources; water accessibility

INTRODUCTION

The West African drought has now lasted for nearly 40 years. It has had tragic consequences in the Sahel countries, such as desertification. This drought, which is notably characterized by a decrease in rainfall, decrease in surface-water flows, and with changes in the rainy season, contributes to reduced water availability in the Niger River basin. This shift in climate characteristics must be borne in mind in order to understand the present hydrology and water uses in the basin.

The River Niger rises in the Futa Jallon Highlands in Guinea, with an average altitude of 1100 m. It flows northeast and during the rainy season forms a vast flood plain in Mali known as the inland delta. Away from the delta the river meanders in Mali then flows southeast to Nigeria, where it is joined by the River Benue and empties into the Atlantic Ocean. Nine countries sharing the active basin are members of the Niger basin Authority (NBA): Benin, Burkina Faso, Cameroon, Guinea, Ivory Coast, Mali, Nigeria, Chad and Niger. Algeria has an important part of the inactive desert basin.

From the standpoint of water resources, the Niger basin can diagrammatically be divided into four zones with more or less homogenous physical and geographical characteristics (Fig. 1):

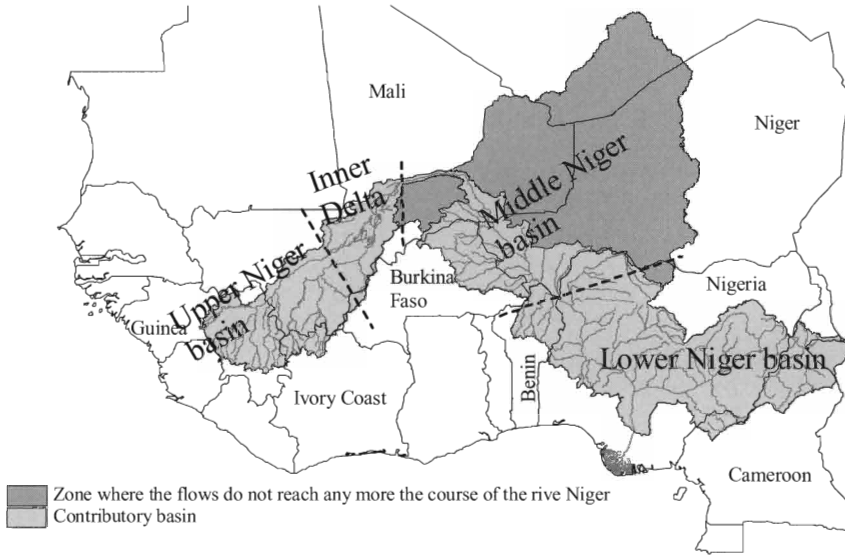

Fig. 1 Niger River basin.

The Upper Niger basin is located in Mali, Guinea, and Ivory Coast. It has an area of 257 000 km^2, of which 140 000 km^2 are situated in Guinea, serving as the major watershed, and is seen as the dominant portion, which can be used to partially regulate water flow throughout the length of the river.

The inland delta is entirely situated in Mali, covering a rectangular area facing southwest and northeast, with a length of 420 km and a width of 125 km between Ke-Macina and San in the south and Timbuktu in the north. It has a surface area of 84 000 km^2 and comprises four agro-ecological zones: the living delta, the middle Bani-Niger, the dead delta and the lacustrine zone between Gao and Timbuktu. It accounts for almost all of the rice cultivation, which is the staple food in Mali. This is done thanks to irrigation from the Markala Dam.

The Middle Niger basin lies within Mali, Niger, Benin and Ivory Coast. It stretches from Timbuktu to Benin, covering an area of 900 000 km^2, 230 000 km^2 of which are inactive. It is made up of a series of irrigated terraces. Water flow in this basin largely depends on additional influx from the delta and navigation is hampered by waterfalls.

The Lower Niger basin lies between Cameroon, Nigeria and Chad. It is characterized by large dams for hydro-electric power production, irrigation and for industrial activities throughout the basin. Energy production is mainly derived from the Kainji, Lagdo and Jebba dams, which supply 68% of Nigeria's electricity needs and 22% of her total energy needs.

WATER RESOURCES IN THE BASIN AND THEIR VARIABILITY

Inventories of data are available by consulting the database of the NBA and the SIEREM base from HydroSciences Montpellier Laboratory. Direct observation of surface water flow on the topographic slope of the Niger enables us to realize that some parts are not hydraulically linked to the river. These include the Algerian section of the basin (the Tassir Oua Ahaggar region) and those of Tamesna and Tahoua found in Mali and Niger. The large tributaries of the Niger, which

used to drain these regions at humid times, presently only exist as dry valleys covered by thick sand. Even the Continental Terminal aquifer found in the Iullemeden sedimentary basin is cut off from the hydrological system of the River Niger. The same situation exists with the Gando and the Liptako regions at the boundary between Mali and Burkina Faso.

Rainfall and climatology

The rainfall regime of the Niger River depends on the fluctuations of the Atlantic Monsoon, which generally occurs between May and November. The intensity of the phenomenon is relatively homogenous on the east–west axis, but experiences a serious gradient on the north–south axis following the scale of the basin. There are 530 rainfall stations and 105 climatic stations with at least 20 years of observations. Data from Nigeria and Guinea are difficult to obtain. The average annual rainfall rises to 2000 mm in portions further south in the basin, while it decreases to less than 400 mm in the north under Sahelian and semi-desert climate (Fig. 2).

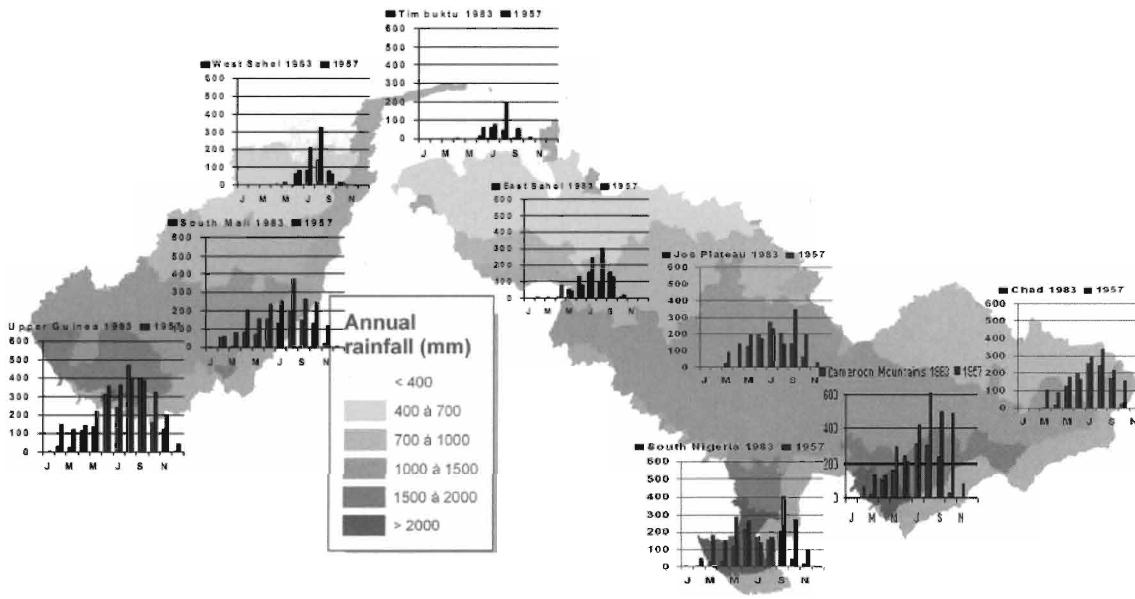

Fig. 2 Niger River basin: climatic zones and monthly rainfall illustrations.

FLOWS

Rainfall–runoff variability

The hydrological time series for the Niger began in 1907 with the installations of stations in Koulikoro (Mali) and Jebba (Nigeria). The present hydrological observation is estimated at 250 stations, including the specific network meant to check the river flow within the framework of the Hydroniger Programme. The volumes discharged are lower in the upper basins, and increase markedly when entering Nigeria where rainfall is now heavier over the Niger basin (Fig. 3). The hydrological regimes strongly changes for the upper Niger when passing through the delta, where the flood flow is delayed by 2–3 months, and is reduced from 24 to 48% during extremely dry years.

The River Niger basin has had a severe rainfall deficit since 1970, which has occurred over the whole basin. All the sub-basins experienced a reduction of runoff. The 1980s were the driest decade since the beginning of the 1900s (Fig. 4). The rainfall deficit is less in the southern part of the basin, mainly over the Benue River basin. However, the Niger basin can be divided into three

main areas: the upper basin of the River Niger in Guinea, Mali and Ivory Coast, where the runoff deficit is very large (Fig. 5); the lower River Niger basin, including the Benue River, where the runoff deficit is limited; and the Sahelian tributaries, mainly in Mali, Burkina-Faso and Niger, where the runoff has increased, due to changes in land use (Fig. 6).

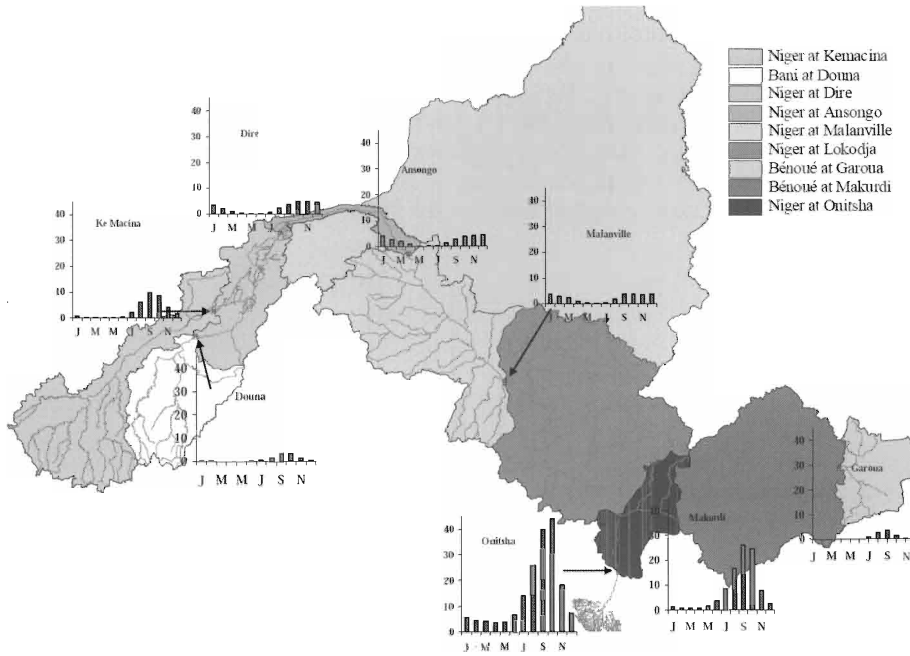

Fig. 3 Monthly average volumes (in billion of m^3) (1960–1990).

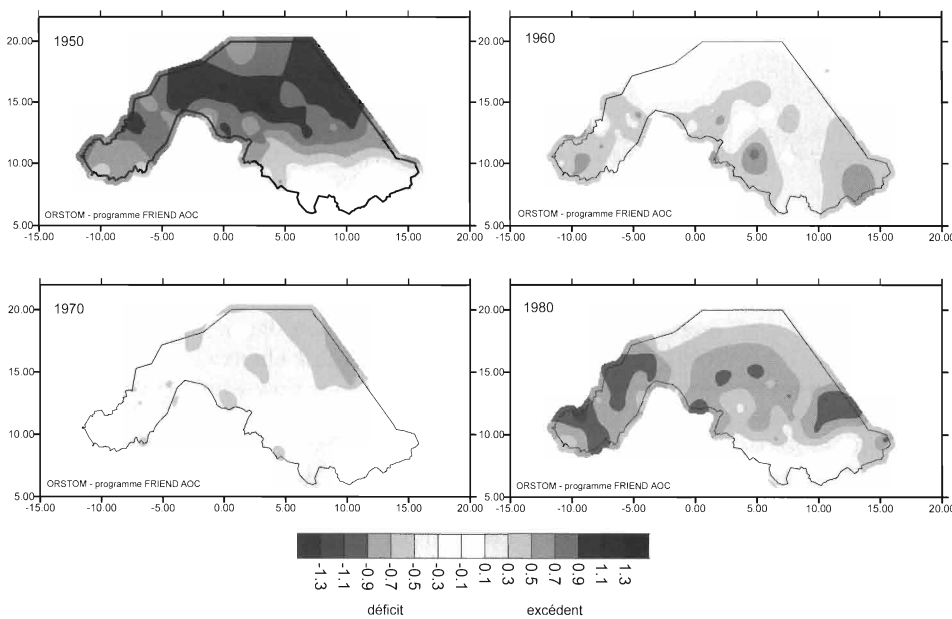

Fig. 4 Rainfall index over the River Niger basin (Paturel *et al.*, 1997).

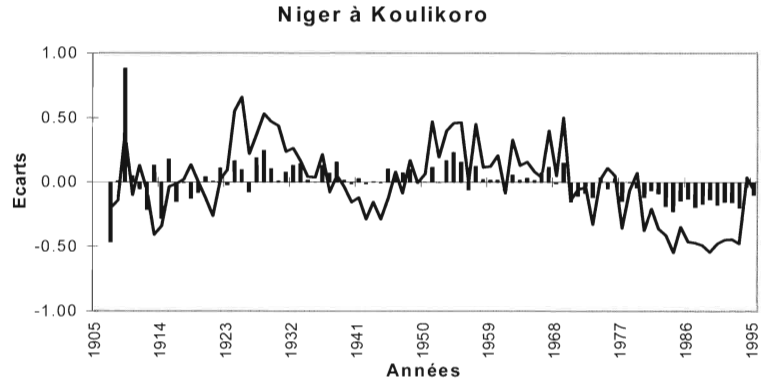

Fig. 5 Rainfall–runoff in the Soudano Guinean part of the River Niger in Mali and Guinea.

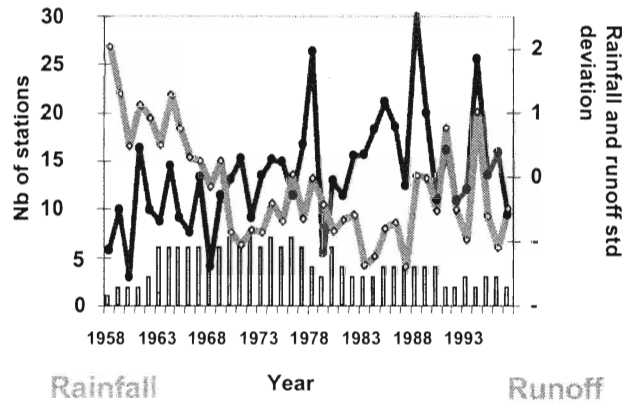

Fig. 6 Rainfall–runoff relationships in Sahelian tributaries of the River Niger.

In the Sahelian parts of the basin runoff coefficients have seriously increased, which has led to higher flood peaks, erosion, sediment transport and dam silting (Fig. 6). This is linked partly to the climate change-related rainfall reduction, but mainly to the increase of the cultivated surfaces, and the related disappearance of the natural vegetation. In Soudano-Guinean parts of the Niger River basin, the runoff decrease has been much greater than that of the rainfall, due to the cumulative (memory) effect of the rainfall lasting shortage on the groundwater levels (Mahe *et al.*, 2005).

Groundwater resources

Discontinuous aquifers are mainly found on the right bank in the Niger (Guinea, Mali, Ivory Coast, Burkina Faso and Niger), in the Guineo-Sudanian zones and the Sudano-Sahelian zone. Pipe-borne water projects in villages make use of such aquifers. Specific flows and the rates of failure in bore-hole realization are very unsteady (between 30 and 70%). Generalized aquifers can be found in large sedimentary forms, especially on the right bank of the Niger River (Mali, Niger, Chad, Nigeria and Cameroon). On plateau surfaces, superficial aquifers are superimposed on the deeper aquifers. The outer aquifers can be considered to be semi-continuous, thereby forming a hydraulic link with the deeper layer, or it can be discontinuous.

Figure 7 shows the importance of the baseflow in the annual runoff. This is for the Bani at Douna, but this is representative of most of the River Niger tributaries of Guinea, Mali, Ivory Coast and Cameroon, under Soudano-Guinean climate.

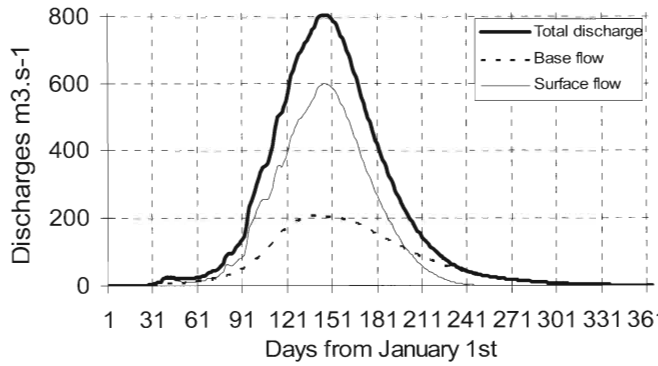

Fig. 7 Annual hydrograph for the Bani River at Douna. Total runoff (bold line) / surface runoff (thin line) / base flow (dashed). Average 1984–1996 (Mahé *et al*., 2000).

ACCESSIBILITY TO WATER AND ITS USES

Reservoirs

Dams can be classified in two main groups: those existing and those still in the project planning phase.

The existing dams comprise of 260 dams identified on the basin slopes of the Niger (Fig. 8). The dam distribution is not regular and there is a concentration in some sections of the basin, in Burkina-Faso (mainly small dams) and in Nigeria (all sizes including large dams).

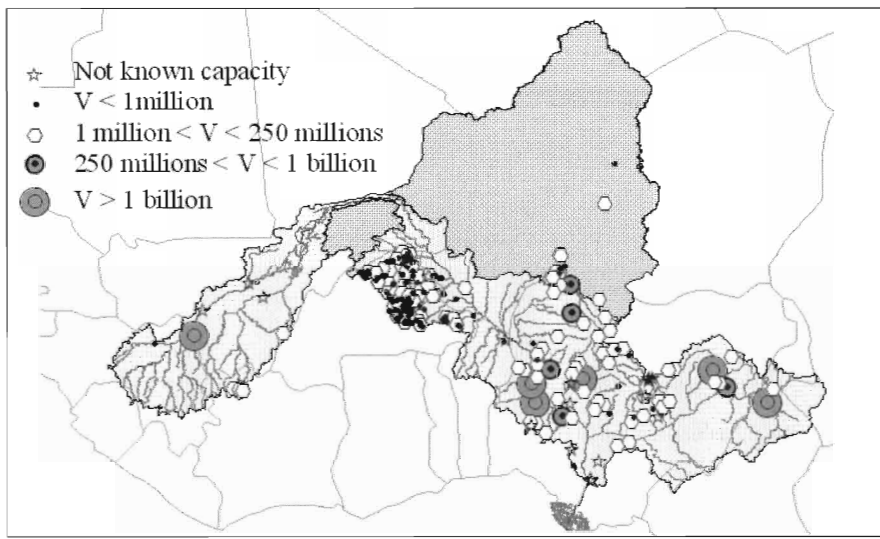

Fig. 8 Niger basin: situation of existing dams.

Capacity of dams varies between 25×10^{-3} million m^3 (Camp de chasse, Tapoa, Niger) to 16 billion m^3 (Kainji, Nigeria). Figure 9 shows the class distribution of the capacity of all the identified dams. From this distribution 50% of them are small dams of <1 million m^3, and there are only six "giant" dams (>1 billion m^3): one in Mali and Cameroon and four in Nigeria.

An evaluation of the capacity of the existing dams places the total volume at 42 billion m^3, which represents 27% of the water influx from the Nigerian Onitsha between the dry periods of

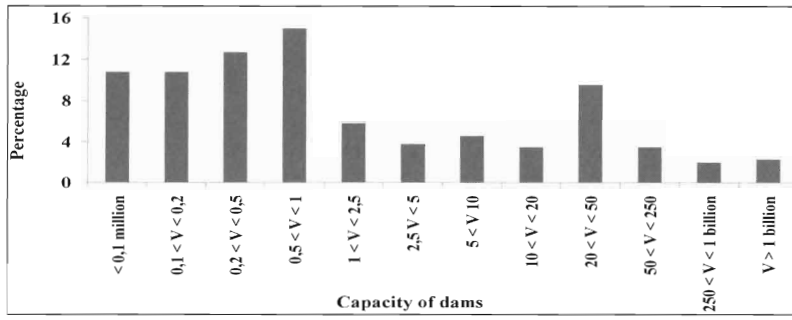

Fig. 9 Class distribution of the capacity of dams.

1971 and 2001; and 22% of the same influx in the same station during the rainy seasons between 1929 and 1970. This situation reflects the low utilisation of water resources in the Niger and its tributaries.

Projected dams

Seventy dams are projected for the basin of the River Niger, mainly in the middle and upper Niger valley, in Niger, Burkina-Faso, Mali and Guinea. The only projected sites for construction works in the lower Niger are those of Makurdi, Lokoja and Onitsha (Fig. 10).

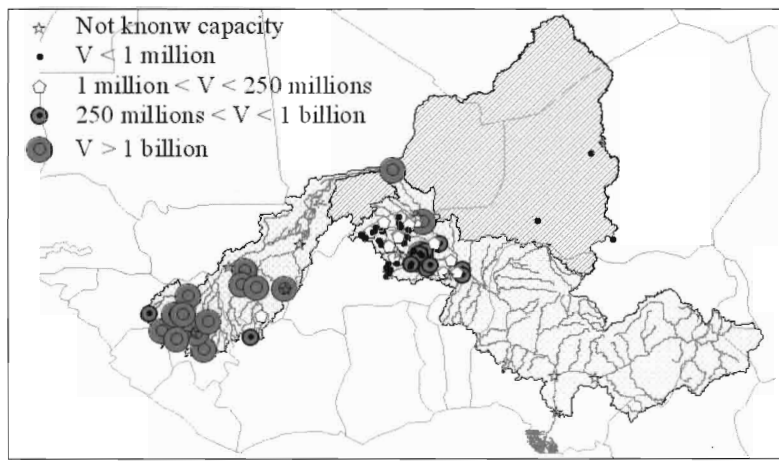

Fig. 10 Niger River basin, situation of projected dams.

Projected capacities reach 6 billion m^3 (Fomi site on the Niandan in Guinea). The capacity of the projected dams for the entire basin is about 48 billion m^3 compared to 42 billion m^3 for the existing ones. More than 80% (39 billion m^3) has been designed to be stored in the Upper Niger and 20% only (9 billion m^3) to be kept in the Middle Niger.

Considering the existing and projected dams in the Upper Niger, the volume of water stored will be slightly above 41 billion m^3. If this figure is compared to the discharged volume at the entry point of the delta (Ke-Macina and Douna) which is 75 billion m^3 in a wet year and 21 billion m^3 in a dry year, then it means that >55% of all flows will be stored in a wet year and flows in a dry year in the upper basin will be insufficient to fill all the reservoirs. This situation, which has been exacerbated by the drought, will have drastic consequences on the lower delta.

Downstream depletion

Depletion for purposes of irrigation 171 retention points for irrigation purposes have been identified along the Niger and its tributaries. Approximately 5412 billion m^3 are extracted annually to irrigate a surface area of 264 550 ha, giving an average of 20 000 m^3 per inhabitant. The retained volume from each country depends on the surface of the basin slope of the country concerned (Table 1). In this connection the largest volume is kept aside in Mali, followed by Nigeria and Niger.

Table 1 Retained volumes and irrigated surface area per country.

	Number of uptakes	Total surface irrigated in 2005 (ha)	Annual total volume taken in 2005 (Million of m^3)
Benin	2	1006	23
Burkina Faso	3	1482	9
Cameroon	3	5300	107
Ivory Coast	10	2495	46
Guinea	8	8984	104
Mali	8	117348	3825
Niger	43	43315	454
Nigeria	94	82620	847
Total	171	264550	5412

Retention for potable water supply Various water catchments areas have been set up on the Niger and its tributaries to supply many towns with potable water. The estimations are for 2005 based on 20 L per inhabitant per day for the rural areas and 40 L per inhabitant per day for urban areas.

Potable water retentions for livestock breeding The estimate of reserved volumes for livestock is difficult because of its diffused nature. Calculation of water needs associated with livestock is based on a need for 30 L per UBT (Unité de Bétail Tropical (Unit of Tropical Cattle)) per day. Estimates show in 2005, about 223.6 million m^3 of water was used for about 2 771 000 UBT. The largest reserved volumes are found in those countries with the largest areas of land within the basin (Nigeria, Niger). Mali is noted for its livestock, numbering 8 640 000 UBT. However, reserved water for livestock is small (14.2 million m^3).

But it should be noted that part of the riverine population gets its water from the water-bearing beds of the river. The results of many estimates give this as the maximum level of extraction, without taking into account other sources of water.

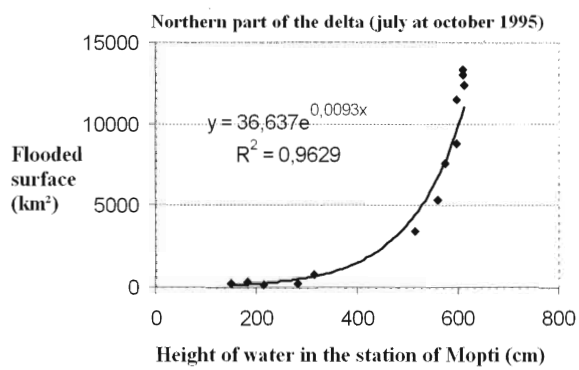

Fig. 11 Correlation between water height and flooded area in the upper inner delta, Mali.

CHANGE IN WATER AVAILABILITY

The case of the Niger River inner delta in Mali

For the Niger inner delta, an integrated model of the Niger inner delta called MIDIN has been developed. It integrates several relationships between water, biology and human activities along the different hydrological entities, including channels, lakes and flood plains.

Figure 11 shows the correlation between the flooded surfaces, as depicted by NOAA images between 1990 and 2000, and the water heights at the main gauging station of Mopti in the delta. This correlation allows the flooded area of the upper delta area to be determined according to the Mopti water level. This relationship allows the prediction one month in advance of the water height in the northern part of the delta (north of the central lakes) from the water height at Mopti.

CONCLUSION

Nigeria has many dams, including very large dams, while Burkina-Faso has many small dams. However, there are only a few dams upstream of the River Niger in Mali/Guinea/Ivory Coast. It is therefore likely that several dams (including a few very large dams such as in Fomi in Guinea) will be built in the Niger basin in the coming years. It is very important before building these dams to take into account the past years variability of climate and river regime. It is particularly important to consider the very marked runoff decrease in the tropical humid sub-basins, and the runoff increase in the Sahelian ones.

It is also noticeable that most of the GCM outputs predict a rainfall reduction still to come during the next decades of the 21st century. Several tools such as Water Use Account, MIDIN and rainfall–runoff modelling should be used as prediction tools at NBA.

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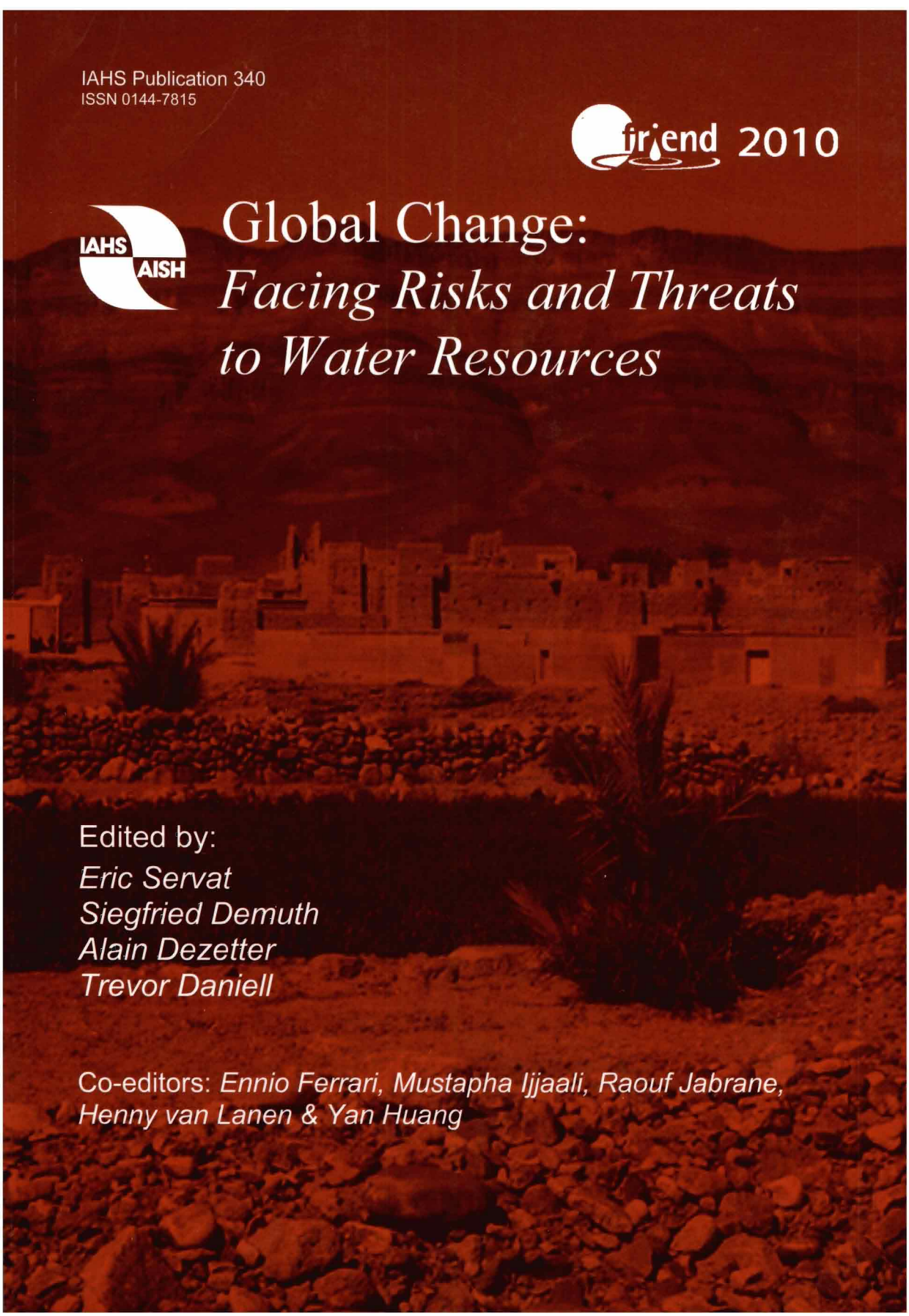

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