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Health Impacts of Small Reservoirs in Burkina Faso

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Project

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Acronyms and Abbreviations

CEGET	Center for Tropical Geography (Centre d'Etude de Géographie Tropicale, Bordeaux, France)
CIEH	Inter-African Committee for Hydraulic Studies (Comité Inter Africain d'Etudes Hydrauliques)
CNLP	National Malaria Control Center (Centre National de Lutte contre le Paludisme)
CNRFP	National Malaria Research and Education Center (Centre National de Recherche et de Formation sur le Paludisme)
CRDI	International Development Research Centre (Centre de Recherches pour le Développement International, Canada)
DGAEP	Direction of drinking water (Direction Générale de l'Approvisionnement en Eau Potable)
DGIRH	Direction of Hydraulics (Direction Générale de l'Hydraulique, Ministère de l'Environnement et de l'Eau)
DGRE	Direction of Water Resources (Direction Générale des Ressources en Eau)
FCFA	West African Francs. Throughout this report a conversion rate of 757.97 FCFA to US$1.00 was used according to Universal Currency Converter in March 2002 (www.xe.com)
IGB	National Geographical Institute (Institut Géographique de Burkina Faso)
IIMI	International Irrigation Management Institute, currently known as IWMI
INSD	National Institute of Demographical and Statistical Studies (Institute National de la Statistique et de la Démographie)
IRD	(French) Institute for Development Research (Institut de Recherche pour le Développement), previously known as ORSTOM
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
MAHRH	Ministry of Agriculture, Hydraulics and Fisheries (Ministère de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques)
NTU	Unit of turbidity (Unité de turbidité néphélémétrique)
OCCGE	Organization for the Fight against Major Endemics (Organisation pour la Coordination et la Coopération dans la lutte contre les Grandes Endémies) of the Muraz Center in Bobo-Dioulasso
OCP	Onchocerciasis Control Program
ORSTOM	Previous institute of scientific research for development (Office de la Recherche Scientifique et Technique Outre-Mer), now IRD
PNLSc	National Schistosomiasis and Soil-Transmitted Helminthiasis Control Program (Programme National de Lutte contre la Schistosomiase et les Vers Intestinaux)
SRP	Small Reservoirs Project, PN46 of the Challenge Program on Water and Food

Summary

In this paper we discuss health impacts of small reservoirs in Burkina Faso. Small earth reservoirs have been increasingly promoted in several West African countries since the 1980s but the environmental and health impacts resulting from this type of intervention remain poorly documented. However, some secondary information turned out to be available in "gray" literature such as students' theses. Data from different sources were combined into national maps and synthesized for small reservoirs in different climatic zones.

In Burkina Faso, around 1,700 small dams were constructed, most of them during the last 30 years, to provide water to people and livestock in drought-prone areas. In the drier parts of the country, these reservoirs are still mainly used for watering livestock. In other areas, the water is increasingly used for irrigation of vegetables. Almost everywhere these man-made lakes appear as multiple use systems. A new government strategy initiated in 2002 foresees the construction of more dams and 20,000 ha of new village irrigation systems. In many places, the creation of small reservoirs in Burkina Faso has resulted in increased household income through productive agricultural activities upstream and downstream of the reservoir. However, in almost all cases no preventive measures have been taken to ensure that the small reservoirs do not have adverse environmental and health impacts.

The water-related diseases most directly linked to the construction of small reservoirs are schistosomiasis and malaria, though emerging pathogens such as cyanobacteria are expected to present major health risks in the near future. For schistosomiasis, some field studies found increased transmission after construction of the reservoirs, especially in the semiarid north, where the reservoirs provided perennial water bodies in an area where previously the intermediate snail host depended on temporary pools. Human behavior regarding water use and hygiene however is more important than the presence of snails as a determinant of transmission. For malaria, the link is even more complicated as mosquitoes hardly breed in the reservoir itself and an increase in vector mosquitoes does not necessarily lead to increased malaria prevalence.

Knowledge of water-related diseases, including causes and avoidance measures, remains low in Burkina Faso. Public awareness campaigns are necessary to explain to communities the possible impacts of reservoirs and irrigated agriculture on their health. This should be done even before the promotion of preventive and curative measures against the water-related diseases. Alternative water sources for domestic supply should be developed if possible. The reduction of the negative impacts of small reservoirs on the environment and public health requires an integrated approach, which specifically identifies the enhancing and limiting factors that influence environmental impacts and the transmission of diseases in the reservoir environment. It is only from a good knowledge of the risks that effective environmental management and disease control programs can be developed in a way that fits with regional strategies for poverty alleviation and sustainable development.

INTRODUCTION

Small Reservoirs in West Africa

The West-African landscape is today characterized by the presence of many small water reservoirs for livestock watering, irrigation, flood protection, groundwater recharge, human consumption and other purposes. Storage of surface flow that concentrates in the inland valleys during the rainy season is a traditional and simple technique used widely in rural areas with important water deficits (Reij et al. 1996). Most of the existing small reservoirs are located between the Sahel zone where annual rainfall is less than 500 mm and the Sudanian area with less than 1,100 mm/year. In Sahelian countries like Burkina Faso, Niger and Mali, the purpose of implementing these small dams has been firstly to resolve the water needs of the people and cattle located in the arid areas, particularly after the two waves of drought spells that occurred in the seventies and eighties. Most of the small dams were thus implemented after 1980. Their numbers vary significantly over the three countries, with an estimated 1,700 in Burkina Faso (Cecchi et al. 2009b), more than 1,000 in Mali and some dozens in Niger. Most of them are localized in areas with high population density, e.g., in Burkina Faso most of the small reservoirs are found in the Nakambé (former White Volta) Basin where population densities can reach 100 inhabitants/km^2 (INSD 2000). The limitation of rural emigration was also an objective in providing new employment opportunities for people in their native regions, as was the case in the Dogon region in Mali (Diawara 1997). Subsequently, the reservoirs have attracted people and thus contributed to increasing population pressure in the same area (Morin 1990).

In the southern parts of West Africa, where annual rainfall is more than 1,000 mm, the presence of the small reservoirs is justified not by climatic constraints alone as it is the case in the Sahelian areas. In Côte d'Ivoire for example, with nearly 300 small reservoirs in the north and the center of the country, the implementation of the water reservoirs had different objectives: water provision for livestock (269 reservoirs) and irrigation (19 reservoirs) (Anonymous 1992; Cecchi 2007a). The construction of small dams started here in the 1970s following the successful control of onchocerciasis (river blindness) that previously infested the inland valleys. Now the valleys could be developed for crop production (Cecchi 1998; Fromageot 2003). The pastoralist demand for watering points increased tremendously after the droughts in 1973/74 and 1982, which had considerably reduced the available sources of water as well as the pastures in the Sahel countries. An additional motive for investing in water for livestock was the desire to fix the migrating pastoralists of neighboring countries in Côte d'Ivoire and thereby reduce the costs of meat importation (Ancey 1997; Coulibaly 2003).

Health Impacts

The small perennial or temporary reservoirs create new aquatic ecosystems in previously (semi) arid zones, where the presence of surface water is an innovating fact and may appear as a disturbing element (Dejoux 1988). The establishment of small reservoirs is accompanied by important modifications of the local environment and changed density (migration) and behavior of the benefiting population (Lassailly-Jacob 1984; Cecchi 2007a). Together, these factors may support the development of water-related diseases and subsequently lead to higher levels of endemics or, in some cases, even cause epidemics (Patz et al. 2000). Although a significant proportion of such burdens of disease is caused by 'classical' water-related pathogens (e.g., typhoid or cholera), newly emerging pathogens

and new strains of established pathogens are being discovered that present important additional challenges to both the water and public health sectors. Between 1972 and 1999, 35 new agents of disease were discovered and many more have reemerged after long periods of inactivity, or are expanding into areas where they have not previously been reported. Amongst this group are pathogens that may be transmitted by water (WHO 2003). Agents of disease (e.g., bacteria, protozoa, viruses, algae) as well as transmitting insects or intermediate hosts (e.g., mosquitoes, snails, flies) may develop in the water bodies while people may get infected through ingestion, by water-skin contact, by mosquito bites or even by inhalation. In West Africa the main diseases associated with the implementation of the small reservoirs are schistosomiasis, malaria and diarrhea, the latter of which is actually a symptom that can have many causes. Positive health impacts may occur as well, related to better nutrition, increased income and improved hygiene (Fromageot et al. 2005, 2006; Savy et al. 2006). However, in this paper the main focus is on water-related diseases.

The development of schistosomiasis around small reservoirs is an indicator of the relation the human population maintains with this water resource since its transmission takes place through water contact during activities of a domestic (e.g., bathing, laundry) or productive (e.g., irrigation, fishing) nature (Etard and Borel 1992; Kloos et al. 1998; Ernould 2000; Boelee and Madsen 2006). Though there are few detailed studies available, spread of this disease was noted in various areas in West Africa with the development of small reservoirs (Mott et al. 1995; Hunter 2003; Cecchi 2007b). The new seasonal or perennial water bodies provide spatial and temporal refuges for the intermediate host snails previously confined to ponds and temporary rivers in the rainy season (Vercruysse et al. 1994; Schutte et al. 1995; Traoré 1996; Cecchi et al. 2007).

In Mali a strong prevalence of *Schistosoma haematobium* infection (urinary schistosomiasis) has been found in the Dogon region after the creation of many small reservoirs for horticulture (Pleah 1976; Brinkmann et al. 1988). This productive activity attracted important concentrations of people around these reservoirs leading to their overexploitation, much water contact and subsequent high infection rates (Morin 1990). The same impacts of small reservoirs on the development of schistosomiasis were described in Burkina Faso (CEGET 1983; Poda 1996; Poda and Traoré 2000). With a national prevalence of almost 30%, some pockets with high endemicity generally appeared in the zones where small reservoirs were established. In the inland valleys located in the center and in the north of Côte d'Ivoire, the development of schistosomiasis in relation to small reservoirs was mentioned as well (N'Goran 1994, 1997). Clear evidence was also provided for Northern Ghana (Hunter 1981; Hunter et al. 1982). Ten years ago, an economic evaluation already highlighted the deleterious impacts of such high prevalence (Audibert and Etard 1998; King et al. 2005).

Despite strong evidence of a negative impact of these dams on urinary schistosomiasis revealed by different studies, not all studies found such evidence systematically (Ratard et al. 1990; Grosse 1993). Situations may differ regarding the type of schistosomiasis considered (e.g., urinary and. intestinal) and the locations of studies (Yapi et al. 2005). Hybridization of different species of parasites (e.g., *S. haematobium* and *S. bovis*) may constitute a new hazard, though their pathogenic potential is not clear (Brémont et al. 1993). The construction of a small reservoir may also have limited influence on schistosomiasis transmission, as prevalence may remain low or was already high before implementation (Pugh et al. 1980; Betterton et al. 1988). Natural seasonal ponds are sometimes very common and may constitute more dangerous transmission sites than artificial reservoirs created by dams or impoundments (Doumenge 1984). Ecological variations in snail populations and thus parasitic potential may sometimes be more determinant (Grosse 1993).

Irrigation schemes downstream of the small dams may constitute favorable biotopes for the development of *Anopheles* mosquitoes that can be vectors of malaria. The burden of malaria is a well-known challenge to human development manifesting itself as a cause and consequence of underdevelopment (Gallup and Sachs 2001). However, water resources development as such does not always lead to increased transmission of malaria, depending on climatic and anthropogenic factors (Henry et al. 2000). In the irrigated plain of Banzon on the Mouhoun River, mosquito aggression is definitely higher than that in the savanna zone without irrigation (Koné 1992; Tia et al. 1992). In the drier Sahelian zones where transmission is primarily seasonal, the few rare studies indicate that malaria could grow to epidemic proportions after the establishment of a water reservoir and irrigation system (CNLP-press 1998). In Mali, rice cultivation in a semiarid sub-Saharan environment altered the transmission pattern from seasonal to perennial, but reduced annual incidence more than twofold (Sissoko et al. 2004).

In the Sahel, the availability of drinking water in sufficient quantities throughout the year is still very low. Hence, many people depend on water from the small reservoirs, though this is rarely suitable for consumption. As a result, diarrhea still constitutes one of the major causes of mortality among children in rural areas, especially where part of the drinking water comes from the reservoirs (De Lorenzi and Volta 1987; Duboz and Vaugelade 1987; Duboz et al. 1988). Water quality in small reservoirs is directly influenced by anthropogenic factors. Agricultural intensification is most often associated with an increased – sometimes even abusive – use of pesticides that may contaminate reservoirs (Leboulanger et al. 2009). There is also a growing concern about the development of cyanobacterial populations as many aquatic cyanobacteria species produce harmful toxins (Codd et al. 2005). Twenty genera and more than 40 species of cyanobacteria are known for their potential toxicity. Exposure to cyanotoxins has been reported to induce specific health disorders depending on the exposition route, the quantities absorbed and the toxicity of cyanobacterial species or strains (for review see Codd et al. 1999a). Freshwater contamination by cyanobacterial blooms may represent a serious issue for the functioning of ecosystems and human society that depend on them. A provisional threshold of 1 µg/l equivalent microcystin-LR (MC-LR or microcystin-LR is the most toxic and widespread cyanobacterial hepatotoxin) is thus indicated by WHO for drinking water, with higher thresholds for recreational water or other uses (Chorus and Bartram 1999). However, health hazards associated with potential toxic cyanobacterial proliferations remain, to date, poorly documented for most of sub-Saharan Africa (see Figure 5 in Carmichael 2008).

Several detailed studies on the impact of small reservoirs on human health were carried out in Burkina Faso during the last 30 years, especially with a focus on schistosomiasis. Most of the results have not been published formally or are not available in English. New studies have revealed other important emerging health issues, such as cyanobacteria in Burkina Faso (Cecchi et al. 2009c) and Buruli ulcer in Côte d'Ivoire (Brou et al. 2006, 2008) and Cameroon, where prevalence was higher in areas near slow-flowing water (Porten et al. 2009).

The synthesis of results in this paper will make it possible to measure the consequences of the local environmental modifications induced by these small reservoirs and the resulting interactions between people and this new aquatic environment regarding risk of disease. Most of the impacts discussed in this paper give an underestimation of the health risks as it was not possible to adequately quantify and assess the effect of human and animal migration related to the small reservoirs.

SMALL RESERVOIRS IN BURKINA FASO

Water Resources

The rainfall pattern in Burkina Faso is governed by the West African monsoon, driven by the latitudinal oscillation of the Inter-Tropical Convergence Zone. It is characterized by a strong north-south gradient (Figure 1), with increased yearly rainfall and length of wet season in the southern part of the country. The year to year variability is important. Most (> 90 %) of the received rain is returned to the atmosphere through plant transpiration and soil evaporation. Water resources are highly dependent on the rain patterns; and, apart from the main course of the upper Pendjari in the southeast and the Mouhoun in the west of the country, most rivers dry up seasonally. The trend is globally oriented towards a diminution of precipitations since the dry period in 1970. Paradoxically, at the same time, the runoff coefficient increased from 1.5 to 3.0% in the northern part of the Nakambé Basin, resulting in increased discharge albeit reduced rainfall (Mahé et al. 2005). Floods appear sometimes very violent and induce severe – and recurrent – damage to hydraulic and circulation infrastructures (such as dikes and bridges).
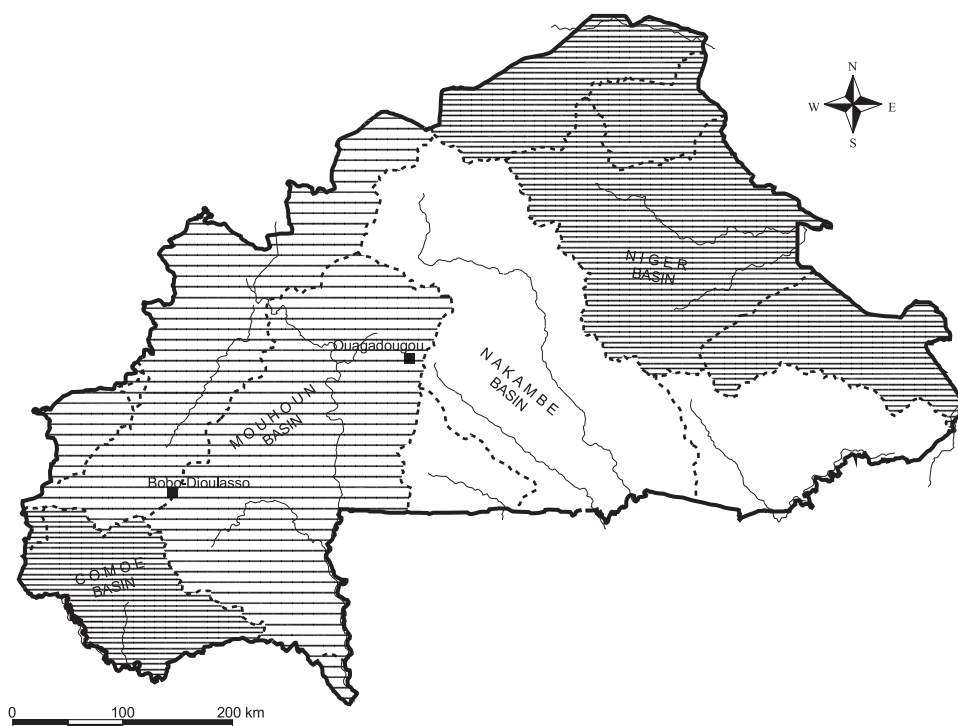
FIGURE 1. River basins in Burkina Faso (Koné and Boelee, after Ministère de l'Eau 1989, 1991; Nébié 1984).

Despite the relatively dense hydrographic network that drains Burkina Faso, most of the country suffers from physical water scarcity with dry riverbeds during several months/year and irregular distribution of groundwater availability. In 1996, around 1,685 m^3 of renewable water resources/capita/year were thought to be available for a population estimated at around 10.5 million (Postel 1996). Using the reported water availability estimates from FAO, 1995 and population prediction figures, Yang et al. (2003) estimated that by the year 2030 Burkina Faso (as three other countries

in West Africa: Niger, Nigeria and Togo) will experience water scarcity (defined as available water less than 1,500 m^3/capita/year).

These climatic conditions are globally unfavorable to the development of rain-fed agriculture and livestock breeding that together represent more than two-thirds of the domestic production of Burkina Faso. The agriculture sector employs nearly 90% of the population, mainly in the rural areas, and contributes 40% to the Gross National Product (GNP). The total population was around 10.5 million in 1996, estimated to be over 14 million a decade later, with an annual growth rate of 3.1% (INSD 2008). Life expectancy has increased from 53.8 years in 1996 to 56.7 years in 2006 (INSD 2008). Spread over the land surface of 274,200 km^2, the average population density is 38 inhabitants/km^2, varying from 19 in the north to more than 70 in the central region (INSD 2000).

Usually, three main climatic zones are distinguished, based on precipitation and temperature: Sahelian, Sahelo-Sudanian and Sudanian (Table 1 and Figure 5). The rainfall is unequally distributed spatiotemporally; primarily concentrated in 3 months in the Sahelian zone and spread over 6 to 7 months in the southern part of the Sudanian zone.

TABLE 1. Main climatic zones in Burkina Faso (FAO 1996).

Name	Annual rainfall	Temperatures (low in January and high in April)
Sahelian zone	< 500 mm	10–40 °C
Sahelo-Sudanian zone	500–900 mm	13–38 °C
Sudanian zone (southwest)	900–1,100 mm	12–38 °C

The water resources of the country can be divided into three large basins and a smaller fourth (Ministère de l'Eau 1989; Figure 1 and Table 2).

Comoé Basin. With a surface area of 17,590 km^2 covering 6.4% of the territory surface, this is the smallest of the four basins. Bordering Mali and Ivory Coast, it is located in the Sudanian climatic zone with tropical characteristics and two well-marked seasons: a dry season from November to June and a rainy season from July to October. Annual rainfall varies from 1,100 to 1,300 mm. The basin is drained by the Léraba and Comoé rivers, which are perennial, and by several temporary rivers such as Kodoum, Baoué and Iringou. The total annual surface discharge is estimated at 1.6 billion cubic meters (Bm^3) of which 85 million cubic meters (Mm^3) are retained by dams (DGIRH 2001).

Most of the country (63.1%) is covered by the upper end of the Volta Basin, largely comprising two large watersheds: the Mouhoun (former Black Volta, 53% of the Volta Basin's area in Burkina Faso) and the Nakambé (ex-White Volta, 47%).

Mouhoun Basin (Black Volta). With a surface area of 91,000 km^2 this basin is the largest in the country, covering 33% of the territory. It comprises the main subbasins of upper Mouhoun (20,978 km^2), lower Mouhoun (54,802 km^2) and Sourou (15,256 km^2). Almost half the average annual water potential of the country flows in this basin: 2.6 Bm^3 including 290 Mm^3 retained by dams (DGIRH 2001).

Nakambé Basin (White Volta). With a surface area of 82,000 km^2 this basin covers 30% of the territory and includes the subbasins of Nakambé (41,407 km^2), Pendjari-Kompienga (21,595 km^2), Nazinon (former Red Volta, 11,370 km^2) and Sissili (7,559 km^2). This large basin is influenced by

all three major climatic zones. The annual discharge is estimated at 2.4 Bm^3, more than 90% of which is held by dams (DGIRH 2001).

Niger Basin. Covering 30.5% of the national territory, the Niger Basin is located mainly in the northern and eastern parts and covers an area of 83,442 km^2. Its average annual water potential is the lowest of the country with less than 1 Bm^3 of which 100 Mm^3 are stored in small and large dams (DGIRH 2001).

TABLE 2. Some data on major river basins in Burkina Faso (DGIRH 2001).

Name of the basin	Surface (% of Burkina Faso)	Potential (Bm^3)	Stored in reservoirs (Bm^3 and % of potential)
Comoé	6.4	1.55	0.08 (5%)
Mouhoun	33.2	2.64	0.29 (11%)
Nakambé	29.9	2.44	2.20 (92%)
Niger	30.5	0.86	0.10 (12%)
Total	100	7.5	2.70 (36%)

Owing to their different characteristics (size, latitude, etc.), these basins carry very different quantities of water across Burkina Faso's borders. With more than 5 Bm^3 of water flowing annually towards Ghana via the Nakambé and Mouhoun rivers (Table 2), the Volta Basin appears as the most important transboundary watershed of Burkina Faso (Andreini et al. 2002): its importance is crucial to the water balance of the Volta Lake in Ghana.

From Table 2 it is clear that water reservoirs make up a considerable part of the surface water retention in Burkina Faso, particularly in areas where the flows are seasonal. The importance of reservoirs is particularly significant during the dry season, as shown in the north of Ivory Coast where the contribution of small reservoirs to surface water varied between 19% and 30% from the end of the rainy season towards the middle of the dry season (Cecchi et al. 2009a). In fact, except for the extreme west and southeast of Burkina Faso, the runoff is seasonal in the remainder of the river basins. The geology of the country partly comprises (weathered) old granite rocks with a weak water-holding capacity (Anonymous 2001). Hence, surface runoff and evaporation prevent much infiltration of water in most of the river basins. Water storage reservoirs reduce water losses, especially in the Nakambé Basin, where most of the surface water potential is stored in reservoirs.

Water Resources Development

In Burkina Faso, several large dams have been constructed, initially for the generation of electricity (Table 3). The two large dams, Kompienga and Bagré, built for hydropower during the last 20 years, deliver 20-30% of the country's energy needs today (DGIRH 2000b). The Kompienga Dam with a capacity of 2 Bm^3 is only used for hydropower and fishing, while the Bagré Dam with its 1.7 Bm^3 capacity feeds a downstream rice irrigation system. Other major irrigated areas can be found in the Kou Valley in the western part of the country (1,200 ha) where local rice production helped absorb migration from neighboring countries. In the Sourou Plain, located in the northwest of the country, 860 ha are irrigated for rice, cotton, maize, sorghum and horticulture with water from the Lery Reservoir (370 Mm^3). In the Comoé Province in the southeast a national sugar

TABLE 3. Major water uses in Burkina Faso (DGIRH 2001).

Water use	Volume exploited	
	Mm^3	%
Drinking water supply		
- Rural and semi-urban	67	3
- Urban	37	1
Irrigation	323	12
Livestock	72	3
Industrial	6	0
Energy	2,091	81
Total	2,596	100

company has developed irrigation in the Bérégadougou Valley. In this area, inland valleys have also been exploited for rain-fed rice (DGIRH 2000a, b).

The water requirements for irrigation are highest in the two basins of Comoé (2000 m^3/ km^2/ year) and Mouhoun (1,000–1,900 m^3/km^2/year) because of the large irrigation schemes that require two-thirds of these amounts (Figure 2). In the Nakambé Basin the water requirements are more diverse, though similar for large- and small-scale irrigation, inland valleys and horticulture. In the northern Nakambé and the Niger Basin, where most of the country's livestock are concentrated, animals are the main consumers of water (Figure 3). They need more than 200 m^3/km^2/year.
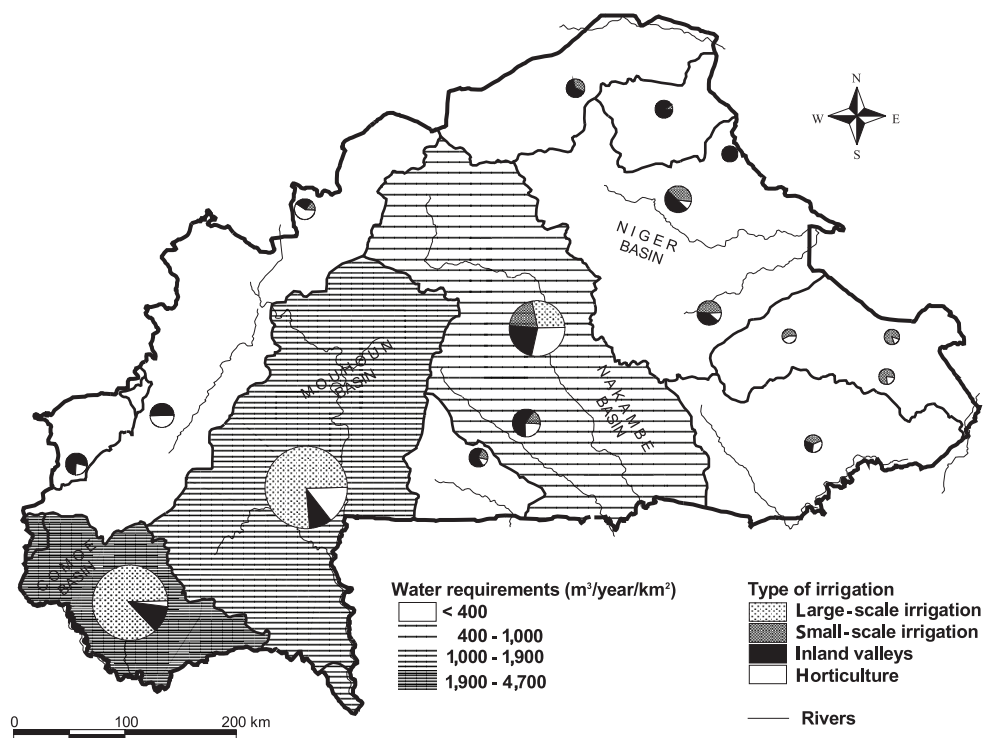
FIGURE 2. Water requirements for irrigation in Burkina Faso (Koné and Boelee, after DGIRH 2000b).

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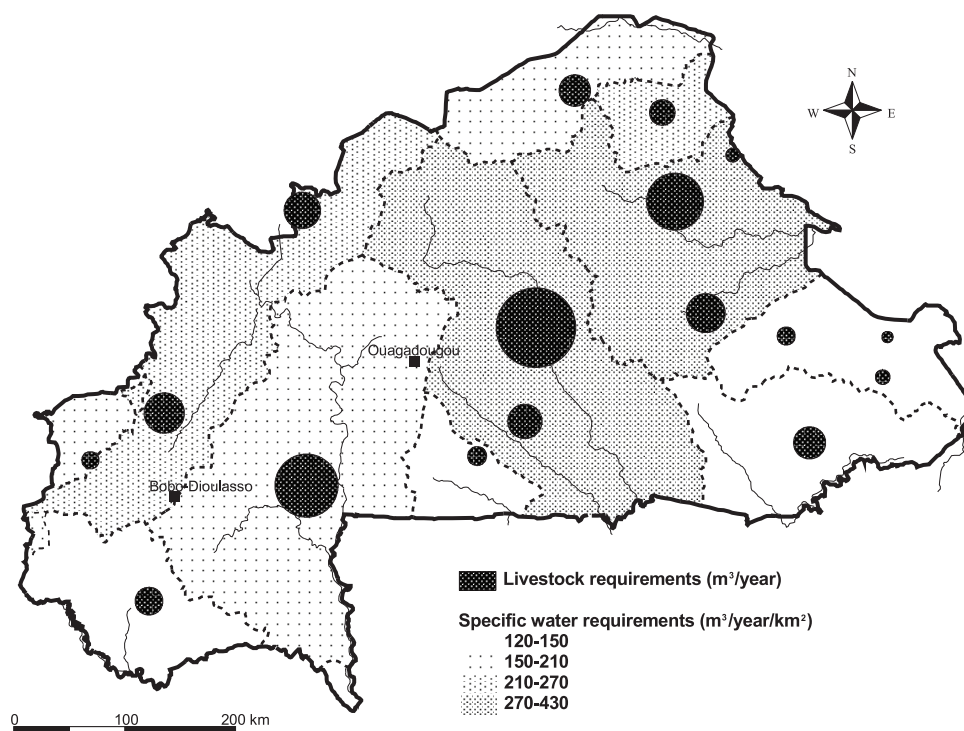
FIGURE 3. Water requirements for livestock in Burkina Faso (Koné and Boelee, after DGIRH 2000b).

Water Policy

In 1984, a separate ministry for water was inaugurated to emphasize the role of water and the development of inland valleys in the fight against food insecurity and poverty. The mobilization of surface water for people and livestock is of paramount importance in the country (Sawadogo 1994). In addition to the Kompienga and Bagré dams mentioned above, a third large dam, Ziga (200 Mm^3), devoted to urban water supply in Ouagadougou was inaugurated in 2004. Another large reservoir (Yako-Kanazoé Reservoir, 75 Mm^3) was constructed on the same main course of the Nakambé River in the 1990s. Water from this reservoir is used mainly for irrigated agriculture.

From 2002 Burkina Faso has initiated a program to develop village irrigation, which facilitates the exploitation of all the irrigable area around the small reservoirs and in the inland valleys. This should increase the cereal production in the dry season and reduce migration towards the large irrigated areas. The program is financed with around US$13 million[1] for 6 years in seven administrative units with many small dams. If successful, the program will reduce the annual import of rice to 12%, reinforce the capacity of 70 farmer groups including 30 women's groups, rehabilitate or construct 40 dams, rehabilitate 2,150 ha in degraded irrigation systems and implement new irrigation systems in 20,000 ha (DGIRH 2000b).

The Ministry of Agriculture, Hydraulics and Fisheries (MAHRH) is in charge of water resources in Burkina Faso. On 22 March 2006, a recent decree approved the creation of a new general water division (Direction Générale des Ressources en Eau) within MAHRH to replace the previous separate divisions on water resources (DGIRH, Direction Générale de l'Inventaire des Ressources

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[1] Using a conversion rate of US$1.00=FCFA757.97 in March 2002 (www.xe.com); the original amount was FCFA10,150,000,000.

en Eau) and drinking water (DGAEP, Direction Générale de l'Approvisionnement en Eau Potable). This new direction was mandated to elaborate, apply and follow national policies in integrated water resources management (IWRM) as well as in drinking water supply and sanitation.

Since 2003, Burkina Faso has been dynamically involved in the application of the principles of IWRM (DGIRH 2005). Governance and institutional frameworks have been adjusted and now correspond to a "basin focus" approach, which includes different levels of decentralization, from large Basin Agencies towards Local Committees in charge of water resources management at their own scales. In the future, these local committees will constitute the main management units of water resources. A recent audit of the implementation of the principles of IWRM revealed that while the political and institutional instruments appear operational, the global performance of the water sector in terms of IWRM objectives remains weak, particularly when considering water productivity (Rey et al. 2008). This reorganization was further complicated by the recent administrative redivision in Burkina Faso. In 2006, 13 "territorial collectives" (*collectivités territoriales*) were set up to complement 49 new urban "communes" and 302 new rural "communes" that more or less correspond geographically to the still existent "departments" (*départements*).[2] In terms of governance and responsibilities, there is a transfer of administrative capacities to the local level, where the new institutions have to define and further implement their own development planning and strategies. This decentralization, which concerns now both – but separately – the management of water resources and the administrative leadership is said to be the best way to provide an appropriate framework for sustainable development in Burkina Faso (Sanou 2008).

Characteristics of Small Reservoirs

In Burkina Faso, a small reservoir is defined by the height of the dam, which should be below 10 m. The maximum storage capacity or volume is not a criterion because most reservoirs are vast but very shallow with important seasonal variations. The latest estimate gives a total of 1,451 dams, half of which are located in the Nakambé Basin, 29% in the Mouhoun Basin, 19% in the Niger Basin and 2% in the Comoé Basin (DGIRH 2000b, 2001). This appears to be an underestimation, particularly regarding the number of the smallest-size reservoirs, but a minimum of 1,700 water bodies seems valid (Cecchi et al. 2009b). Four types of dams are identified in Burkina Faso (DGIRH 2000a, 2001):

- Dams intended to create water reserves. These are built on seasonal rivers and retain surface water during the rainy season to meet the human and animal water requirements. In practice, some of the reservoirs are used for industrial production, urban energy and fishing, and serve to recharge the groundwater for drinking water supply. Most of the small dams of Burkina fall in this category.

- Regulation dams for flood management.

- Dams for regulation of local streams.

- Diversion dams in rivers. These dams are used to block the rivers, raise the water level and feed a canal and they are relatively scattered in the country while those found on rivers of the valleys of Kou, Karfiguela and Banzon in the southwest of the country are the best documented.

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[2] Law n° 55-2004/AN du 21 décembre 2004 portant Code Général des Collectivités Territoriales au Burkina Faso.

Though most of the small reservoirs in the first category are used for livestock and domestic purposes, around 100 (out of the officially documented 1,500) support gravity irrigation schemes (Sally 2002). More often, horticulture takes place around the reservoirs and the crops are watered by hand or sometimes by pumps. A study of five small reservoirs revealed that the irrigation schemes often, but not always, allow for double cropping, leading to cropping intensities between 93 and 202% (Sally 2002). Crop production appears to be declining (IIMI 1997).

The temporary or permanent character of these water reservoirs varies according to their type and rainfall. Nowadays, an estimated 500 reservoirs retain water year-round (DGIRH 2000b). In the southwestern part of the country more than half the number of reservoirs retain water year-round (Ministère de l'Eau 1991). In the Nakambé Basin the situation varies from north to south. In the north, more than two-thirds of the dams are temporary reservoirs; in the central part of the basin practically half of them are temporary and to the extreme east most reservoirs are perennial.

Although the creation of small reservoirs started in Burkina Faso at the beginning of the last century, it was during the 1980s that about half the number of inventoried reservoirs were created (Figure 4). Before 1960, about 100 dams were constructed by missionaries and the colonial administration to secure human and animal water supply (CIEH 1985). This made it possible to move livestock and people away from the river valleys infested with the vectors of the onchocerciasis (river blindness) and trypanosomiasis (sleeping sickness). From 1960 to 1970 some 100 dams were constructed by European engineering companies with international donor funding. Even now, some of these dams are in a perfect state.
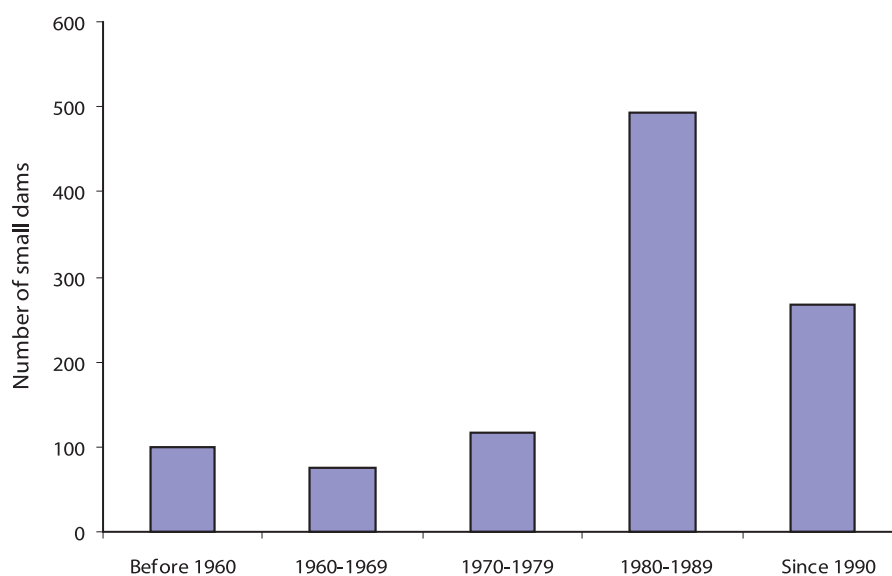
FIGURE 4. Rate of implementation of small dams in Burkina Faso over time (DGIRH 2001).

From 1970 onwards the speed of dam construction increased following the big climatic crisis of 1973/74 which had disastrous consequences for agricultural production and livestock in Burkina Faso. Donors implemented an emergency program for the entire Sahel region with food aid and support for the creation of water reservoirs or wells in most drought-affected areas. In areas where the soil had high water-retention potential, wells were dug and elsewhere earth dams were

constructed. These works generally had low holding-capacity and were seldom permanent (Bliss 1997). However, the reservoirs do contribute to groundwater recharge near them and thus guarantee the use of nearby wells throughout the year. This period also marks the beginning of the implementation of irrigation systems such as in the Europe-funded project for the development of 150 ha downstream of the reservoirs. Larger-scale irrigation schemes were implemented in the Kou Valley. Following another drought in 1982 the number of new small reservoirs increased fast in the 1980s. About half the number of small dams in the country were built during this decade. Most of these were constructed by NGOs and through international cooperation, and also by local actions under the development program of the revolutionary regime (CIEH 1985).

In merging information obtained through remote sensing by the National Geographical Institute of Burkina Faso (IGB, Land Cover database) in 2002 and the census of the reservoirs provided by DGRE at the same time, it has been possible to estimate both the minimal surface and shoreline lengths of the reservoirs at the national scale (Cecchi et al. 2009b). An impressive total of around 1,000 km^2 can be attributed to 620 lakes and reservoirs larger than 5 ha, allowing a significant annual fish production. This can be considered a positive impact of these water bodies, in terms of both economical income and nutritional supplement. The length of the associated shoreline has been estimated to be around 4,000 km.[3] In applying the mean national population density of 37.6 inhabitants/km^2 to the area covered by a 3 km buffer along these shorelines allowed the identification of half a million inhabitants, mainly rural, described as the population at risk from water-related diseases (McCartney et al. 2007). Keiser et al. (2005) proposed a distance of 2 km away from the shoreline of reservoirs to delineate the potential biting area of mosquitoes. Steinmann et al. (2006) used a distance of 5 km when considering schistosomiasis. Cecchi et al. (2009b) adopted an intermediary value of 3 km, which is actually less than the distance traveled daily by many rural people to use water from reservoirs. More important than this buffer zone is the shoreline itself, as it is the contact area between users and water bodies: a place of labor, for domestic purposes, for small-scale productive activities, and also for leisure, particularly for children. The shoreline is the principal hot spot for contamination and transmission of various water-related diseases.

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[3] These estimations are probably all low. The water-covered areas and shoreline lengths are deduced as intermediate or even minimal values because of the dry-season fluctuations. The size of 11 pixels/ha with Landsat TM also leads to a huge underestimation for water-surface areas and shorelines. In addition, the number of reservoirs in the databases is underestimated, as our field observations have confirmed (Cecchi et al. 2009b).

SPECIFIC HEALTH IMPACTS OF SMALL RESERVOIRS IN BURKINA FASO

The program for village irrigation launched in 2002 leads to important modifications of the environment around the small reservoirs. The effects on the development of certain diseases may or may not be comparable to the situations already described in the large irrigation systems in the region (Kou Valley in Burkina Faso, Manantali in Mali and the Senegal River Valley). In Burkina Faso, in several studies, the health impact of large dams and irrigation schemes was investigated (Carnevale and Robert 1987; Chastre 1994; Poda and Traoré 2000). Much less is known about the environmental impacts of small reservoirs.

Environmental Impacts

The construction of small dams in a catchment area has impacts on the environmental, human and hydrological characteristics of this catchment area as well as on the downstream area. On the hydrological level, it is established that the creation of one or several water reservoirs can effectively control the seasonal floods. Clusters of reservoirs have reduced the floods and contributed to a more beneficial use of the water in Burkina Faso. The floods have become less violent while river flows have been prolonged and erosion of the riverbeds reduced. Now more water from floods can infiltrate into the soil. To the north of the town of Kaya in the central part of the country, the presence of a dozen reservoirs in a small catchment area reduced the flood flow from 38 m^3/s to 23 m^3/s, while the time of flow was prolonged from one and a half to 4 days. Unfortunately, it led to a prolonged submersion of the easily flooded zones, and part of the agricultural land could not be exploited because of the excess water. These new moisture conditions may favor the breeding of disease vectors like mosquitoes that can transmit malaria, dengue fever or filariasis and intermediate snail hosts of schistosomiasis (CEGET 1983). The water balance of small reservoirs appears also influenced by the presence of nearby reservoirs sharing the same groundwater table. In that case, usually upstream mountain reservoirs act as zones of focused recharge and provide water to the groundwater, whereas downstream reservoirs generally act as groundwater discharge zones (Gower 2008).

On the demographic level, the establishment of small reservoirs led to a redistribution of the human population. For example, in most of the villages around the Yitenga Dam, 140 km east of Ouagadougou in the Kouritenga Province, the population increased dramatically, leading to urbanization and to degradation of the ecosystem (Yonkeu 2008). In contrast, one village lost half of its population because it was flooded by the reservoir and another disappeared almost entirely because its inland valley could no longer be used for commercial horticulture (Yonkeu 2002). The same author made a historical analysis of the land use around the Yitenga Dam by comparing the situations in 1979, 1993 and 2001 (Table 4). After construction of the dam, a much smaller area was inundated after the floods. Forest and savanna vegetation was replaced by degraded secondary vegetation, man-made savanna and gardens as a result of increased population. In addition, 120 ha of dense forest were destroyed downstream of the dam. The high population density increased pressure on the land for homesteads and cultivation, pushing people to marginal ground and reducing the fallow period. Collection of wood for domestic use and intensive collection of crop residues after harvest exposed the soil to erosion in the rainy season. The reservoir got polluted by solid wastes and sewerage draining into the water. Human waste and domestic garbage that drained into the reservoir by the stream, thus contributed to pollution of this resource. The areas under rice irrigation and horticulture increased and people

planted exotic tree species in the savanna such as *Azadirachta indica* (neem), *Eucalyptus camaldulensis*, *Mangifera indica* (mango tree) and *Psidium guajava* (guava tree). All these environmental changes may have serious consequences for the population using the reservoir (Yonkeu 2002).

TABLE 4. Dynamics of land use around the Yitenga Dam between 1979 and 2001 (Yonkeu 2002).

Land use	Area in 1979 (ha)	Area in 1993 (ha)	Area in 2001 (ha)	Difference 1979-2001 (ha)	Difference 1979-2001 (%)
Koupéla town	115	207	1,663	+1,548	1,346
Pouytenga town and villages	90	182	958	+868	964
Fallow	186	292	257	+71	38
Open water	24	152	131	+107	446
Easily flooded zone	491	217	217	-274	-56
Rice-growing and horticulture	10	61	79	+69	690
Cultivated area	12,266	11,207	9,483	-2,783	-23
Man-made savanna (with useful species)	0	543	540	+560	-
Degraded savanna	0	466	1206	+1206	-
Shrubby natural savanna	822	781	781	-41	-5
Forest	54	42	42	-12	-22
Total	14,058	14,150	15,357		

Schistosomiasis

Geographical Distribution of Schistosomiasis

As far back as 1957, it was believed that the whole territory of what is now known as Burkina Faso constituted a single, vast area endemic to schistosomiasis (Marill 1957). Several subsequent studies have confirmed that no region of the country was free of transmission, and the prevalence and intensity of infection are frequently high, as reviewed by Poda et al. (2004a). Because of the climatic conditions, most watercourses in Burkina Faso are temporary, and natural perennial water masses are rare. However, during the rainy season, numerous temporary swamps and pools develop, scattered all around the country. Historical studies have revealed that almost all molluscs sampled in these water bodies were infected with helminths (Doumenge et al. 1987) and that schistosomiasis has been an endemic pathology for a long time (Moreau et al. 1980). Temporary and perennial water bodies such as those created by small dams offer ideal conditions for the aquatic and amphibian snails that are potential intermediate hosts of human and bovine schistosomiasis. According to studies carried out in Burkina Faso in the last 20 years, the prevalence of this disease has been about 30% with important local variations (Poda 1985, 1996; Poda et al. 2004a). The most frequent form in the country is urinary schistosomiasis caused by *Schistosoma haematobium.* Within the main climatic zones of Burkina Faso, the heterogeneity in the transmission pattern of schistosomiasis is closely linked to the water systems. In general, irrigation systems and small permanent water bodies are preferred breeding sites of the snail hosts as well as principal points of contact between people and the parasite. Hence, the spatial

distribution of schistosomiasis is closely correlated to that of the intermediate hosts and climate (Poda 1996). The highest prevalence of *S. haematobium* was observed in villages with at least one dam. These decrease from north to south. Specific differences that are characteristic of the climatic zones (Table 1) are discussed in more detail below (Poda and Traoré 2000). Figure 5 shows the mean of low and high prevalence in villages with a small reservoir, calculated from Poda 1996.
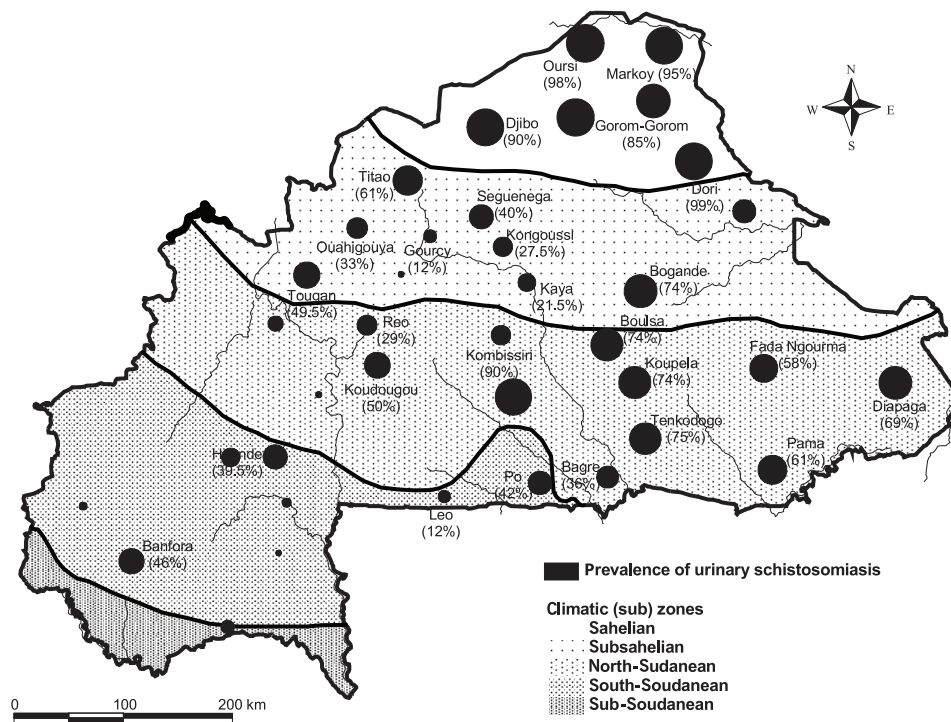
FIGURE 5. Climatic zones and subzones with average schistosomiasis prevalence in villages with small reservoirs (Koné and Boelee, after Poda 1996 and DGIRH 2001).

Transmission foci in the Sahelian climatic zone. Beyond the 14° northern latitude, annual rainfall does not exceed 500 mm and perennial water surfaces are very few, mainly consisting of occasional reservoirs and natural temporary ponds (e.g., Dori, Oursi, Markoy, Soum, Darkoy). The fast draining of the majority of the rivers and water reserves at the beginning of the dry season does not allow a continuous development of the intermediate hosts, and transmission takes place here only during the rainy season. People and livestock are highly concentrated around the few water bodies throughout the year, which support constant circulation of the parasite and lead to hyper-endemic transmission levels of urinary schistosomiasis (Poda 1996).

Transmission foci in the south-Sahelian climatic zone. Between the 13th and 14th parallels rainfall varies from 500 to 750 mm annually with a dry season that lasts for 7 to 8 months. This area also has some natural lakes (Bam, Dem, Siam) and small reservoirs with irrigated horticulture (Ouahigouya, Yalogo, Tougouri, Louda, Mani). The epidemiological situation is as heterogeneous as the variety in water systems. Urinary schistosomiasis is meso-endemic with some pockets of

hyper-endemy around small reservoirs. In Bogandé, near a reservoir for livestock (capacity 2 Mm^3) built in 1966, a prevalence of 62% was found. The small reservoir (1.2 Mm^3) in Mani had a local prevalence of 82%. Finally, the highest prevalence of 100% was observed in Thion with a genuinely small reservoir (0.2 Mm^3) built in 1957 (Poda 1996). The presence of small reservoirs does not lead everywhere to increased transmission. In the village of Louda, prevalence was 10% in spite of the presence of a small reservoir of 3.2 Mm^3 and rice cultivation (Villenave 1985).

Transmission foci in the north-Sudanian climatic zone. Between latitudes 13° and 11° 30´ annual rainfall ranges from 750 to 900 mm with a 6 to 7 months' dry season. Many contributing streams to important rivers run through this zone and about half the number of small reservoirs (700-800) of the country are located here. It is estimated that the construction of such a large number of small reservoirs enabled the spread of urinary schistosomiasis to meso-endemic proportions. In the central part around Ouagadougou, high prevalence was observed in certain villages of Oubritenga that had small reservoirs. It is the case in the village of Daguilima where the prevalence was 85% and Tanguiga where it was 55% (Traoré 2001). This prevalence is higher than observed in the south around the large Bagré Dam where the prevalence was 33% in 1992 before completion of the dam (Zan et al. 1993). In the extreme east of this zone, prevalences were 52% around the water reservoir of Fada N'Gourma and 70% around Diapaga (Poda and Traoré 2000).

Transmission foci in the south-Sudanian climatic zone. In this zone, between 12° and 10° northern latitudes, most of the rivers and water reservoirs are permanent, offering favorable breeding sites to the intermediate hosts of schistosomiasis. However, transmission is low and prevalence the lowest of the entire country, probably because the high turbidity of the water during the rainy season does not facilitate the establishment of snails or contact with the parasite. The few exceptions of high endemicity were observed around large irrigated areas such as the Kou Valley where *S. haematobium* prevalence was 80% and *S. mansoni* prevalence 40%. In the two villages, Dafiguisso and Dafinso, where commercial horticulture was well developed, the prevalence of *S. mansoni* was 64% and 45%, respectively, while in Dafinso, prevalence of *S. haematobium* was less than 6%. Around the large hydropower Kompienga Dam the prevalence was 31% in 1989 (Poda and Traoré 2000).

Transmission foci in the sub-Sudanian climatic zone. Located at the extreme southwest of Burkina, on average, this zone receives more than 1,000 mm of rain/year. It has a very dense network of permanent streams and rivers. Apart from large works such as Comoé there are also some small reservoirs. The permanent water bodies enable continuous transmission of schistosomiasis, hence *S. haematobium* is hyper-endemic and *S. mansoni* hypo-endemic.

To summarize, transmission of urinary schistosomiasis did increase after the construction of dams, especially in the semiarid north, where the reservoirs provide perennial water bodies in an area where previously the intermediate snail host depended on temporary pools (Poda 1996 and Figure 6). Statistical analyses showed that there was a significant (Pearsons $\chi2=0.41$, $p<0.05$) difference between the prevalence of urinary schistosomiasis in villages with and without dams. At the regional level however, there is no clear connection between urinary schistosomiasis and small reservoirs whether their density is expressed per surface or compared to the human population.
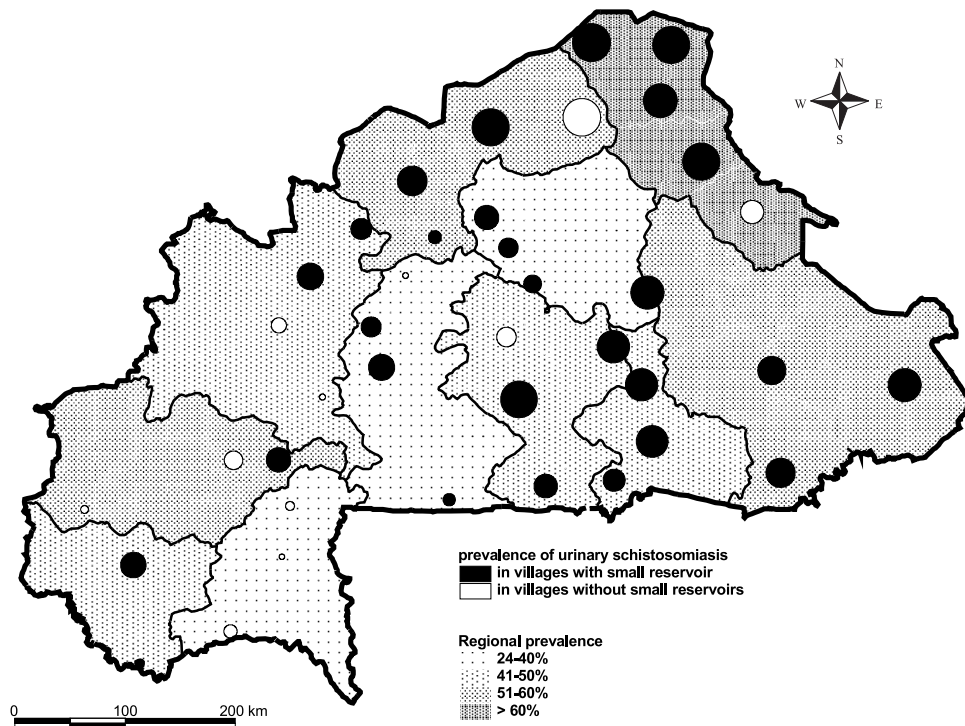
FIGURE 6. Mean prevalence of urinary schistosomiasis as a function of dam density and population density per dam in 11 regions in Burkina Faso (Koné and Boelee, after Poda 1996).

Small Reservoirs, Snails and Schistosomiasis

Snail surveys carried out by Poda and his team from 1985 to 1995 showed the importance of small reservoirs in the distribution of intermediate snail hosts of schistosomiasis in Burkina Faso (Poda 1996). They found 41% of the intermediate hosts in the small reservoirs, 34% in the rivers, 20% in temporary ponds, 3% in the irrigation canals and 2% in natural lakes. Though the study highlighted the strong dispersion of *Bulinus truncatus* across all climatic zones, it also showed the snails' preference for open shallow water bodies such as reservoirs. Especially in the Nakambé Basin a close relationship was found between snail densities and the presence of the small reservoirs. Another potential intermediate host snail, *B. senegalensis*, has a preference for the temporary ponds of the rainy season and further shares the majority of the ecological niches of *B. truncatus*. In addition, *B. senegalensis* is dominant in the southwestern part of the country where temporary rain pools replace the small reservoirs. The other potential hosts like *Biomphalaria pfeifferi* responsible for the transmission of the intestinal schistosomiasis share the habitats with *Bulinus globosus* south of the 12° latitude. The large number of small reservoirs in the Nakambé Basin offered a wide variety of optimal breeding sites to almost all intermediate snail hosts in Burkina Faso (Figure 7). However, the actual transmission of schistosomiasis is also strongly influenced by the water use patterns of the community (Boelee and Madsen 2006).

From a comparative study of three breeding sites (a small reservoir in the village, temporary ponds and another small reservoir outside the village of Donsin and the Djerma stream) of *Schistosoma haematobium* in Burkina Faso by Poda et al. (2001a), it appears that the high prevalence in the village of Donsin is related to the proximity of a small reservoir. Built in 1955,
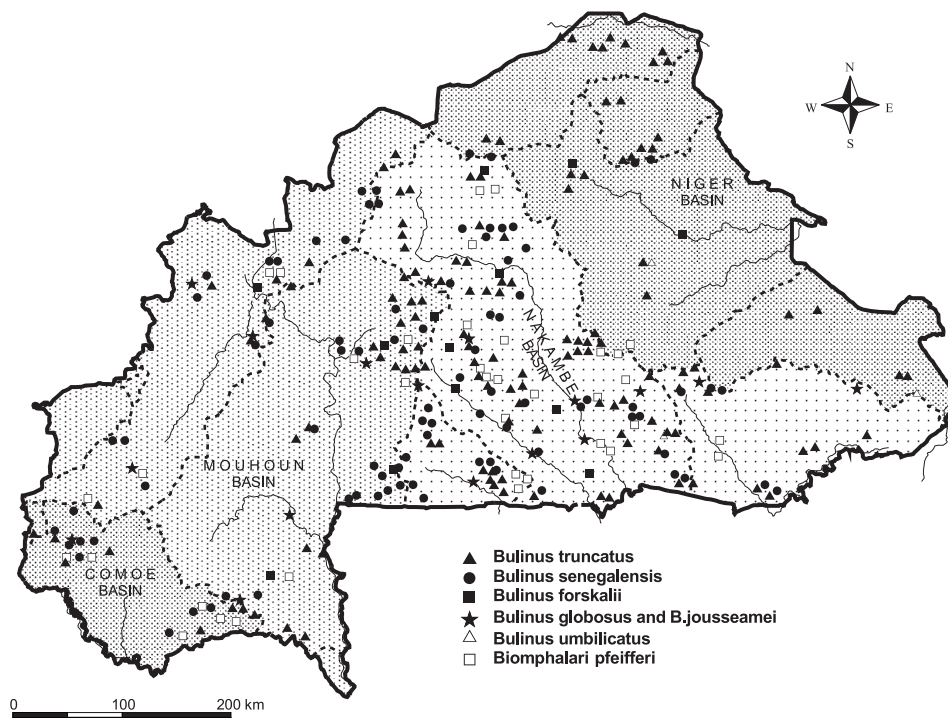
FIGURE 7. Spatial distribution of potential intermediate hosts of schistosomiasis in Burkina Faso (Koné and Boelee, after Poda and Traoré 2000).

this small reservoir of 200,000 m^3 offers optimal conditions for the development of one of the principal intermediate hosts, *Bulinus truncates,* that occurs in 75% of the sites. The reservoir, located near the school, is regularly used by the children for bathing. Around the village of Donsin, *B. senegalensis* and *B. truncatus* were identified in the temporary ponds and the other small reservoir of 75,000 m^3 constructed in 1986, which was hardly used by the villagers. The prevalence of the infection was 38%, in line with the general situation of areas with temporary ponds, where *B. senegalensis* was responsible for all transmissions. From this study, the small reservoirs appear as a water system that can locally modify the transmission of schistosomiasis in areas where previously only temporary water bodies were available (Poda et al. 2001a).

A study carried out in 1983 in the Kaya area, on the other hand, seems to indicate that the mere presence of a small reservoir is not sufficient to modify the epidemiologic profile of the population that uses it (Villenave 1985). By comparing three villages each with different water systems, Villenave highlighted the importance of human behavior in disease transmission. He compared the village of Louda with its 3.2 Mm^3 reservoir from 1958 and irrigated rice to the villages of Damesma, located in a valley with natural lakes and Noaka, with only seasonal access to water. The highest prevalence was found in Noaka, despite its lack of water resources and facilities (Table 5). In fact, the human pressure on the few water points facilitated transmission of schistosomiasis. In Damesma and Louda the epidemiologic situation can be partly explained by the dispersion of the population in hamlets, leading to a dispersed pattern of water contacts. Hence, though the intermediate hosts are present in all three ecosystems, the circulation of the parasite will vary according to human population pressure and water use behavior (Villenave 1985).

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TABLE 5. Prevalence of urinary schistosomiasis (in %) in three villages in Burkina Faso (Villenave 1985).

	Louda	Damesma	Noaka
Males	12	18	41
Females	8	9	25
Total	10	14	33

This observation was confirmed later in the Sourou Valley (Poda et al. 2001b, 2004b). By comparing pilot zones without irrigation systems with those close to irrigation infrastructure, it turned out that scarcity of water led to higher infection rates (65-83%). In the villages where only temporary ponds were available, population density around these was high, facilitating disease transmission. In the village near the irrigation system, prevalence was only 41% (Poda et al. 2003b).

Malaria

Transmitted by the *Anopheles* mosquito, malaria constitutes the principal cause of mortality in children under five in Burkina Faso and accounts for 20% of the consultations at health care facilities (MS/CRDI 2000). It is generally endemic but epidemics occur in certain areas related to important modifications of the water resources. The increase in mosquito-vector density caused by the presence of a small reservoir and irrigated area is a real risk. But as with schistosomiasis, the actual incidence of malaria will vary according to the climatic zone and local socioeconomic circumstances (Danis and Mouchet 1991).

Geographical Distribution of Malaria

In the southern Sudanian or *tropical* climatic zone, with annual rainfall over 1,000 mm and a rainy season of more than 4 months, malaria transmission is high with 100-1,000 infected bites/person/year. The sporozotic index of the main vectors *Anopheles gambiae*, *An. aranbiensis*, *An. funestus* and *An. nili* is 2 to 5%. Resistance is effective from the age of 10 years, and generally adults do not suffer much from the disease. Still, malaria accounts for 30-35% of all fevers, varying between 10% in the dry season and over 80% in the rainy season. Under these climatic circumstances with continuous transmission throughout the year, an increase in the vector population, because of the presence of small reservoirs, will not have an effect on malaria incidence (Henry et al. 2000).

The other climatic zones of the country have less than 1,000 mm rain annually. The variations in rainfall over space and time lead to important variations in mosquito production. The transmission, ensured by *An. arabiensis* and *An. gambiae* s.l. and, to a lesser extent, by *An. funestus,* is concentrated in the short rainy season of less than 4 months. In the northern part, the inoculation rate is around 15-20 bites/person/year. The resistance decreases while going north along with an increasingly unstable character of the disease. In this zone, epidemic episodes are frequent during the period of heavy rains, affecting children under 12 as well as adults. The few studies that have been done in this zone indicate that implementation of a water reservoir with an irrigation system may be followed by malaria epidemics (CNLP-press 1998).

Certain environmental modifications in these two zones can disturb the local transmission pattern of malaria. This can be caused by rivers or lakes and also by the construction of dams and irrigation systems. These may increase the availability of stagnant water and create breeding sites, and also lengthen the transmission period during the dry season. Other emerging factors may increase the health risk posed by malaria, such as rapid evolution of mosquitoes. Two molecular forms of *An. gambiae* (Mopti [M] and Savanna [S]) coexist in Burkina Faso and their distribution followed a clear geographical pattern: the M form dominated in the northernmost arid zones; the S form was generally most abundant in the moister southern regions. Larvae of the M form are more prevalent in larger man-made longer-lasting habitats, such as artificial lakes and rice fields, whereas the S form predominates in rain-dependent smaller ephemeral habitats, such as puddles and road ruts (Pombi 2004). A recent study (Costantini et al. 2009) has established that the two forms are currently evolving from reproductive isolation and, as a consequence, are ecologically diverging with a general increase of the spatial distribution of the vector. Artificially created water masses, such as small reservoirs, seem to contribute to the proliferation of new harmful vectors of malaria.

Small Reservoirs, Mosquitoes and Malaria

The knowledge on impact of water resources development on malaria is largely based on studies in the valleys of Kou (Brengues and Coz 1973; Carnevale and Robert 1987), Banzon (Koné 1992; Tia et al. 1992) and Bagré where the situation around large dams and irrigation systems was analyzed. Only few studies have addressed the impact of small reservoirs on the transmission of malaria. Teams of OCCGE and IRD (formerly ORSTOM) studied the area around Bobo-Dioulasso, where continuous transmission takes place. The CNRFP (formerly CNLP) conducted complementary studies on reservoirs in the Sahelian climatic zone. All studies conclude that the presence of more water surface offers better conditions to the proliferation of malaria vectors.

The presence of three small reservoirs around Ouagadougou strongly increased malaria risk during the rainy season. A resident living near the reservoirs receives on average three to four *Anopheles* bites per night during the rainy season against a single bite for those living in the city center. Parallel to the spatial decrease of mosquito density, the infection rate in children also decreases with increasing distance from the reservoir from 51 to 23%. Likewise, the parasite load of *Plasmodium falciparum* in the blood diminishes from 46 parasites/ml at 100 m to only 4/ml at 800-1,000 m from the reservoir (CNLP-press 1998). More recent studies have specifically addressed the urban setting. Wang et al. (2005) found that prevalence was high in schoolchildren (48%), influenced by the use of insecticide-treated bed nets and education (Baragatti et al. 2009). Breeding of anophelines increased towards the periphery of Ouagadougou and was associated with urban agriculture, rather than with the presence of the reservoirs as such (Wang et al. 2005). The case of Ouagadougou may be unique for West Africa in the sense that it combines large water surfaces and more mosquitoes with very high human density. This same situation of more mosquitoes leading to more malaria may not occur in rural areas.

Recent studies in the irrigated Kou Valley showed very high densities of vector mosquitoes, especially *Anopheles gambie* s.l. and *An. funestus*. People may receive up to 226 bites/ person/ night in the wet season, on average no less than 30,000 *An. gambiae* s.l. bites/year against 1,200-1,800 in areas without irrigation (Baldet et al. 2000). These observations confirm earlier studies in the same area (Carnevale and Robert 1987) and in other nearby irrigation systems (Koné 1992; Tia et al. 1992). In all these cases however, the increase in mosquito aggression was not followed

by increased malaria transmission; in fact, transmission in the irrigated areas is lower than in villages without irrigation. Similar findings have been reported from irrigated rice cultivation in the inland valleys of Côte d'Ivoire (Henry et al. 2003). A combination of factors seems to explain this paradox of more vectors and less transmission (see also Ijumba and Lindsay 2001): high mosquito densities may cause mortality of the vectors, hence many mosquitoes die before the *Plasmodium* cycle is completed; a strong local tendency of *Anopheles* towards zoophagy (feeding on animals) and the generalized use of protective bed nets by the wealthier rice growers. This complex interaction of several factors, including migration and human behavior, cannot be systematically extrapolated to small reservoirs.

Based on a few preliminary case studies of small reservoirs, the situation might be contrary to what has been observed in the large irrigation schemes in Kou and Banzon. An investigation among 366 households around the small reservoir of Yitenga in the southeast of Burkina Faso showed that malaria accounted for 80% of the reported diseases (Figure 8). The banks of this small reservoir with horticulture inside the town of Pouytenga offer perennial breeding sites to the vectors (Yonkeu 2002).
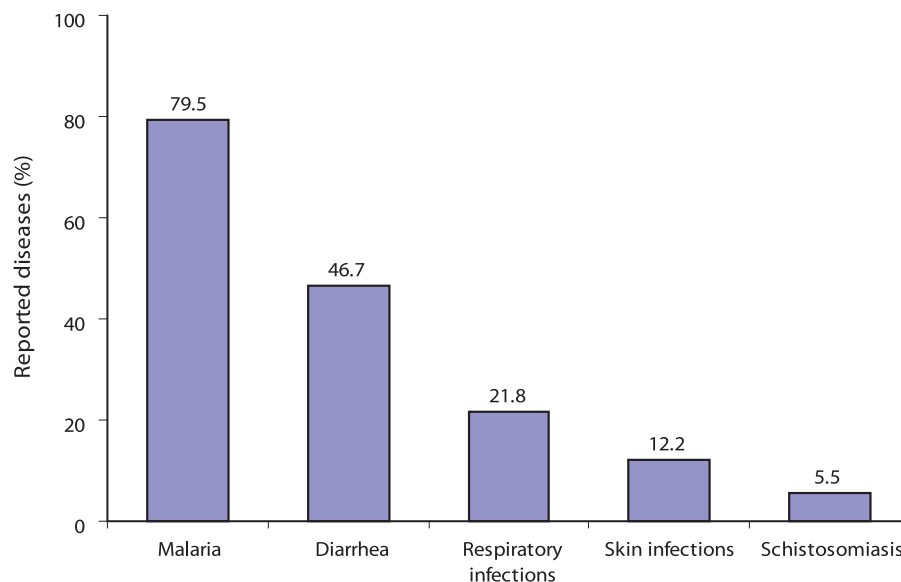
FIGURE 8. Main diseases (in percentages) reported in the town of Pouytenga near the small dam of Yitenga in southeast Burkina Faso (after Yonkeu 2002).

Contrary to the situation for schistosomiasis, the small reservoirs have an indirect impact on the transmission of malaria. The water reservoir itself provides very few breeding sites, and increased malaria transmission is mainly found around small dams with irrigation systems. The impact of such small irrigated areas could be important at the local level in the Bam Province where more than 500 ha around small reservoirs are irrigated, in the Gnagna Province, 225 ha in the Oubritenga Province and 517 ha in the Sanmentenga Province (Figure 9). As these provinces are located in the Sahelian zone of seasonal transmission, it is possible that the irrigation systems around the small reservoirs offer optimal conditions for the transmission of malaria throughout the year.
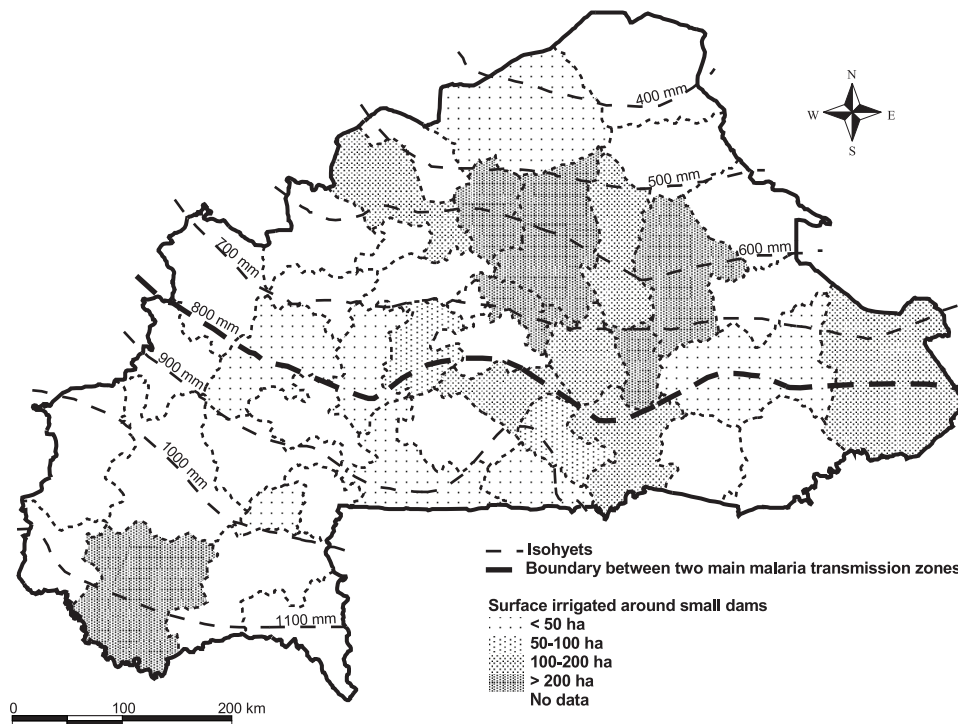
FIGURE 9. Total irrigated area around small dams at provincial levels and boundaries of main malaria transmission zones in Burkina Faso (Koné and Boelee, after DGIRH 2000b and IIMI 1997).

Other Vector-Borne Diseases

After schistosomiasis and malaria, the vector-borne diseases onchocerciasis (river blindness), trypanosomiasis (sleeping sickness) and lymphatic filariasis (of which elephantiasis can be a symptom) have the potential to be influenced by small reservoir development in Burkina Faso and maybe also Buruli ulcer, as reported in Côte d'Ivoire (Brou et al. 2006, 2008). Studies on these are rare. In one study the increased risk of onchocerciasis related to a small reservoir was discussed (Hervouët 1980, 1984): in Loumana in the southwest of Burkina Faso, the construction of a small dam on the Tiao River in 1956/57 completely modified the local epidemiologic situation of this disease. The area under rice cultivation increased from 600 to 1,600 ha, and the water levels in canals and hydraulic structures increased. The stagnant water in the reservoir and on the rice fields was rich in organic matter and created optimal breeding conditions in downstream streams (the vectors, *Simulium* black flies, need fast-flowing water). The population of this inland valley was previously infected at much lower levels and constituted a reservoir of the parasite. In 1962, a quarter of the 10-14 year olds was affected, more than half the number of the adults over 30 years had serious eye lesions and 22% were blind. In 1963, 60 to 70% of the population in nearby districts had cysts. Such a dramatic resurgence of onchocerciasis was never observed thereafter. Later, after the irrigated area was abandoned and structures degraded, only a third of the population was affected. In 1974, one out of 107 examined children was infected and the percentage of blind people had dropped (Hervouët 1980, 1984). The effectiveness of international control programs such as the Onchocerciasis Control Program (OCP) makes it possible today to minimize the risks of transmission of river blindness

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(Thylefors 2004). It is also very well possible that transmission of this disease is reduced by water resources development, especially when fast-flowing water in rivers and streams is replaced by slower-flowing water in canals and adapted structures.

The development of lymphatic filariasis may also be promoted by the presence of the small reservoirs (Hunter 1992; Erlanger et al. 2005). Since this disease can be transmitted by a variety of mosquitoes, an increase in different types of water bodies may offer optimal conditions for almost all vectors. While the infection is endemic in Africa, it especially poses a public health problem in Asia where two-thirds of the infected people are found. Around the small reservoirs of the Mossi high plains in Burkina Faso, high vector densities were found (Brengues and Coz 1973; Brengues 1975). Medication is effective and mass treatment campaigns have reduced prevalence as well as the density of microfilaria in the blood of infected individuals (WHO 2004).

Drinking from the Reservoirs and Waterborne Diseases

In rural areas where access to drinking water is difficult, small reservoirs constitute an important source of water supply to the population. Though more than 33,000 water points have been created in rural areas in recent years (Ministère de l'Eau 1991) access to drinking water remained a major concern for the rural population. In certain provinces, less than half the number of villages have safe water supply (Figure 10). In some areas where more than 90% of the villages have wells, they may dry out so fast that people still have to use water from the small reservoirs. More than half the number of children in Burkina Faso do not have access to drinking water and those who have cannot use more than 20 liters/person/day. Diarrheal diseases account for many deaths, approximately 350,000 children/year (Ministère de la Santé 1993). Around the large Bagré Dam
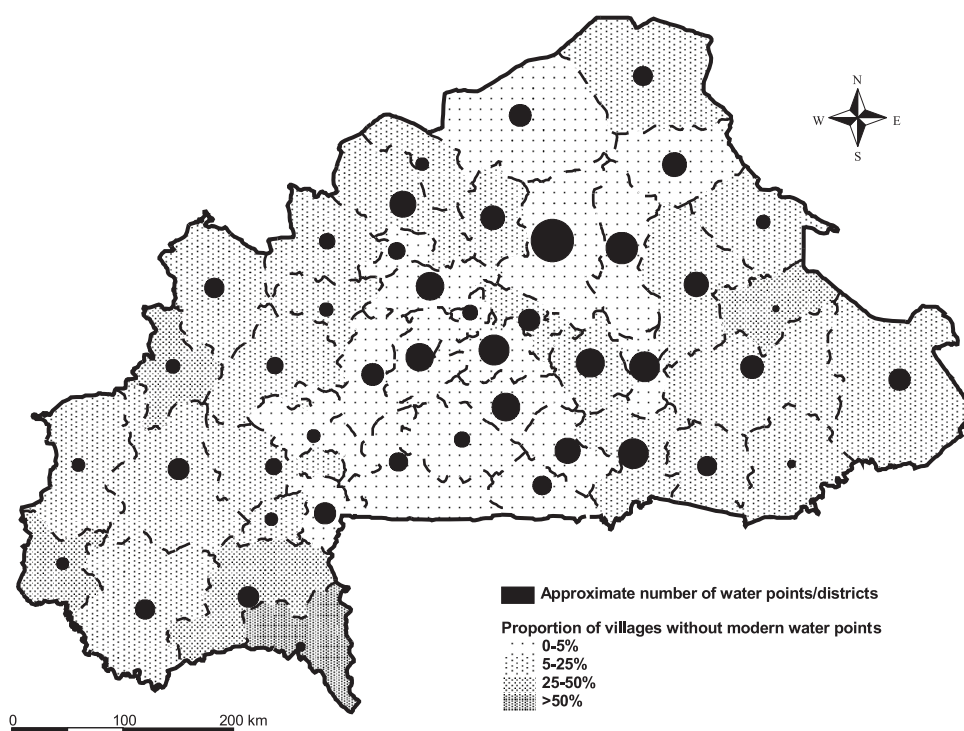

FIGURE 10. Access to drinking water in Burkina Faso (Koné and Boelee, after Ministère de l'Eau 1991).

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children living close to the water had five diarrhea episodes/year and babies between 6 and 18 months suffered even seven episodes. This is significantly (p<0.001) higher than further away from the water (Parent et al. 2002; Ouédraogo et al. 1998).

For small reservoirs we refer again to the study of Yonkeu (2002). Multiple use of the Yitenga Dam in southeastern Burkina Faso led to heavy pollution of the reservoir and surrounding wells. The high human pressure on the environment caused a degradation of the vegetable cover on the catchment area of the small reservoir. Subsequently, the water body became a reservoir for solid and human waste that entered with surface runoff. This level of pollution even harmed the fish population in the reservoir. The turbidity in both wells and the reservoir varied from 52 to 352 units of turbidity (NTU), well above the 5 NTU recommended by WHO for drinking water. Fecal coliform and streptococcal bacteria were present in all analyzed water samples, making the water from the reservoir unsuitable for consumption. Still the water is used for horticulture and for human consumption, leading to disease. More than half the surveyed population suffered from diarrhea or dysentery, making it the second disease after malaria in the town of Pouytenga (Figure 8) (Yonkeu 2002). In an urban environment, pollution of the small reservoirs was very important, especially during the dry season. Consuming raw vegetables constituted a risk of parasitic infections. Young children of the farmers had significantly higher infection rates for several parasites, such as ankylostomes and blastocysts (Cissé et al. 2002). Comparing the studies on large dams with the ones on small dams it appears that the small reservoirs have an unquestionable impact on the development of the diarrheal diseases in Burkina Faso.

Harmful cyanobacterial blooms correspond to the proliferations among the phytoplankton of one or a small number of cyanobacteria species. Permanent cyanobacterial prevalence is regarded as the ultimate phase of eutrophication. This may occur worldwide but, until recently, cyanobacteria have never been explicitly focused on in Burkina Faso (Zongo and Guinko 1999). In June 2003, a toxic cyanobacterial bloom was reported, involving both *Microcystis* and *Oscillatoria* taxa in one of the reservoirs for drinking water supply near Ouagadougou (Cecchi et al. 2004). Planktonic cyanobacteria were further sampled during 2003 in 23 lakes and reservoirs, belonging to the six main subbasins of the country, in order to describe their diversity and to evaluate the associated potential toxicity. Cyanobacteria were identified in all stations except one and were almost exclusive (> 95% of the biomass) in a third of them (Cecchi et al. 2009c). Among the 65 taxa identified, five are known to be potentially toxic. These species have been identified in 19 sites, highlighting the potential threat of their eventual proliferations (Cecchi et al. in prep). Both human and animal populations using surface water from the reservoir for drinking are threatened by this hazard, but the growth of irrigated crops around and downstream of the reservoirs may also be directly impacted, e.g., rice (Chen et al. 2004) or vegetables (McElhiney et al. 2001). Indirectly, the consumption of crops sprayed with water containing significant amounts of cyanotoxins (e.g., in salads) may also affect the health of consumers (Codd et al. 1999b).

Nutritional Impacts

Agriculture in Burkina Faso depends strongly on the climate that does not allow the production of sufficient food for an active and healthy life. The low agricultural productivity is thus a major cause of a precarious nutritional situation that may be locally very serious and deteriorating. Water resources development is considered as a local and national opportunity to increase agricultural production, particularly in the dry season.

The main objective of the earlier-mentioned program for small village irrigation is to reduce food insecurity in the rural areas. The small dams with irrigation systems should make it possible for the producers to increase their income and diversify nutrition. A recent FAO study on the impact of three small irrigation projects on the health and well-being of the population in Burkina, Mali and Tanzania showed that small reservoirs and wells enabled the people to better face the dry periods, to diversify their food intake and to consult health services when needed. The three projects increased production, transformation and preparation of a wide range of indigenous food, supported by education on nutrition and the participation of women's groups (FAO 2001). On the other hand, irrigation systems may also be accompanied by new constraints, such as social and economic reorganizations, and increased workload, especially for women, which will have an impact on the nutritional and health state of the children, as was reported in Côte d'Ivoire (De Plaen et al. 2003).

In Burkina Faso, very few studies have been done on the nutritional impacts of small reservoirs, but some assumptions can be formulated based on investigations at the large systems at Bagré and Sourou. About half the number of children had some form of malnutrition and 90% of them were anaemic. This made them more vulnerable to disease, while exposure to malaria and diarrhea, in turn, reduced their health. The thinness of the children was related to their parents' activities, especially to horticulture, which is practiced primarily by women. In the area of onion cultivation around the Bagré Dam, a woman can rest 2 hours less than those in other villages (Ouédraogo et al. 1998). A similar situation has been described for intra-urban horticulture in Ouagadougou, highlighting the poor health status of children whose parents are involved in this activity (Cissé 1999; Cissé et al. 2002). In the absence of better targeted studies, these findings on horticulture in large irrigation schemes might be extrapolated to small reservoirs since this is the main form of agriculture around these reservoirs.

Studies recently conducted in Gnagna Province, a rural area located in the northeast part of Sahelian Burkina Faso, have specifically highlighted the importance of fresh fish for the nutritional status of women at the end of the rainy season (Savy et al. 2006). This period corresponds to a seasonal food shortage between the depletion of the annual cereal stocks and the next harvest, when agricultural work is intense and seasonal endemic diseases are at their peak, in particular malaria. All these conditions contribute to the impoverished nutritional state of people, regardless of their socioeconomic status. At this time of year, fresh fish, owing to its low cost and local availability, constitutes a significant resource for low-income households, and alleviates the nutritional impact of the shortage season. It is most probable that the fish provided by small reservoirs, although rarely documented (Béné and Russell 2007), is an important component of the diets of many rural poor living near small reservoirs. Our own calculations demonstrate that fish production from these reservoirs can be significant. An estimated 1,000 km^2 of surface water in Burkina Faso in 2002 (Cecchi et al. 2009b), at a minimal production of 50-75 kg/ha (FAO 2009; Villanueva et al. 2006), would together yield 5,280 tons annually, involving 2,000 to 5,000 fishermen. At a low price of 250 FCFA/kg ($0.33/kg), this corresponds to an annual market of FCFA 1.3 billion ($1.7 million). Hence, the scattering of reservoirs contributes considerably to the food security and livelihoods of many Burkinabe.

MANAGING THE THREATS: OPTIONS FOR DISEASE REDUCTION

Schistosomiasis Control

Environmental approaches to schistosomiasis control have the triple aim to eliminate the snail population in the water bodies, prevent (re)infection of people and limit contamination of the water by infected urine or feces.

The ecology of the intermediate host snails of schistosomiasis has been extensively studied in sub-Saharan Africa and many control options are now available (Boelee and Madsen 2006). Here only the control measures that could be applied to small reservoirs will be discussed. Removal of aquatic vegetation from the banks of the reservoir, and from canals and drains, will deprive the snails of food, shelter and refuge from strong currents, and has been proven successful in a comparable situation (Slootweg and Keyzer 1993; Boelee and Laamrani 2004). In Burkina Faso, many of the small reservoirs are shallow and hectares of wooded savanna and forest were covered by a few meters of water. As a result, many trees and bushes can be seen sticking out of the water and may provide an excellent substratum for algae that the snails feed on. Some of the aquatic vegetation in the lake, canals or fields is used for animal feed or local medicine, such as *Palpalum sp., Loudetia togoensis*, *Crotalaria sp*., *Dracaria sp*., *Physalis angulata*, *Aspilia sp*., and *Euphoria hirta* (Yonkeu 2002). Here the local population may not be prepared to clean the aquatic vegetation. For new small dams and related irrigation systems, the design should include positive experiences from other parts of the world, such as free draining structures (Chimbari et al. 1991) and canals that can be dried or flushed (Pike 1987). However, good environmental and water management is equally important to keep the reservoir and irrigated area free of intermediate hosts of schistosomiasis.

The small reservoirs are often used as places for bathing, exposing people to infective *Schistosoma* cercariae. The use of soap will make the bathing safer as most soap is toxic to the larvae. The soap will remain effective in the water for a while after the bath and may thus play an important role in reducing the transmission of schistosomiasis (Combes et al. 1983). However, some regulation or management of the way people come in contact with water, and thus cercariae, may be better to reduce both risks of contamination of people and recontamination of water masses (Woolhouse et al. 1997). This can be done by measures such as ensuring that popular water use points are free of vegetation to reduce the presence of snails locally and thus diminish the transmission risk.

An effective use of sanitary facilities will prevent the inflow of infected urine and feces and thus prevent contamination of the water. This is not always feasible, as even when the facilities are there, they are not always correctly used by high-risk groups such as children. Medication will reduce the worm load in people and hence the amount of schistosome eggs they can excrete into the aquatic environment. For schistosomiasis, effective drugs such as praziquantel are available. This approach is central in all schistosomiasis-control programs and promoted by WHO, to reduce morbidity (disease symptoms) and to break the transmission cycle (Engels 2000, WHO Expert Committee 2002). In areas of very high schistosomiasis endemics, mass treatment can be applied. In Burkina Faso, this led to important reductions in the urinary egg count of *S. haematobium*: 69% in children a year after treatment and 38%, 2 years later. In adults this reduction was higher (respectively 90% and 87%), indicating a high rate of reinfection among children (Sellin et al. 1984). This health care approach has its limitations in Burkina Faso as, in the rural areas, only 10 to 14% of all patients consult the modern health services (MS/CRDI 2000). Moreover, the symptoms of schistosomiasis are not perceived by most people as serious enough to seek medical care (Poda

et al. 2003a), e.g., in areas where urinary schistosomiasis has been endemic for a long time, bloody urine was considered as "menses" of young boys, a necessary step towards adulthood. Therefore, in Burkina Faso as in most African countries special so-called vertical control programs, usually very well equipped against diseases such as schistosomiasis, are much more effective in reaching the population.

Special attention is needed for areas with considerable migration, especially if people come from endemic areas and settle in a high-risk area with many potential breeding sites. An interesting experience in this respect comes from Mali, where fishermen came to settle around the newly constructed (large) reservoir of Sélingué. The formal authorization for settling and fishing was delivered only after a systematical diagnosis and treatment of all schistosomiasis-positive people, to minimize the contamination of snails by infected urine or feces (Traoré 1989).

Still, environmental sanitation, especially the management of human waste is a crucial element in the fight against many water-related diseases. Since it is impossible to prevent all water contact and subsequent "accidents" in a hot climate, health education could focus on the proper use of latrines and encourage people to relieve themselves in a safe place before they enter the water.

Schistosomiasis often coexists with other neglected tropical diseases, such as lymphatic filariasis and soil-transmitted helminthiasis, in the same eco-epidemiological settings. There is an increasing tendency to better coordinate some of the large-scale helminthic control programs (Lammie et al. 2006). An example is the national schistosomiasis and soil-transmitted helminthiasis control program (Programme National de Lutte contre la Schistosomiase et les Vers Intestinaux, PNLSc) that was set up by the Ministry of Health in June 2002 to coordinate control activities against these infectious diseases in Burkina Faso. A large majority (90.8%) of the estimated school-age population in the country has hence been treated with prazinquantel in two periods (October 2004 and October 2005) during a combined school- and community-based drug distribution strategy (Gabrielli et al. 2006).

Malaria Control

Today, the most common strategies to control malaria are the use of impregnated bed nets and early case detection and treatment, with special attention to pregnant women and children. The objective of the bed nets is to reduce, at household level, the contact between vectors and people during the main biting period of *Anopheles*. In addition, the impregnated nets may have a knockdown effect on the mosquito population. In the rice areas of Burkina Faso, the use of nets and curtains impregnated with permethrin decreased the indoor resting density of *An. gambiae* by 99.5% and the number of indoor bites by 83% during 2 years (Pietra et al. 1991). The use of impregnated nets and curtains also has effects on the transmission of malaria at a larger scale. In a 1,000 km^2 area the use of impregnated curtains in 158 villages reduced the biting rate from 218 to 11 bites/person/month (Cuzin-Ouattara et al. 1999; Diallo et al. 1999; Habluetzel et al. 1999). In the Kou Valley the number of infective bites/person/year dropped by 94% after the introduction of bed nets impregnated with deltamethrin (Robert and Carnevale 1991). The nets seem to act against other diseases as well, and Habluetzel et al. (1999) found that they reduced overall child mortality by 15%.

However, the excessive use of insecticides by commercial farmers in some cases led to the emergence of resistance in the vectors. In the rice village of Kafiné, 150 km north of Bouaké in Côte d'Ivoire, the use of impregnated mosquito nets did not reduce the number of bites. This failure was due to the resistance of *An. gambiae* to the used permethrin (Doannio et al. 1999). In this area, more than 20% of the female *An. gambiae*, which make out 92% of the captures

(Dossou-Yovo et al. 1994), survive traditional concentrations of permethrin. Mortality reaches 95% with deltamethrin and lambdacyalothrin, but there is a significant reduction of the knockdown effect (Elissa et al. 1994). The intensive use of insecticides in agriculture, particularly in rice and cotton, appears to be the cause of this resistance. Reports of resistance in the mosquito vector populations in Burkina Faso appeared as early as the 1960s, when *An. funestus* and *An. gambiae* s.l. populations showed resistance to dieldrin and DDT (Hamon et al. 1968a, b). More recent studies have confirmed that resistance to DDT is still prevalent in *An. gambiae* s.l. populations in Burkina Faso, and there is even resistance to certain pyrethroids (Diabaté et al. 2002; Dabiré et al., 2008, 2009). These studies clearly established that agricultural use of insecticides increases resistance in field populations of mosquitoes: *An. gambiae* s.l. was resistant to permethrin and DDT in cotton-growing and urban areas, but susceptible in areas with limited insecticide use (rice fields and control areas).

Another problem with the use of impregnated bed nets and curtains is their low uptake. In the southwest of Burkina Faso only 20% of the distributed impregnated bed nets were found a year later and many of the nets in this rice zone were of very poor quality (Carnevale and Robert 1987). This can partly be explained by the lack of awareness in the communities of the relation between mosquito bites and malaria. For example, in the Banzon Plain the consumption of fruit was regarded as the principal cause of malaria. However, the nuisance caused by high mosquito densities and the high biting rate of 167 bites/person/night led to a generalized use of mosquito nets. Behavior change is crucial if the nets are to be effective. The impregnated bed nets as a main strategy for malaria control only work when people are under the nets during the hours when the *Anopheles* mosquitoes are most active. A study in Burkina Faso showed that the vectors were most active just before midnight, when 39% of the rural population was outside, far from their nets (Procacci et al. 1991).

Though treatment is readily available in Burkina Faso, not all will seek this. A longitudinal follow-up in a rural area of 709 children of 6 to 31 months of age during 6 months in 2003 revealed that 69% of the confirmed sick children were treated at home, 16% at the local health center, 13% at the village and 1% at the hospital. The choice for a certain type of treatment was determined by the accessibility of the medical facilities and severity of the disease (Müller et al. 2003). Other studies showed that in Burkina Faso only 3% of malaria cases are effectively dealt with in the rural communities and 21% of the cases are taken to a health facility (Krauze and Sauerborn 2000). Even in urban conditions, sociocultural beliefs influence behavior in critical situations (Koueta et al. 2007). Another problem is the worldwide ever-increasing resistance of parasites against drugs, which has been registered for a long time in Burkina Faso too, as a supplementary difficulty (Ouedraogo et al. 1991).

Corrective and Preventive Action at Small Reservoirs

The development of water-related diseases around small reservoirs and their sometimes dramatic impact on the neighboring communities are not inevitable. Achievements in biomedical research and disease control allow for a restriction of many of the diseases. The application however is faced with many difficulties resulting from the inadequate health system and the low level of awareness in the populations at risk. In West Africa, primary health care facilities that are closest to the rural population are fixed structures focused on curative care. Field visits are generally only carried out as part of large programs such as vaccination campaigns. Access to health facilities is limited to the population physically as well as financially. Even when these constraints are minimized,

actual consultation of the medical facilities is determined by a range of other factors such as social representation of the disease, the perception of its causes, which may be mystical or religious and its gravity. The fight against water-related diseases around small reservoirs requires two essential actions: health education and integrated management of the infrastructure.

Health Education

Health and hygiene education could play a major role in the fight against water-related diseases. Most of the small reservoirs constitute a new ecosystem the beneficiaries are not used to. After 20 years of using small reservoirs for bathing, laundry and agriculture, the knowledge of water-related diseases has not really improved in Burkina Faso. Public awareness campaigns are necessary everywhere to explain to the communities the possible impacts of dams and irrigation system on their health. This should be the first step before even the promotion of preventive and curative measures against the water-related diseases, as the current level of awareness of these diseases and their cycles is very low in Burkina Faso. For instance, regarding diarrhea, accounting for 57% of the health problems in children under five, only 13% of the mothers knew what caused diarrhea and what rehydration therapy is (Duboz and Vaugelade 1987; Duboz et al. 1988; UNICEF 1988). This average rate hides enormous differences in the rural areas, where the rate of illiteracy reaches 89% in women and 79% in men. With such an educational level, the links between the water reservoirs and the development of water-related diseases are not easily understood. General education is a prerequisite for health education to be effective.

More important for the success of health education however, is the availability of alternatives. Improved water supply and sanitation facilities can contribute significantly to improved health (Esrey and Habicht 1986; Esrey et al. 1991). In the western part of Niger with high infection rates of urinary schistosomiasis, there is a comprehensive health education campaign aimed at changing the behavior of the population at risk. Despite the use of video, public discussions and school programs, more than half the population kept on using the transmission sites, as these were the only sources of water for domestic needs (Garba et al. 2001).

Integrated Management of Small Reservoirs

The reduction of negative impacts of the small reservoirs on the environment and public health cannot be addressed in a sectoral way. The evaluation of the health impacts of water reservoirs should not be limited to research on the ecology of mosquitoes and snails, or to the measurement of disease incidence in the population. Health impact assessments should specifically identify the enhancing and limiting factors connected to the transmission of water-related diseases in the new reservoir environment (Birley 1991, 1995). From a good knowledge of the risk factors, an effective control program can be initiated that fits in with the regional strategies for poverty eradication and sustainable development. It is only by dealing with the health impacts that the increased incomes generated by the small reservoirs really lead to improvements in the well-being of the rural population. Such an approach must be applied at two levels.

At the national level, the implementation of small reservoirs must be included in the regional development plan to ensure an equal spread of interventions over space and avoid high pressure of people and animals around some rare water points. In the planning process, potential spontaneous migration to the new perennial water reservoirs should be taken into account and appropriate

accommodating measures implemented. Especially when the rest of the district remains under-equipped, there is a risk of increased transmission of schistosomiasis. Preventive measures could consist of treating people (and cattle) for this disease before they enter the newly equipped area, rather than treating infected children alone. The success of mitigating the unwanted health impacts of small reservoir development, such as water-related diseases, depends to a large extent on an effective public health system. In West Africa, the current – fixed – health facilities are not sufficient to address the important endemics of schistosomiasis, malaria and diarrhea. Mobile teams may fulfill this task much more effectively and therefore be more cost-efficient as well.

At the local level, a bottom-up community health system will allow a good application and uptake of disease control strategies. Such a structure would also promote the construction and effective use of sanitary facilities, and the use of soap with strong larvicidal potential. In collaboration with other community groups, such as the water committees organized around domestic water supply points, farmer groups, women's groups and especially (agricultural) water user associations, recurrent environmental activities can be planned, such as clearing the reservoirs banks of vegetation and solid waste removal. Hence, the community can take the maintenance of a clean and healthy environment in their own hands and thereby improve their health and well-being. Institutional support for this is imperative, whether from various government line agencies or from NGOs.

Many water-related diseases can be prevented by safe water use. The selection of the source (e.g., wells, rivers, various points along a reservoir) is important as the water quality varies over time and place. Drinking untreated surface water is potentially hazardous, and risks increase as reservoir use intensifies. Where drinking water is sourced from small reservoirs undergoing intensification, alternative sources of drinking water should be sought. One of the Millennium Development Goals proposes to halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation. Substantial financial and human resources have been mobilized in several countries to reach this goal. Some of these can be used for water resources development. Ideally, drinking water supplies should be separated from those used for other purposes. Water in reservoirs typically has numerous uses that conflict with the storage of quality drinking water. In particular, pollution from pesticides and cyanotoxins is not easily remedied. Where small reservoirs have already been built, access to water can sometimes be improved by diversifying the community's water sources. Areas around reservoirs can be "zoned" for different activities, such as livestock watering, washing clothes or brick-making that can be a profitable activity in some areas (Senzanje et al. 2008). Vegetative cover can act as a buffer to influxes of pollutants into reservoirs, for which reason maintenance of vegetation along reservoir shores is highly recommended (Atwill et al. 2002). Wells or boreholes can be constructed downstream of the dam. Because of horizontal filtration, seepage water into these wells may be of generally higher quality than water in the reservoir and would be suitable for drinking and cooking. In favorable circumstances, rainwater harvesting can be used at the community (watershed) or individual household level.

However, even if the water is clean at the source, how it is stocked and used at home may considerably influence its quality: microbial contaminations during collection, transport and home storage have been documented extensively (e.g., Esrey et al. 1985; Robidoux et al. 1998a, b; Ghedin et al. 1993; Jensen et al. 2002; Clasen and Bastable 2003; Wright et al. 2004). Household water treatment is increasingly recognized as an effective means of reducing the burden of diarrheal disease among low-income populations without access to safe water (Mintz et al. 1995; Quick et al. 1999, 2002; Clasen and Cairncross 2004; Clasen et al. 2005; Devi et al. 2008).

CONCLUSION

The fight against poverty in West Africa depends on making available sufficient quantities of water to the population, both to satisfy their domestic needs and to make it possible to increase agricultural production through irrigation. The creation of small reservoirs in (semi) arid areas is part of this strategy. The studies we discussed on impacts of small reservoirs in Burkina Faso have highlighted the importance of these reservoirs for increasing food security and household income through fisheries and productive agricultural activities upstream and downstream of the dam. However, no preventive measures have thus far been taken to ensure that the small reservoirs do not further degrade rural public health. While most prevalent water-related diseases that affect the population near the reservoirs, mainly schistosomiasis and malaria, are sufficiently known and control measures are available, these are hardly applied in planning, design and management of the small reservoirs. This is even truer for the widespread prevalence of diarrhea, which can have multiple causes and is associated with poor hygiene. More research is needed on the role of human migration in spreading water-related diseases to new areas and in bringing uninfected groups near small reservoirs that provide attractive areas as well as health risks at the same time because of the more or less permanent presence of surface water.

The situation described in Burkina Faso is not specific. Most of the sanitary and health questions related to planning, presence and multiple uses of small reservoirs are shared by other tropical countries in development. There is an ongoing process of expanding the multidisciplinary knowledge of small reservoirs, and cross-comparisons between situations are expected to improve the efficiency of remediation strategies (Andreini et al. 2009). The documentation presented here aims at contributing to the sharing of experiences. Practical tools have now been developed for participatory health impact assessment of small reservoirs, which will help communities to develop their own preventive and mitigating measures (Boelee and Laamrani 2009).

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