10 Water and Agricultures in the Niger Basin through the Twentieth Century

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INTRODUCTION

The Niger River basin gathers 100 million people over 2.1 million km^2, ten countries and six agroclimatic zones, ranging from Saharan in the north to Equatorial coastal around the Gulf of Guinea. Its scale and diversity provide a remarkable cross section of the efforts placed by African smallholders to produce the required 2,500 kcal/day/capita despite limited means and unreliable water resources, through traditional low input rainfed agriculture, livestock and localized fishing. Significantly, the trajectory of livelihood strategies over the twentieth century provides valuable insights into the ways the societies have adapted as a result of changes in water availability, rapid demographic growth (doubling of the African population over the past 30 years) and rising competition for land and natural resources. Historical accounts can help understand these complex hydro-socio-ecosystems and pave the way towards strategies on how to prepare for future climatic changes, rising pressure on land, water and resources, as a result of demographic pressure and external investments ('land grabs'), increased development of dams for energy and irrigation and complex transboundary water management.

This chapter seeks to describe in the first instance the change in climate over the past century, highlighting the severe drought which characterized the later part of the twentieth century. Its detrimental (though sometimes paradoxical) effects on surface and ground water resources throughout the region are described and the growing influence of anthropic changes such as surface water impoundments upstream and land use changes are discussed. The distribution of agricultural water uses and their transformation over the past century are then described. Livelihood strategies include agropastoral systems, nomadic pastoralism, and fisheries within aquatic ecosystems of river stretches and wetlands. The way that agricultural systems spread and diversified across the region, notably as a result of agrarian policies implemented by the range of institutional actors:

state, international aid and NGO programmes, are presented. Significantly, the way users adopted and abandoned techniques, adapted or modified their practices and strategies to cope with changes in water availability and to their natural environment are highlighted.

HYDROMETEOROLOGICAL CHANGES

When considering water and agriculture, the concepts of blue and green waters are now increasingly used. Blue waters refer to water available in streams, aquifers and lakes, while green waters designate the share of rainfall which is directly evapotranspired by vegetation. This distinction reflects a recent paradigm shift (Falkenmark 1995) whereby agricultural water management seeks for enhanced consideration of rainfed agriculture.

Green water characteristics

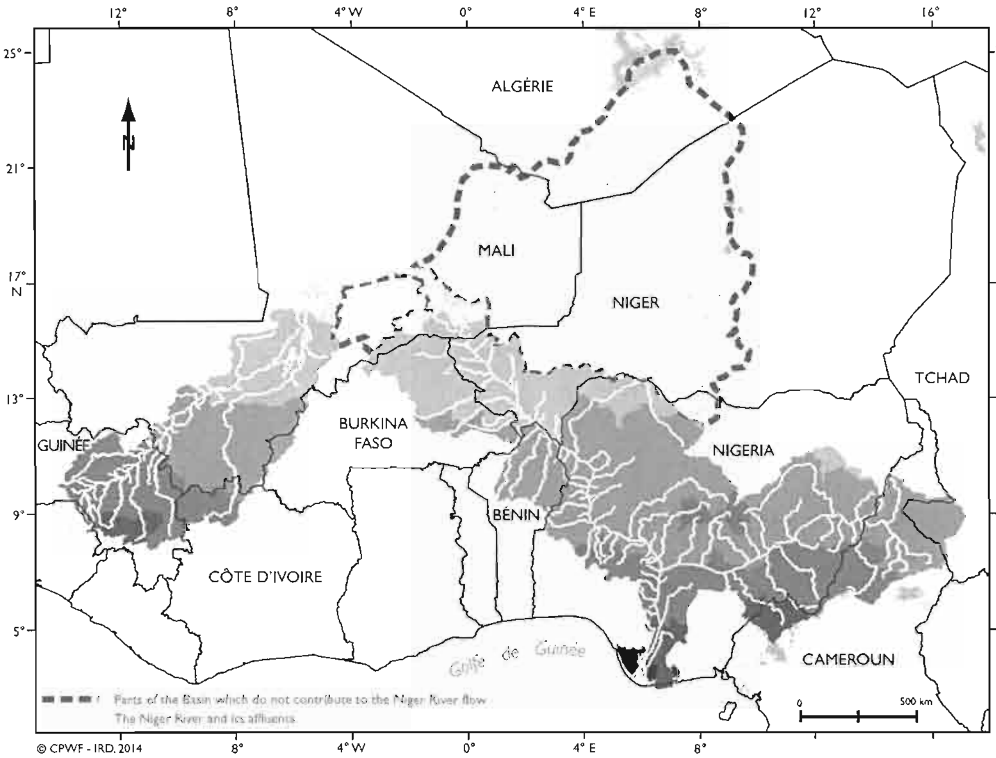
Bordered and influenced by the Atlantic Ocean to the south and west, and the Sahara desert to the north, the Niger Basin displays a sharp decline in rainfall as one travels north, related to the seasonal shift and intensity of the Intertropical Convergence Zone (ITCZ). Created from the convergence of trade winds from each hemisphere near the equator, the ITCZ moves into the northern hemisphere during its spring and the dry northerly trade winds such as the Harmattan in the Sahel are replaced by the south-westerly monsoon winds. This West African Monsoon generates advection of moisture from the Gulf of Guinea, reducing evaporation demand and bringing rainfall on the southern part of the basin from March onwards and around May in Sahelian regions. The ITCZ moves abruptly northwards in July–August from 5°N to 10°N latitude (Sultan & Janicot 2003) producing a peak in rainfall in the dry northern regions of the catchment during August. The ITCZ retreats south again during the months of September and October, after which rains cease and evaporation demand increases. In the far south of the catchment, the northerly position of the ITCZ in August produces a second, short dry season during one month. The intensity and trajectory of the phenomenon is relatively homogenous on an east-west axis (marginally drier in the east of the basin) and defines the contours of six climatic zones distributed along a latitudinal gradient (namely Saharan, Sahelian, Sudanian, Guinean, Subequatorial and Equatorial coastal; see Figure 10.2). From north to south, mean annual rainfall (over 1950–2000) ranges from under 300 mm in northern Mali and Niger to over 4,000 mm in parts of southern Nigeria and Cameroon. These stark spatial differences have essential implications on agricultural strategies (presented below), considering that 95 per cent of agricultural land in

Figure 10.1. The West African monsoon (© T. Lebel, IRD).

the catchment is rainfed. Furthermore, the significant interannual variability observed on rainfall over the twentieth century led to lasting changes in the natural environment and agropastoral strategies. Especially in the Sahel regions where annual rainfall remains below 750 mm and water becomes the agricultural limiting factor, annual variations in rainfall can have devastating consequences on the yields and livelihoods of farmers.

Blue water characteristics

The Niger River presents the significant hydrological curiosity of flowing in a north-east orientation, directly towards the Sahara desert, before buckling back south towards Niger, Nigeria and the Atlantic Ocean. This particular morphology is understood to originate from two rivers merging together as a result of stream capture and the Sahara drying in 4000–1000 BC (Gupta 2008, Gasse 2000). Flowing as far north as Gao and Timbuctu, where rainfall is below 300 mm, the river constitutes a valuable resource for local smallholders who lack alternate water resources. Irrigation projects remain limited with only up to 5 per cent of cultivable land irrigated compared to 20 per cent on average worldwide. Blue waters are used punctually through direct river withdrawals and localized irrigation projects, notably small reservoirs in Burkina Faso and larger dams such as Selingué in Mali and Markala which diverts water



	Annual rainfall (mm)	Climatic zone	Plant associations	Agricultural activities
	< 300	Saharan	Desert steppe	No crops, occasional seasonal pasture
	301 - 750	Sahelian	Semi-desert grassland, shrubland and bushland	Occasional millet, seasonal pasture
	751 - 1 200	Sudanian	Grassland, woodland and savannah parkland	Millets, sorghum, green beans, groundnut, sesame
	1 201 - 1 800	Guinean	Semi-evergreen rainforest, or woodland, and secondary grassland	Sorghum, maize, groundnut, coco yam, peas
	1 801 - 2 500	Subequatorial	Lowland rainforest and swamp forest. Grassland above 1 000 m	Maize, cotton, sugar cane, rice, sweet potato, yam
	> 2 500	Equatorial coastal	Secondary forest, mangroves and grassland	Fruits, cassava, sugar cane, tea, plantain

Figure 10.2. The Niger River Basin and agroclimatic zones (modified from Clanet and Ogilvie, 2014).

to the 80,000 ha *Office du Niger*. Traditional irrigation, however, such as flood recession cropping, notably in floodplains (*bas fonds*) of the south of the basin and across the Inner Delta dominate in terms of surface areas and concern larger shares of the population. The river indeed fans out into a vast Inner Delta in Mali, spanning more than 40,000 km^2 (and a much greater area at its apogee around 6000 BC), where up to 1M herders and farmers depend on this annual flood. Changes in the flow regime, as a result of rainfall variations but also natural and anthropic changes within the catchment, can thus have stark detrimental effects on water availability and livelihoods of small scale farmers. Finally in selected areas, where shallow aquifers are accessible, such as in the Nigerian *fadamas* (lowlands in Hausa), agriculture also depends on groundwater.

Historical time series

Rainfall and hydrometric time series have been available in the Niger River basin since the end of the nineteenth century and provide insight into the modifications over time of rainfall and hydrological flows. Hydrometric gauging stations are scarce compared to other parts of the world and to climatic stations, but the importance of the large rivers of Africa, notably to the colonial powers, means that substantial records since the beginning of the twentieth century are available for the Niger, Senegal and Volta rivers. No flow measurements are readily available for the nineteenth century, and only occasional limnimetric gauges were installed (Sircoulon 1987) at the end of the 1800s for fluvial navigation purposes, as observed on the Senegal River at the end of 1890s on sills, and at Segou where gauge readings were noted during the flood in 1864–1865. By 1899, stations upstream and downstream of the Inner Delta had been installed and in 1907 the Koulikoro station was commissioned by the Compagnie Générale des Colonies. The station was maintained over the years and still operates today. During the 1950s, a coherent, organized monitoring network was developed partly with the support of French assistance and the Orstom (Office de la recherche scientifique et technique outre-mer). In the Inner Delta, considering its importance, several reports exist, however the measurement of the flood is inherently difficult and therefore relies on hydrological modelling or remote sensing (aerial photography and now satellite imagery). Punctual information also exists on lakes such as lakes Faguibine, Haribongo, Korarou in northern Mali, which provide qualitative information since 1908 for some years when lakes were full and exploitable (Haribongo and Korarou 1924–33, 1955–67, Faguibine 1894, 1930, 1955) or dry (1910, 1924, 1941, 1984, (Sircoulon 1987)).

Green water variability through the twentieth century

Serious prolonged drought periods occurred in 1910–16, 1940–49 and most emphatically, the whole region has been subject to a vast and significant decline in rainfall levels, since 1968. The drought after 1968 was the largest on records since 1896 in West Africa and the combination of its duration and spatial coverage extending across West Africa down to coastal areas make it one of the most significant climatic events worldwide in recent history (Hulme et al. 2001, Mahé & Paturel 2009). Mean rainfall over 1960–90 was around 20 per cent lower than previous decades in the century (Lebel & Ali 2009, Descroix et al. 2009) and this decline led to a shift in isohyets by 150–200 km south. The reduction reached its paroxysm during the 1980s, notably in 1983–4, leading to widespread famine notably in the Sahel regions. Rainfall levels recovered only slightly in the 1990s (more so in the west of the basin) remaining as low as during the 1970s (Mahé & Paturel 2009). Variability also increased, creating more dry spells during the cropping season. These variations are intimately coupled to changes in the monsoon dynamics (Eltahir & Gong 1996) and are believed to be driven by changes in sea surface temperature (SST) in the Atlantic, which follow natural low frequency (multi decadal, 65–80 years) oscillations, termed the Atlantic multi decadal oscillation. The precise dynamics and combination of factors driving decadal and multi decadal shifts as observed during the twentieth century remain somewhat uncertain (Hulme et al. 2001). Multiple large scale forcings and feedbacks are believed to exacerbate the effect of changing SST, notably changes in land cover and associated albedo. Conversely, significantly wet periods occurred over the years 1925–35 and 1950–65. These long lasting dry and wet periods were also observed over at least the past three millennia in paleohydrological data, and with often greater magnitude (Gasse 2000). More recently, a long term drought lasting 250 years (1450–1750) was detected during the Little Ice Age when temperatures were cooler than currently (Gasse et al. 1990).

In parallel, over the twentieth century, temperatures reportedly increased by 0.5°C over Africa, but this rise reached up to 1–1.5°C in parts of Mali and Niger (Hulme et al. 2001) notably since the late 1970s. The associated increase in potential evapotranspiration is estimated to be around 1–1.5 per cent (Mahé & Paturel 2009) and results in an increase in crop water requirements.

Blue waters: climatic and anthropic influences, the Sahelian paradox

The 20 per cent decrease in rainfall over West Africa since the late 1960s was reflected in the flow measurements of many large catchments, including the Niger and Senegal rivers where annual discharge reduced twice as much as rainfall (Descroix et al. 2009). The greater amplitude of the reduction in runoff compared to rainfall is remarkable and can be explained by the cumulative effect of reduced groundwater recharge over successive years (Olivry 2002). Reduced rainfall and recharge led to a progressive lowering of the water table, decreasing baseflow contribution and therefore annual flows. This phenomenon was confined to the southern part of the catchment (south of 750 mm) where baseflow is an important component of surface water flows (Mahé & Paturel 2009), notably around Koulikoro and on the River Bani where runoff over 1970–90 reduced by 55 per cent and 70 per cent respectively compared to 1950–70. In 1984, mean annual flow barely reached 640 m^3/s at Koulikoro, compared to 1,400 m^3/s over 1950–90 and up to 2,300 m^3/s in 1925 (Olivry 2002, Descroix et al. 2009).

In drier Sahelian regions, a paradoxical phenomenon was observed on small and large catchments, whereby following the 20–30 per cent reduction in rainfall, runoff increased by 40–60 per cent (Descroix et al. 2009). This increase in the runoff coefficients (i.e. the amount of runoff generated from the amount of rainfall) observed after the 1970s was due to a change in the hydrodynamic properties of the soil, caused by natural and anthropic changes. Declining rainfall levels reduced the volume of water potentially converted into runoff (blue water) but were accompanied by predominant changes in land cover and land use. Droughts led to reduced biomass, while the increase in population densities resulted in deforestation (cutting or burning bushes, shrubs, trees, grasses, etc.), conversion to crop land but also shorter fallow periods, increased fuel wood collection, etc (Lebel et al. 2009). In the Nigerien Sahel but also in Burkina and northern Cameroon, cultivated land increased from 10 per cent to 80 per cent of available land (Cappelaere et al. 2009, Descroix et al. 2009). These changes, most visible around densely populated areas, led to an overall reduction in the water holding capacity and the soil compaction led to the creation of an impermeable crust. More influenced by the alterations in land cover than the changes in baseflow and rainfall, runoff increased in these Sahelian catchments.

At Niamey the combined effect of the reduced upstream flow from the Niger and the increased runoff from the numerous left bank Sahelian tributaries generated an overall reduction of 35 per cent over 1970–90 compared to 1950–70. Local flood dynamics also shifted, and in 1984 and seven occasions thereafter, the earlier flood produced by the Sahelian tributaries (100,000 km^2) even exceeded the amplitude of the flood produced from the upstream Niger river (300,000 km^2) catchment for the first time since records began in 1923 (Descroix et al. 2009). Such changes in runoff volume and in the timing and duration of floods have implications on the feasibility, planning and productivity of irrigation practices. The change in flows was so severe that modifications to hydrological design norms (for dams notably) were recommended (Mahé & Paturel 2009).

In the Niger Inner Delta, most of the inflow is provided by runoff constituted upstream in the Guinean Sudanian regions. Inundated surface areas, though hard to assess (Ogilvie et al. 2012, Zwarts et al. 2005), are estimated to have decreased to below 5,000 km^2 during drought years compared to up to 20,000 km^2 during wet years. The Inner Delta also comprises several lakes, including Lake Faguibine, which in 1983–4 remained dry as river levels remained below the threshold where these lakes become connected to the river (Sircoulon 1987).

Physical modifications to the Upper Niger River regime remain relatively modest compared to other large rivers and the nearby Volta and Senegal rivers, with notably few large scale dams upstream, except Selingué and Markala in Mali. Several dams were developed in the downstream Nigerian part of the river, but their influence on water availability remains limited, considering the significant rainfall and resources available. Dams foreseen on the upstream reaches of the Niger River, such as Fomi, will however have far greater consequences on the water availability downstream, notably on fisheries in the Inner Delta and on the *Office du Niger* irrigation scheme.

In the endoreic regions of the basin, where runoff does not flow out to sea, the increase in runoff also led to the increase in the number, size and depth of small ponds and to the raising of the water table (Favreau et al. 2009, Leduc et al. 2001), opening up and reinforcing new opportunities for farmers. In the exoreic regions of the Sahel, the greater proportion of rainfall converted to runoff reduces infiltration and lowers the water table (Descroix et al. 2009) notably in plutonic basement rocks of Western Niger and below endoreic Lake Chad. In Niger, this loss of groundwater resource led to the recent need for new surface storage solutions (Descroix et al. 2009).

Changes in temperature and increased potential evapotranspiration should have also reduced runoff, however in Sahelian tributaries the reduced water holding capacity and reduced biomass from land use changes may have conversely reduced actual evapotranspiration and increased runoff. The recent relative recovery of rains in the catchment led to a slight increase in runoff but as with rainfall levels these remain level with 1970s values. Conversely, the return of rainfall is also accompanied by a gradual recovery of vegetation, which may also reduce runoff coefficients in Sahelian regions.

AGRICULTURAL WATER MANAGEMENT TECHNIQUES AND PRACTICES

Agriculture relies on one hand on techniques and organizations that are designed to match water needs with available water resources. These are based on available knowledge and develop over the years, through inventions, borrowings, introductions and sometimes abandon. Practices (Blanc-Pamard & Milleville 1985) on the other hand represent the techniques adopted and employed by a particular society. New practices (or innovations) depend on local or introduced inventions as well as the effectiveness of techniques in meeting their targets considering available means, capacities and social standards. Innovations notably result in adjustments and repercussions on multiple levels. The evolution of agricultural water management techniques and practices from so called traditional early twentieth-century agriculture is the focus of this historical investigation and will show how in addition to continued adaptation of practices to a local context, these evolved during the later part of the twentieth century as a result of the extreme climatic conditions and the introduction of development aid. Analysis is based on detailed research work in Burkina Faso (Serpantié & Lamachère 1992, Serpantié & Milleville 1993, Douxchamps et al. 2014) as well as regional research and syntheses (Ogilvie et al. 2010, Venot & Krishnan 2011, Venot 2014).

The geographical diversity of practices

In the Niger River basin, the following range of practices, representative of those found at similar latitudes across West Africa, is observed from north to south (Figure 10.3). At one extremity, the oases of the south Sahara (annual rainfall under 300 mm) employ traditional irrigation techniques, using water pumped from wells by animals and social arrangements for farmers to each irrigate palm groves and market gardens alternately. Water pumps are nowadays sometimes mechanized and groundwater levels recharged from infiltration by dams situated along the *wadis*.

The semi-arid Sahel (annual rainfall between 300 mm and 750 mm) is divided between agropastoral land dependent on rainwater and areas irrigated from the Niger river. Farming traditionally focuses on rainfed millet (*Pennisetum glaucum*), the only tropical cereal able to withstand a short and intermittent rainy season. Faced with recurring droughts, the small lowlands (bas fonds) formerly reserved for grazing and gathering wild fonio (*Panicum leatum*), have gradually been turned over to cultivating sorghum. Ever since the colonial period, the *Office du Niger*, currently supported by private investment, has been planting Mali's *Delta mort* (an ancient branch of the Niger River) with irrigated cotton and rice crops under full control irrigation. Supporting two crop cycles, this area produces increasingly large harvests. Traditional agriculture in the Niger Inner Delta and other well-watered areas (the Nigerien dallols, the Nigerian *fadamas*

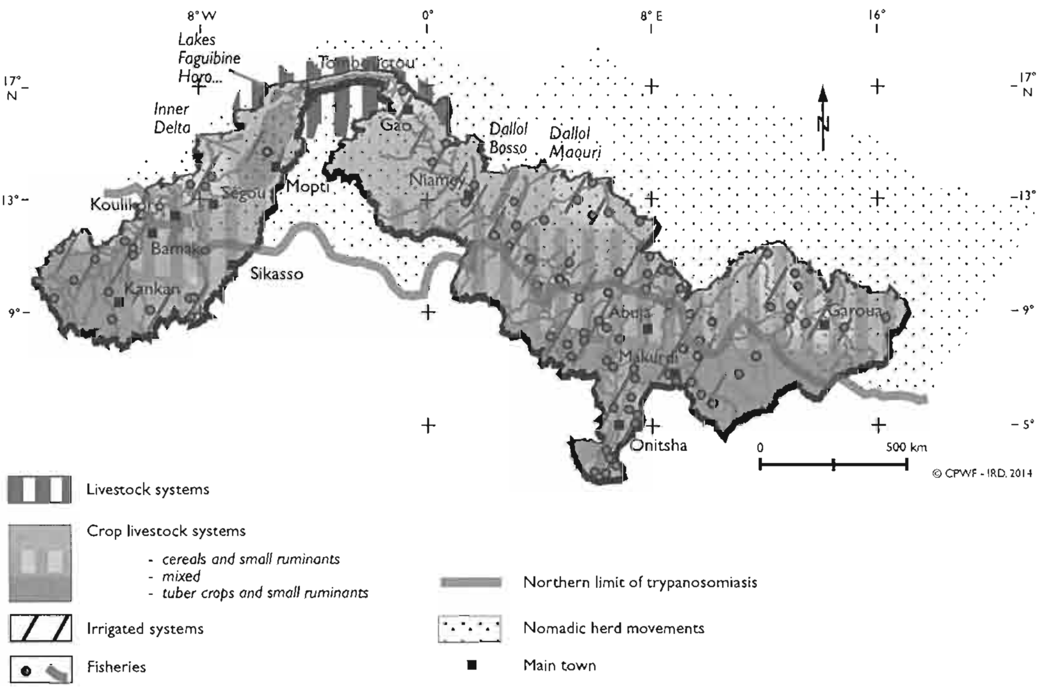


Figure 10.3. Agricultural systems (modified from Clanet and Ogilvie, 2014).

and the Sudano-Sahelian lowlands) developed several farming techniques on clayey soils, where intermittent floods turn water deficits into water excess. Traditional techniques include free flooding, a form of submerged rice farming carried out in floodplains, using local rice varieties with indefinite growth periods (floating rice) that are harvested by dugout canoes. The so-called recession flooding takes advantage of residual soil humidity and its capillary action as the flood recedes to grow rice and sorghum on the edges of rivers and lakes. Since the 1970s, dykes and canals have been built locally to improve water management, as in the Opérations Riz at Mopti and Ségou, to improve control of the submerged areas.

In the northern Sudanian areas (annual rainfall between 750 mm and 1,200 mm), rainfed sorghum combined with black-eyed pea cultivation dominate crop cycles, since sorghum is less sensitive to rainfall variations than maize. Maize yields indeed bear a positive relationship to rainfall, confirming that water remains a limiting factor. The seaboard climate of the Gulf of Guinea with its two rainy seasons supports similar crops though maize yields are more reliable. In the low-lying flood plains the traditional crop is African rice (*O. glaberrima*), combined with small market gardening (vegetable crops) during the dry season. Since the 1980s several projects (supported by NGOs and governments) developed small irrigated perimeters in these areas for rice growing and dry season market gardening. Likewise in Nigeria, the *fadamas* floodplains were intensely cultivated through the development of wells equipped with motorized pumps.

In the sub-humid and humid areas (annual rainfall over 1,200 mm), water is often in excess and crops with a long growing cycle and high tolerance to water excess predominate. These consist of maize and cotton, then rice and root vegetables, and in the wettest parts, plantains. Practices seek to reduce the risk of water excess by managing drainage, via mounds and oblique ridges. Lowlands, previously left virtually uncultivated, are being brought into increasing use as paddy-fields under controlled flooding by means of earthworks (dykes and small embankments) or more rarely, through full control irrigation via dams, irrigation channels and drainage works.

The case of semi-arid areas

The relationship between agriculture and water is most significant in the Sahelian and northern Sudanian areas of the basin and West Africa, where the large populations depend on limited and unreliable water resources. Over the latter part of the twentieth century this area was subject to two dominant trends: first the considerable reduction in rainfall which reached its paroxysm in the 1980s combined with rising temperature and increased climatic variability, and secondly the growing rural population resulting from high fertility rates, reduced mortality and reduced migration notably to urban centres. These affected the balance between land and water demand from the population and available resources. The increased pressure on resources led on one hand to a Malthusian dynamic of rural migration, land degradation and social tensions, and on the other hand to a creative positive pressure of innovation and intensification as suggested by the Boserup theory and facilitated by national policies and foreign aid. Both types of processes were observed simultaneously and alternately.

In these areas of low annual rainfall and with a short rainy season, traditional agriculture and community organization developed over generations to make the best of available water resources. The production system is based on manual rainfed diversified cereal agriculture, often combined with fruit and fodder trees and shrubs, extensive animal husbandry, and storage of grain and cattle. Storage reduces vulnerability to the interannual climate and biological hazards. Farming is undertaken in a family nuclear group or over several generations. It is designed to be self-sufficient, any surplus being stored or sold off. The farmer adapts his plots of land to the available water through adequate crop selection (timing of cycles, photoperiodicity, drought-resistance, rooting depth) and the cultivation system (sowing on first rains without tillage, sowing repeated in case of failure, low density, little fertilization, weeding and hoeing to reduce maximal evapotranspiration, fallowing). The water retained in the sub-soil during the dry season is also put to good use through catch crop cultivation (sorghum on clay soils), tree plantations and parklands (especially *Vitellaria p.*, *Parkia b.*, *Faidherbia a.* and other shrubs). Finally, reacting to the temporal and spatial variability of the climate combined with a diversity of livelihood strategies (gathering, extensive and intensive farming, semi-nomadic agropastoralism, tree harvesting) enable farmers to manage their water needs and exploit the diversity of available land (sloping ground, lowlands, rangelands). The flexible land rights system managed between descendants supports this mobility. Though traditional strategies are essentially based on adapting demand to the available water, some techniques also manage the water supply itself. They rely on favouring rainwater infiltration (*zaï*: funnel-shaped hoeing with manure to break up the soil, localized mulching, weeding and hoeing, building small stone lines and walls on steep slopes) and manual watering of small market gardens.

Climate variations and development projects represented great drivers of change

During the 1950s and 1960s when rainfall was abundant, water was not considered a priority. Development project leaning on bilateral cooperation focussed on cash crops and increasing yields and labour productivity through the introduction of draught power. Punctual projects introduced soil conservation works, notably GERES (Groupement

Européen de Restauration des Eaux et des Sols) [the European Group for Water and Soil Restoration] in Burkina Faso, but these were often poorly adopted by the local population, due to both the fragility of these earthworks and social reasons, namely, the lack of participation and appropriation by the local population as well as land rights issues.

Following the major droughts of the 1970s and the initial emergency measures, development programmes tended to favour improvements to rainfed subsistence farming and better access to water for livestock. Pastoral wells were drilled, populations were transferred to 'new lands' free of endemic diseases and projects to build small reservoirs were introduced. The proposed activities did not however always coincide with people's priorities or with the local organization of society. Those colonising the new lands rejected the preconceived strategies and the confinement to allocated plots of land, preferring to reproduce their original practices.

When the extreme droughts occurred in the 1980s, the failure of previous projects led to criticism over the techniques introduced and the modus operandi of initiatives which applied preconceived models and lacked partnerships. National governments became marginalized by foreign donors in their development operations and the NGOs proliferated as new substitutes for the state, acting as middlemen between donors and the local population. Traditional practices were seen as the required starting point and community participation was encouraged through local associations, with external financial and scientific support. The livelihoods approach was designed to address jointly the ecological, social and economic aspects through multi-disciplinary teams consisting of farming systems research, NGOs and the local people. Local techniques were recognized for their value, including *zaï*, stone lines and localised mulches. Intermediate techniques better suited to the means of local people and of civil society organizations emerged from these partnerships. These were designed to increase labour productivity, and relied on drought tillage or small-scale irrigation (rice and market gardens) with motorized pumps notably around the banks of small dams. Contour stone lines replaced the fragile soil ridges that had previously been used to reduce runoff and erosion. The dissemination of rediscovered traditional techniques, small mechanization and small dams was facilitated by numerous forms of financial support. At the same time, major conventional dams and great irrigation projects were launched to meet the needs of urban centres (water, electricity, fruit and vegetables, rice and even wheat).

Around 1990, bilateral projects gave way to international development programmes which resulted in a large scale dissemination of these intermediate technologies. Small reservoirs in Burkina Faso notably rose to more than 1,700 leading to an increase in market gardens (typically privately owned, less than 1 ha, watered by watering cans or motorized

Figure 10.4. Watering onions in Burkina Faso (© J. Lemoalle, IRD).

pumps and supplying urban centres during the dry season with rice and vegetables) but also exacerbated conflicts with herders around watering points. International donors introduced decentralization and environmental policies, where sustainable resource management approaches were designed to optimize coordination between land users and optimize biophysical techniques. These led to proposals of new techniques and concepts (improved stone lines, improved *zaï*, mechanized half-moons, water use efficiency, conservation agriculture), but once again, these initiatives lost sight of development concerns, including participation, livelihoods, viability and the regulation of tensions.

Consequently, from the year 2000, there was a return to integrated land management, using the concept of *land husbandry* focussing at the scale of landscapes and communities. This involved integrating technical, commercial and institutional strategies, while addressing sensitive issues, such as land rights, the role of women, corruption and the hoarding of public investments by the elite, as well as conservation. The new arrangements for negotiating water allocation (IWRM, water user associations) put forward by projects represented a form of 'social engineering' and led to extremely diverse arrangements in practice. The involvement of multiple stakeholders led to the risk of fragmentation while the legal pluralism created by the overlap of traditional, state and project governance created confusion and conflicts (Ogilvie et al. 2010). In recent years, projects to increase water productivity ('more crop per drop') and reduce blue water losses have been instigated. Ponds for instance are used to provide supplementary irrigation to maize crops, drip irrigation is encouraged through social enterprises, while large dams for energy and irrigation are again being promoted (Barbier et al. 2009). More widely, the private sector is increasingly proposing access to technological innovations and financial facilities, tuning in to the considerable market and potential profits.

THE HISTORY OF WATERING LIVESTOCK

In the Niger Basin nomadic grazing systems are faced with two constraints: water and fodder, whose availability divides the region into two parts. In the south, where water and vegetation are abundant, small village herds of livestock have adapted to the often excessively damp climate and the predations of the tsetse fly. The animals are mainly dwarf guinea goats and shorthorn cows. In the Equatorial secondary forests and Guinean secondary grasslands (Figure 10.2), the small local herds have access to resources on the outskirts of villages without needing to be moved over long distances.

The second area covers the Sudanian savannahs (shrubland and bushland), Sahelian semi-desert grassland and the hydrologically inactive desert fringes. The rainy season maintains grasslands and creates temporary ponds, as far as the extreme north of the area. The herds graze the rangelands using the ponds as watering-holes, while in the dry season they are restricted to grazing land close to wells. Pastoralist herders must then structure the daily displacement of livestock to ensure that the benefits derived from exploiting a resource (water or grazing) are not counteracted by the physical efforts required by the herds to access it. Herders have therefore learnt to adapt to the seasonal and spatial variations of watering holes and pastures.

In order to focus on livestock-rearing in the Sahelo-Sudanian arid areas, this paper has not taken into account the small herds reared at the oases, nor those in the cotton-growing areas, where pigs, sheep and goats are bred and share the watering facilities designed to supply the villagers. In any case, wealthy landowners pay *Fulbe* herders to look after their stock. The introduction of pastoral hydraulic policies in the early twentieth century as a result of colonization disrupted the traditional pastoral systems. Veterinary services also opened up new land for herds by installing new facilities. However, since independence, signs of overgrazing and the difficulties due to emerging and changing social interactions have called pastoral hydraulic policies into question.

Traditional water use in pastoral areas, 1895–1945

At the start of colonization, in 1900, the agrarian society of the Niger Basin consisted of crop-livestock systems run by village communities who grew cereals or root-crops while managing small herds, and of nomadic pastoral systems migrating north in the rainy season away from the crop-growing regions (Figure 10.3) before returning to take advantage of the rains in the south over nine months of the year. Excluding the population living along the river banks, the year in the hinterland was divided into two distinct seasons. The wet rainy season when temporary ponds abound and it is unnecessary to dig wells as water stagnates in the smallest impluvia. In the dry season when ponds have dried up, only wells can access the water from the aquifers. The back-breaking pumping of water used to be performed by slaves, manually or with the help of pack animals, and could last for more than an hour to water a herd. All societies of the Niger Basin used to employ slaves (Bernus 1989, Hiskett 1973, Stilwell 2000) as domestic servants or to water their herds and flocks. By ending slavery, colonization *de facto* removed part of the breeders' workforce.

Household water was also drawn up from the well, another chore performed by women, who then transported water balanced on their head in clay jars or goatskin water bags, or with donkeys when wells were more than 1 km away. The traditional wells were narrow, sized so that the low-caste well-diggers employed by the dominant tribes could fit into them. Less than a metre wide in diameter, the well's were lined with logs roughly joined with plugs of rot-proof grasses. Depending on their topographical location, they could last for two to three years before collapsing and were rarely more than 40 m deep. Built using picks and shovels to remove the rubble, they could not be dug in unstable soils (pebbles, sandy ridges of the Koutouss in Niger) or on hard ground as in Tahoua, in the Azawad Region of northern Mali.

The traditional pastoral systems of the Niger Basin have exploited surface and ground water resources in five different ways. The pastoral Sahelo-Saharan Tuaregs use straw stacks and wells (Gallais 1975); to the south, the *Fulbe* follow the ITCZ to remain permanently within reach of ponds and new vegetation (Stenning 1994). Conversely, *Songhaï* and *Fulbe* livestock breeders are chased in the opposite direction by the floods of the Niger Inner Delta (Gallais 1975). Other herders execute small migrations to ponds and hollows between the dunes in the eastern part of the Basin or in the Soum (Barral 1974). Finally, the Tuareg camel-herders drive their herds long distances between the lowlands in the rainy season and the higher ground of the Aïr during the dry season (Bernus 1989), watering them at the *gueltas* (depressions fed by rainwater or karstic springs). Along the river reaches, ponds and lakes, very strict customary rights governed the seasonal use of water, as well as fishing

Figure 10.5. Fulani herders in the Inner Delta (© O. Barrière, IRD).

and access to fodder notably during the flood in the Niger Inner Delta (Gallais 1975). Tenacious, these customary rights continue to be upheld today throughout the Basin.

Colonial pastoral hydraulic policies, 1946–69

The colonial conquests only truly ended with the end of the the Kaocen Tuareg revolt in 1917, and in the south, when the British replaced the sultan of the Caliphate of Sokoto in 1903. Between the two world wars, colonial powers focussed on taking inventories and censuses, controlling trade and introducing cash crops (cotton and groundnuts) in the southern parts of the region. It was only after the 1945 armistice that the administration began to take an interest in the pastoral scene (Merlin 1951, Receveur 1960). This had previously been neglected in African agricultural policies and the various attempts to sedentarize nomadic breeders had failed.

Starting in 1948, pastoral hydraulic policies relied on the combination of various amenities (ponds, wells and mechanically pumped boreholes) to provide water throughout the dry months. Though it is relatively easy to calculate the watering capacity of wells and the required distance between successive wells, the livestock capacity that rangelands can support vary widely, leading to discrepancies in how policies were implemented and their success (Bernus 1991, Thébaud 2002). Furthermore, though an annual rainfall deficit may have only a moderate effect on the well's pumping rates, it can reduce by more than 50 per cent the number of cattle that can be fed from surrounding grasslands.

The waterworks built in Mali and Niger starting in the 1950s (Merlin 1951, Receveur 1960) notably consisted of deepened ponds with a minimum capacity of 6,000 m^3, 40 m deep wells located between 5 km and 10 km apart that could provide water for between 3,000 and 5,000 LU (livestock units)[1] and boreholes 20 km apart. All these were managed by herdsmen registered at the prefectures while the mechanized equipment was maintained by specialists. Boreholes drillings were opened between February and June according to a calendar fixed by the authorities, after consultation with local technical departments. The rules further provided that during this period a 20 km perimeter surrounding water works could not be exploited. A wider 40 km perimeter was reserved for grazing needs of residents only. The authorities were supposed to implement this legislation by decree, accounting for local conditions (Bernus 1991).

By independence, the programme had become a success and rangelands were covered with waterworks designed for watering cattle. In the northern Sahel (Tahoua, Agadez, etc.) the network was very dense and rangelands, had extended by two, and even three times their original size. Only a few limited sectors remained 'dry', namely the complex hydrogeological regions in north-eastern Sikasso (Mali) and Yaga and Seno (Burkina Faso). Unfortunately after independence, the budgetary constraints experienced by the budding states, their political instability and endemic corruption soon raised the issue of financing and maintaining these facilities. These issues were soon overshadowed by the drought starting in 1968 which 'benefitted' from unprecedented media coverage, displaying images of families dying of thirst and expanses covered with desiccated animal carcasses, while satellite images revealed circular patches of desertified land surrounding boreholes. These succeeded in moving public opinion and mobilizing donors.

Recent concerns over livestock hydraulic policies

The terrible droughts that hit the Sahel between 1969 and 2005 caused major environmental damage and decimated the herds. In 1973, Mali lost 50 per cent of its cattle and Niger 25 per cent (Maïga 1997). These drastic reductions in the size of herds ended the opulence experienced since 1950 when herd numbers grew constantly as a result of abundant rainfall and the pastoral waterworks programmes.

Worldwide concern over the repeated climatic disasters generated an influx of funds, mobilized international aid and led to various studies on climatic variations and the resilience of the pastoral and crop-livestock systems (developing notably the *Range Management* approach).

This attention shed light on the problems of financing waterworks, revealing financial mismanagement and implementation problems. Multiplied efforts to provide watering points for livestock were beneficial and were not the ecological disaster that they are sometimes claimed to be. However, the arrangements to protect the rangelands were poorly respected. Bernus (1991) found that certain boreholes supported herds three to four times greater than intended when nearby boreholes became no longer operational. On several wells, the influx of herds from other areas deprived them of their rangelands. When the situation became critical, several groups of herdsmen requested, and obtained, for their boreholes to be shut, preferring to pursue with their traditional manually dug wells. According to recent studies, sustainable governance and management of pastoral waterworks hinges on two aspects, namely allowing the local people to take ownership of the equipment provided and helping them correctly assess the availability of their resources.

FISHERIES AND AQUATIC ECOSYSTEMS

Inland fishing is widespread in Africa, since it supplies almost half the proteins found in local diets (Lemoalle & De Condappa 2009). Fish are caught using simple traditional techniques and with the exception of fishers in coastal waters, fishing is undertaken mostly by rural farmers drawn to this activity out of necessity or by dedicated fishing communities such as the *Bozo*. Together they make good use of the natural aquatic biotopes of the Niger Basin. Though fishing practices barely changed during the colonial era, the artificial biotopes created by the large dams built in the 1960s altered the way in which the aquatic ecosystems were used, attracting new fishers and promoting fish-farming.

Continued influence of traditional fishing

The Niger Basin is part of the ichthyological Nilo-Sudanese province extending from the Atlantic coast to the Indian Ocean and whose hydrographic basins have a large number of fish species in common (Lévêque & Paugy 1999). About 243 species of fish have been recorded in the Niger Basin. This diversity allows for extensive occupation of the various biotopes, and the richness of each area has always been protected by strict usage and custom. Tribal chiefs control land and water resources and regulate the seasonal fishing, which may only be practised under certain conditions and for limited periods.

In the upstream catchments, beside natural lakes and along rivers, fishing continues to be practised using the age-old techniques of lines, nets or very simple creels. On larger expanses of water, part-time fishermen, mostly rural farmers or herders for whom it's a supplementary or complementary activity, use small rafts or dugout canoes. Their catch barely exceeds a few dozen kilograms per year and serves for personal consumption, though in rare instances may be dried or even smoked in order to be sold.

In the river-floodplain aquatic ecosystem (Morand et al. 2012, Lemoalle & De Condappa 2009), created by the vast Niger Inner Delta, fishing is practised under very different conditions. There, the annual renewal of fish stocks depends largely on the extent of the annual flood and consequently on rainfall levels in the upstream catchment. The resulting quantity of fish caught is then heavily related to the amplitude of the flood which can vary by a factor of three over recent years. In these amphibious areas, fishing is still practised by ethnic groups traditionally recognized as professional fishers such as the *Bozo*, or ethnic sub-groups of the *Malinke* and *Songhaï*, for whom it's also a full time livelihood strategy. The Niger Inner Delta and its surroundings alone account for 62,000 full-time fishers out of the 100,000 fishermen officially identified within the basin (Lemoalle & De Condappa 2009). Although these fishers still use ancient fishing techniques and the handmade narrow boats that are characteristic of these inland waterways, their canoes are now motorized and their lines and nets are made of synthetic fibre. Drying, smoking and conditioning the fish catch for its transport remain largely traditional processes, although favoured species are now quickly transported to collection points where refrigerated trucks await them.

The colonial era and the large reservoirs

European colonization only indirectly affected fishing in the Niger Basin. Policies designed to regulate it mainly concerned fishing methods, rarely mentioning seasonal restrictions for juveniles. Laws were poorly implemented and the catch marketed through traditional outlets was rarely consumed by expatriates. During the first half of the twentieth century, most of the fishing resources remained under the control of local hierarchies.

The main changes to fishing sector were the result of several factors. These included the import of industrially manufactured hooks and the introduction of lines made at first from cotton then subsequently of synthetic fibres which in the 1950s started to replace lines made locally from plant fibres. These were followed by the import of outboard motors. Fish trading however was an ancient tradition in the Basin, especially in the Niger Inner Delta, unlike other parts of Africa. In the 1960s and 1970s, many African countries began building large reservoirs to develop irrigation and hydroelectricity. The upstream part of the Basin

Figure 10.6. Fishers transporting fish traps on the Niger River (© J. Lemoalle, IRD).

contains the sizeable Sélingué dam (1980; 410 km^2) on the Sankarani River and the Markala dam further downstream, which diverts water to the large *Office du Niger* irrigation scheme. These impoundments produced a significant change in the river's hydrology and notably on the flood in the Niger Inner Delta, considering that a decreased inflow of $1m^3/s$ is estimated to reduce fish catch the following year by nearly 28 tonnes. The numerous hydraulic structures built downstream, consisting of artificial lakes holding 28 billion m^3 of water have also standardized the river's flow and that of its main tributaries.

These modern artificial lakes encouraged fishing practices since they can be more productive than other biotopes, even though the diversity of species caught may be lower. Traditional fishermen abandoned their sectors following droughts to settle along the lake shores, where roads also allowed them to export their catch. Other climatic refugees turned to fishing to supplement their income and gradually settled there as full time fishermen. All of these people (about 13,000 in total) use dugout canoes paddled by two to three people. Their equipment is very varied but dominated by traps, creels, nets and lines. Seine fishing carried out from the shore (beach seine) or in the water is thought to be responsible for destroying fish resources. In recent years, tilapia fish farming has developed in the Basin in small local or medium-sized enterprises, mainly in Nigeria. Fishing the restocked waters of small lakes and ponds has so far not proven to be economically efficient.

CONCLUSIONS

Agricultural livelihood strategies in rural areas of the Niger Basin have evolved following a long tradition of adapting to the often hostile environmental constraints. Precolonial empires, such as the *Songhaï* in today's Mali or the *Kanem-Bornu* in Chad, notably thrived over several centuries in the Sahelo-Saharan region of northern Africa, capable of adapting their techniques and practices to a variable and often scarce water supply. The second part of the twentieth century was marked by an extreme drought, remarkable in its amplitude, duration and geographical spread. Witnessed from Mauritania to Ethiopia, it was most devastating in the Sahel where rainfall deficits between 1969 to the early 2000s yielded large scale famines notably in 1972–4 and 1983–4. The prolonged drought had significant consequences on the dominant agropastoralism livelihood strategy, affecting rainfed agriculture and natural rangelands. The reduced rainfall also generated long term effects on river flows, groundwater levels, and the flooding of water bodies such as the Niger Inner Delta, further affecting millions of blue water users. Though the region experienced remarkable droughts and famine over previous centuries, the unprecedented worldwide concern relayed by modern media and the associated development aid it generated led to wider structural changes. Traditional, successful strategies to adapt practices to water supply were not affected and changes focussed largely on improved water access, through the construction of dams and small reservoirs, as well as waterworks and designated rangelands to support nomadic livestock. The introduction of imported solutions unsuited to local resources and customs combined with poor implementation of policies at the local level led however to mixed results. Recent independence, recurrent sociopolitical crises and inadequate governance further compounded these difficulties.

Recent policies and programmes have evolved as a result of further environmental changes (continued drought, population increase), exogenous ideas (environmental awareness, research in social sciences), and feedback from earlier projects, leading to more community participation, integration of traditional methods and gender considerations. Despite local successes, land and water productivity must continually improve and adapt to the growing population. Additional cognitive and financial investments accompanied by political and institutional changes remain vital to provide 2,500 kcal/day/capita sustainably and face further climatic changes.

NOTES

1 An LU (or tropical livestock unit) is a 'correspondence coefficient' concept, for example 1 camel LU =1.0; cattle 0.7; sheep or goats 0.1 (and subject to small variations).

REFERENCES

Barbier, B., Yacouba, H., Maiga, A.H., Mahé, G., Paturel, J.E. 2009. 'Le retour des grands investissements hydrauliques en Afrique de l'Ouest. Les perspectives et les enjeux'. *Géocarrefour* 84(1–2): 31–41.

Barral, H. 1974. 'Mobilité et cloisonnement chez les éleveurs du nord de la Haute-Volta: les zones dites d'endodromie pastorale'. *Cahiers ORSTOM. Série Sciences Humaines* 11(2): 127–35.

Bernus, E. 1989. 'L'eau du désert'. *Etudes Rurales* 115–6: 93–114.

——— 1991. 'Hydraulique pastorale et gestion des parcours'. In Grouzis, M., Le Floch, E., Bille, J.-C., Cornet, A (eds) *L'aridité, une contrainte au développement, caractérisation, réponses biologiques, stratégies des sociétés.* Paris: Orstom.

Blanc-Pamard, C., Milleville, P. 1985. 'Pratiques paysannes, perception du milieu et système agraire'. In *A travers champs agronomes et géographes.* Paris: Orstom, pp. 101–38.

Cappelaere, B., Descroix, L., Lebel, T., Quantin, G. 2009. 'The AMMA-CATCH experiment in the cultivated Sahelian area of south-west Niger – Investigating water cycle response to a fluctuating climate and changing environment'. *Journal of Hydrology* 375(1): 34–51.

Clanet, J.-C., Ogilvie, A. 2014. 'Water, agriculture and poverty in the Niger River Basin – Eau, agriculture et pauvreté dans le bassin du Niger', Challenge Program on Water and Food, Colombo and IRD, France, Agropolis International Editions.

Descroix, L., Mahé, G., Lebel, T., Favreau, G., Galle, S., Gautier, E., Olivry, J.-C., Albergel, J., Amogu, O., Cappelaere, B. 2009. 'Spatio-temporal variability of hydrological regimes around the boundaries between Sahelian and Sudanian areas of West Africa: A synthesis'. *Journal of Hydrology* 375(1): 90–102.

Douxchamps, S., Ayantunde, A., Barron, J. 2014. 'Taking stock of forty years of agricultural water management interventions in smallholder systems of Burkina Faso'. *Water resources and rural development* 3(1–13).

Eltahir, E.A., Gong, C. 1996. 'Dynamics of wet and dry years in West Africa'. *Journal of Climate* 9(5): 1030–42.

Falkenmark, M. 1995. 'Land-water linkages – A synopsis, in Land and Water integration and river basin management'. *FAO Land and Water Bulletin* 1: 15–16.

Favreau, G., Cappelaere, B., Massuel, S., Leblanc, M., Boucher M., Boulain, N., Leduc, C. 2009. 'Land clearing, climate variability, and water resources increase in semiarid southwest Niger: A review'. *Water Resources Research* 45(7).

Gasse, F. 2000. 'Hydrological changes in the African tropics since the Last Glacial Maximum'. *Quaternary Science Reviews* 19(1): 189–211.
Gupta, A. (ed.) 2008. *Large Rivers: Geomorphology and Management*. Chichester: John Wiley & Sons.
Hulme, M., Doherty, R., Ngara, T., New, M., Lister, D. 2001. 'African climate change: 1900–2100'. *Climate research* 17(2): 145–68.
Lebel, T., Ali, A. 2009. 'Recent trends in the Central and Western Sahel rainfall regime (1990–2007)'. *Journal of Hydrology* 375(1): 52–64.
Lebel, T., Cappelaere, B., Galle, S., Seguis, L. 2009. 'AMMA-CATCH studies in the Sahelian region of West-Africa: an overview'. *Journal of Hydrology* 375(1): 3–13.
Leduc, C., Favreau, G., Schroeter, P., 2001. 'Long-term rise in a Sahelian water-table: the Continental Terminal in south-west Niger'. *Journal of hydrology* 243(1): 43–54.
Lemoalle, J., Condappa, D. de, 2009. *Water Atlas of the Volta Basin – Atlas de l'eau dans le bassin de la Volta,* Colombo: Challenge Program on Water and Marseille: Food and Institut de Recherche pour le Développement and also online at http://hal.ird.fr/ird-00505116/fr/ (accessed 14 April 2015).
Lévêque, C., Paugy, D., 1999. *Les poissons des eaux continentales africaines: diversité, écologie et utilisation par l'homme.* Paris: Orstom.
Mahé, G., Paturel, J.E. 2009. '1896–2006 Sahelian annual rainfall variability and runoff increase of Sahelian Rivers'. *Comptes Rendus Geoscience* 341(7): 538–46.
Morand, P., Kodio, A., Andrew, N., Sinaba, F., Lemoalle, J., Béné, C. 2012. 'Vulnerability and adaptation of African rural populations to hydro-climate change: experience from fishing communities in the Inner Niger Delta (Mali)'. *Climatic Change* 115: 463–83.
Ogilvie, A., Mahé, G., Ward, J., Clanet, J.C. 2010. 'Water, agriculture and poverty in the Niger River basin'. *Water International* 35(5): 594–622.
Ogilvie, A., Belaud, G., Delenne, C., Bailly, J.S., Bader, J.C., Oleksiak, A., Ferry, L., Martin, D. 2015. 'Decadal monitoring of the Niger Inner Delta flood dynamics using MODIS optical data'. *Journal of Hydrology* 523(1): 368–83.
Olivry, J.C. 2002. *Synthèse des connaissances hydrologiques et potentiel en ressources en eau du fleuve Niger.* Washington D.C.: World Bank and Niamey: Niger Basin Authority.
Serpantié, G., Lamachère, J.M. 1992. 'Contour stone bunds for water harvesting on cultivated land in the North Yatenga region of Burkina Faso'. In Hurni H., Tato K. (eds), *Erosion, conservation and small scale farming*. Berne: Berne University, pp. 459–70.
Serpantié, G., Milleville, P. 1993. 'Les systèmes de culture à base Mil et leur adaptation aux conditions sahéliennes'. In Hamon, s. (ed.), *Le Mil en Afrique*. Paris: Orstom, pp. 255–66.
Sircoulon, J. 1987. 'Variation des débits des cours d'eau et des niveaux des lacs en Afrique de l'Ouest depuis le début du 20ème siècle'. *The influence of climate change and climatic variability on the hydrologic regime and water resources* 168: 13–25.
Sultan, B., Janicot, S. 2003. 'The West African monsoon dynamics. Part II: The "preonset" and "onset" of the summer monsoon'. *Journal of climate* 16(21): 3407–27.

Venot, J.P. 2014. 'Rethinking commons management in Subsaharan West Africa: public authority and participation in the agricultural water sector'. *Water international* 39(4): 1–15.

Venot, J.P., Krishnan, J. 2011. 'Discursive framing: debates over small reservoirs in the Rural South'. *Water Alternatives* 4(3): 316–24.

Zwarts, L., van Beukering, P., Kone, B., Wymenga, E. 2005. *The Niger, a Lifeline. Effective Water Management in the Upper Niger Basin*. Lelystad: RIZA.

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