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Water, agriculture and poverty in the Niger River basin

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Livelihoods in the Niger River basin rely mainly on rainfed agriculture, except in the dry extreme north. Low yields and water productivity result from low inputs, short growing seasons, dry spells, and excessive water. The overlap of traditional and modern rules impedes secure access to water and investments in agriculture by generating uncertain land tenure. Improved agriculture and water management require technical, sociological, and regulatory changes to address the wider causes of poverty. Illiteracy and poor water quality, both correlated with high infant mortality, are pressing problems. Rapidly increasing population, climatic changes and dam construction contribute to rural vulnerability.

Keywords: agriculture; integrated water resource management; water poverty; water productivity; institutions; West Africa; Niger River

Introduction

The Niger River basin is the largest basin in West Africa. It covers six agro-climatic zones in nine countries (Figure 1) and presents a cross-section of the complex development issues of West African societies. The main livelihood is traditional, low input, rainfed farming, but ranges from nomadic pastoralism in the north, irrigated and fertilized agriculture in parts of Mali, Niger and Nigeria and fishing throughout. The Inner Delta in Mali is one of the largest wetlands and multi-use systems in Africa at three million hectares with over one million herders, fishermen and farmers. Much of the population in the basin suffers from extreme, chronic poverty and remains vulnerable to droughts and malnutrition. The rich ethno-linguistic diversity, recent independence and ongoing political insecurity further complicate the development of the basin.

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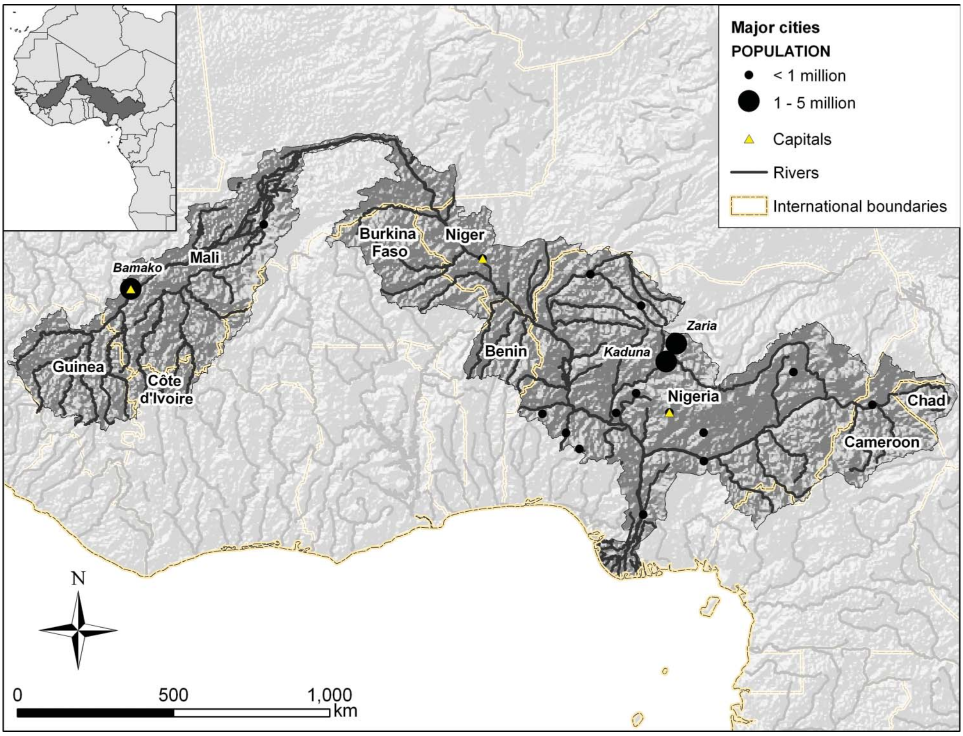

Figure 1. Niger River basin.

This paper reports the links between water, food and poverty in the Niger Basin. We diagnose the hydrologic and agronomic systems and identify how better agricultural water management may reduce vulnerability in the basin. We examine statistical relations between water and poverty, and analyse major future threats and opportunities, as well as the critical influence of institutions on water and agricultural development. Faced with increasing food and water insecurity as a result of climatic, demographic and land use changes, we discuss issues of water productivity in the basin.

Characteristics of the Niger River basin

Geography and hydrology

The Niger River is 4200 km long, the third longest in Africa after the Nile and Congo/Zaire. It rises in the mountains of Guinea and Sierra Leone (50 km^2 are in Sierra Leone) before flowing northeast towards the Sahara, and the vast flood plain of the Inner Delta in Mali. After the Inner Delta it flows southeast, is joined by the River Benue and finally reaches the Atlantic Ocean through the Niger Delta in Nigeria.

Spread across ten West African countries, the basin is 2,170,500 km^2 in area, the ninth largest in the world (Showers 1973). The northern section of the basin, extending across the Sahara desert into Algeria, is hydrologically inactive. The *active* basin, which we call hereafter the basin, covers 1,272,000 km^2 (Table 1) and nine countries: Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Guinea, Mali, Nigeria and Niger. They are all members of the Niger Basin Authority (NBA).

Table 1. Countries of the Niger Basin.

Country	Area	Proportion of basin within country	Proportion of country within basin
	km²	*%*	*%*
Benin	44,967	3.5	38.7
Burkina Faso	86,919	6.8	31.5
Cameroon	86,381	6.8	18.4
Côte d'Ivoire	23,550	1.9	7.3
Guinea	98,095	7.7	39.9
Mali	263,168	20.7	20.9
Niger	87,846	6.9	7.4
Nigeria	562,372	44.2	61.5
Chad	19,516	1.5	1.5
TOTAL Active basin	1,272,814	100	

Source: Marquette (2008).

Demography

Population of the basin was estimated at 94 million in 2005 (CIESIN/CIAT 2005), of which 71% live in Nigeria. Due to a high fertility rate, populations of most countries in the basin increased by 50% between 1990 and 2005 (Tabutin and Schoumaker 2004) and the growth rate of the population is currently estimated at 3.2% (Bana and Conde 2008, Guengant 2009). Demographers estimate, according to the lowest scenario, that the population of the basin will double by 2050, but, if the fertility rates remain constant, the population could increase fourfold by 2050 (Figure 2). This could jeopardize current and future development.

Population density in the basin is four to five times greater than the national averages, as people concentrate along their lifeline, the Niger River. The population is 64% rural.

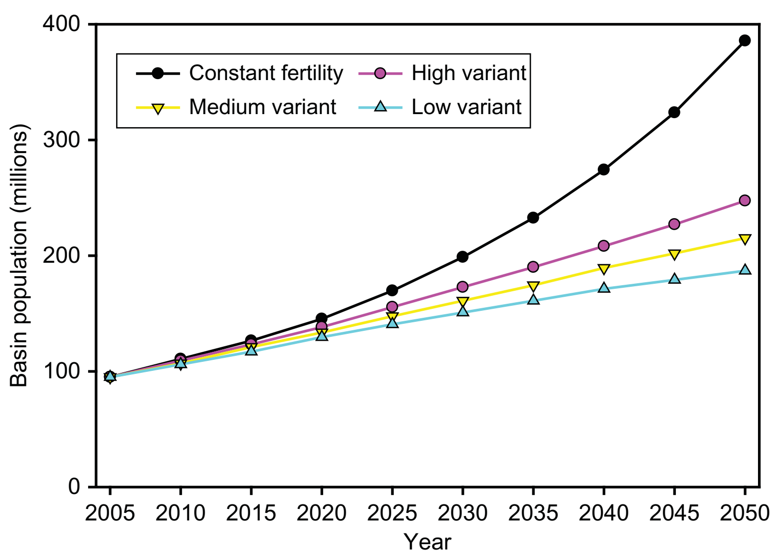

Figure 2. Evolution of Niger Basin population 2005–2050.
Source: based on United Nations Population Division (2006).

However, this is changing rapidly and by 2025 the majority may be urban. Urbanization is fuelled by a massive rural exodus, as well as a century-old migration from the inland to coastal areas and is sustained by recent political and climatic crises. The population is young (44% are under 15 years of age) and largely illiterate (with 35% overall literacy rates and only 18% for women).

Economy

When ranked by gross domestic product (GDP) (purchasing power parity, per capita), all nine countries of the Niger Basin fall in the bottom quarter of national incomes. Agriculture represents a large part of the Niger Basin GDP, with crops making up 25–35%, livestock 10–15%, and fishery 1–4%. The main livelihood/agricultural systems in the basin include dry- and wet-season cropping, pastoral systems, crop-livestock systems and fishing. The major crops are yams, cassava, rice, groundnuts, millet, sorghum, plantains, cocoa beans, maize, sugarcane and cotton.

The basin countries have important mineral resources, including gold, bauxite and uranium. Nigeria is the region's largest oil and gas producer, with 3% (36 billion bbl) of the world reserves, mostly in the Niger Delta (CEDEAO 2007). Installed hydroelectric capacity is 6185 GWh, less than 21% of the basin's potential. As in many parts of Africa, the Niger Basin suffers from a huge deficit in transport infrastructure, which undermines economic growth and regional integration.

Poverty

The United Nations Human Development Index, a composite ranking based on national income, life expectancy and adult literacy rate, ranks all of the Niger Basin countries in the lowest quintile of countries (Table 2) (UNDP 2007). Life expectancies (on average 50 years) are in the bottom 15% of all countries worldwide (Aboubakar 2003, Bana and Conde 2008).

Niger Basin childhood mortality rates (death prior to the age of five) of up to 250 per 1000 live births are two to three times higher than those in neighbouring countries in northern and southern Africa (Balk *et al.* 2003, Guengant 2009). After respiratory diseases, water-related diseases, namely malaria and diarrhoeal diseases are the largest causes of child mortality (UNICEF 2008, OMS 2006, ECOWAS-SWAC/OECD 2008). HIV infection rates are 1.1–7.1%, significant but less than in southern Africa.

The proportion of people living below the poverty line (US$1.25 per day) is high throughout the basin and is especially acute in Burkina Faso (70.3%), Guinea (70.1%) and Niger (65.9%) (World Bank 2009). There are an estimated 138 million poor in the basin countries, most of whom are rural. Table 2 provides a snapshot of the development status for these countries according to an array of commonly applied poverty metrics.

Sociology and institutions

The ethno-linguistic diversity in the basin is one of the richest in the world with over 400 vernacular languages and five official languages. Though half of these could disappear by 2050, the sheer number of them restricts the circulation and dissemination of information and innovations.

Traditional customs, influenced by animist culture, continue to define local activities and practices (Clanet 1994). Partly from the inability of central government administrations to implement their directives, village and land chiefs maintain considerable influence and

Table 2. Poverty and water situation indicators for countries of the Niger Basin.

Country	GDP[1]	Population below poverty line[2]	Life expectancy at birth	Under-five mortality rate	TARWR[3]	WPI[4]	Basic human needs index[5]	SVI[6]	HDI[7]	HDI world rank	Gini Co-efficient[8]
	$US 2007	*%* 2007	*years* 2007	*%* 2007	*m3/yr/capita* 2005	2002	*L/day* 2000	*index* 2004	*index* 2007–8		2007
Benin	1500	47.3	55.4	19.1	3820	39.3	15	0.584	0.437	163	36.5
Burkina Faso	1200	70.3	51.4	15.0	930	41.5	17	0.658	0.370	176	39.5
Cameroon	2300	32.8	49.8	14.9	17,520	53.6	33	0.640	0.532	144	44.6
Chad	1600	61.9	50.0	20.8	4860	38.5	11	0.618	0.388	170	–
Côte d’Ivoire	1800	23.3	47.4	19.5	4790	45.7	28	0.584	0.432	166	44.6
Guinea	1000	70.1	54.8	15.0	26,220	51.7	26	0.562	0.456	160	38.1
Mali	1200	51.4	53.1	21.8	7460	40.6	6	0.585	0.380	173	40.1
Niger	700	65.9	55.8	25.6	2710	35.2	20	0.725	0.374	174	50.5
Nigeria	2200	64.4	46.4	19.4	2250	43.9	24	0.621	0.470	158	43.7
OECD mean[9]	37,500	n/a	78.3	0.52	39,090	39.7	n/a	n/a	0.939		10.4
Non OECD	10,900	n/a	66.1	6.76	26,800	23.6	n/a	n/a	0.686		18.6

Note: [1] Gross domestic product at purchasing power parity, per capita.
[2] US $1.25/day.
[3] TARWR = Total actual renewable water resources.
[4] WPI = Water poverty index (100 = lowest poverty; 0 = highest poverty).
[5] 50 L is the commonly accepted minimum; Gleick (1996).
[6] SVI = Social vulnerability index (higher index is more vulnerable).
[7] HDI = Human development index (higher index is more developed).
[8] Gini coefficient: 100 = complete inequality, 0 = complete equality.
[9] Organisation for Economic Co-operation and Development (OECD) mean based on the 27 high-income countries as defined by the World Bank (2009).
Source: Ward *et al.* (2009).

power (Jacob 2005). Internal political tensions and peripheral rebellions also undermine central governments and their development efforts.

Water availability and access

Rainfall and agro-climatic zones

Rainfall depends on the Atlantic monsoon between May and November and gives a wet season and dry season. In the most southern part of the basin in Nigeria, the wet season is subject to a period of reduced rainfall: the second, short dry season. Climatic zones vary from hyper-arid to sub-equatorial and annual rainfall fluctuates from over 4000 mm in southern Nigeria/Cameroon to less than 400 mm (with no rain in some years) on the fringes of the Sahara desert in northern Mali and Niger (Figure 3).

In the Sahelian climate of the far north, even short-season crops cannot be grown reliably, but in the rest of the basin, rainfall is broadly sufficient for rainfed agriculture. Rainfall is spatially and temporally variable, however, causing water excess and droughts, which are more problematic for agriculture than low annual rainfall (Mahoo *et al.* 1999 cited by Rockstrom *et al.* 2002). In the north of the basin, short (two-to-four-month-long) wet seasons restrict the growing season, while in the south, both dry spells during the wet season and excess rainfall can cause crop failures.

During the 1970s and 1980s isohyets over the whole basin shifted south by about 150 km with devastating droughts across West Africa (Conway *et al.* 2009) and the Sahel in

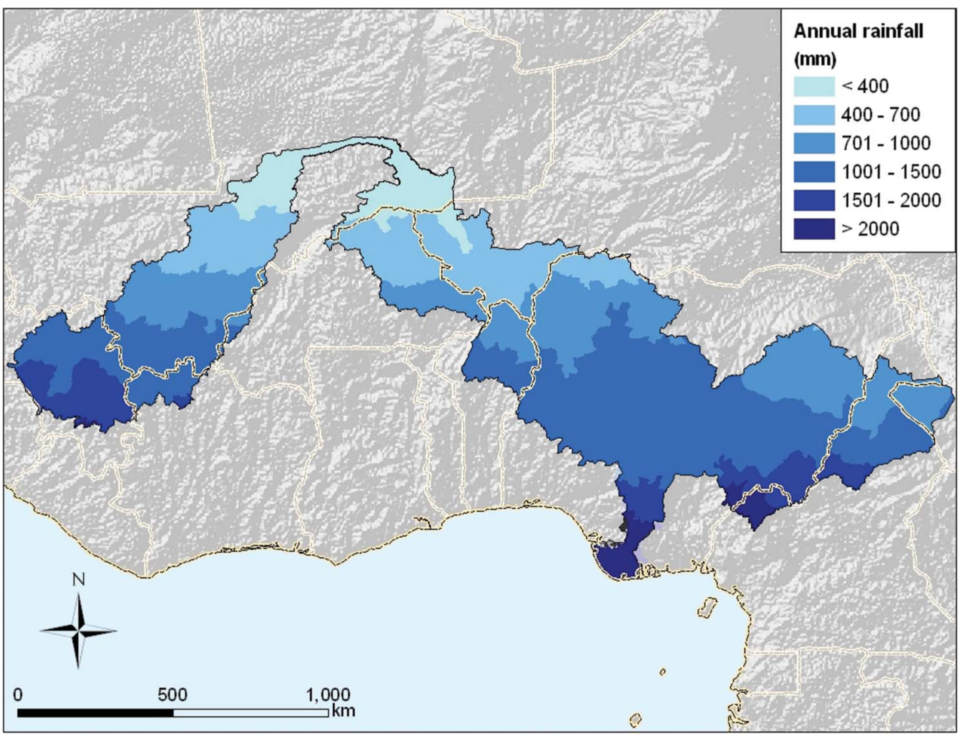

Figure 3. Niger River basin: annual rainfall.
Source: Mahé *et al*. (2009a).

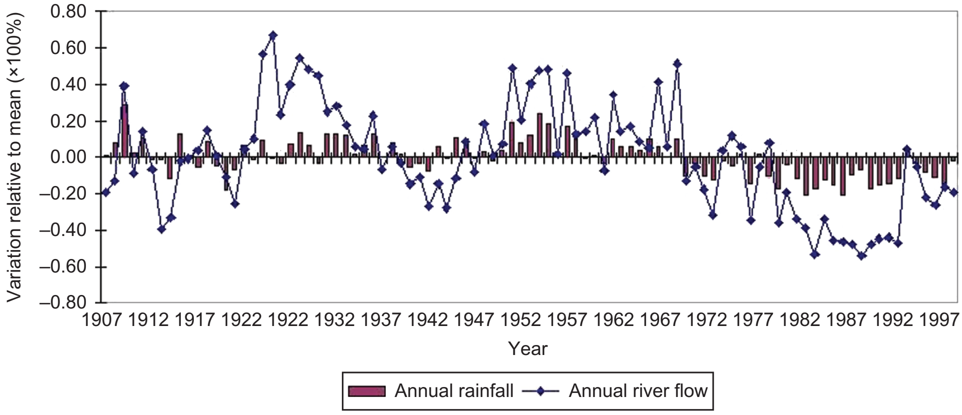

Figure 4. Rainfall-runoff in the Soudano-guinean part of the River Niger in Mali and Guinea. Source: Mahé *et al*. (2009a).

particular. Rainfall has increased since 1994, but remains erratic with more periods of severe drought (Mahé and Paturel 2009), which continue to reduce water availability in the basin. Rainfall–runoff graphs over the last century in the upper Niger Basin reflect the major droughts (Figure 4).

Evaporation

Potential evapotranspiration (ET_p) is high across the basin, especially in the north, due to advection from the Sahara. This dries up areas of inland drainage and causes high losses in water reservoirs. When rainfall (P) exceeds ET_p, the surplus infiltrates the soils, recharges groundwater and, excluding supplementary irrigation, defines the cropping season. In the north of the basin, this only occurs during the months of July and August. When rainfall is less than ET_p, November–April across the basin, plants exhaust soil water reserves and there is neither runoff nor infiltration.

Flows

The annual mean flow into the Inner Delta from Guinea and Mali is 46 km^3, but the mean outflow at Taoussa is only 33 km^3. The delta, whose area can reach 30,000 km^2 during the flood, changes the hydrology of the Niger by delaying the flood by two to three months, and reducing the flow 24–48% in dry or wet years respectively (Mahé *et al*. 2009b). The middle section of the Niger receives six tributaries from Benin and Burkina Faso and the mean annual flow entering the lower Niger in Nigeria is 36 km^3. With the contribution of its main tributary, the Benue River in Nigeria, and heavy rainfall, the mean annual discharge at the mouth exceeds 180 km^3.

The Niger River is highly seasonal with fairly high interannual variation. Runoff in all the sub-basins has lessened substantially since 1970, reflecting the decreased rainfall (Figure 4). Runoff proportionally fell most in the upper basin (upstream of the Inner Delta), caused directly by reduced contribution from rainfall and indirectly by less groundwater recharge and related baseflow. In the lower basin, including the Benue River basin, runoff was less affected because the rainfall decreased less. In contrast, in the Sahelian parts of the basin, runoff coefficients increased, partly due to reduced rainfall and soil compaction effects but mainly to increased agriculture and reduced cover by natural vegetation, leading to higher flood peaks, erosion, sediment transport and dam silting (Mahe *et al.* 2005). These variations in climate and river regimes have important implications for designing the projected dams in the basin as well as on the water available for agriculture.

Groundwater resources

Groundwater can provide a valuable water supply for dry season agriculture and quality drinking water. Studies have shown that under the Soudano-Guinean climate (Guinea, Mali, Côte d'Ivoire and Cameroon), baseflow from groundwater makes an important contribution.

There are large aquifers in sedimentary strata in Mali, Niger, Chad, Nigeria and Cameroon, and discontinuous aquifers in the Guineo-Sudanese and the Sudano-sahelian zones of Guinea, Mali, Côte d'Ivoire, Burkina Faso and Niger. Groundwater recharge is variable and depends on the geology, topology, climate and crop cover. Recharge rates vary from 20 mm/year in the Sokoto region of Nigeria (Adelana *et al*. 2006) to 136 mm/year in Katchari in northern Burkina Faso (Filippi *et al*. 1990). Around Niamey, Niger groundwater recharge increased fivefold to 25 mm/year when natural savannah was replaced by millet crops (Leduc *et al.* 2001). Extrapolation to other parts of the basin is uncertain and resources remain largely unknown.

Withdrawals are poorly quantified, but are estimated to be less than 5 km^3/year in Mali and Niger (WWAP 2009). There are proposals to develop groundwater and intensification may be worthwhile, but the impact must be carefully monitored to ensure that the amount pumped is sustainable.

Water balance

At the scale of the whole basin, evapotranspiration is the main component of the water balance. The mean rainfall of 690 mm over the total basin gives a gross input of 1500 km^3/yr. Flow at the confluence of the Benue and Niger rivers is 183 km^3, and discharge at the mouth is about 200 km^3 (blue water), which indicates high availability of water in the lower basin. Consumptive withdrawals for humans, livestock and industry are low and groundwater storage may be assumed constant. The difference, 1200–1300 km^3 or 80% of the basin water resources, is therefore evapotranspired. Mainuddin *et al.* (2010) indicate that grassland is the dominant water use compared with woodland and rainfed agriculture, but this is subject to classification difficulties. Water evapotranspired from irrigation is extremely low and highlights the importance of exploiting green water effectively.

Crops, livestock and fisheries

Rainfed and irrigated agriculture

There are over 2.5 million ha of arable land in the Niger Basin, of which only 20% are exploited. Although the Niger Basin possesses one of the largest wetlands, and has 27 large dams (ABN and BRLi 2007) and over 5000 small dams (Cecchi 2009), irrigation remains poorly developed and 85% of the cultivated area is rainfed. Agriculture has therefore adapted to rainfall and cropping zones roughly follow the isohyets. In the extreme north, rainfall is just sufficient for seasonal pasture. As one moves further south there is millet and sorghum, then banana, plantain, cassava, yam and finally rice in the south as well as in irrigated areas in Inner Delta in Mali, and in Niger and Nigeria.

Subsistence agriculture represents 78% of total agricultural production (Niasse 2006) and dominates all forms of rural activities. It remains an itinerant agriculture with extensive characteristics: low mechanization, lack of inputs (except Nigeria, which possesses fertilizer factories, thanks to its petroleum [Serpantié 2009a]), and with much of the labour provided by women and children. This agriculture is currently the only option available to farmers facing climatic uncertainties, inadequate support and weak commercialization possibilities (Serpantié and Lamachère 1989). On the positive side, agriculture has met the increased demand in food, as daily per capita production has been stable for 25 years at 2000 kcal. The projected demographic increase, however, is likely to make it difficult to reach a desired level of 2500 kcal/capita/day (CEDEAO 2007).

The Niger Basin Authority reports that 265,000 ha are under full control irrigation, of which 117,000 ha are in Mali, 46,000 in Niger and 84,000 ha in Nigeria. These countries have invested in large perimeters and full control irrigation over the decades, but traditional systems such as recession flooding, lowland and free flooding still dominate in terms of surface area. Farmers and donors now increasingly attempt to control water supply better, notably due to recent droughts. While the NBA favours large-scale developments to reach one and a half million hectares by 2025 according to its investment plan, many donors currently favour small-scale irrigation, preferably privately funded and owned. A number of small dams already exist in Burkina Faso, Mali, Côte d'Ivoire and are being actively developed as part of public, private and non-governmental organization (NGO) projects.

There is a vast land potential for irrigation. However, surface waters could not supply the amount of total irrigable land. Current agricultural withdrawals in the dry season already have an impact on the Inner Delta wetlands of Mali (De Noray 2003, Zwarts *et al.* 2005), on the Niger Delta in Nigeria (NDES 1999, Uyigue and Agho 2007) and on production of hydroelectricity of the Kainji Dam in Nigeria. Faced with food crises and climatic changes, donors are funding the expansion of irrigation, mostly in Nigeria and Mali. This could push agricultural withdrawals from 9 km^3 to nearly 30 km^3 by 2025, more in Mali than in Nigeria as the latter consumes less water per unit area. New dams are being built, notably to extend dry season irrigation in the Office du Niger in Mali. However, new dams to support low flows risk further reducing flows in the Inner Delta, lessening the extent of the flood, affecting livelihoods of a million herders, fishers and traditional rice growers as well as the wetland ecosystems (notably hippopotamus and manatees in the both the river and Inner Delta). As a result, irrigated agriculture will need to improve its water efficiency and the economic gain derived from the water used to justify the heavy investments it demands.

Livestock

Scattered over more than 1.5 Mkm^2 distributed over nearly 13° latitude, the 50 M herders of the basin maintain 138 M livestock units (Diop *et al.* 2009a). The north–south distribution of species is a function of their resistance to drought and their ability to exploit natural rangelands. Camels constitute the dominant form of breeding in the north of the basin and may be found to 13°N. At lower latitudes, zebu (*Bos indicus*) cattle follow to 8°N, the northern limit of trypanosomiasis. Below this latitude, only *Bos taurus* cattle and smaller ruminants tolerant of the endemic survive. There are small ruminants, mostly goat and sheep, across the basin.

There are two major livestock production systems in the basin: nomadic herders, who live on Sahelo-Saharan fringes and who have large herds of zebu cattle, and sedentary

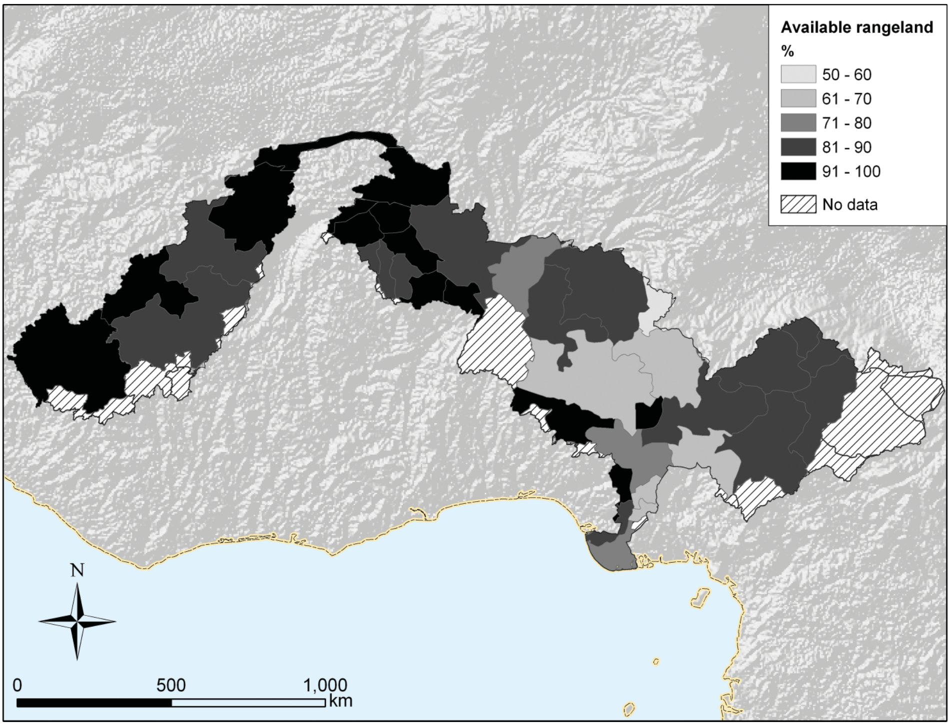

Figure 5. Amount of rangeland (total area-cultivated area) available in the Niger Basin.
Source: Serpantié (2009b).

agro-pastoralists, who typically own fewer than 10 small ruminants and some larger bovines. Nomadic herds make up 5–15% of livestock units and can travel over 800 km in their annual transhumance (Diop *et al*. 2009a). Livestock is an important livelihood strategy in the basin, and provides food, income and cash reserves. Livestock numbers have increased in all countries over the last 30 years and are expected to continue to rise, responding to the projected population increase and the increased demand for meat and dairy products in local diets (Diop *et al*. 2009b).

Livestock production remains predominantly extensive and can be severely impacted by the development of agriculture, which restricts the nomads' access to grazing land and water points. Despite possible synergies between farmers and herders, whose animals graze crop residues and return manure/fertilizer, conflicts are increasing. Contrary to what is often reported, natural rangeland is widely available throughout the basin (Figure 5). The upper basin, the Sahelian zones, the Inner Delta and the less populated eastern part of Burkina Faso have the most available rangeland and are therefore most capable of supporting increased livestock numbers. Even in central Nigeria, where rangeland is scarcer largely due to higher population density, 50–70% of the land is not cropped and therefore potentially available for grazing. Resolution of the conflict requires the correct implementation of institutional support for nomad pastoralists.

Fisheries

Fishing is mainly concentrated around the large floodplains of the Inner Delta or in the Sélingué, Kainji, Jebba and Lagdo reservoirs. The fishers in the basin may be divided between full-time fishers, mostly belonging to ethnic groups recognized as fishers, agro-fishers who spend a part of the year growing crops, and occasional or part-time fishers for whom fishing is a secondary activity. When they have access to land, the "full-time" fishers also practise rainfed or flood recession cultivation. Of 100,000 professional fishers in the basin, supporting roughly 900,000 people, 62,500 are in the Inner Delta and 13,000 in the large reservoirs (Morand *et al.* 2009). Total fish catch in the basin (not including the estuarine delta) is about 240,000 t/yr (Neiland and Béné 2008), with a value of almost US$100 million. Fish are an important source of animal protein in Africa, ranging from 40% in Nigeria to 49% in Cameroon (Food and Agriculture Organization [FAO] 2009). Total demand for marine and inland fish is estimated at 730,000 tonnes, assuming an average fish consumption of 7.7 kg/capita/year (the value for Africa).

According to recent surveys on the Inner Delta and the lakes of Kainji, Lagdo and Sélingué, lack of nets and canoes, the variability of the hydrology and the poor strength of their fishers' associations are secondary constraints to their livelihoods. They rank first food shortage, and second the lack of access to health care, to good quality household water, to school, or to credit. Lack of access to land occurs specifically in some regions where the fishers are considered to be new settlers. Poor enforcement of both traditional and modern (legal) fisheries regulations by communities or the state make both fishers and fish stocks vulnerable. Difficult access to markets in some regions of the basin and the competition from marine fish trade lead to low prices. The projected demographic increase as well as the construction of dams and water withdrawals will exert increasing stress on fishers, notably through increased competition for space, conflicts with the other activities (herders, farmers), and degraded environments. The effect of climate change on all rainfall regimes (IPCC 2007) may further increase the vulnerability of fishers.

Fish culture in ponds, around irrigated perimeters, and in cages in reservoirs can constitute a valuable solution to perturbed fisheries. By gathering the fishing communities in a reduced number of sites, it may also allow for better access to markets and increased recognition. Shifting from hydrologically highly variable natural systems to regulated systems can also remove uncertainty and reduce risk. The communities presently involved in fishing are poorly prepared to manage this new activity, however. Furthermore, migration may result in loss of rights (especially for access to land). Nigeria is one of the few African countries, with Zimbabwe, Ghana and Egypt, where some fish culture has developed, mostly as small- and medium-scale enterprises. Two thousand fish farms, covering 60,000 ha, produce 80,000 tons of fish per year, and the number is increasing rapidly (Brummett *et al.* 2008, FAO 2009).

National or pro-poor policies have not, up to now, taken into account the fisheries sector, partly because its importance has not properly been evaluated. New policies (NEPAD 2006), along with the creation of new infrastructure, such as ice plants, and fishing harbours around new water bodies, may give better access to markets, better prices and better living conditions for the families.

Agricultural water productivity

Rainfed water productivity

We calculate water productivity (WP) in rainfed agriculture using dry yield cereal production as the numerator and total rainfall or "evapotranspirable water" (ETW) (Serpantié 2009b) as the denominator. Total rainfall provides a measure of water supplied to rainfed agriculture on a given area, while ETW corresponds to the fraction of rainfall actually

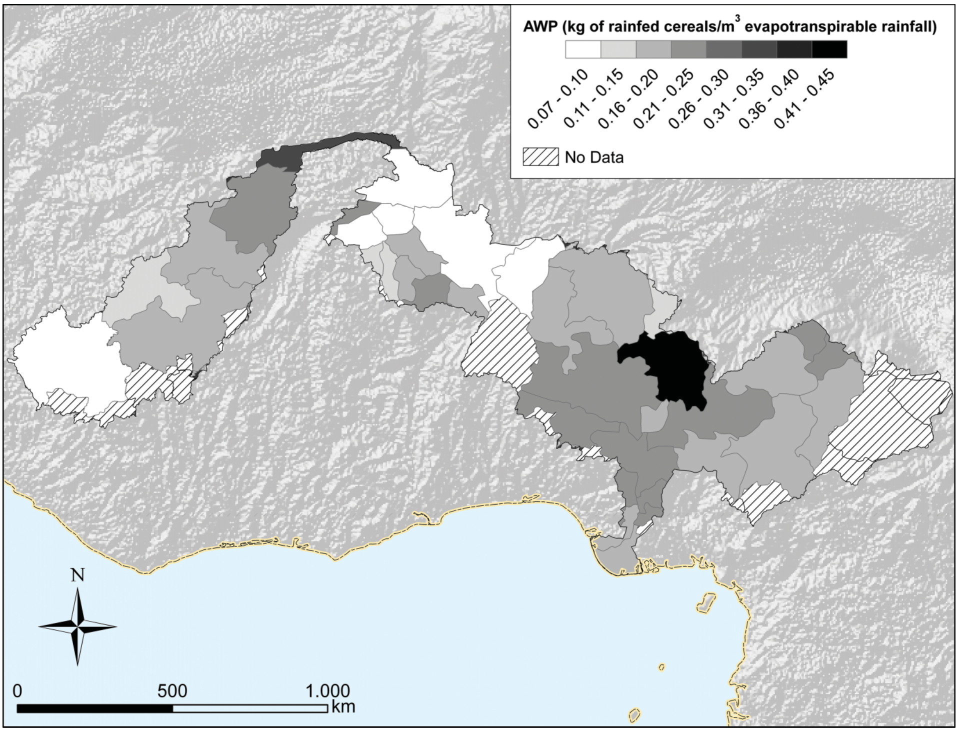

Figure 6. Water productivity (WP) based on ETW for provinces in the Niger Basin in 1999. WP is the ratio of annual average provincial yield for rainfed cereals in kg/ha to the average annual ETW in m^3/ha.

Source: Serpantié (2009b).

available to the plant and excludes rain that falls when the plant cannot exploit it or in excess of the demand (drainage). ETW therefore better reflects agricultural performance in strictly rainfed conditions and results (Figure 6) appear closer to the yield maps (Figure 7), except in very dry or very humid climates. ETW also allows a better comparison of water productivity in different climates, as only water directly useful to rainfed agriculture is taken into account. It does not, however, take into account the additional rainfall that could potentially be harnessed through rainwater harvesting.

Using both methods, rainfed water productivity is around 0.1 kg/m^3, around 10 times lower than in temperate agriculture. Kaduna state in Nigeria has the highest WP because of its fertilized and more intensive agriculture, while north of the 800 mm isohyet, the low WP of Niger is due to its low yields. In southwest Guinea, where the dominant crop is irrigated lowland rice, low WP is due to the low-yielding fonio (*Digitaria exilis*).

There are four main strategies to improve WP of rainfed agriculture: increase the area of rainfed production; increase the productivity of rainfed agriculture independently of water by the use of fertilizer and crops with longer growth cycles; increase water-use efficiency where water is scarce (essentially north of the 700 mm isohyet with millet and sorghum); and increase plant tolerance both to drought and to excess water. Solutions such as rainwater harvesting may extend the cropping season and reduce exposure to drought and to dry spells, which affect rainfed agriculture more often and more widely than low total rainfall. By reducing the risk of crop failure, supplementary irrigation could also encourage

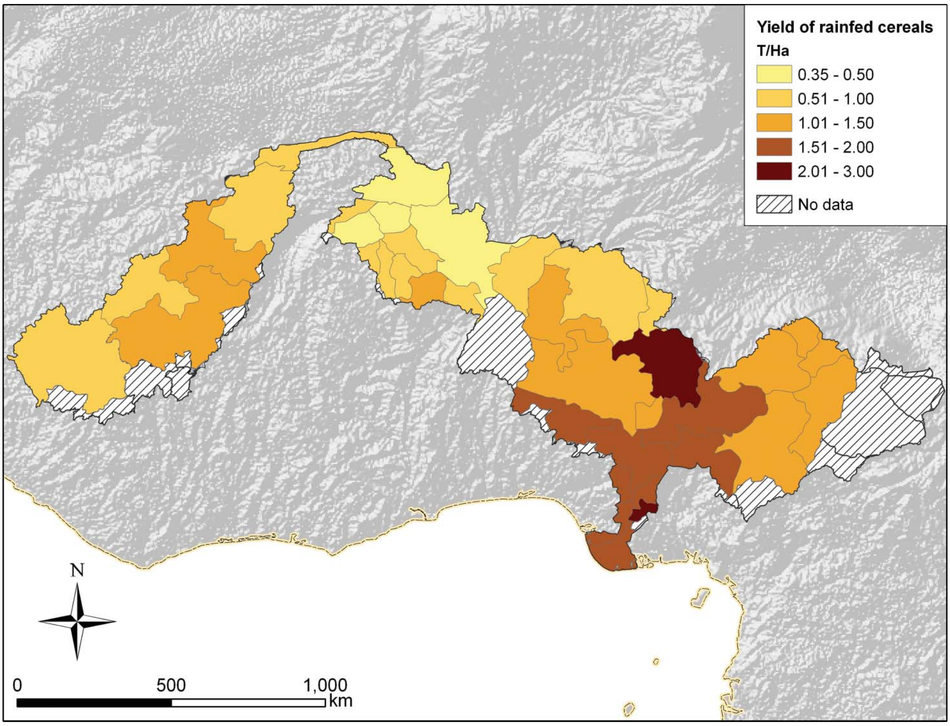

Figure 7. Average annual yield of rainfed cereals for provinces in the Niger Basin in 1999. Source: Serpantié (2009b).

farmers to increase fertilizer use (Rockstrom *et al.* 2002), which is currently marginal. Adopting supplementary irrigation, however, requires investment and capacity building, and may only be feasible where storing and distributing water can be done at costs coherent with the farmers' income and the production's value (i.e. high value or high productivity crop).

Water productivity in irrigation

We calculated WP for irrigated crops by using sample yields and dividing by estimates of water applied (Barbier *et al.* 2009). WP for irrigated rice is relatively low, 0.14–0.67 kg/m^3 similar to FAO's (2008) 0.05–0.6 kg/m^3. Values in the dry season can be as low as 0.06 kg/m^3 especially when counting distribution losses.

Excessive withdrawal, wasted water and low yields all contribute to low WP of rice. Improvements are possible but countries do not perceive the need to increase water productivity. The recent wetter period, and construction of dams to provide dry-season flows further reduces the perception. Current priorities instead are better satisfaction of crop water needs to obtain maximum yields, guarantee food security and create jobs.

Plans to extend the Office du Niger irrigated area to several hundred thousand hectares by 2025 may reduce water wastage as the higher density of plots will decrease distribution losses. Dams built to enable dry season production will increase water consumption due to higher evapotranspiration and may undermine WP increases. Market gardens in the dry season, which produce high-value crops with less water wastage, have much higher WP than rice. Small-scale private irrigation in which users pay for the fuel to pump water is more water efficient, but its expansion also implies more dry season withdrawals. There is a strong case to develop small-scale irrigation in a sustainable and equitable way.

Whatever type of irrigation, substantial increases in yield and water productivity are possible without excessive investments, as farmers gain experience, increase fertilizer input, and the industry becomes more organized. Agricultural groups must be supported to improve provision of inputs and seeds, storage and post production and reduce wastage of water. Rice yields in Mali and Niger are increasing while those in Nigeria are falling. Nigeria suffers from a dysfunctional public sector due to which full-control irrigation perimeters have been abandoned. Nigeria now prioritizes the expansion of rice production on to lowlands, which yield less but are profitable.

Livestock water productivity

It takes a large dataset to calculate livestock WP (Diop *et al.* 2009c). We have to account for the variety of products and services that livestock provide (meat, milk, fertilizer, animal traction, leather and skins), to estimate the water consumed by the animals and evapotranspired by the fodder and crop residues. We could not obtain homogeneous data at same spatial scales for the basin, so we calculated WP using kg of livestock for 1999 divided by a theoretical average water consumption for animal feed using rain use efficiency (RUE) (Serpantié 2009b).

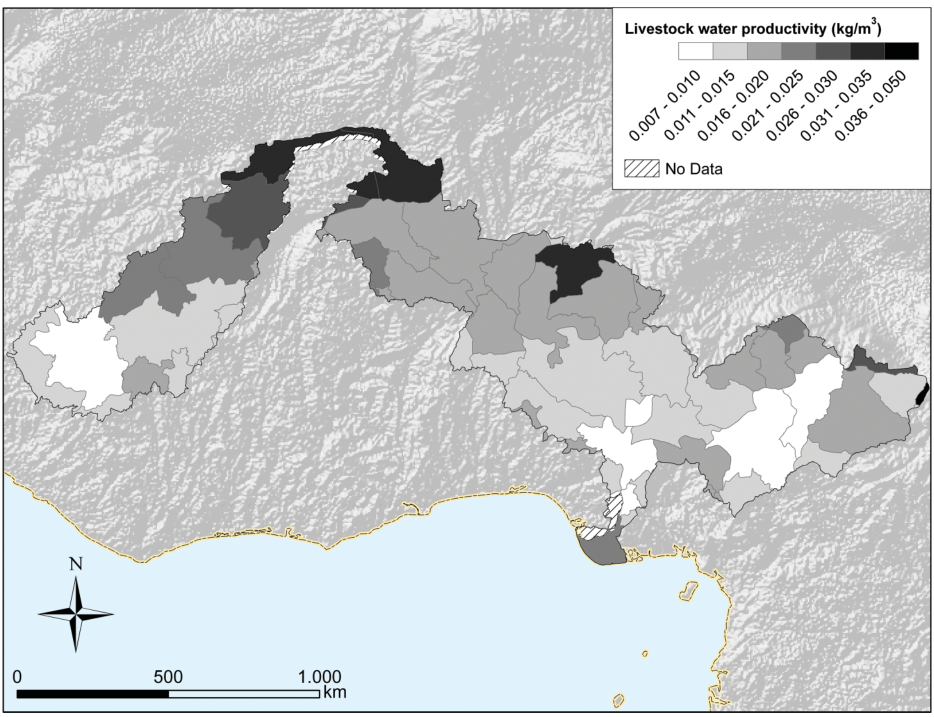

Figure 8. Livestock water productivity in the Niger River basin (maximal values using RUE range). Source: Serpantié (2009b).

LWP of livestock (0.002 to 0.05 kg per m^3 water) is low compared to WP of rainfed and irrigated crops, which is in accord with the place of herbivores in the trophic chain. The best water productivities are in the Sahel and the lowest in the zones above 1200 mm rainfall (Figure 8). WP could also be calculated using energy or dollar value to reflect the superior value of meat over many crops.

Options to improve productivity and water productivity include better animal health and vaccination coverage, selective breeding, commercialization of crop residues, fodder and animal byproducts and increased planting and selection of shrubs and trees for use as fodder. Institutionally, legislation is required to support nomadic herders, first by designating transhumance routes and water access (Clanet and Ogilvie 2009).

Water productivity in fisheries

Traditional fishing does not consume water, so that we use a marginal concept in which water management, such as water level in a dam, can be related to a change in the fish catch. Fisheries are vulnerable to river flows, which are affected by changing rainfall but also by dams and their management. In the Inner Delta, inflow controls the flood level, which in turn is related to the fish catch. A decrease of the inflow to the delta of 1 m^3/s, equivalent to 13 Mm^3 in the July–September flood discharge, decreases the fish catch in the next year by about 28 tonnes (Laë 1992, Morand *et al.* 2009). This gives a marginal WP for the Delta fishery of 0.002 kg/m^3, at the lower end of the range for livestock.

Interpreting water productivity

WP implies that water quantitatively limits production everywhere, which it clearly does not. Where rainfall is sufficient, or more (broadly in the basin >800mm for maize, >700mm for sorghum and millet (Serpantié 2009c)), water ceases to be a productive factor and may even be detrimental in excess. Improvements in yield and WP then depend on other factors such as soil fertility. This implies that the low WP of southern Nigerian crops should not be interpreted uncritically that agriculture is not performing or exploiting water well. Where water does limit production, cautious interpretation is also required. The high WP of crops in northern Mali reveals an efficient use of water but does not imply a good agricultural investment due to the very low and insecure yields. To interpret WP one needs to take account of both the numerator (production) and the denominator (water resource).

Water losses in agriculture may be beneficial to other parts of the system (Seckler *et al*. 2003). Excess water contributes to groundwater recharge, river flow, ecosystem services or even climate regulation (Monteny and Casenave 1989). In the Office du Niger, 44% of the water losses return to the Fala stream (Barbier *et al*. 2009). Stakeholders wishing to reduce water losses to improve WP must therefore consider the current uses and value of the drained water. New methodologies may assist in calculating WP effectively in multi-use systems at varying scales. Moreover, standard definitions for the numerator and denominator in WP (Molden *et al*. 2003), especially for rainfed crops and livestock production, would increase possibilities to compare WP values and formulate recommendations (Bessembinder *et al*. 2005).

Institutional analysis

The continued authority of traditional chiefs on one hand and the influence of former colonial powers on the other create a complex and fragmented institutional context in the Niger Basin. The heavy dependence on transboundary flows in countries such as Niger (91%) adds to this complexity (WWAP 2006).

At the regional level, the Economic Community Of West African States (ECOWAS), which gathers all basin countries except Chad and Cameroon, plays a major role in the regional process towards the implementation of integrated water resource management (IWRM). ECOWAS adopted a regional action plan for IWRM in 2000 (RAP-IWRM/WA) and created the permanent framework for co-ordination and monitoring IWRM in West Africa (PFCM WA). This structure supports the Niger Basin Authority and basin countries in implementing transboundary IWRM and elaborating national IWRM plans.

At the basin level, the NBA, created in 1980, is responsible for co-ordinating equitable development of water resources in the basin according to the principles of IWRM. The NBA adopted the Water Charter project 2008 for a legal and regulatory framework and has devised an Action Plan for Sustainable Development (PADD) that is linked to an Investments Program.

The institutional framework to manage natural resources in the basin remains at the national level, but is undergoing major reforms driven by international pressure. In contrast to the trend towards privatization in land tenure, reforms to water legislation have sought to assert state control over water resources and introduce mechanisms to administer and allocate water rights at the local level (Hodgson 2004). With time, decentralization will confer the main role in agriculture and water issues to new local institutions and increase the involvement of local people, who currently have little say (Bazie 2006).

Legal pluralism

Decentralization, participatory governance, and NGOs through water user associations introduce new structures and new rules at the local level. Together with economic, social and demographic changes, they encourage new practices, which, even if not official (Lund 2000), can contest the legitimacy of, and weaken, traditional authorities (Lavigne Delville 2005). This creates a legal pluralism (Caron 2009) in which rules based on different, or even contradictory, principles coexist. Arbitration becomes more complex, and can lead to problems of land and water governance (Figure 9) and conflicts (Lavigne Delville 2005, Cotula 2006). The result of this change dynamic varies between ethnic groups and communities, but in some cases legal pluralism leads to positive institutional innovations, such as recognition of women, youth, or minority groups who are often discriminated against under traditional law.

Impact on land tenure

Existing informal land tenure agreements are often denied by recent reforms to land tenure legislation, which create a dual and separate system (Hodgson 2004, McAuslan 2006). The reforms fail to recognize communal tenure as viable and introduce registration systems to secure land rights and their transactions. These procedures have not helped poor rural smallholders, women, and young people (McAuslan 2006, Toulmin 2008) who can not get title to their land, partly due to high costs and corruption. New participative systems of land titling, in line with the commitment to decentralization of the water legislation, are required to help to protect the customary land tenure rights of the poor. These require an innovative design rather than attempting to use imported systems.

As water rights are associated with land rights in most systems (Ramazzotti 1996, Caron 2009), insecure land tenure affects secure access to water, and restricts investment in agriculture (Figure 10). Legal pluralism, which creates insecurity in terms of definition, allocation and enforcement of land rights, is then a cause of stagnant agricultural productivity and rural poverty. The literature suggests that institutions, by affecting

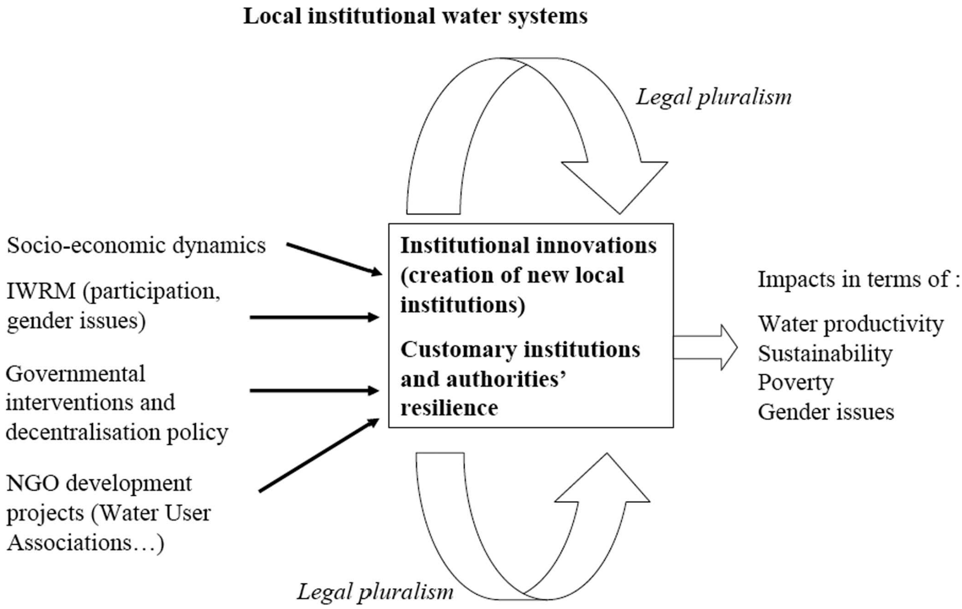

Figure 9. Influence of legal pluralism on water productivity.
Source: Caron (2009).

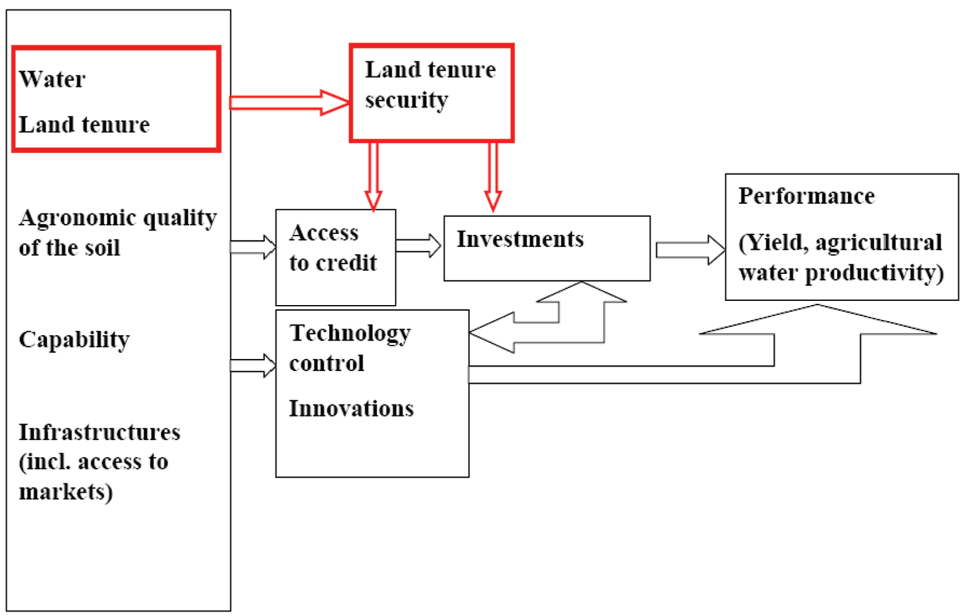

Figure 10. Factors affecting agricultural water productivity.
Source: Caron (2009).

stakeholders and their behaviour (Ostrom 1990, North 2005), play a major role in the dynamics of both development and poverty (Meisel and Ould Aoudia 2007). Here, by affecting land tenure security and the behaviour of farmers, institutions influence the performance of agriculture in the basin, which remains low despite considerable hydrologic and agronomic potential.

A case study of the Talo Dam and associated irrigated perimeters in Mali confirmed the importance of property rights to promote efficient, equitable and sustainable water use (Cotula 2006, Caron 2009). The decentralized land-allocation process was inadequate in securing land rights for women and young people, despite being an objective of recent law reforms such as the Malian *Loi d'Orientation Agricole* (2005). Cattle breeders were also marginalized, losing access to water and land without compensation (Caron 2009).

Institutional indicators

Figure 11 summarizes information on the security of land tenure (IPD 2006, UNDP 2007, OECD 2009). The institutional indicators and their analysis are qualitative and subjective, and moreover were not available for Guinea nor at the sub-national scale. Property rights for agricultural land are mainly traditional and informal in all eight of the states in the basin for which there are data. Except in Cameroon and Côte d'Ivoire, the scale of collectively owned land is high or very high. Security over traditional land property rights and transactions is low, except in Chad and Nigeria.

Further analysis using component multiple analysis of the institutional characteristics of the basin countries also highlights the lack of homogeneity between the countries, despite tendencies to group them as "informal-fragmented" (Meisel and Ould Aoudia 2007). Nigeria contrasts with other countries (Niger, Benin, Burkina Faso and Cameroon) possessing good internal security and subject to strong exogenous pressures. Chad is low due to the relative absence of both public freedoms and the autonomy of the civil society.

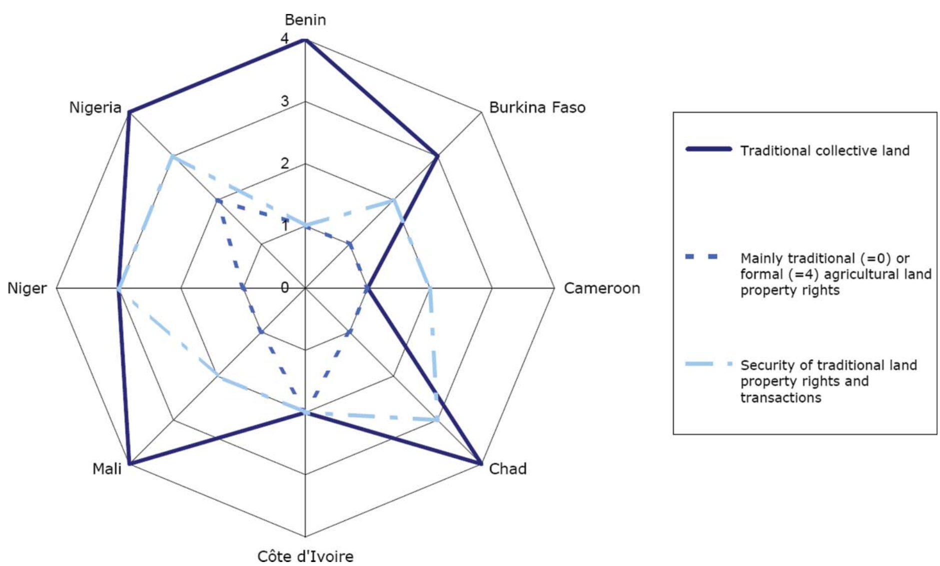

Figure 11. Traditional property and security of rights transactions in agricultural sector. From 0 (very low) to 4 (very high).
Source: Caron (2009).

Water poverty analysis

Water poverty

Water poverty occurs when people are either denied dependable water resources or lack the capacity to use them. Water scarcity is commonly thought to arise due to physical or economic constraints, though Molle and Mollinga (2003) distinguish three further causes of scarcity: managerial, institutional and political scarcity, reflecting the complex nature of water poverty.

The lack of a comprehensive metric that reliably captures the multi-factorial characteristics of water poverty has led to a raft of measurement techniques, each with advantages and disadvantages (Table 2). Such indicators have become increasingly widespread and favoured by decision makers, as they provide a more legible, though often simplified view of the reality on the ground. The added simplicity facilitates communication and comparison, but reduces objectivity and representativity. The widely used Falkenmark "water stress index" (Falkenmark *et al.* 1989) defines a threshold of 1700m^3 of renewable water resources per capita per year, under which a country is deemed to suffer from water scarcity. All countries except Burkina Faso exceed this threshold; however, the indicator fails to capture spatial and temporal variations, crucial in a country such as Mali, which ranges from a sub-humid to a hyper-arid climate. A more comprehensive measurement of water poverty is the water poverty index, which notably takes into account communities' abilities to access and use water but suffers from the use of arbitrary weights and which must ideally be generated at a local rather than a national or a regional scale (Sullivan and Meigh 2003). Variables that measure a relatively mono-dimensional and objective situation (Molle and Mollinga 2003) (e.g. childhood mortality rate) may instead offer the closest depiction of the real situation in these communities.

Relations between water and poverty

Indices may provide an overview of the poverty and water situations but they do not reflect the linkages between water and poverty. Composite indices intrinsically mask the importance of each factor, making interpretation of the potential causes behind water poverty and formulation of subsequent interventions difficult. To detect and analyse a hypothetical relationship between water and poverty, we estimated statistical relationships, using poverty maps and correlation coefficients. Significant correlations do not imply causality but point towards water resource factors that may influence poverty.

At the national scale, weak correlations between widely used water (Falkenmark's Water Stress Index, Water Poverty Index [WPI]) and poverty metrics (headcount ratio, Human Development Index [HDI], Social Vulnerability Index [SVI]) were identified for all African nations (excluding small island states). With little evidence for a strong association between a country's water situation and its development performance on the African continent, relations, if they exist, must be sought at a greater spatial resolution with more representative variables.

Poverty mapping

To account for a high proportion of subsistence livelihoods and a large non-market, hybrid economy, we used child mortality, child stunting and a composite wealth index as poverty metrics. The wealth index is country specific and cannot be compared internationally (Rutstein and Johnson 2004). Data were taken from the demographic and health surveys (Measure DHS 2008) and interpolated to estimate values in non-sampled regions.

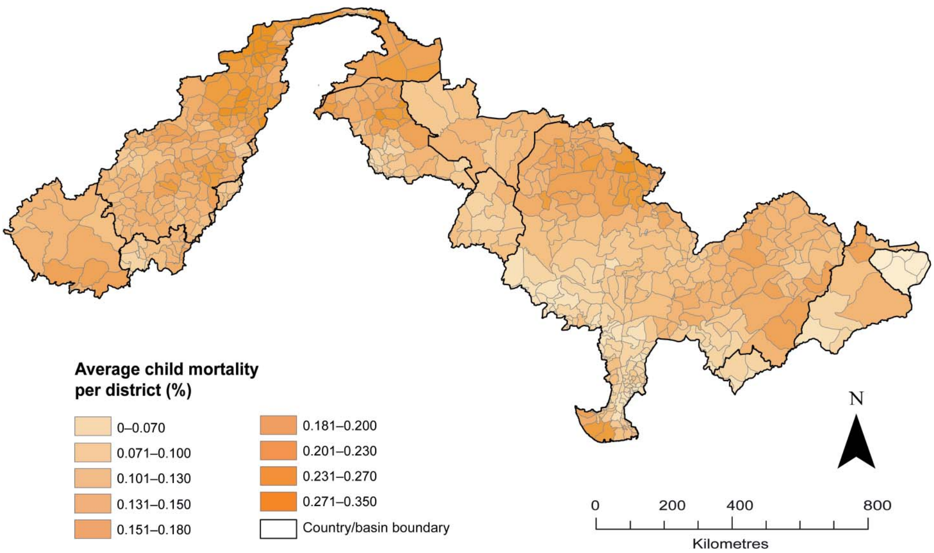

Figure 12. Estimated child mortality (proportion of children who die before age 5) across the Niger Basin (based on births recorded since 1980).
Source: Ward *et al.* (2009).

Figure 12 illustrates the spatial distribution of child mortality in 630 administrative districts across the basin.

The poverty indices were assessed for statistical correlation with an array of possible poverty determinants, both water and non-water related. This was undertaken in the first instance at a basin scale using geographically weighted regression (GWR) and at a sub-national scale using local indicators of spatial association (LISA) clusters and spatially explicit regression analysis. Ward *et al*. (2009) give further details on the methods and results. The analysis of spatially referenced child mortality, child morbidity and the wealth index identified three major poverty hotspots in the Niger Basin, situated in southern Mali and the Inner Delta, northeast Burkina Faso and northwest Nigeria (Figure 13). We expect communities situated in regions of intersecting hotspots for the three poverty metrics to face the greatest poverty and vulnerability challenges.

Links between poverty and water, poverty and agricultural productivity

Increased education and water quality, measured by the proportion of people drinking from unprotected water sources, were most clearly associated with decreases in poverty. These variables are significant and relatively stationary across the study area, and can therefore be addressed with whole-of-catchment-scale policies with less attention to regional differences. A statistical relationship between water quality and child health poverty measures seems consistent with the vital role given to water and sanitation in alleviating poverty (UNDP/SEI 2006). Insufficient access to clean water is known to impact on human health, through the development of water-borne diseases (e.g. diarrhoea, cholera) and water-washed diseases (e.g. scabies, trachoma) (Bradley 1974). Diarrhoea is the third cause of child mortality in West Africa after malaria and respiratory infections (ECOWAS-SWAC/OECD 2008) and new water-borne diseases such as Whipple disease are still emerging (Fenollar *et al.* 2009).

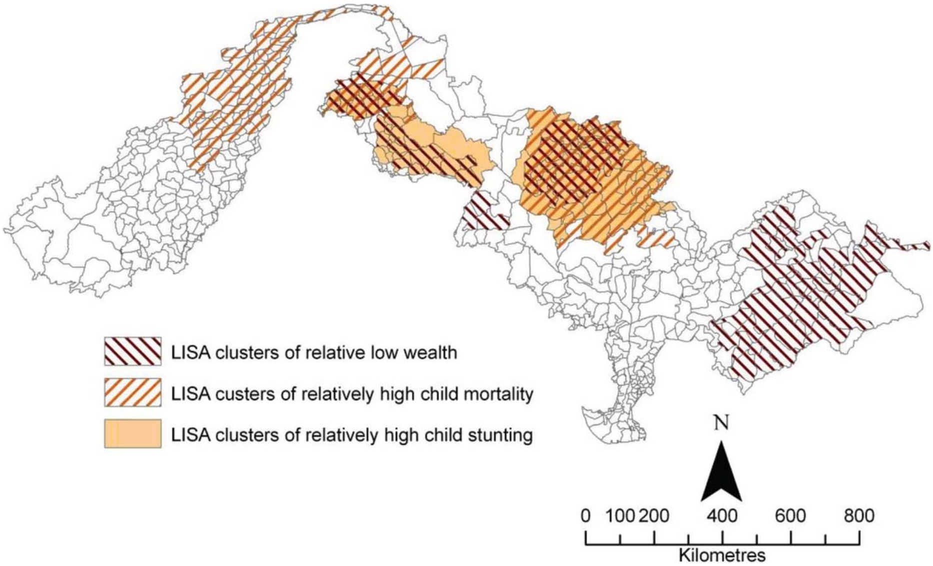

Figure 13. Overlapping map of significant statistical poverty hotspots.
Source: Ward *et al.* (2009).

The literature suggests that agricultural water management also has the potential to reduce rural poverty (Namara *et al.* 2010). We found weak correlations between agricultural water determinants and poverty variables. Total actual renewable water resources (TARWR) does not account for difficulties in accessing water and therefore only provides a theoretical indication of the water potentially available for agriculture. The metric also does not translate annual variations, crucial in countries that may experience drought and flooding in the same year (Rijsberman 2006). Though TARWR is a commonly used indicator, in the Niger Basin it does not accurately reflect the situation of a community with regard to water availability nor its poverty status.

Hussain and Hanjra (2004) argue that increased irrigation and proximity to dams provide a pathway out of poverty, indicating community opportunities and capacity to access and transform water into food. We found the relationship to hold in only some instances. The spatial regression analyses suggest either that irrigation's contribution to rural welfare is low in the Niger Basin, or that the spatial extent of irrigation is too limited at present to cause any detectable reduction in poverty at this scale of analysis. It may also be that the benefits of irrigation do not (yet) accrue to the people engaged in its practice, or that they do so at levels too small to register in our analyses. Variables demonstrated to be statistically non-stationary (i.e. their influence varies across the landscape) may be more appropriately addressed using a geographically targeted policy approach.

Agriculture-related indicators, including primary productivity, soil quality or livestock numbers, provided little explanatory power over poverty. A similar study in Malawi (Benson *et al.* 2005) found that a rise in maize yields actually resulted in increased poverty, presumably due to equity issues, with higher yields not benefiting local populations. Despite growth in agricultural productivity being expected to reduce poverty in the rural agriculture-dominated economies of West Africa (Thirtle *et al.* 2003), poverty prevails in areas of good soil quality, high productivity and sufficient available water.

Similar studies evaluating the significance of explanatory variables in poverty mapping have found limited correlations between poverty and agro-ecological or socioeconomic determinants (Hyman *et al.* 2005). This points to the complexity of transforming available water into adequate food production and a pathway out of poverty. Beyond reliable access to water, the ability to derive profit from water depends on several additional conditions such as access to land, labour, seeds, fertilizer, pesticides, tools and machinery, fuel, storage, transformation processes, roads, markets and political security. Hanjra *et al.* (2009) point to significant correlations between these variables and agricultural productivity, but variable interactions are critical in determining resultant poverty. Some of these factors may be stationary at the regional scale (such as roads and access to markets); others such as access to land may vary widely within the same village from one family or ethnic tribe to another, and thus require detailed analysis. Structural causes of poverty such as the positioning of individuals in the socioeconomic structure (Mulwafu and Msosa 2005) may have heavy influence.

Overall, it is difficult to isolate one contributing factor to poverty. Interactions between environmental, social and institutional factors are complex and an evaluation of poverty and its causes requires analysis at multiple spatial resolutions. Access to water for agriculture and productive purposes plays a crucial role in poverty alleviation but is not a sufficient condition and much depends on the capabilities and endowments (Chambers and Conway 1992) (e.g. level of training, diverse income sources, capital and support networks) of a given household or community. These, not simply the absence, presence or quality of water, determine whether they will fall or subsist in a state of poverty.

Threats and opportunities

Interventions

Successful interventions to reduce poverty have been introduced in certain areas over the years, but solutions to achieve sustained and widespread impacts are still lacking. Recommended interventions are highly contextual and require rigorous analysis for each watershed in the basin. They vary according to climatic and socio-economic conditions and according to the livelihood strategies and agricultural systems (Namara *et al.* 2009). Policy solutions must therefore rely on mixes of sequenced instruments tailored to address temporally and spatially diverse patterns of poverty.

Recommended interventions include developing infrastructure (wells, reservoirs), multiple-use systems (notably integrating livestock and fisheries with agriculture), adapting crop demands to water supply and vice versa (sowing dates, water harvesting, supplemental irrigation), drought-tolerant crops, fertilizer use and so on. Improvements in rainfed agriculture can have an important impact on poverty reduction and food security due to the large population dependent on it. Current farmer strategies to reduce risks due to rainfall deficits prevent intensification. Solutions to reduce soil-water stress and the risk of crop failure, such as rainwater harvesting and drought tolerant crops, are necessary if farmers are to invest in fertilizer and other inputs that are essential to boost yields.

Farmers also need to be linked to input and output markets and financial services, and have access to training and storage, but also to have secure access to land and water, possibly through communal land tenure arrangements. Mitigation strategies such as early-warning systems and storage options are also required to help reduce the impact of extreme events. Transparent, participatory governance is required to ensure water resources are developed in an equitable, participatory and sustainable way. Exogenously driven institutional dynamics must be viewed as a source of opportunities to develop new pertinent, culturally- and context-adapted regulation frameworks blending customary and Western law, which respond to the needs of rural poor, both men and women, who are the majority of landholders in all the member countries. The recognition of collective rights to water and land may help guarantee the access to water by the rural poor.

In certain areas of the basin, upstream and downstream conflicts coming from the development of the Niger River are inevitable and are expected to be intense, given the increasing demands for water from more users (population growth) and uses (industry, hydropower, ecosystem). IWRM is emerging in the basin but water resources are typically managed at a local or national scale. Nevertheless, as resources become scarcer, a transboundary, basin approach to water management appears both relevant and necessary. This is especially true in the upstream part of the river between Guinea and Niger, where rainfall decreases as the river flows downstream making northern populations extremely reliant on the river. In Nigeria, the substantial rainfall and contribution from the Benue River makes transboundary water management of the Niger River less of a priority, but the added presence of dams in Mali and Niger can be expected to impact negatively on water availability and hydroelectric production in western Nigeria.

Several tools such as Water Evaluation and Planning (WEAP), Modèle Intégré du Delta Intérieur du Niger (MIDIN) and rainfall/runoff modelling should be implemented by stakeholders as predicting tools, along with companion modelling tools. In addition to regulatory measures to determine and restrict maximal abstractions, measures such as payment for environmental services should be considered. These could come from hydroelectric production financing interventions upstream to reduce water consumption and improve water availability.

Future threats

Agriculture in the Niger River basin notably suffers from high spatial and temporal variations in rainfall, poor soil fertility, inadequate communication and transport infrastructure, as well as a critical lack of a cohesive, transparent social and institutional context conducive to agricultural investment. In addition to these constraints, the basin faces an array of development challenges in the years to come. Of these, three appear to be vital, due to the severe and widespread difficulties they may cause. These are population increase, climate variability and intense river development (dams, abstractions). Surveys in the basin confirm the growing concern of the rural poor over these issues (Mills *et al.,* 2009).

Projected population increase in the basin could well jeopardize current and future development efforts. The basin population estimated around 95 million in 2005 is expected to double by 2050 in the lowest scenario and could be multiplied by four if fertility remains constant. Current fertility rates exceed six to seven children per woman and as mortality has started decreasing, demographic increase rates now exceed 3% per year (Bana and Conde 2008). More worryingly, in countries like Mali (unlike Ghana) fertility is not decreasing, resulting in a progressive rise in the demographic increase rate. Future population trends will therefore depend on the speed of fertility decrease and the prevalence of pandemics such as HIV/AIDS (Guengant 2009). Clearly the additional demand on water and food resources to feed up to 300 million additional people added to the projected change in diets, climate change and water demand for industry and hydropower will lead to significant pressure on natural resources and ecosystems and increase vulnerability of rural poor communities.

Results from climate-change modelling present many uncertainties and contradictions. However, on average there is a trend towards: an increase in temperature; in variability and extreme events; a later start to the rainy season; more dry spells; and an overall increase in rain in the central part of West Africa and a decrease in the west (Mahé *et al.* 2009a). The effect on yields increases the uncertainties as we must account for increased evaporation, possible decreased rainfall and increased CO_2 fertilization, but there is little doubt that climate change will increase the strain on already-vulnerable agriculture.

Under the NBA investment plan, several large dams are due to be built, notably Fomi in Guinea, Taoussa in Mali and Kandadji in Niger. These offer important opportunities to triple the irrigated area of land, up to 400,000 hectares in Sahelian countries, but will have effects on both local populations and people downstream. Various scenarios have been studied in the literature, which all inherently impact on one element of the system. Trade-off analysis must be undertaken in consultation with local stakeholders to ascertain which element must be favoured – hydropower, irrigation, fisheries and ecosystems – and how to minimize negative impacts. Allocation of resources will inevitably be prioritized, putting vulnerable populations at risk. Expansion of the Office du Niger irrigation project for instance will result in a decreased flood in the Inner Delta, affecting traditional rice growers, herders and fisheries. Fish production could be reduced by 8500 t/yr.

Conclusions

This project aimed to acquire an interdisciplinary view of the relations between water, food and poverty in the Niger Basin. Water availability in the basin is not as low as common perception may suggest, but is subject to severe spatial and temporal variations. Rainfed agriculture is concentrated over less than two months in the north and more than nine months in the south of the basin, and is affected by repeated dry spells as well as severe rainfall deficits as in the 1970s and 1980s. Climatic scenarios predicting increased temperatures, higher variability, dry spells and extreme events as well as reduced rainfall in western parts of West Africa will increase the strain on an already vulnerable agriculture.

Livelihood strategies, though varied, rely predominantly on rainfed agriculture, which suffers from multiple problems, including low mechanization, lack of supplementary irrigation, low fertilizer input, inadequate support and the absence of commercialization. Institutional analysis reveals that the progressive introduction of new rules and structures (decentralization, IWRM, NGO projects) and the continued dominance of customary laws create a legal pluralism, leading to confusion and conflicts. Land tenure, which conditions secure access to water resources and investments in agriculture, is notably affected by the legal pluralism and the reforms that favour individualized tenure and land titles. Improvements in rainfed agriculture hold the greatest potential to tackle poverty thanks to the large population dependent on it, but notably require innovative, participative initiatives to protect the tenure rights of the poor.

Statistical analysis of correlations between poverty measures and water variables identified the importance of water quality in reducing poverty but highlighted the complex relation between agricultural water management and poverty. The pathway linking these is more complex, and resultant poverty depends on the interactions between environmental, social and institutional factors. Assessing the causes of poverty in the basin requires detailed and close-up analysis, and related interventions must be geographically targeted to account for these complicated interactions. In light of the current constraints and the impending challenges the basin will face as a result of demographic and climatic changes, concerted efforts are required by all basin stakeholders to improve agriculture and water management through technical, sociological and regulatory means.

Agricultural withdrawals already impact ecosystems and projected dam building to extend dry-season irrigation will exert further pressure on environments such as the Inner Delta, which provides for the livelihoods of over a million herders, fishermen and traditional rice growers. Trade-off analysis in consultation with local stakeholders must be undertaken especially in the upper basin to determine priorities and to seek to minimize negative impacts. Water productivity, though a partial measure whose calculation and interpretation must be refined, could in time assist stakeholders to highlight where additional value can be derived, especially as the Niger moves towards becoming a closed basin and water resources constitute a limiting factor.

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