The Behavioral Determinants of Intestinal Schistosomiasis Transmission: Water Contact, Hygienic Practices and Risk Prevention. A study in Northern Senegal

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Content

Chapter 1

General introduction

1.1 Schistosomiasis

Schistosomiasis (bilharzia) is one of the major parasitic diseases in the world, ranking second only to malaria in terms of its socio-economic and public health importance in tropical and subtropical areas (WHO, 1985; WHO, 2002). At least 200 million people are infected and 600 million at risk. An estimated 85% of all cases occur in Africa. Schistosomiasis is caused by infection with blood-dwelling fluke worms (trematodes) of the genus *Schistosoma*. These are transmitted by fresh water snails and contracted through the skin during water contact. Humans can be infected by five different species of the parasite, each of which has its own characteristics and effects. Except where mentioned differently, this thesis considers *S. mansoni,* the parasite of intestinal schistosomiasis in Northern Senegal.

Epidemiology

In a given locality, schistosome transmission dynamics depend upon both macro-ecological effects of topography, hydrology, water quality, settlement patterns, agriculture, sanitation, human behavior, and the micro-ecological factors of host parasites relationships in man and in the snail. The total system is complex, and many gaps in scientific understanding remain. For successful transmission, man must live near bodies of surface water that have characteristics (e.g. temperature, chemistry, pH, plant life, velocity) necessary to support the appropriate species of snails. For transmission from man to snail to take place, fresh human excreta or urine must reach these bodies of water where snail colonies are living. For transmission from snail to men to operate, there must be a pattern of behavior in the community that causes people to regularly enter surface waters that harbor the snails and have been polluted by excreta. Numerous animals have been identified to carry the same schistosome species that infect humans. These so-called ‘animal reservoirs’ can add to the contamination of snail habitats with schistosome eggs. However, their importance in the transmission among human populations is considered to be negligible for *S. mansoni* (Mansour, 1973; Sène *et al*. 1996; Duplantier & Sène, 2000).

An important aspect of schistosomiasis transmission is the presence of snail hosts. The proportion of snails infected with schistosomes depends upon several factors including the distribution and behavior of the human hosts, the relative susceptibility to infection of a particular snail host and climatic factors such as temperature and rainfall. In Africa, it is common for schistosomiasis transmission to take place in ponds and waterholes in the wet season. This process reaches a peak as water bodies shrink and human water contacts become focal in the early dry season, but ceasing later when the ponds dry up. As a result, the snails aestivate in the mud and wait for the next rains (Vercryusse *et al*. 1985; Southgate *et al*. 2001). Focal transmission occurs if it is associated with specific streams or ponds that are polluted by excreta, which support the correct snails species, and which are visited by people for working, domestic or leisure activities. The identification of these sites is essential for the design of control measures aiming at preventing transmission.

The parasite and its life cycle

Schistosomes have a complex life cycle, in which cercariae, free-living larvae, in fresh water can penetrate healthy human skin. After penetration, the head of the cercaria transforms into an endoparasitic larvae, the schistosomula. Schistosomulae pass several days in the skin, enter the venous circulation and eventually migrate to the lungs (generally within 5 to 7 days after penetration). They then travel through the circulatory system to the hepatic-portal circulation (after fifteen days) where they mature into adult worms and mate. Depending on the species, the schistosomes migrate to their final infection site on either the bladder or the intestine where the females begin egg production. These eggs are attached to the wall of the lumen and eventually penetrate it. They are then expelled in the urine or feces. The miracidium, liberated from an egg, searches for a snail host. After entering the snail it develops into a sporocyst stage that eventually results in free-living cercariae that search for human hosts that are in contact with water.

Five species have been identified as the causative agents of human schistosomiasis: *S. mansoni* (Africa and South America), *S. haematobium* (Africa and the Middle East), *S. intercalatum* (Africa), *S. japonicum* (Far East, South East Asia, The Philippines), and *S. mekongi* (Laos, Kampuchea and South Thailand). The species differ, among others, in geographic locations, snail hosts, patterns of egg-laying, disease patterns, and responses to treatment. Figure 1.1 illustrates the life cycle of *S. mansoni*, the parasite causing intestinal schistosomiasis in Africa (including Senegal), and the other two main species most important in causing disease in men: *S. haematobium* and *S. japonicum*.

As for all *Schistosoma* species, the adult female *S. mansoni* worm is held in the gynaecophoric canal of the male. The paired worms are normally found in the mesenteric veins and may live up to 20-30 years, with a mean life span of 3-8 years (Jordan & Webbe, 1982). Each worm pair produces 100-300 eggs per day (WHO, 1985). The yellowish eggs are non-operculate and have a lateral spine. The miracidium develops inside the egg over a period of 6 days. Eggs passing through the intestinal wall contain an embryo, which is usually visible, mobile and ready to hatch when passed in feces. Not all the eggs laid are successful in achieving this passage; some are carried away with the venous blood and become lodged in the liver or other organs where they can survive for 11-12 days, before transforming to granulomas, which are the basis of the advanced pathology.

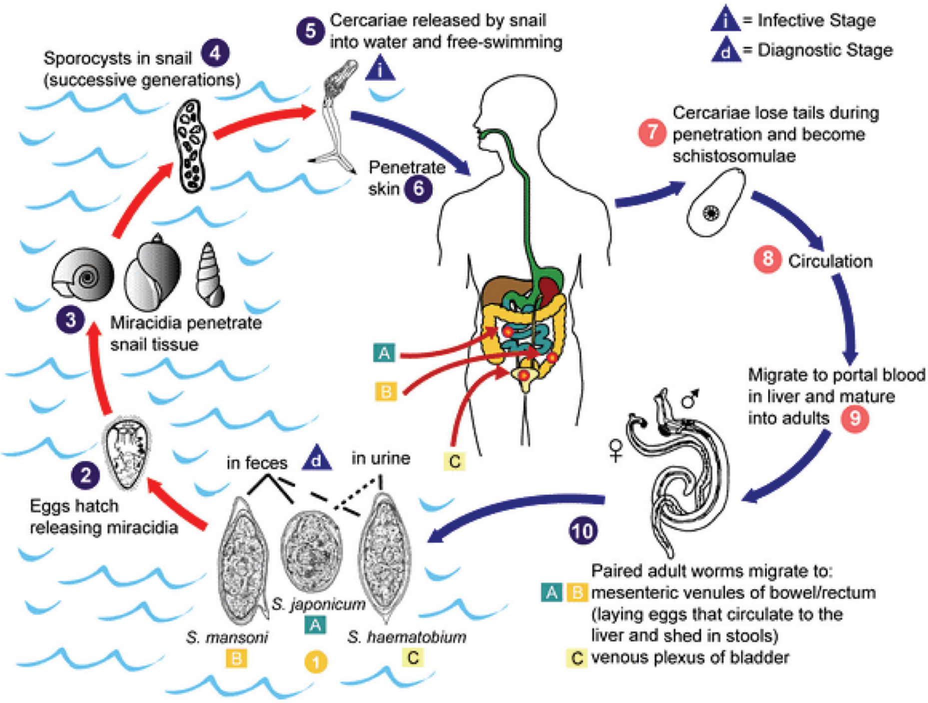

Figure 1.1 Human schistosomiasis life cycle. Source: CDC (www.cdc.gov).

S. mansoni eggs that are passed in the feces hatch if they come into contact with fresh water and the process is simulated by warmth and light. Once free, the miracidium swims actively to the snail host (i.e. *Biomphalaria* for *S. mansoni* in Senegal). Miracidia respond positively to stimulus of light and are negatively geotropic. There is evidence that the ecology of miracidia is related to the ecology of their host (Webbe, 1962; Prentice *et al*. 1970). Miracidia remain infective to their snail intermediate host some 8 to 12 hours, swimming randomly in long sweeping lines (Chernin, 1974). The mechanisms by which the snail host *Biomphalaria* is located by *S. mansoni* miracidia are still unclear.

A single miracidium will result in the development of thousands of cercariae, all of the same sex. It takes 3-5 weeks from the time of miracidial penetration to the time of production of mature cercariae, the actual period depending upon environmental temperature (Anderson & May, 1979). Mature cercariae emerge from snails when stimulated by light and usually at a temperature between 10°C and 30°C. The number of cercariae produced by *Biomphalaria* is on average 500 per day and rarely exceeds 1500 per day (Sturrock, 1989; Sturrock & Sturrock, 1970; Klumpp & Chu, 1987). Snails can continue producing cercariae for several months. Cercariae of *S. mansoni* can survive while swimming in water for up to 48 hours. From the knowledge of the life cycle, it can be seen that measures directed towards control of schistosomiasis transmission will have to take into account the human definitive host and any reservoirs, the snail intermediate host and the parasite specifically in relation to its eggs, miracidia and cercariae. These facets are discussed in Chapter 1.3.

Schistosomiasis mansoni pathology and morbidity

The percutanous penetration of cercariae can provoke a temporary rash that sometimes persists for days as papulo-pruriginous lesions, especially after primary infections. A similar so-called *swimmers' itch* is frequently caused by cercariae of animal trematodes in temperate climate zones. This acute schistosomiasis (Katayama fever) is a systemic hypersensitivity reaction against the migrating schistosomulae, occurring a few weeks to months after a primary infection (Liang *et al*. 2006; Farrell, 1996; Kurtis *et al*. 2006). The disease starts suddenly with fever, fatigue, myalgia, malaise, non-productive cough, eosinophilia, and patchy infiltrates on chest radiography. Abdominal symptoms can develop later, caused by the migration and positioning of the mature worms. Most patients recover spontaneously after 2–10 weeks, but some develop persistent and more serious disease with weight loss, dyspnoea, diarrhea, diffuse abdominal pain, toxaemia, hepato-splenomegaly and widespread rash (Kager & Schipper, 2001; Schwartz *et al*. 2000). Katayama fever due to *S. mansoni* is rarely seen in chronically exposed populations, possibly owing to under-diagnosis or in-utero sensitization. It is common, however, in tourists, travelers, and other people accidentally exposed to transmission. Most cases in western travel clinics are imported from sub-Saharan Africa, many in family or group clusters (De Clercq *et al*. 1995; Ndamukong *et al*. 2001).

The amount of disease in the *S. mansoni* infected individuals is generally related to the amount of eggs present in the tissues, i.e. it depends on the intensity and the duration of the infection (Gryseels, 1992; Van der Werf *et al*. 2002a). In endemic areas, it is generally observed that a high prevalence of heavy infection in the community gives rise to significant health problems, whereas in low endemic areas, the public health importance of intestinal schistosomiasis is limited (Sukwa *et al*. 1986; Urbani *et al*. 1997; WHO, 2002). In communities with heavy infections, bloody diarrhea is frequently reported to be a consequence of *S. mansoni* infection, and in severe cases, intestinal bleeding may cause anemia. In areas of heavy transmission, a high frequency of hepatomegaly (liver enlargement) and splenomegaly (spleen enlargement) may occur, and in children, the severity of hepato- and splenomegaly is usually related to heavy infections (Gryseels & Polderman, 1987; Firmo *et al*. 1996; Ouma *et al*. 2001; Zaki *et al*. 2003; Kabatereine *et al*. 2004). Intestinal involvement is more important in terms of public health implication, but hepatosplenic complications constitute the most serious risks of fatal effects.

Geographical distribution

Probably, both *S. mansoni* and *S. haematobium* may have originated from somewhere in Africa (Nelson *et al*. 1962). The earliest record of schistosomiasis in Africa dates back to about 1000 BC, based on the detection of calcified schistosome eggs in Egyptian mummies (Chastel, 2004).

An estimate 170 million in Africa are infected either with *S. mansoni* or *S. haematobium*, which are endemic in most countries of Africa. The distribution of *S. haematobium* is confined to Africa and some adjacent regions, extending through Arabia to Iran and to the Indian Ocean islands of Madagascar and Mauritius. *S. mansoni* is widespread in Africa and can be found in some parts of South America and the Eastern Mediterranean (Brooker *et al*. 2000; Chitsulo *et al*. 2000).

Two factors that can cause changes in geographical spread are:

- Agricultural development programs such as large-scale irrigation projects may increase the snail population, the geographic migration of the snail host, and the contact of humans with water. For example, the construction of a dam in Egypt brought schistosomiasis into previously unaffected areas (Waddy, 1975). Steinmann *et al*. (2006) present a comprehensive review of the impact of water resources development and management on human schistosomiasis.
- Economic development and mobility of population groups may create another important risk for rapid increase of the disease. When infected individuals travel to unaffected places (e.g. after intensive control) where snail hosts are (still) present, the region immediately becomes highly vulnerable to the return of the infection (Jobin, 1999; Abdel-Wahab *et al*. 2000). Mobility of human populations (rather than the mobility of snails) is suggested to be the most important threat to the geographic containment of the disease (Boisier *et al*. 1995; Nooman *et al*. 2000).

1.2 Human behavior and water-related diseases transmission

Water-related diseases can be classified into four major (though not mutually exclusive) categories, based on the mode of transmission (Bradley, 1970): (1) water-borne diseases, caused by consumption of contaminated water; (2) water-washed diseases, caused by the use of inadequate personal hygiene; (3) water-based diseases, where an intermediate aquatic host is required; and (4) water-related vector/vector-borne diseases, spread through insect vectors associated with water.

Most of the diseases within the first two groups (water-borne and water-washed diseases) fall under the so-called fecal-oral diseases, whereby a lack of hygiene, particularly of hands and food, allows the transmission from infected individuals (sick people or carriers) to uninfected individuals (Cairncross & Feachem, 1993). Examples are cholera and hepatitis A. Typical examples of water-based diseases are schistosomiasis and dracunculiasis (Guinea worm disease), with a fresh water snail and a water flea (cyclops) as intermediate aquatic hosts, respectively. The most well-known water-related vector-borne disease is malaria, transmitted by the *Anopheles* mosquito. Other examples are dengue and onchocerciasis (river blindness).

Here, we focus on schistosomiasis, which is transmitted by human contact with infested water (washing clothes, bathing, etc.) and contamination of water with human excreta, and as such intrinsically related to human behavior.

Patterns of exposure to schistosome infection

Several studies have been carried out to determine water contact patterns (Dalton & Pole, 1978; Kloos *et al*. 1983; Kvalsvig & Schutte, 1986; Lima E Costa *et al*. 1998; Klumpp & Webbe, 1987; Scott *et al*. 2003; Adewunmi, 1991; Sturrock *et al*. 2001; Théron & Coustau, 2005). Studies of human water contact patterns conducted in schistosomiasis endemic communities have different goals. One goal is to identify which groups (e.g. based on age, gender, occupation, etc.) are most at risk of exposure to infectious water (Kvalswig & Schutte, 1986; Chandiwana, 1987; Klumpp & Webbe, 1987; Lima E Costa *et al*. 1987; Kloos *et al*. 1990; Wu *et al*. 1993; Akogun & Akogun, 1996). Other studies use water contact observations to design interventions (e.g. health education, sanitation facilities) aimed at disrupting the transmission cycle (Kloos *et al*. 1998; Watts *et al*. 1998). Another goal is to use individual water contact observations in immuno-genetic studies to control for exposure to infection when assigning a phenotype of 'resistant' or 'susceptible' to re-infection after chemotherapy (Wilkins *et al*. 1987; Rihet *et al*. 1991; Dunne *et al*. 1992; Kabatereine *et al*. 1999;

Woolhouse *et al*. 1998; Scott *et al*. 2003). Unfortunately, there is a lack of ideal methodology to capture the complexity of water contact patterns (see Chapter 7.2).

In endemic situations, typical age-related *Schistosoma* intensity patterns are usually observed, with a rapid increase in children, a peak in adolescents, and a strong decline in adults. This has been attributed to age-related differences in exposure as well as resistance (Bundy & Blumenthal, 1990). The long debate over the relative importance of exposure and resistance to infection in determining the observed age-intensity patterns of schistosomiasis has never been satisfactorily resolved (Fulford *et al*. 1996).

The Senegal focus is considered the most important epidemic of *S. mansoni* in recent years. After the outbreak, extremely high infection levels were observed, while infection intensities had similar age-related patterns as in conventional endemic situations in sub-Saharan Africa (Stelma *et al*. 1993). See Chapter 1.4.3 for a brief overview of the outbreak. Undoubtedly, the unique epidemic situation in Northern Senegal can give and has already provided us new insights about the role of age *vs.* experience in resistance to schistosome infection (Stelma *et al*. 1993; Gryseels *et al*. 1994; Polman *et al*. 1995). While several immuno-epidemiological studies have been reported from this area, no detailed studies of water contact observations have been published so far. The study by Scott *et al*. (2003) contained water contact measurements using questionnaires, but these have intrinsic methodological limitations (see also Chapter 7.2). This lack of detailed water contact studies has left some (basic) questions on the role of exposure answered. It is still unclear if and to what extent the observed extremely high infection levels and peculiar age-related infection patterns in Northern Senegal were due to intense and/or differences in exposure levels, i.e. human water contact patterns. In Chapter 3 we will present the results of the analysis of a unique set of detailed water contact observations during the first years of the *S. mansoni* epidemic in Northern Senegal.

Human defecation behavior and schistosomiasis infection

The level of environmental contamination with *S. mansoni* eggs is important in understanding the epidemiology of the disease. In the absence of control measures, this level will largely depend on the defecation habits of the people, in relation to presence and use of sanitary practices. Our knowledge of defecation habits and latrine use is still limited (Chandiwana, 1986).

Studying defecation behavior is difficult due to the intrusive nature of observational studies, as people in all cultures consider defecation as a private act. Husting (1965) looked at some aspects of human excretory behavior relevant to schistosomiasis transmission in Zimbabwe. He noticed that latrines, if present at all, were not often used, but he did not go into detail about the reasons why. Also others have observed that people may have latrines but still not use them (Cousens *et al*. 1996; Mertens *et al*. 1992; Curtis *et al*. 2003). It can be imagined that the benefits of using latrines may have been poorly explained to populations that are confronted with them for the first time. In the intestinal schistosomiasis outbreak area of Northern Senegal, provision of latrines was accompanied with intense health education about their usefulness and how to use them. In Chapter 4 we will report about the resulting latrine use in this area.

Cheesmond & Fenwick (1981) used discrete observation and the interpretation of circumstantial evidence to study excretory behavior of residents and migrant laborers in Gezira, Sudan. They found that 93% of defecations occurred in remote and quiet sites, far removed from any water body. This indicates that privacy is a more important consideration than proximity of water in the selection of a place for excretion. It also suggests that there is only limited regular contamination of water bodies by *S. mansoni* eggs under the observed conditions. However, 31% of the people washed themselves in surface water after excretion, which may entail a so far poorly appreciated risk of contamination of water with infected stools. In Chapter 5 we will look further into this for the situation in Northern Senegal, where hygienic bathing after defecation is a very common practice.

1.3 Control options for schistosomiasis

The control of schistosomiasis involves three targets, namely that of the human definitive hosts and any reservoir, that of the snail intermediate host, and that of the worm, in relation to its eggs, miracidial larvae and cercariae. Control may have the objective of limiting the spread of infection, reducing morbidity, or curbing and eventually stopping transmission (eradication) (Jordan *et al*. 1980; Wilson & Coulson, 1984; Ximenes *et al*. 2001).

Control of schistosomiasis was initially thought in terms of snail control, mainly by chemicals (molluscicides), but also by biological control (snail eating fish) or changes in snail habitats. However, the impact was mostly short-lived since snails usually repopulated their habitats soon after control was terminated. Furthermore, (chemical) snail control does not lead to additional benefits (Sturrock *et al*. 2001; King *et al*. 2006; Kariuki *et al*. 2004). In contrast, for example, provision of safe water supplies or latrines has obvious general benefits to rural communities, apart from the prevention of schistosomiasis. Chemical snail control has further been criticized for killing fish, an important source of protein in many schistosomiasis endemic areas (Sturrock & Sturrock, 1970).

Over the past years, WHO has supported mass drug administration with the anthelmintic drug praziquantel (PZQ) as the leading option in schistosomiasis control (WHO, 1979). However, this is still a relatively expensive option, usually depending on foreign funds, and consequently having a poor sustainability (WHO, 1979). However, the use of drugs can be minimized by only giving it to those that need it most, i.e. patients that have developed (early) morbidity and report at a health facility, or people with the highest risk of acquiring infection, such as children and specific occupational groups (fishermen).

Given the fact that schistosomiasis is in the first place a behavior-generated disease, changing behaviors is often considered a useful (additional) option to control. However, it should be noted that it is unrealistic to expect much from behavior change if no alternatives to the usual behaviors are offered. Below we introduce the three most important behavior-related control options.

Reducing exposure

Measures to prevent human water contact with potentially infective water include housing away from canals and ponds, providing adequate, safe water and sanitation, protecting surface water by covering pipes or fencing, and providing protective facilities for bathing, water recreation and laundering. Although drinking water is not a major route of infection, collecting water from infected sources is a marked risk. Safe water supply as a control measure against schistosomiasis supposes that adequate water is offered permanently, and that the system is convenient and acceptable for populations it is designed for (Curtis *et al*. 2003). Apart from its role in the control of schistosomiasis, water supply has also obvious other social and health benefits.

Reducing contamination

The fundamental reason for the transmission of schistosomiasis is the low level of sanitation in endemic areas, with the result that fecal material or urine containing viable schistosome eggs reach natural water bodies infested with fresh water snails susceptible to infection (Jordan, 1985). The environmental method to reduce contamination is offering basic sanitation facilities such as latrines. Unfortunately, these have a poor reputation because of poor maintenance and limited use (Macdonald, 1965; Béria *et al*. 1998; Curtis *et al*. 2003). In addition, latrines are unlikely to control urinary schistosomiasis; the temptation to urinate while bathing presents a real problem that even a health education campaigns cannot overcome (Jordan *et al*. 1980; Ouma *et al*. 2001). Poor use of sanitation facilities is further illustrated by people such as rice farmers, who spend much of their working time outdoors and are unlikely to leave the field to use latrines.

Health education

The objective of health education is to increase the awareness of the population about the disease, its transmission and complications, and to enhance health-seeking behavior. It has usually failed to give significant results as people's knowledge and attitude towards the disease remain poor (Mehanna *et al*. 1997; Schall *et al*. 1995; Uchoa *et al*. 2000). Health education implies a long-term commitment and should ideally be integrated in the general education system. Such an approach has been extensively experienced in Brazil, still with modest results (Schall *et al*. 1995; Massara & Schall, 2004).

1.4 Schistosomiasis mansoni outbreak in Senegal

Prior to the construction of two dams in the Senegal River, a number of health-assessment surveys were performed to determine the probable effects of the construction of the dams on the health of the local communities. The major health threat, if any, was expected to be an increase of malaria and possibly a spread of urinary schistosomiasis (Monjour *et al*. 1981; Chaine & Malek, 1983; Diaw *et al*. 1991; Verlé *et al*. 1994; Kongs *et al*. 1994; Diop & Jobin, 1994). No spread of the intestinal schistosomiasis intermediate host was predicted since no autochthonous human cases of *S. mansoni* had ever been reported in the area (Chaine & Malek, 1983; Talla *et al*. 1990, 1992). Still a severe outbreak of *S. mansoni* infection occurred rapidly after completion of the dams.

The country and its climate

The republic of Senegal is in Western Africa, bounded in the North by Mauritania, in the East by Mali, in the South by Guinea and Guinea-Bissau, and in the West by the Atlantic Ocean (Figure 1.2). The republic's total area is 196,722 km^2. The Senegal River Basin covers about 290,000 km^2 spread in four countries: Senegal, Mauritania, Guinea and Mali (Diop & Jobin, 1994).

The Senegal River is one of the major West African rivers (Figure 1.2). It stretches over 1,790 km. Its source is situated in the mountains of *Fouta Djallon* in Guinea. Most of Senegal has a transitional climate from the dry desert zone in the North to the moist tropical zone in the South. The rainy season lasts from July to October in the North, where rainfall averages 350 mm.

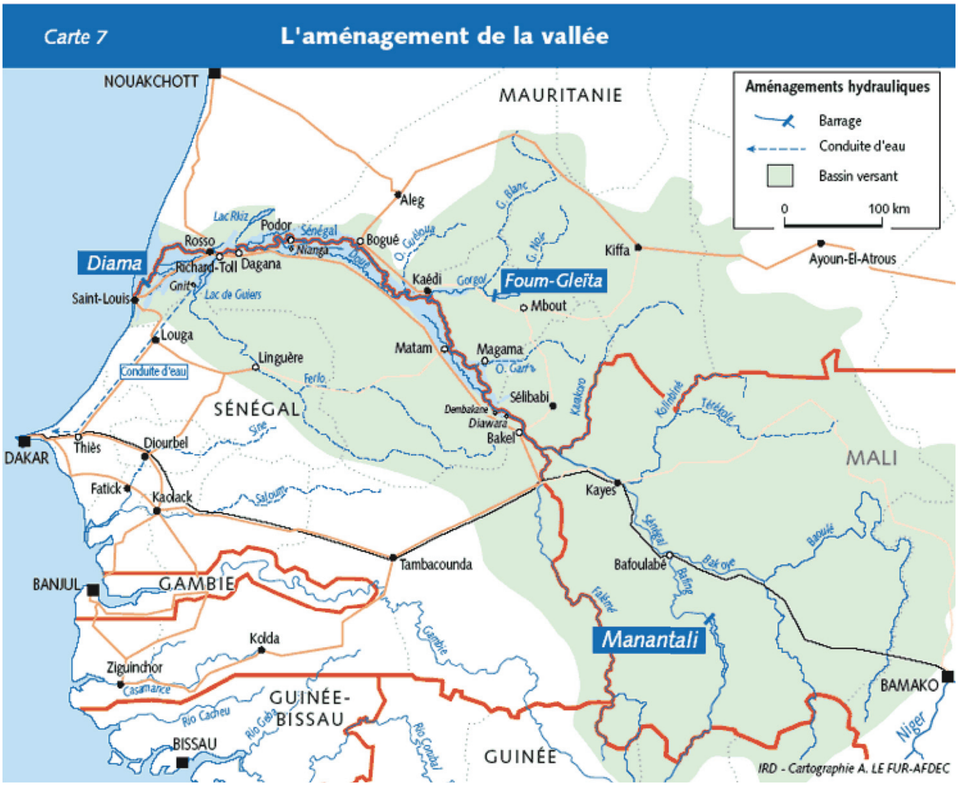

Figure 1.2 Map of Senegal and the Senegal River Basin

The climate in the Senegal River Basin results from its tropical latitude and its position in the extreme west of the African continent. The climate is dominated by intermittent air masses constituted of trade wind, the so-called *Harmattan* (hot and dry wind blowing from the Sahara) and *Monsoon*. The average temperatures vary from 22°C to 32°C.

The water resources development projects in the Senegal River Basin

In 1972, Mali, Mauritania and Senegal decided to create the OMVS (*Organisation pour la Mise en Valeur du Fleuve Sénégal*) – the Senegal River Basin Management Authority, which was in charge of the development of the river basin. The aim of the OMVS was to develop water resources in the region in order to improve the living conditions of the population of the river valley.

The full water development project was achieved with the construction of two dams in the riverbed. Completed in 1986, the Diama anti-salt dam situated 25 km downstream to the river mouth was constructed in order to stop the intrusion of seawater into the low valley during the dry season. In 1988, the Manantali dam constructed 2000 km upstream in the Bafing River (one of the major tributaries of the Senegal River) became operational allowing for a regulation of the flow of the river water. In order to maintain a transition period for the existing production system based on the flooding agriculture, a system of controlled flooding was also planned.

The objective of the OMVS project was to provide 240,000 ha of irrigable land to Senegal, 126,000 ha to Mauritania and 9,000 ha to Mali. The project aimed also at maintaining the dry season flow at 300 cubic meters per second for navigation and producing 800 gigawatt-hours per year of electricity for the three member states. Furthermore, the water impoundments led to a perennial presence of fresh water allowing year round agriculture (Diop & Jobin, 1994; Ross *et al*. 2001).

The post dam era epidemiological transition in Northern Senegal

In Northern Senegal, the extension of fresh water bodies resulting from the construction of the dam, has led to an increase in the number and size op populations of *Biomphalaria pfeifferi*, the snail host of *S. mansoni*. Prior to the construction of the dam, this snail was only present in some parts of the Guiers Lake (Lac de Guiers, Figure 1.2) and no cases of *S. mansoni* had ever been described in this area (Chaine & Malek, 1983). After the completion of the dam and subsequent ecological changes, the snail progressively invaded the Guiers Lake, irrigation canals and the Senegal River, resulting in a spectacular increase of *Biomphalaria* snails from South to East (Diaw *et al*. 1991).

In 1988, the first cases of intestinal schistosomiasis were identified in Richard Toll. A survey conducted in 1990 revealed a *S. mansoni* prevalence of 60% in the city and its surroundings (Talla *et al*. 1990, 1992). Subsequent studies reported prevalences of 75-100% with the highest intensities of infection ever described worldwide (Stelma *et al*. 1993, 1995; Gryseels *et al*. 1994; Picquet *et al*. 1996; Ernould *et al*. 1999). This situation gave rise to a considerable challenge to the health care system.

In 1994, medical authorities initiated a regional schistosomiasis control program in order to minimize the consequences of the epidemic. The program focused mainly on the distribution of praziquantel through selective treatment of schoolchildren and passive case detection at all levels of the health system. Other specific actions included health education, inter-sectoral actions for sanitation and water supply, and general strengthening of the health system including training of staff and equipment

(Van der Werf *et al*. 2002b). Southgate (1997) provides a detailed overview of the schistosomiasis outbreak.

1.5 Aim and research questions

General objective

To better understand the behavioral aspects of transmission of *Schistosoma mansoni* and the impact of behavioral interventions in Senegal.

Specific research questions

1. What is the impact of water resources development projects in Northern Senegal on the epidemiology of water-related diseases?
2. What is the pattern of water contact behavior in the Senegal River Basin and can it explain the high *Schistosoma mansoni* infection rates?
3. What is the contribution of hygienic practices to the contamination of the water with schistosome eggs?
4. What is the impact of behavioral interventions on the reduction of schistosomiasis transmission in Northern Senegal?

Structure of the thesis

Question 1 is addressed in the next chapter (**Chapter 2**), which describes the epidemiological transition following the completion of two dams along the Senegal River Basin. This was investigated by a health documentary survey, based on reported clinical cases in the medical records in four districts in Northern Senegal. **Chapter 3** responds to research question 2 about water contact behavior through extensive observational studies over a two-year period in a traditional rural village. Question 3 is dealt with in **Chapters 4** and **5**, which present a questionnaire study on defecation and sanitary behavior, and a series of small field studies focusing on the role of hygienic bathing after defecation, respectively. Research question 5 is addressed in **Chapter 6** through an investigation about the comprehension of the disease transmission mechanisms by the local community, which has been exposed to intense health education programs. Finally, in **Chapter 7** we discuss to which extent the research questions have been answered and list the general conclusions resulting from this thesis.

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Chapter 2

Water-related disease patterns before and after the construction of the Diama dam in Northern Senegal

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2.1 Summary

Ecological changes caused by projects for the development of water resources are known to affect the epidemiology of water-related diseases. The effects of the construction of the Diama dam (completed in 1986) in the Senegal River on the epidemiology of malaria, urinary and intestinal schistosomiasis, diarrhea and dysentery were investigated in four districts in Northern Senegal. To make allowance for any general trend in reported morbidity (caused by changes in demography or the healthcare system), the number of cases of these illnesses reported by the basic healthcare facilities before and after the completion of the dam were compared with those of respiratory disease.

Prior to the construction of the dam, malaria was the most encountered water-related disease in the medical records of all districts, followed by diarrhea, dysentery and urinary schistosomiasis. This order remained the same after the completion of the dam. Despite the optimism of health-assessment reports prepared prior to the construction of the Diama dam, the unexpected appearance and spread of intestinal schistosomiasis as well as an increase in the incidence of urinary schistosomiasis have aggravated public health in the Senegal River Basin. It remains to be judged whether the economic benefits of the dam will counterbalance its adverse effects.

2.2 Introduction

Having faced cycles of drought during the 1970s, the states bordering the Senegal River Basin decided to construct two dams in the Senegal River. The Diama dam, near the mouth of the river, was completed in 1986, to prevent saline water flowing inland during the dry season and permit the development of irrigated agriculture along the river valley. In 1988, the construction of the Manantali dam in Mali, 2000 km upstream, further stabilized the river flow (resulting in enhanced irrigation), allowed the production of energy, and improved inland navigation.

Such projects for water-resources development often entail ecological and demographic changes that affect the transmission of water-related diseases, sometimes dramatically (Waddy, 1975; Hunter *et al*. 1982; Mouchet & Brengues, 1990; Molyneux, 1997). For instance, the building of the Aswan dam in Egypt led to increases in prevalence of urinary schistosomiasis (Khalil Bey, 1949; Farid, 1972). The construction of the Akossombo dam in Ghana was followed by a massive increase in the prevalence of urinary schistosomiasis (Obeng, 1975). More recently, the construction of the Bargi dam in India resulted in an epidemic of malaria (Singh *et al*. 1999).

The development of irrigation is often accompanied by population movements. Poor sanitation, insufficient supplies of safe water, and demographic pressure may then create the ideal conditions for the development of diarrhea and other diseases (Kolsky, 1993). Moreover, the increased risk of communicable diseases, such as malaria and schistosomiasis is often under-estimated. Feasibility studies mainly emphasise the economic benefits rather than the environmental and health hazards of water-resources developments. As a result, little attention is given to disease prevention during the planning stage of such projects.

Bradley (1987) split water-related diseases into four main categories. Bacterial diseases, such as cholera, that result from drinking water polluted with excreta are 'water-borne'. The 'water-washed' diseases, such as some other diarrheal disorders and trachoma, are not primarily spread by water but they increase in importance when insufficient clean water is provided. Schistosomiasis, dracunculiasis and the other 'water-based' diseases each depend on an aquatic organism for a part of their life-cycle. The pathogens causing the 'water-vectored' diseases, such as malaria and onchocerciasis, are transmitted by insects that are dependent on water for breeding or feeding.

In the Senegal River Basin (SRB), the extension of freshwater bodies resulting from the construction of the Diama dam has led to an increase in the number and size of populations of *Biomphalaria pfeifferi*, the intermediate snail host of

Schistosoma mansoni. This, in turn, probably resulted, in 1988, in an unexpected outbreak of human infection with *S. mansoni* in Richard Toll (Talla *et al.* 1990; Diaw *et al.* 1991; Verlé *et al.* 1994). This epidemic then spread to neighbouring villages, where very high intensities of infection were observed (Stelma *et al.* 1993; Gryseels *et al.* 1994). Similarly, although *S. haematobium* was endemic in many parts of the SRB before the Diama or Manantali dams were built (Monjour *et al*. 1981; Chaine & Malek 1983; Vercruysse *et al.* 1985; Diaw *et al.* 1991), new foci were discovered after the dams were constructed (Ernould & Ba 1994; Verlé *et al.* 1994). The incidence and distribution of human infection with *S. haematobium* in the SRB apparently continue to increase (Piquet *et al.* 1996) and there is some evidence that the construction of the dams has led to an increase in the problem caused by other water-related diseases, especially malaria (Handschumacher *et al.* 1992).

The main aim of the present study was to assess and quantify the extent to which the recent outbreaks of human infection with *S. mansoni* or *S. haematobium* in the SRB were followed by an increase of schistosome-attributable morbidity in the human population and a growing demand for healthcare. Possible changes in the health burden posed by other water-related diseases, such as malaria, diarrhea and dysentery, were also investigated. The study was based on the annual numbers of cases of each illness reported in the 4 years before and 10 years after the completion of the Diama dam, as registered in the medical records of the healthcare facilities in four districts along the Senegal River. In order to take account of the concurrent population growth and improved attendance of the healthcare system, these numbers were compared with those of cases of diseases that were not water-related. Out of a range of candidates, respiratory disease was chosen to represent the general trend in reported morbidity.

2.3 Materials and methods

Study area

This documentary study was performed in four of the five health districts in the medical region of St Louis, in Northern Senegal, close to the border with Mauritania. The Senegal River flows through large expanses of scarce Sahelian vegetation in the region. The river is permanent but the water level varies considerably. The St Louis medical region is subdivided into five health districts: St Louis, Richard Toll, Dagana, Podor and Matam. Data were obtained from the health records in the districts of Richard Toll and Dagana, covering the upper delta of the river, the Podor district, in the middle valley, and, as a control, the St Louis district, at the mouth of the river.

(The Diama dam should have only small effects on water-related diseases in the St Louis district since the water bodies in the district, which lies downstream of the dam, have remained salty.)

The districts of St Louis and Podor have the largest populations but Richard Toll has shown the highest growth rate over the study period (see Table 2.1). The district of St Louis is mainly urban or peri-urban and has an important influx of immigrants. Richard Toll forms the heart of Senegal's agricultural industry and consequently attracts seasonal workers from all neighbouring areas and countries. Its extensive sugar estates are traversed by 900 km of irrigation channels. Although the city of Dagana is a dormitory suburb, the Dagana district is mainly rural and most of its labour force consists of cane cutters and rice farmers. Podor district is rural and is covered by hundreds of small villages with mainly subsistence farmers. In all districts, the dams (Diama and Manantali) have increased the availability of fresh surface water. Most people still have to resort to the main river, small streams or irrigation channels (especially in Richard Toll) for their daily water supply.

Table 2.1 Temporal changes in the population size and number of health units in four districts in Northern Senegal

District	Population size in:			Growth rate [c]	No. of health units in: [d]	
	1976 [a]	1988 [a]	1996 [b]		1982	1996
St Louis	120,028	157,038	198,805	2.8	7	10
Richard Toll	58,418	80,213	109,548	4.4	8	15
Dagana	25,925	48,628	62,383	3.3	6	10
Podor	140,061	154,723	174,596	1.8	33	43

[a] Based on the general population census in that year.
[b] Projected population size, based on the growth rate.
[c] Estimated from the 1988 census.
[d] Hospitals not included.

The health system: structure and administration

In Senegal, the health system is organized as a pyramidal structure, with health posts referring to health centres, which in turn refer to the regional hospital (for the study area the regional hospital is in St Louis city). Each health post is run by a nurse whereas each health centre is generally run by two physicians and is always located in the main city of the district. Since the implementation of decentralization in the health sector in 1992, the 'health hut' (*case de santé*) has become the most peripheral level of the health system. These huts are run by community health workers who provide basic healthcare, such as treatment of wounds and the giving of injections and treatments prescribed by the nurse in charge of the nearby health post. In each district investigated, the number of health units increased during the study period (Table 2.1).

Health posts and health centres register each case observed; the nurse in each health post completes a monthly report recording all treated or referred cases and the illnesses most frequently encountered or important. The primary-healthcare supervisor of each district compiles the information from all the health posts and the health centre. Annual reports from each district are handed over to the regional medical officer.

The records analysed for the present study were mostly taken from the district-level databases for the period 1982-1996 (i.e. 4 years before and 10 years after the completion of the Diama dam in 1986). As Richard Toll was part of Dagana district until 1992, data for Richard Toll until the separation came from the Dagana health centre. St Louis only became an independent district in 1993, and medical records until that year were kept at the regional medical office in St Louis city. Data from St Louis were only available from 1985 onwards.

Case definitions

Patients complaining of blood in urine (haematuria) are considered to be cases of urinary schistosomiasis and, if they come from or have visited a known endemic area, they are immediately treated with praziquantel, without further investigation. Otherwise, diagnostic confirmation is sought by means of a urine examination (microscopical or dipstick) at the health centre. Until 1994, a case of intestinal schistosomiasis was identified by the detection of *S. mansoni* eggs in a direct stool smear of a patient presenting with signs indicative of intestinal schistosomiasis (mainly bloody diarrhea or abdominal pain); the microscopical confirmation was only possible in a health centre. In 1994, however, a simple algorithm for the identification of intestinal schistosomiasis in areas of different endemic levels was introduced by the regional schistosomiasis-control programme. A patient from an area known to be hyper-endemic who presents with bloody diarrhea, for instance, is assumed to be infected with *S. mansoni* and given praziquantel without laboratory diagnosis.

The diagnosis of malaria in the study area is usually based on fever, other symptoms and the results of a clinical examination performed by medical or paramedical staff, without microscopical confirmation. A case of diarrhea is a patient who complains of loose or watery stools (WHO: 1990). A patient with dysentery has diarrhea with visible blood in the stools, with or without mucus. It is clear that the clinical case definitions of intestinal schistosomiasis, diarrhea and dysentery overlap and can easily be confused. Information on dysentery was missing in Podor.

All the diseases affecting the respiratory tract (such as asthma, pneumonia, and bronchiolitis) and detected by clinical examination were grouped as 'respiratory disease'. Tuberculosis was recorded separately in the medical records, as an infectious (not respiratory) disease.

Data analysis

The trends in the water-related diseases - malaria, diarrhea, dysentery and intestinal and urinary schistosomiasis - were analysed by plotting the yearly number of reported cases on a logarithmic scale. On such plots, a linear curve would be expected if incidence (cases/1000) remained the same while there was gradual population growth. Any effect of the Diama dam on the incidence of water-related disease might be apparent as a significant change in the curve, shortly after 1986.

Apart from the size of the population, other factors may cause a change in reported morbidity. The increase in the number of health units over the study period (Table 2.1) has reduced the distance to the nearest health post for part of the population, and may therefore have improved the tendency to seek healthcare. Moreover, the socio-economic improvement brought about by the water-resources development and the health sector reform in 1992 may have made healthcare more accessible. Respiratory disease was therefore selected to represent, for each district, the 'general trend' in disease reporting and the trend to be expected in all recorded illnesses if the dam had no effect. Poisson regression analysis [$\log_{10}$ (no. of cases) = β(year-1982) + α] was used to describe the evolution of the number of cases of respiratory disease over time. The trends in the annual numbers of water-related diseases reported were then compared with that general trend.

2.4 Results

The plots in Figure 2.1 show that the increases in the annual numbers of cases of respiratory disease in St Louis, Richard Toll and Dagana follow simple log-linear trends, with b-values of 0.020, 0.065 and 0.038, respectively. As the minor fluctuations around the fitted curves do not follow a consistent pattern, occasional periods of poor data recording or other confounding events do not seem to have occurred. The ranking of the slopes (that for Richard Toll being steeper than that for Dagana which was, in turn steeper than that for St Louis) is in line with the corresponding population growth rates (Table 2.1). The slope of the log-linear curve fitted to the Podor data was even steeper than that for Richard Toll (b = 0.070). However, a second- order polynomial provided a better fit to the number of cases in Podor (on a log-scale), indicating that there was a slow initial increase (probably reflecting the low rate of population growth rate; Table 2.1), followed by a faster increase from the early 1990s onwards.

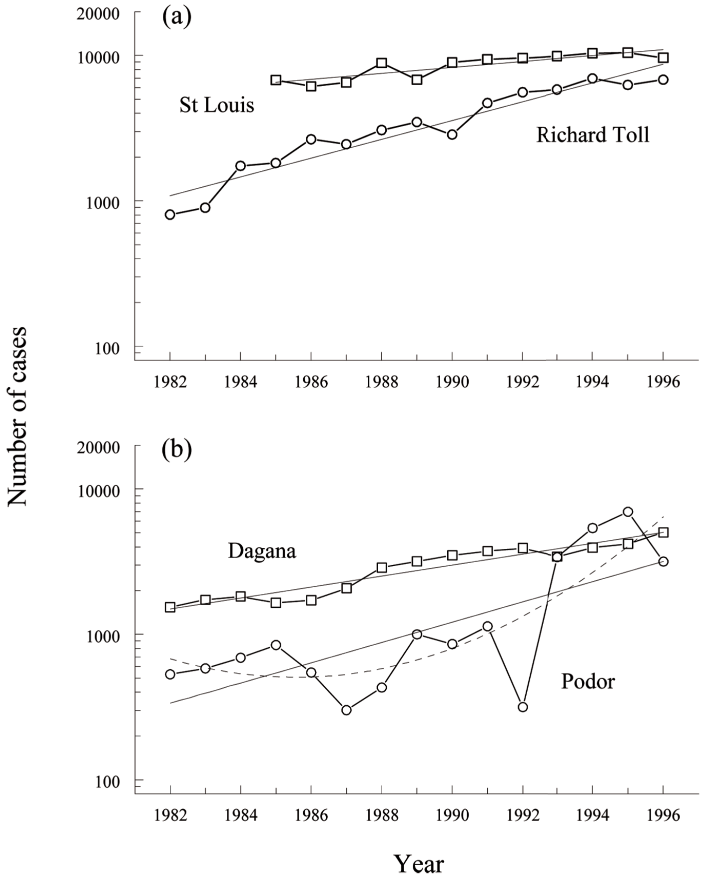

Figure 2.1 The annual numbers of cases of respiratory disease reported in the districts of St Louis and Richard Toll (a) and Dagana and Podor (b), in Northern Senegal. The straight lines indicate the best-fitting, log-linear plots according to a Poisson regression. The dashed line represents an alternative fit for the trend in Podor, using a second-order polynomial curve.

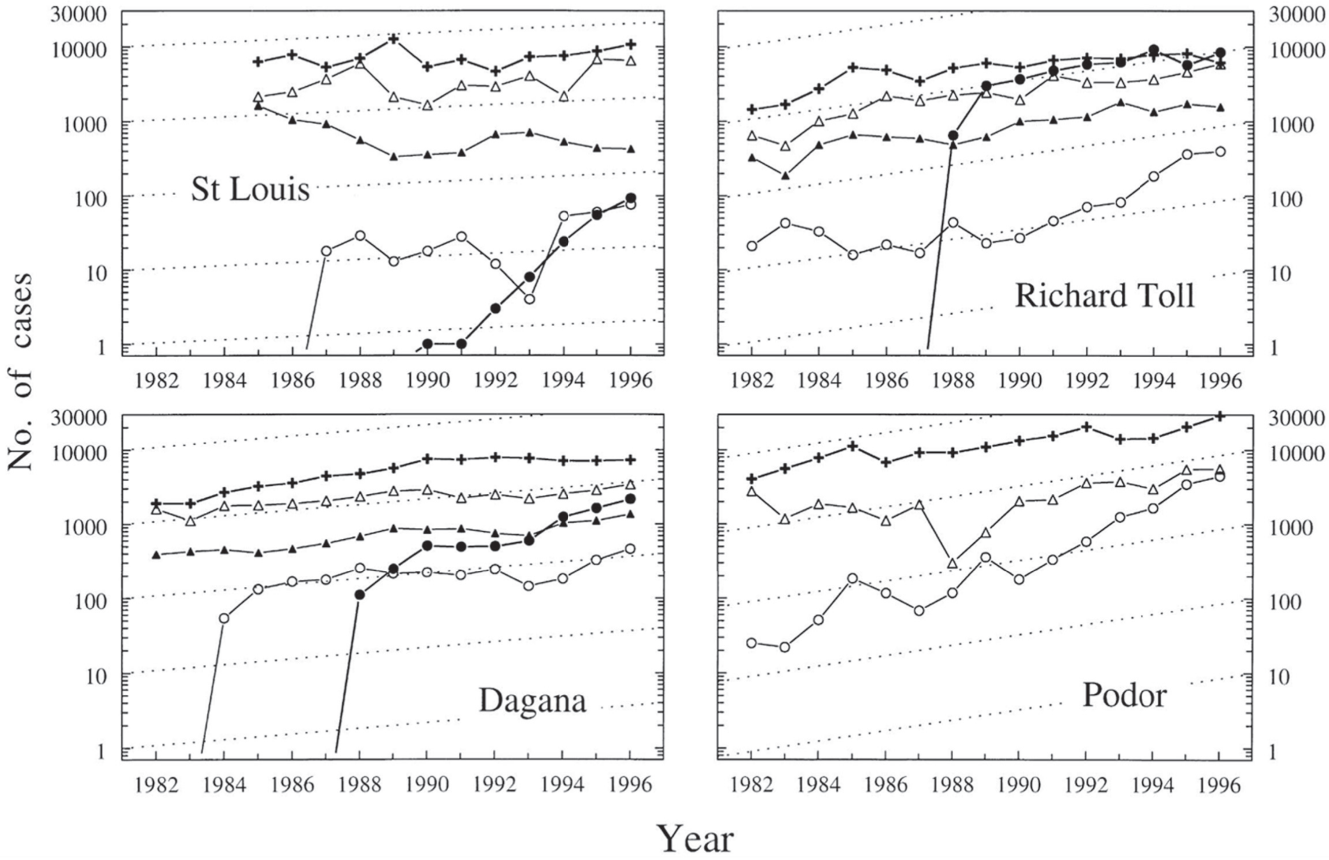

Figure 2.2 The annual numbers of cases of malaria, diarrhea, dysentery, intestinal schistosomiasis and urinary schistosomiasis, reported in the districts of St Louis, Richard Toll, Dagana and Podor, in Northern Senegal. The dotted lines represent the trend expected if the construction of the dam had had no effect on the numbers, as derived from the numbers of cases of respiratory disease reported in each district (see Figure 2.1). In Podor, no cases of schistosomiasis were reported in the health records, and information on dysentery was not available.

Malaria appeared to be the most frequently reported water-related disease in all of the study districts throughout the study period, followed, in descending order, by diarrhea, dysentery and urinary schistosomiasis (Figure 2.2). The epidemiological profile of intestinal schistosomiasis was clearly different.

Although the annual numbers of reported malaria cases did increase considerably over time in all of the studied districts, the trends followed the general trend in reported morbidity (as reflected by reported respiratory disease). In Richard Toll and Podor, the upward trend in reported malaria cases was even less marked than that seen in respiratory disease. The annual numbers of reported diarrhea and dysentery cases increased at similar rates before and after the dam construction except in St Louis, where the reported annual numbers of dysentery clearly decreased from 1985 to 1989. Generally, the upward trend in the reported annual numbers of diarrhea and dysentery cases over the study period tend to be less marked than the general trend.

Urinary schistosomiasis was recorded in the health reports of the four study areas. Whilst in Richard Toll and Podor this disease was endemic throughout the study period, in Dagana and St Louis the first cases appeared in the health records after 1984 and 1987, respectively. The reported annual numbers of cases of urinary schistosomiasis initially followed the general trend in each district, but started to increase beyond it around 1994, particularly in Richard Toll.

The first cases of intestinal schistosomiasis were reported in 1988 in the districts of Richard Toll and Dagana. Since then the annual number of cases in Richard Toll has increased dramatically, to reach the same level as that of malaria from the mid-1990s onwards. In Dagana, the epidemic was less explosive but the number of cases continued to grow faster than the general trend. In St Louis the disease was reported only after 1990, but the number of cases remained relatively low (as for urinary schistosomiasis). Intestinal schistosomiasis was totally absent from the health records in Podor.

2.5 Discussion

Prior to the construction of the two dams in the Senegal River, a number of health assessment surveys were performed under the supervision of the *Organisation pour la Mise en Valeur du Fleuve Senegal* (OMVS) – The Senegal River Basin Authority. Although the aim of each of these studies was the same – to determine the probable effects of the construction of the dams on the health of the local communities – the predictions lacked consistency. The first environmental-impact study, conducted by United States Agency for International Development (USAID) together with OMVS, concluded that the water-management project would probably not create serious health problems (Downs & Sacks, 1977; Diop & Jobin, 1994). A second USAID/OMVS report mentioned the possible spread of urinary schistosomiasis (Chain & Malek, 1983). The third report predicted not only that there would be no extra health threat to the local communities after the project but that, thanks to increased agriculture productivity and the subsequent increases in the per-capita incomes of local farmers, there would be an overall improvement in health (Anon, 1980). All three reports shared a certain optimism and none mentioned the threat of *S. mansoni* being introduced.

Between 1988 and 1996, about 55,000 patients visited the healthcare units of Richard Toll and Dagana with complaints attributable to intestinal schistosomiasis. Until 1994, all of the suspected cases were parasitologically confirmed by stool examination; later on, many of the suspected cases were diagnosed on the basis of clinical signs only. It was surprising that the major outbreak of intestinal schistosomiasis in Richard Toll stabilized within 2-3 years of its onset, the annual numbers of reported cases subsequently following the general trend. In Dagana, a smaller outbreak occurred but the annual numbers of cases increased beyond the general trend from 1994 onwards. This could possibly be explained by the spread of the infection to new foci in the district of Dagana, whereas all possible foci in Richard Toll were almost immediately affected (Picquet *et al.* 1996). The change in case definition and the application of the diagnostic algorithm may also have played a role. Most of the cases in Richard Toll were reported by the district health centre, where parasitological diagnosis was available and commonly carried out. In Dagana, on the other hand, health posts – where only the recommended algorithm was used – reported most of the cases. Although projects for the development of water resources often entail health risks in both upstream and downstream areas (Xu *et al.* 1999), St Louis did not show an equally spectacular increase in intestinal schistosomiasis. However, the salt content of most water bodies in the St Louis district presents an effective barrier to colonization by the snail hosts of *S. mansoni.* All of the schistosomiasis cases reported in St Louis were, in fact, imported or referred from elsewhere, their numbers rising steadily with immigration from areas in which *S. mansoni* was becoming even commoner. By the end of the study period, *S. mansoni* had not reached the district of Podor, although Podor is only 125 km from the epicentre of the outbreak at Richard Toll. Podor is protected because the *Biomphalaria* used as intermediate hosts by *S. mansoni* probably do not occur in the area (Vercruysse *et al*. 1994). However, the continuing ecological changes may permit these snails to migrate towards the middle valley and lead to an outbreak of intestinal schistosomiasis there.

Urinary schistosomiasis was endemic in all the studied districts apart from St Louis, where the few clinical cases seen were all imported. Following the completion of the Diama dam, a rapid increase was reported in the number of foci where *S. haematobium* was transmitted (Ernould & Ba 1994; Verlé *et al.* 1994; Piquet *et al.* 1996). However, this does not appear to have led to a large increase in the numbers of reported cases of urinary schistosomiasis immediately after the dam was completed. The disproportionate rise in the numbers of reported cases in about 1994 may reflect a delayed, dam-related outbreak but it could also be the result of a regional health-education campaign to raise awareness about schistosomiasis. As the clinical signs and symptoms of urinary schistosomiasis are easier to recognize than those of intestinal schistosomiasis, such a health-education campaign is likely to have most impact on the reported numbers of cases of the urinary disease. Moreover, the substantial and gradual reduction in the price of praziquantel from 1992 onwards may have facilitated early healthcare-seeking behavior.

The present study produced no evidence that construction of the Diama dam had any effect on malaria, dysentery or diarrhea during the study period. The upward trend seen in the annual numbers of reported cases of malaria (or illness considered to be malaria) was not greater than that seen in respiratory disease. This finding confirms the doubt expressed by entomologists, who believed that physicians over-estimated the problem posed by malaria in the area (Faye *et al*. 1995). The most important malaria vector in Richard Toll and Dagana, *Anopheles pharoensis* (Petrarca *et al*. 1987), can breed in brackish water but has a low survival rate and this limits its role in malaria transmission (Carrara *et al.* 1990; Faye *et al.* 1993). In Podor, the most frequent vectors - *An. gambiae* and *An. arabiensis*- are particularly aggressive in irrigated areas but their anthropophilic index remains low and their attempts to bite villagers are often thwarted by bednets, the use of which is widespread in the region (Faye *et al.* 1993). The relatively high numbers of malaria cases reported throughout the study period undoubtedly represent over-estimates of the true incidence, since few such cases were parasitologically confirmed.

In all of the study districts, the annual numbers of reported cases of diarrhea and dysentery either followed the general trend or increased more slowly. Only St Louis showed two incidental peaks, in 1988 and 1995 - perhaps the result of uncontrolled immigration. Some reported cases of diarrhea or dysentery may have been the result of *S. mansoni* infection, perhaps even before 1988. The results of an epidemiological study conducted in 1993 revealed that 43% of diarrhea cases near Richard Toll city were related to intestinal schistosomiasis, the rest being caused by *Escherichia coli* or *Shigella* spp. (Rogerie *et al.* 1997). An equivalent drop in the number of reported cases of diarrhea did not mirror the increase seen over the study period in the numbers of cases of intestinal schistosomiasis.

In a study such as the present investigation, it is crucial to have a reference with which to compare the evolution of each water-related disease, so that increases related to the water-resources development can be distinguished from those resulting from an expanding population and/or increases in health-service use. A disease which is unlikely to be influenced by the dam or any other related exogenous factor makes a useful reference, and respiratory disease appeared to be the best candidate for the present study. Initially, wounds (and abscesses), burns, food or chemical poisoning, skin diseases and sexually transmitted diseases (STD) were also considered as potential controls (data not shown). In general, wounds and abscesses showed trends similar to those seen in respiratory disease and seemed promising alternatives. However, the number of wounds in St Louis unexpectedly decreased over time, perhaps reflecting improved safety in this district as a whole or in St Louis city. The annual numbers of cases of poisoning were rather low and therefore subject to large fluctuations. The use of STD as a reference standard was discounted when it became evident that the annual numbers of cases reported rose markedly in all districts in the 1990s, possibly reflecting increasing awareness among high-risk individuals during the modest HIV epidemic in Senegal (Kane *et al.* 1993). Burns showed a very different pattern, with a general decrease in the numbers of cases reported over time in all districts, reflecting, perhaps, the concurrent, general improvement in housing. In Podor, two village fires caused very unusual peaks in the numbers of reported burns cases. Finally, skin diseases accounted for only few consultations and the coding of such disease was not consistent between the districts.

Apparently, the general increase seen in the numbers of reported cases of disease reflects more than just the demographic growth that occurred over the same period. The increase seen over the study period in the annual numbers of cases of respiratory disease (and also of malaria, dysentery and diarrhea) reported in each district was at least twice as much as the apparent increase in population size. In Dagana for example, the annual number of recorded cases of respiratory disease quadrupled (Figure 2.2) whereas the projected population size only doubled during the study period (Table 2.1). Various factors may explain this phenomenon. Firstly, the population may have grown much faster than expected since the last census in 1988. The water-resources development has itself attracted a new labour force to the area and the sugar-cane estates and other agricultural businesses in Richard Toll have offered many job opportunities. Also, many people have moved from the arid plains, where they used to practise rain-fed and flood-recession subsistence farming, to the irrigation schemes along the riverbanks (Crousse *et al.* 1991). Moreover, in 1989, there was an influx of about 50,000 refugees from Mauritania. Secondly, the accuracy with which the health records were kept and archived has improved during the study period. Some of the old records in Dagana were compiled on varying handwritten forms at the health-post level and stored in large dusty files. Changes in health-district administration (in Richard Toll and St Louis) provided many opportunities for data to be lost or mislaid. Since 1992, the UNICEF initiative to promote use of a geographical information system has improved the recording of health statistics. Nowadays, each district uses computers. Thirdly, the construction of new healthcare facilities, the economic development of the region, and the health-sector reform of 1992 may have enhanced accessibility to healthcare and increased health-seeking behavior.

The construction of the Diama and Manantali dams in the SRB has certainly had positive socio-economic impacts. The change from traditional subsistence farming towards modern irrigated agriculture has increased productivity, employment and the socio-economic status of the communities involved. People living in irrigated areas now have access to more varied food and have improved their nutritional status (Benefice & Simondon, 1993). These positive results were foreseen by the OMVS-sponsored, pre-dam, feasibility studies but rated above the potential health hazards, such as a further spread of urinary schistosomiasis; the outbreak of intestinal schistosomiasis was not even anticipated. To minimize the negative effects of any water-resources development on local ecosystems and human populations, there must be an holistic approach, involving specialists of different backgrounds, from the onset. Even then, some effects may simply not be predictable. In the SRB, uncontrolled immigration, insufficient water supply, poor sanitation facilities and unprepared health services contributed also to the post-dam problems.

In conclusion, it is difficult to judge if the economic benefits of the Diama dam will eventually outweigh the problems posed not only by the schistosomiasis outbreak but also by an outbreak of Rift valley fever on the right bank (in Mauritania), the displacement of populations and the consequent communal violence (Jobin, 1999). Pre-dam assessments should always be followed by post-dam impact studies. Local health systems should always be strengthened to prevent or at least reduce any negative effects on health.

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Chapter 3

The contribution of water contact behavior to the high *Schistosoma mansoni* infection rates observed in the Senegal River Basin

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Submitted for publication

3.1 Summary

We have conducted detailed water contact observations in a village in Northern Senegal during the first years of a massive *Schistosoma mansoni* outbreak to determine the role of human water contact in the extent of the epidemic. This resulted in over 120,000 recorded water contacts for 1651 subjects over 175 observation days. Bathing was the main activity, followed by household activities. Frequency and duration of water contact depended on age and sex rather than season. Water contacts peaked in adolescents, women spent almost twice as much time in the water than men, and water contacts were more intense in the afternoon than in the morning, with sex-specific intensity peaks. These patterns of water contact are not unusual and have been described before in various other settings in sub-Saharan Africa. Moreover, water contact levels were not exceptionally high and thus cannot explain the extremely high infection intensities as observed in Northern Senegal. Comparison with fecal egg counts in the respective age and sex groups further revealed that water contact levels did not correspond with infection levels, indicating that other factors than exposure have principal importance in determining intensity of infection.

3.2 Introduction

In the late 1980s, Northern Senegal was confronted with a severe outbreak of *Schistosoma mansoni* infection after the construction of a dam on the Senegal River and subsequent water resource development. In a few years, the prevalence in Ndombo, the epicenter of the epidemic, rose from 0% (non existing) before 1988 to 75-100% in 1992, with the highest intensities of infection ever described world-wide (Stelma *et al.* 1993; Gryseels *et al.* 1994). These were attributed to intense transmission and the supposed lack of acquired immunity in this recently exposed community. Epidemiological studies in four successive cohorts, however, showed that infection intensities had similar age-related patterns as in conventional endemic situations in sub-Saharan Africa, i.e. with egg counts and antigen levels increasing to a peak in adolescents and strongly declining in adults (Stelma *et al.* 1993; Polman *et al.* 1995). This would leave age-related exposure differences as the most obvious explanation for the observed patterns. As the available water contact data at that time did not support this possibility, alternative explanations of age-specific mechanisms other than acquired immunity or exposure were put forward, such as skin permeability or hormonal factors (Gryseels *et al.* 1994; Polman *et al.* 2002; Scott *et al.* 2003). Nevertheless, important questions on the role of exposure remain to be answered. It is still unclear if and to what extent the observed extremely high infection levels in Northern Senegal were due to intense exposure, and in how far the endemic-like age-related infection patterns were due to differences in exposure levels, i.e. human water contact patterns.

Many studies have attempted to measure individuals' exposure, either by directly observing behavior at water sources (Bundy & Blumenthal, 1990; Coulibaly *et al.* 2004; Dalton & Pole, 1978; El Katsha & Watts, 1997; Fulford *et al.* 1996; Kabatereine *et al.* 1999; Kloos *et al.* 1983; Kvalsvig & Schutte, 1986; Ofoezie *et al.* 1998; Tayo *et al.* 1980; Watts *et al.* 1998; WHO, 1979; Woolhouse *et al.* 1998), or indirectly by interview/questionnaire (Barbosa & Barbosa, 1998; Barreto, 1993; Coura-Filho *et al*. 1994; Da Silva *et al*. 1997; Lima e Costa *et al*. 1987, 1998; Moza *et al*. 1998; Firmo *et al*. 1996; Ximenes *et al*. 2001). Only few studies attempted to quantify variables that are important in determining age and sex patterns of exposure from the corresponding patterns of water contact (Brinkmann *et al.* 1988; Chandiwana *et al.* 1987; Kloos *et al.* 1983; Watts *et al.* 1998; Gazzinelli *et al.* 2001; Bethony *et al.* 2001) and even less tried to relate these to infection levels and patterns (Kabatereine *et al.* 1999; Woolhouse *et al.* 2000; Scott *et al.* 2003).

We have maintained detailed direct water contact observations in Ndombo during the first years of the *S. mansoni* epidemic in Northern Senegal. The analysis of this unique dataset, amounting to over 120,000 recorded contacts, is presented here. We quantified water contact activities in terms of frequency and duration, and described how these vary with age and sex. In this way, we aimed to determine whether water contact patterns in Ndombo were exceptional or comparable to those in traditional schistosomiasis endemic communities in sub-Saharan Africa. Moreover, we assessed the relationship between water contact- and infection intensity patterns to further elucidate the contribution of exposure to the transmission of schistosomiasis.

3.3 Materials and methods

Study site and population

The study took place in Ndombo, a village situated 3 km south of the city of Richard Toll in the Delta of the Senegal River Basin (Northern Senegal). The village counts about 3000 inhabitants, mostly Wolof ethnic group of Muslim faith. The majority of the population works in rice farming, small-scale market gardening, fishing, or is employed in the nearby sugar cane estate. The climate in the area is arid and characterized by a hot dry season with temperatures up to 45°C (April to June), a hot and humid period (July to October), and a relatively cold dry season between November and April in which temperatures can drop to 10-15°C. The village is situated along a man-made canal and marshland (Taouey) that connects the sugar cane plantations, the Senegal River, and an inland lake. The population depends largely on this water source for domestic, recreational as well as occupational purposes, and most water contact activities take place at five well-defined sites on the banks of the canal and the marshland (Figure 3.1).

Data collection

Direct observations of individual water contacts were carried out from September 1991 to September 1993 (25 months). The sites selected for the study were the main water contact sites in the village where most activities leading to schistosomiasis infection occurred (see Figure 3.1). Twelve observers with formal education were chosen among the villagers and submitted to one week of training before the start of the study. The water contact behavior of the whole population of Ndombo was observed from 6 a.m. till 7 p.m. (13 hours) seven days each month. For each site, the observers were divided into pairs. The first shift with the first observer was from 6 to 12.30 a.m., the second from 12.30 to 7 p.m. For the most crowded site (site II in

Figure 3.1), two teams of observers were selected, whereby one team observed the males and the other team observed the females. A local supervisor randomly visited the observers several times per observation day to make sure that the observations were accurate and standardized.

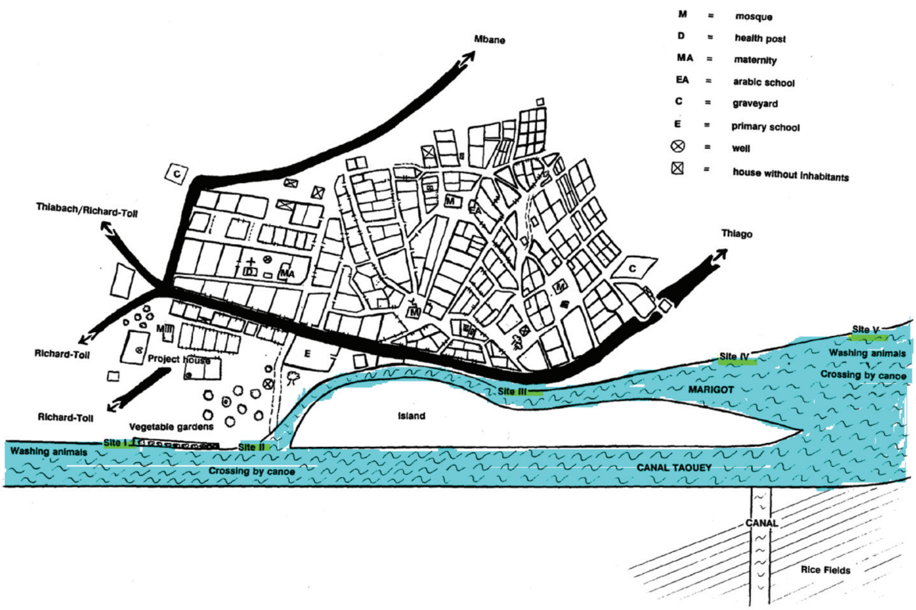

Figure 3.1 Main water contact sites in the village of Ndombo, Northern Senegal.

Each individual entering the water was identified by the observer and recorded in a notebook by name, age, sex, type of water contact activity, time of entrance into, and exit out of the water. Nine different types of activities were recorded: a] *(Dis)embarking*: embarking or disembarking a boat to cross the stream; b] *Small bath*: small bath, ablution and/or drinking; c] *Bathing*: bathing with or without soap, swimming and/or playing; d] *Collecting water*: fetching water for domestic purposes; e] *Household*: doing laundry and/or dishes; f] *Animals*: watering and/or washing animals in the water; g] *Private toilet*: washing of genitals, bottom; h] *Fishing*: fishing related activities in or near the water; i] *Irrigation*: irrigation and/or removing vegetation from the water. If a range of activities, i.e. more than one type of activity, took place between time of entrance into the water and exit out of the water, these were noted down consecutively, and marked as combined activity. Among the water contact recordings of the total population, only those individuals belonging to the four studied cohorts were considered in our study. These cohorts consisted of random population samples of approximately 400 subjects each, selected at 8-month intervals between 1991 and 1994, and examined for *S. mansoni* infection by egg counts in stools, using the Kato-Katz method (Stelma *et al.* 1993; Gryseels *et al.* 1994). Their corresponding individual codes were recorded in the notebooks retrospectively. The data were entered daily into a Microsoft Excel database, and extensively checked for errors, suspicious values and outliers.

Data analysis

Two exposure indices were used, frequency and duration of water contact. Frequency was defined by the number of water contacts, irrespective of the (type of) activity. A range of two or more observed activities was considered as one water contact. Table 3.1 lists the single and combined activities which were used to determine frequencies. Duration was defined by the time spent in the water during a water contact activity. In case of a combination of two or more observed activities the most dominant was chosen, based on degree of exposure and/or duration of contact, or they were split up when one was not clearly dominant over the other (Table 3.2). Table 3.3 shows the resulting total and average durations of activities.

Frequencies and durations of water contact data were further categorized per age group (0-9 years, 10-19 years, more than 20 years old) and sex. They were divided according to season (hot wet, hot dry, and cold dry), time of the day (divided into hourly intervals) and type of activity (see above). These exposure indices were averaged and related to intensity of infection, as expressed by the arithmetic mean eggs per gram feces (EPG), both pre-control and measured 1 year after treatment.

3.4 Results

The number of recorded contacts was 121,771 (Table 3.1) with 1,257,985 minutes of observed water contact spread over 2 years (September 1991 - September 1993). Bathing/swimming appeared to be the main activity, both in terms of duration and frequency, followed by household activities. Some categories took relatively long, but occurred rarely, such as fishing; for other activities, such as collecting water, it was the other way around (Table 3.3). Fishing, (dis)embarking, small bath, animals, private toilet and irrigation played a negligible role, both in terms of frequency and duration.

Table 3.1 Overview of all 121,771 observed water contacts of the 1,651 members of four epidemiological cohorts in Ndombo, Northern Senegal, during 175 days (7 days in each of 25 successive months) of observations. First the frequency and duration of all nine single water contact activities are given, followed by the most frequently observed combined activities.

Activity	Description	Total duration (min)	Total count	Average duration (min)
a	(Dis)embarking	8858	4407	2.0
b	Small bath	11781	3670	3.2
c	Bathing	617543	54844	11.3
d	Collecting water	55659	29141	1.9
e	Household	91404	3282	27.9
f	Animals	13353	1215	11.0
g	Private toilet	510	216	2.4
h	Fishing	9353	383	24.4
i	Irrigation	11979	1572	7.6
Subtotal		820439	98730	8.3
a + b	(Dis)embarking + small bath	957	368	2.6
b + d	Small bath + collecting water	5018	945	5.3
b + g	Small bath + private toilet	368	102	3.6
c + d	Bathing + collecting water	213561	14285	15.0
c + d + e	Bathing + collecting water + household	6711	203	33.1
c + e	Bathing + household	144252	3740	38.6
c + f	Bathing + animals	18889	1221	15.5
c + h	Bathing + fishing	2440	81	30.1
c + i	Bathing + irrigation	10331	483	21.4
d + e	Collecting water + household	34494	1453	23.7
d + g	Collecting water + private toilet	317	120	2.6
Other	Combined activities with <50 observations	208	40	5.2
Subtotal		437546	23041	19.0
Total	All activities	1257985	121771	10.3
	Per individual	762	74	
	Per individual per day	4.4	0.42	

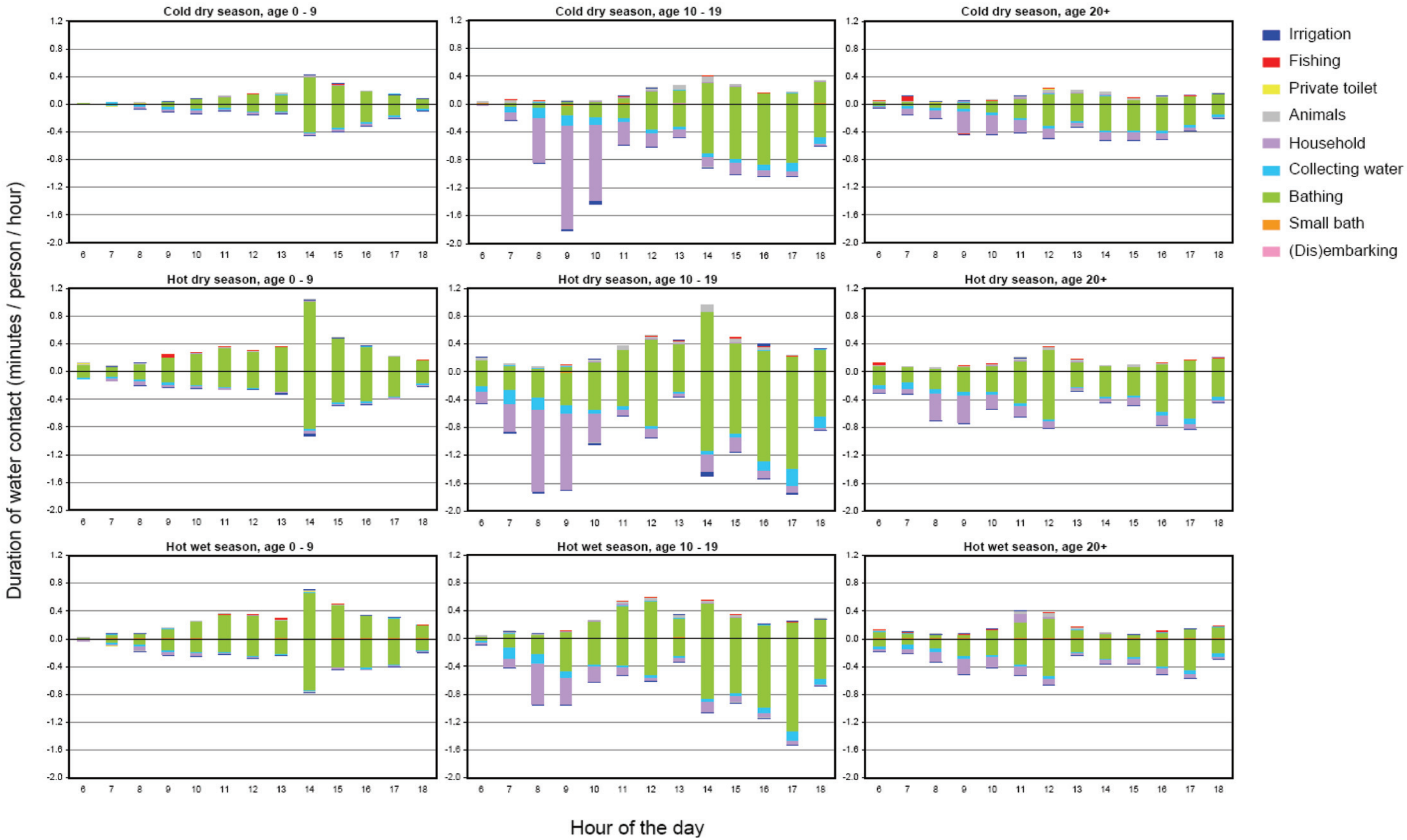

Figure 3.2 Duration of water contact by season, hour of the day, age, sex (boys up = positive values; girls down = negative values), and type of activity (see legend) for 1,651 inhabitants of the rural village of Ndombo in Northern Senegal as recorded during 175 days of observational studies. This graph reflects the division of the total durations (i.e. 1,257,985 min) given in Table 3.3. Hour of the day is the first moment of each one-hour interval.

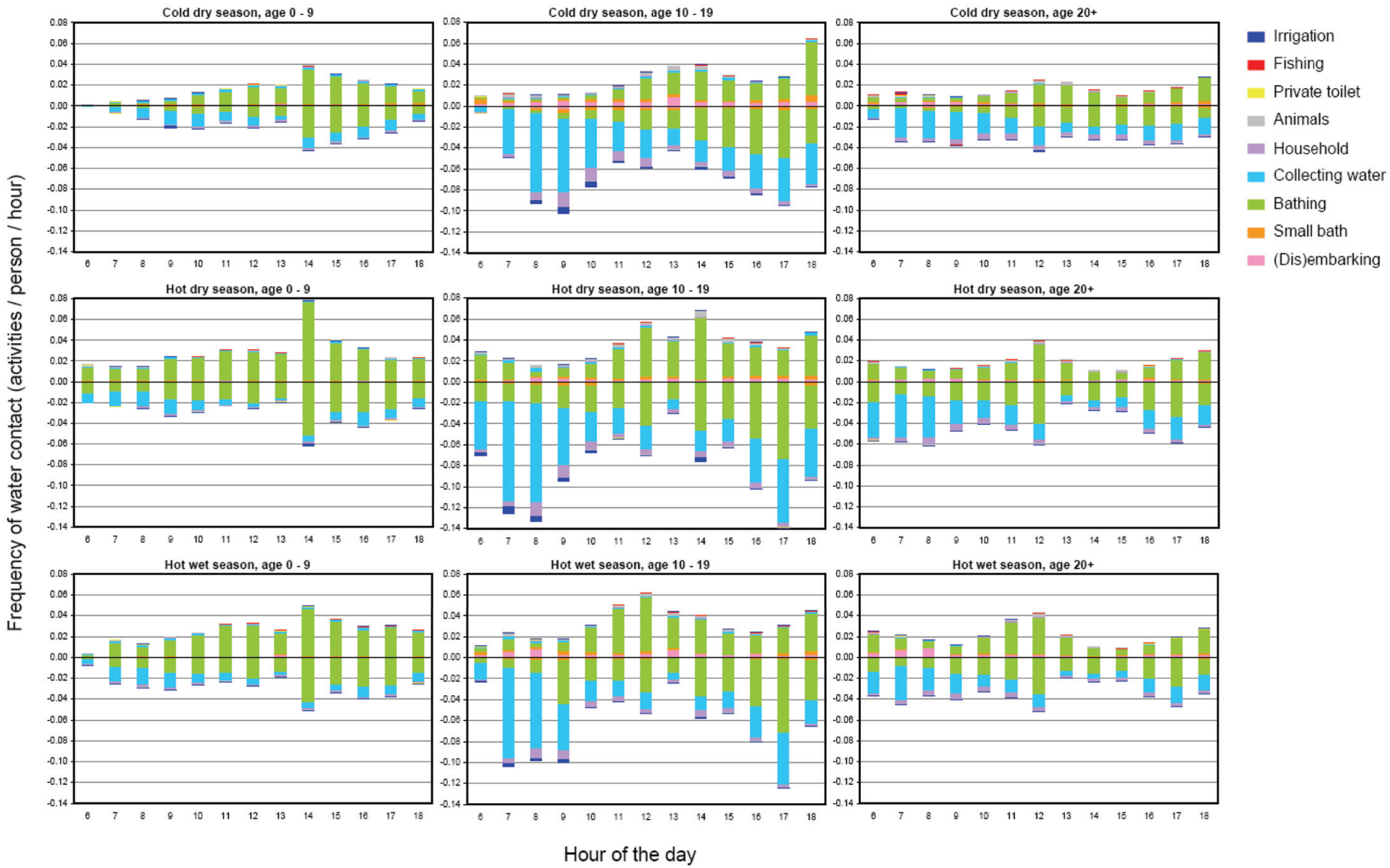

Figure 3.3 Frequency of water contact by season, hour of the day, age, sex (boys up = positive values; girls down = negative values), and type of activity (see legend) for 1,651 inhabitants of the rural village of Ndombo in Northern Senegal as recorded during 175 days of observational studies. This graph reflects the division of the 121,771 total frequencies given in Table 3.1, where combinations of two or three activities were attributed to the corresponding single activities with weight of 0.50 and 0.33, respectively. Hour of the day is the first of moment of each one-hour interval.

Table 3.2 Decision triangle illustrating how combined water contact activities were dealt with. The left column and lowest line indicate single activities (bold). The corresponding cell represents the decision made: (1) one of both activities was considered dominant (only the dominant activity is given in the cell); or (2) both activities were considered relevant (both are given). In the latter situation, for calculations of durations per activity (Table 3.3 and Figure 3.2), the combined activity was split proportionally to the average durations of the single activities (upper half of Table 3.1). All combinations were treated symmetrically, i.e. the decision about 'a + b' and 'b + a' was the same. Combinations of three activities followed the same procedure. For example, 'a + b + c' results in 'c', and 'g + h + i' results in 'hi'. The meaning of the codes for the nine single activities is given in Table 3.1.

a									
b	ab								
c	c	c							
d	d	bd	cd						
e	e	e	ce	de					
f	f	f	cf	f	e				
g	ag	bg	c	dg	e	f			
h	h	h	ch	h	e	h	h		
i	ai	i	ci	i	e	f	i	hi	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**

Figure 3.2 and 3.3 show the duration and frequency of water contact per season, age and sex. Although in the hot dry season water contacts were slightly more intense than for the other seasons, patterns of both duration and frequency depend much more on age than on the season. In the age group of 10-19 years, longer and more frequent water contact was observed than in the other age groups. Women showed substantially more and longer water contact than men; for the older age groups (10-19 and more than 20 years), duration and frequency of water contact in women were even twice that of men. Female adolescents (10-19 years) showed the most intense water contact, which is mainly due to collecting water more often and a longer time spent on household activities. Most intense water contact occurred between noon and 2 p.m. for men; for women two distinct peaks were observed, one between 2 and 5 p.m., and one between 8 and 10 p.m.

Table 3.3 Overview of the total and average durations of the nine types of water contact, after dealing with the combined activities. See Table 3.1 for the number of subjects and observation time.

Activity	Description	Total duration (min)	Total count	Average duration (min)
a	(Dis)embarking	9255	4802	1.9
b	Small bath	15755	5100	3.1
c	Bathing	859996	74857	11.5
d	Collecting water	91184	46158	2.0
e	Household	230961	8678	26.6
f	Animals	22683	2436	9.3
g	Private toilet	882	473	1.9
h	Fishing	11076	466	23.8
i	Irrigation	16194	2060	7.9
Total	All activities	1257985	145015	8.7
	Per individual	762	88	
	Per individual per day	4.4	0.50	

Figure 3.4 shows for each age- and sex group the infection intensity in relation to duration and frequency of water contact. It is clear that EPG-values (both pre-control and 1 year after treatment) are not linearly related with water contact. Especially adult females had lower egg counts than would be expected from the duration and frequency of their water contacts, while male adolescents appeared to have the highest EPG/water contact ratio. The average number of water contacts per person per day in this population was 0.42; the average time spent in the water per person per day was 4.3 minutes.

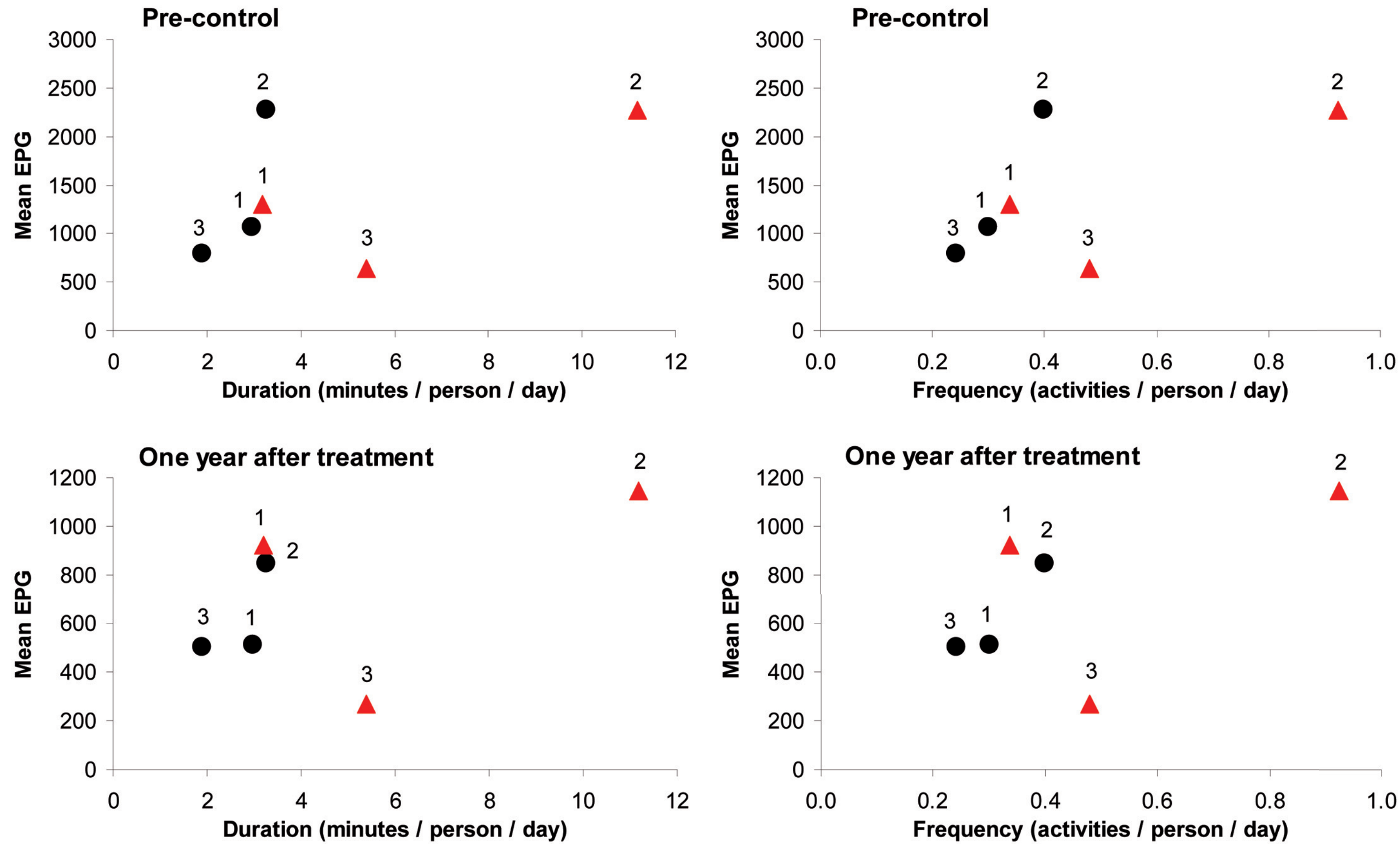

Figure 3.4 Infection intensity (arithmetic mean EPG, both pre-control and one year after treatment) in relation to duration and frequency of water contact, for six demographic groups based on three age categories and both sexes. The durations are the accumulation over season, hour of the day, and type of activity of the values for each demographic group in Figure 3.2. Similarly, the frequencies are the accumulation of values in Figure 3.3. Black dots = males, red triangles = females; 1 = 0-9 years, 2 = 10-19 years, 3 = 20 years and above.

3.5 Discussion

After the outbreak of a *S. mansoni* epidemic, extremely high infection rates and typical endemic-like age-related infection patterns were observed in Ndombo, Senegal. The main justification of the current study was to determine the contribution of water contact behavior to these exceptional observations. Descriptive analysis of the water contact activities showed that bathing was the main activity, followed by household activities; water contacts peaked in adolescents; women spent almost twice as much time at the water than men; water contacts were more intense in the afternoon than in the morning, with sex-specific intensity peaks; and frequency and duration of water contact depended on age and sex rather than season. These findings are not unusual and have been described before in various other settings (Fulford *et al.* 1996; Chandiwana & Woolhouse, 1991; Watts *et al.* 1998; Gazzinelli *et al.* 2001; Coulibaly *et al.* 2004; Kloos *et al.* 2006; Ndassa *et al.* 2007; Pinot de Moira *et al.* 2007). Since infected snails were attested to be present throughout the year (Sturrock *et al*. 2001) and marked seasonal variations of water contact behavior appeared to be absent, transmission in this area is likely to be perennial.

Also in terms of the number of water contacts per person per day, our results in Northern Senegal did not show marked differences with other schistosomiasis endemic countries where intensive observational water contact studies have been performed. Indeed, our finding of an average of 0.42 contacts per person per day is within the range of Fulford *et al.* (1996), who reported a mean annual frequency of 12.8 to 162 water contacts/person among seven *S. mansoni* endemic communities in Kenya, which is 0.04 to 0.44 contacts/person/day (median 0.17). Exact average water contact durations for these communities were not reported, but from the graphs it can be deduced that this was about 880 minutes/person annually, and thus 2.4 minutes per day. Again, this is of the same order of magnitude as the average duration of 4.3 minutes spent in the water per day as presented here for Northern Senegal. Chandiwana & Woolhouse (1991) reported a mean rate of water contact of 0.43 contacts/person/day (ranging from zero to 3.3 contacts/person/day), in a *S. haematobium* endemic area in Zimbabwe, which is remarkably similar to our values for Senegal. Other water contact studies based on direct observations used different exposure indices, which precludes straightforward comparison (Wilkins *et al.* 1987; Demeure *et al.* 1993; Woolhouse *et al.* 2000). Nevertheless, from the available observational water contact studies we can conclude that the water contact levels in Ndombo are not exceptionally high and thus cannot explain the extremely high infection intensities in this area as compared to the other studies.

Both infection- and water contact patterns in this community were found to be clearly age-and sex-related. Looking at these patterns more closely however, we found that in the respective age- and sex groups more or longer water contact did not unequivocally lead to high infection intensities (Figure 3.4). In the oldest two age groups, women showed substantially more and longer water contact than men, while infection levels were comparable. An explanation for this finding could be that male water-related activities entail relatively intense water contact. Indeed, the main male activity was bathing, which can be considered a more risky behavior in terms of body exposure as compared to typical female activities such as collecting water or doing laundry/dishes. Moreover, in men most intense water contact occurred between noon and 2 p.m., the part of the day when cercarial emission has been reported to be highest in the Senegal River Basin (Southgate *et al.* 2001), while women's water contact peaked in the afternoon and evening. On the other hand, male adolescents showed much higher infection levels than the other male age groups, while they did not bath significantly more or longer than young or adult men, nor at different times of the day.

Despite observed differences in infection- and water contact patterns depending on age and sex, there is thus no evidence suggesting that exposure has an important influence on intensity of infection before or one year after treatment in this *Schistosoma* epidemic focus. Similar conclusions resulted from studies in stable endemic situations (Wilkins *et al.* 1987; Butterworth *et al.* 1988; Hagan, 1992; Kabatareine *et al.* 1999). A few have found some relationship between water contact and infection intensity, although not very strong/convincing (Kloos *et al.* 1983, 1998; Chandiwana & Woolhouse, 1991). It should be noted that for any of these studies, including ours, it cannot be excluded that exposure factors other than those taken into account, may have somehow contributed to the observed age- and sex-related differences in infection levels (Wilkins *et al.* 1987; Scott *et al.* 2003). In the specific case of Ndombo, an obvious alternative explanation for the extremely high intensity levels other than exposure would be the absence of acquired immunity in this recently exposed, supposedly non-immune community, but this does not correspond with the observed endemic-like age-related infection patterns in this community (Stelma *et al.* 1994; Polman *et al.* 1995).

For women, the ratio of infection intensity to water contact (i.e. the slope of a hypothetical line from the origin to a point in Figure 3.4) clearly decreased with age, suggesting an increasing degree of resistance with age. In an epidemic focus like Ndombo, immunity should not, or at most partially, have developed at the time of the data collection. Thus, this resistance is more likely to be due to some other age-related, innate factor (Gryseels *et al*. 1994; Polman *et al*. 2002; Scott *et al*. 2003).

In men, however, this pattern seemed to be absent (Figure 3.4). As yet, there is no biological evidence that could explain why such resistance would only occur in adult women and not in adult men. Post-pubertal hormonal or other (both age- and sex-related) factors may play a role. For example, Fulford *et al.* (1998) suggested that gonadal steroids affecting the immune system may lie behind the common observation, originally made by Butterworth *et al.* (1984), that women are usually infected less heavily than men yet generally have more water contact.

To our knowledge, this is the largest dataset published so far of directly observed recorded water contacts, spanning a two year time period in the early years of an *S. mansoni* epidemic. Direct water contact observations have more quantitative and qualitative value than water contact information based on questionnaires, which are easy to perform but have inherent well-known limitations such as overreporting, recall bias and information bias (Friedman *et al.* 2001; Payne *et al.* 2006). This is illustrated by a questionnaire-based study in four villages in the same *S. mansoni* affected area as Ndombo (Scott *et al.* 2003). This study reported a mean of 4.4 water contacts per day with a median duration of 57 min per day, which is in sharp contrast with the relatively low numbers found in the present study. It has been noted before that levels and patterns of contact can vary dramatically between culturally similar communities, and even within a single village (Fulford *et al.* 1996; Pinot de Moira *et al.* 2007), but these extreme numbers are more likely to be due to the way the water contact information was collected (Payne *et al.* 2006).

A few limitations are present in this study. All water contact measurement tools, including direct water contact observations are only an indirect measure of true exposure, i.e. exposure to infectious cercariae. It is impossible to determine true exposure (Fulford *et al.* 1996). Different authors have approximated and compared exposure from water contact behavior in various ways (e.g. Hagan *et al.* 1985; Wilkins *et al.* 1987; Sama & Ratard, 1994; Fulford *et al.* 1996; Woolhouse *et al.* 2000; Scott *et al.* 2003; Bethony *et al.* 2004; Kloos *et al.* 2006), but the possibility will always remain that their and our conclusions are based on an inadequate understanding of how water contact translates into exposure. Moreover, direct water contact observations may be subject to 'observer effects', and cannot provide information on activities taking place outside the limits of observation time or of observation sites (Gazzinelli *et al.* 2001). For example, we did not observe a single act of direct defecation into the stream, even though such an activity would occasionally be expected, at least for children, to explain the intense transmission of *S. mansoni* in this area (Sow *et al.* 2008). Also, some fishing-related contacts may have gone unnoticed, as fishing by its nature is much dispersed (Pinot de Moira *et al.)*

In conclusion, the water contact levels in Ndombo are not exceptionally high and thus cannot explain the extremely high infection intensities as observed in this area during the *S. mansoni* epidemic. Absence of an effective acquired immunity could play a role, but this is in contrast with the strongly decreasing ratio of infection intensity/water contact with age that we found for women, as well as with previous immuno-epidemiological studies in the same area (Stelma *et al.* 1994; Polman *et al.* 1995). Although both infection- and water contact patterns in this community were found to be age- and sex-related, there is no clear relationship between exposure and infection intensity, neither before nor one year after treatment in this *Schistosoma* epidemic focus. The finding that water contact and infection levels do not correspond with each other, indicates that in this population other factors than exposure have principal importance in determining intensity of infection. Further research is needed, with respect to the translation of water contact data into actual exposure, as well as the relation between exposure and actual *Schistosoma* infection at the individual level.

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Chapter 4

Hygienic practices and contamination risks of surface water by schistosome eggs: the case of an infested village in Northern Senegal

Sow S, De Vlas SJ, Polman K, Gryseels B

Translated from:

Pratiques hygiéniques et risques de contamination des eaux de surface par des oeufs de schistosomes: le cas d'un village infesté dans le nord du Sénégal

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4.1 Summary

The transmission of intestinal schistosomiasis presumes that faecal material containing viable schistosome eggs reaches natural water infested with snail intermediate host. So far there is little knowledge about the contamination dynamics of streams with schistosome eggs. We conducted a pilot study on defecating behavior and hygienic practices in a *Schistosoma mansoni* endemic focus in Northern Senegal. Questionnaires were used to obtain quantitative data on hygienic practices and the use of latrines in 59 children. Although the community was well endowed with pit latrines, most of the children declared that they usually defecated somewhere else, in particular near the streams where the vegetation offers hideouts. Observations based on mapping of defecation sites showed that a considerable number of stools were left just a few meters from the riverbank, thus bearing a high risk of being washed off into the water. All these practices can easily lead to contamination of water bodies with schistosome eggs. In order to improve hygienic practices and reduce fecal pollution of the environment, a health education model respecting local beliefs and customs would be indispensable.

4.2 Introduction

The continuity of the life cycle of the most important African schistosomes, *Schistosoma mansoni* and *S. haematobium*, depends on the deposition of schistosome eggs in water bodies inhabited by snails intermediate hosts. This phenomenon is probably the least understood part of the parasite life cycle (Jordan *et al*. 1981). For *S. haematobium*, it is probable that children and also adults urinate directly into the water. For *S. mansoni* however, it is less conceivable that defecation in the water plays an important role in the contamination of streams. It is more likely that stools are deposited near the water and washed into the streams through various routes, influenced by human, environmental, technological or geographical factors (Rosenfield & Bower, 1979). For a better understanding of *S. mansoni* transmission, as well as for designing adequate sanitation measures to reduce schistosomiasis transmission, a good knowledge of the mechanisms that lead to the contamination of water sources is essential. So far, only few studies have been devoted to this subject (Chandiwana, 1986; Cheesmond & Fenwick, 1981; Husting, 1965). These studies were essentially based on direct observations and therefore at risk for observer bias.

The main objective of this pilot study was to determine how some hygienic practices contribute to the contamination of surface water, in order to better understand one of the least studied aspects of schistosomiasis transmission dynamics.

4.3 Materials and methods

In March 2002 (dry season), we carried out a pilot study in the village of Kassak-Nord, situated near the epicenter of an intestinal schistosomiasis epidemic in the Saint Louis region in Northern Senegal. The village is located on the left side of the Lampsar, a tributary to the Senegal River. The population is estimated at 1200 inhabitants, and 90% of the households have latrines. According to the files of the local health centre, the prevalence of *S. mansoni* infection is around 60% among schoolchildren.

A questionnaire about hygienic practices and defecation habits that may lead to contamination of water bodies was submitted to 30 randomly chosen schoolchildren (age 6 to 12 years; 5 children per classroom in a school with 6 classes). For comparison, an identical number of mothers of pre-school children were interviewed about their child's hygienic practices. Due to a lost questionnaire the total number of subjects for analysis was 59 instead of 60. Also, mothers were interviewed about their practices regarding baby diapers after use.

In order to visualize the environmental fecal pollution, the defecation sites near the streams were mapped. During one week, fresh stools were counted every day and spotted on a map, and the distance of the stools situated closest to and furthest away from the water were estimated on a daily basis.

4.4 Results

The responses to the questionnaires revealed the following. There was an average of 2 defecations per person per day (see Table 4.1). Twenty-four percent of the interviewees defecated in the open air. All respondents cleaned themselves after defecation. Means to do so varied, but a majority of the respondents used water (81%). 'Private toilet' was practiced in both age classes, with the difference that some schoolchildren also washed their hands (38%). Bathing in the streams just after defecation was reported by 8% of the children. Defecations at the banks of the streams were two fold more frequent among schoolchildren than among the younger group. In addition, 44% of all respondents stated that some of their friends also defecated close to the streams. Concerning latrine use, 69% of the schoolchildren never or very rarely used them. The reasons for not using latrines varied considerably (see Table 4.1).

Twenty-seven percent of the parents washed the baby diapers in the river, 20% at the banks, and the others washed them at home (53%).

The mapping of defecation sites showed that all the stools followed up during one week were still present. Some dried up but had not completely disappeared. The mapping also showed that the risk of pollution of water with fecal material was not negligible. Indeed, 22% of the stools were located between 0 and 2 meters from the edge of the water courses, 37% between 2 and 10 meters and 41% at more than 10 meters.

4.5 Discussion

This preliminary survey does not pretend to describe all aspects that contribute to the contamination of water with schistosome eggs. A more comprehensive study is ongoing. Here, we attempted to assess certain behavioral factors that might contribute to the infestation of water courses with schistosome eggs.

It is remarkable that 24% of the interviewees claimed to defecate in the open air, specifically on the banks of the water bodies where vegetation offers hideouts

(Table 4.1). Therefore, the probability that these stools somehow reach the water is considerable. Although all respondents claimed to clean themselves after defecation, plants or wooden sticks may not entirely remove fecal material adhering to the peri-anal region. Thus, when these people would enter the water after defecation, they could contaminate natural water bodies, as has been suggested by Husting (1965) and El Katsha & Watts (1997). In addition, during the rainy season, part of the stools deposited in the open air would be washed into the river by heavy tropical rains.

The study village is relatively well provided with latrines but their use remains marginal. An important fraction of the children never use them because they are dirty, which highlights issues of hygiene and over-use. Indeed, in these rural areas, a household may contain up to 60 or more individuals. Moreover, the design of latrines is not always secure, particularly for young children, some of whom are afraid to fall in; apparently the latrines are not adapted to the local socio-cultural context. It is also possible that children do not see any advantage in using latrines when they can just go in the open air where anonymity is guaranteed and where they are close to their playing or working grounds. Moreover, they still have little sense of shame, so they have no problem to defecate in any environment.

One third of the mothers stated that they washed their baby diapers in the streams. The same practice has been observed in Egypt (El Katsha & Watts, 1997). Obviously this only constitutes a risk of contamination if very young children are indeed affected by the disease. In fact, in a study carried out in the same area, Stelma *et al.* (1993) observed a prevalence of around 30% among children of 0-4 years.

It can be concluded from the present pilot study that local schistosomiasis transmission is strongly determined by the disposal of excreta and by individual hygienic practices, which thus represent a major risk of pollution of surface waters. The mapping of defecation sites has revealed a clear tendency to defecate in nature where privacy is usually ensured. These habits certainly arise from a lack of knowledge of the role of excreta in the contamination of water bodies, but also from a certain community perception of hygiene and sanitation.

The hygienic behavior of schoolchildren deserves particular attention. Indeed, the role of children in the transmission is worrying, since 20% claimed to defecate near the streams, and since this is the age group that has the highest infection intensities and produces the majority of eggs. In addition, children play a central role in the transmission of schistosomiasis because of the importance of their contacts with infested waters (Schall, 1998). The lack of knowledge and the attitudes and traditions of the local population require more detailed studies to allow appropriate management.

Table 4.1 Defecation behavior in the two age groups (Figures represent percentages)

Question	Pre-schoolchildren (n=30)	Schoolchildren (n=29)	Total (n=59)
Number of stools per day			
One stool	27	21	24
Two stools	57	52	54
Three stools	17	28	22
Defecation sites			
At home	80	45	63
At school	7	21	14
In the open air	13	35	24
Means used to clean oneself			
Plants/grass	7	3	5
Paper sheets	3	7	5
Water	83	79	81
Wooden sticks	7	10	8
Body parts cleaned			
Bottom	80	55	68
Hands and bottom	10	38	24
Bathing	10	7	8
Defecation near the water			
Yes	13	28	20
No	87	62	75
Don't remember	0	10	5
Other children defecating close to the water			
Yes	47	41	44
No	40	17	29
Don't remember	13	41	27
Latrine use			
Always	-	31	31
Sometimes	-	24	24
Never	-	45	45
Reasons for not using latrines			
Absence of latrine	-	15	15
Latrine too dirty	-	25	25
Latrine often occupied	-	20	20
Phobia of latrines	-	20	20
Use of school latrines	-	20	20

The prevention of risk of contamination of surface waters with schistosome eggs should arise from a behavior change, focusing on individual hygienic measures and the promotion of systematic use of latrines, through a model of health education adapted to the local context. Meanwhile, local authorities, scientists, technicians and other stakeholders should make an effort to better adapt interventions and infrastructure to the attitudes, preoccupations and expectations of the local population.

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Chapter 5

The role of hygienic bathing after defecation in the transmission of *Schistosoma mansoni*

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5.1 Summary

Transmission of *Schistosoma mansoni* depends on fecal eggs reaching water, but the way this happens is poorly understood. We studied the role of hygienic bathing after defecation in the contamination of water with *S. mansoni* eggs. Individuals in an endemic community in Northern Senegal (*n* = 991) were examined for *S. mansoni* infection and a random sample (22%) was interviewed about stool disposal practices and hygienic behavior. We assessed the presence and viability of *S. mansoni* eggs adhering to the peri-anal region of 13 infected volunteers, by counting the miracidia in the water they had used for hygienic washing; for 10 of them (77%) miracidia were demonstrated. From the population infection distribution, average number of defecations per day, proportion of individuals bathing after defecation, and association between miracidial counts and infection intensity, we calculated a daily population miracidial output of about 30,000 through hygienic bathing. For comparison, one complete stool reaching the water was calculated to yield about 2,500 miracidia. Thus, 12 individuals in this population should defecate into the water every day to produce the same number of miracidia as through hygienic bathing. Our results suggest a major role of hygienic bathing after defecation in the transmission of *S. mansoni*.

5.2 Introduction

Transmission of *Schistosoma mansoni*, a parasitic worm responsible for intestinal schistosomiasis, depends on viable eggs in human excreta reaching water inhabited by snail intermediate hosts. The way in which this happens is probably the least understood part of the life cycle of the parasite. For urinary schistosomiasis, caused by *S. haematobium*, it is conceivable that children in particular but also adults urinate directly into the water. For intestinal schistosomiasis, however, direct defecation into the water seems much less likely. In fact, the act of defecation is a cultural taboo in many traditional societies, and direct deposition of stools into streams is considered unacceptable, even for children (Chandiwana, 1986; Curtis *et al*. 1993). Nevertheless, *S. mansoni* transmission is very efficient, as appears from the high re-infection rates that are commonly observed after treatment programs (Gryseels, 1996).

Many have favored the hypothesis that infected stools deposited on the banks of rivers and ponds are washed into the water by heavy rains or floods (Vercruysse *et al*. 2001). This undoubtedly occurs, but can account for transmission to humans only during the rainy or post-rainy seasons, given the limited life span of infected snails (Anderson & May, 1979; Sturrock *et al.* 1979; Theron & Coustau, 2005). Nevertheless, infection and re-infection is known to be rather common in the dry season (Chandiwana, 1986; Sturrock *et al*. 2001). Another possible, although rather coincidental, cause of contamination of water with *S. mansoni* eggs is by animals (e.g. cattle, dogs) walking through defecation sites and carrying the human feces on their hooves or legs into the water. Animals may also act as reservoir hosts of human schistosomiasis and as such contribute to the transmission cycle, as suggested by different reports on natural infections with *S. mansoni* in rodents (Mansour, 1973; Rollinson *et al*. 1986). However, the role of animal reservoirs in *S. mansoni* transmission is usually considered to be modest or even nonexistent (Adewunmi *et al*. 1991; Duplantier & Sène, 2000).

We hypothesize that bathing after defecation (with small amounts of fecal material with viable schistosome eggs adhering to the peri-anal region being washed into the water) plays an important role in the transmission of *S. mansoni*. Transmission of this type (henceforth indicated as 'hygienic bathing' or 'hygienic washing') is expected to be year-round and does not depend on a series of accidental events. The aim of this study in Northern Senegal was to determine the presence and viability of *S. mansoni* eggs trapped in the peri-anal region of infected individuals, and to estimate the relative importance of hygienic bathing in the contamination of water with *S. mansoni* eggs.

5.3 Materials and methods

Study population

This study was performed in September 2003 in Thiago, a village of about 1,200 inhabitants in Northern Senegal, endemic for *S. mansoni*, close to a stream and with a school and a functional community health center. A study on defecating behavior and hygienic practices in children in the same area showed that most of them never or rarely visited latrines, but defecated somewhere else (Sow *et al*. 2004). A popular place appeared to be in nature, in particular near streams. This was confirmed by observations based on mapping of defecation sites, which showed a considerable number of stools just a few meters from the riverbank. Most children reported using the water to clean themselves after defecating (i.e. hygienic bathing).

For all individuals of 5 years and above who agreed to participate in this study after informed consent, the intensity of *S. mansoni* infection was determined based on the number of schistosome eggs counted in a duplicate 25 mg Kato-Katz smear of two stools (Katz *et al*. 1972). Subsequently, a number of sub-studies were conducted to provide an estimate of the overall population miracidial production per day through the habit of hygienic bathing after defecation, compared to occasional direct defecation into the stream.

Data collection

First, a group of 13 volunteers (eight boys and five girls, all between 5 and 20 years old) with relatively high egg counts agreed to participate in the study to determine the presence and viability of parasite eggs in the peri-anal region, providing a measure of contamination through hygienic washing in the stream after defecation. Each participant received a kettle filled with 35 cl of 0.85% saline spring water and a plastic bucket. Instead of using water from the stream to wash after defecation, they were asked to use the provided saline water, collect the water with fecal remnants in the bucket and bring it to the laboratory. The water was then tested for the presence of miracidia (i.e. the developing larvae in the *Schistosoma* eggs) by a hatching test, and the number of miracidia per individual was counted.

A second group of 12 volunteers (nine boys and three girls, 5 to 20 years old) was willing to test the hatchability of eggs in fresh stools, providing a measure of contamination through occasional direct deposition of stools into the stream. For that purpose, each participant was asked to defecate in private and then bring the complete stool to the lab as soon as possible (which was always within 10 min). After homogenization, a sample of 2 g was taken from each fresh specimen for the hatching test.

Sample analysis

The number of viable miracidia for both groups was determined by a slightly adapted hatching procedure (Cheever, 1978; Upatham *et al*. 1976) (Tchuem Tchuente, personal communication). The samples were flushed and, for the second group, pressed through a nylon 500 µm tea strainer above one or more cone-shaped plastic cups of 100 ml. The strainer was rinsed with 0.85% saline spring water. The cups were left for sedimentation for 20 min. The supernatant was discarded, and saline water was added again. This procedure was repeated three times until the water cleared. Spring water was added to the sediment and poured into a side-armed flask. Water was added to the flask up to the brim. The flask was then covered with aluminum paper, except for the top of the side arm (2 cm), which was illuminated with a cold light torch. With a Pasteur pipette, approximately 1 ml of the supernatant was picked up after half an hour of exposition and directly placed into a cell well and checked for miracidia with a binocular microscope. This was repeated every 20 min and continued until 5 h after the start of the experiment. Samples that continued to show miracidia at the end of the day were re-checked the next morning. For each individual, the miracidial counts of all wells were aggregated and related to their egg load (eggs per gram, epg) as determined by Kato-Katz smear (see above).

Furthermore, a simple questionnaire was administered to a random sample of a quarter of the population about their defecating behavior. Questions included the average number of defecations per day and whether or not the interviewee practiced habitual bathing after defecation.

Finally, to provide crude estimates of average daily stool weights, five infected volunteers (two children and three adults) were asked to collect their 24 h stools for two consecutive days in a labeled plastic bucket (with cover) with a cellophane bag inside.

Statistical analysis

Linear regression was used to calculate the association between the log-transformed number of miracidia and the egg load, both for the group of 13 volunteers that provided anal wash water and the group of 12 volunteers that provided fresh stool samples.

From the above sub-studies, we calculated the overall population miracidial output through hygienic bathing and compared this value with the number of miracidia resulting from a complete stool reaching the water. The ratio between both values provides an estimate of the number of stools needed to be deposited into the water to equal the contribution from hygienic bathing to the contamination of water with *S. mansoni* eggs.

We applied univariate sensitivity analysis by varying the parameters underlying this ratio, including the 90% CI of the statistical associations between miracidial and egg counts. For the average daily stool weights, we used the median results of a bigger stool sample study on another parasitic worm disease in St Lucia as alternative values: 90 g (5-9 years), 122 g (10-14), 145 g (15-19), 160 g (20-29), 173 g (30-39) and 186 g (40 and above) (Bundy *et al*. 1987).

5.4 Results

Of the 991 inhabitants of Thiago (5 years and above) that agreed to participate in our study, 62% were found positive for *S. mansoni* infection. The overall mean intensity was 340 epg and did not show a marked pattern with age (Table 5.1). In total, 218 subjects (i.e. 22% of the study population) were interviewed about their defecating behavior. The average reported number of defecations per day was 1.6. This value ranged from 1.9 among the youngest age group to 1.2 among the oldest. On average, 47% reported practicing habitual bathing after defecation. This behavior occurred more often among children (52%) than in the oldest age group (33%). The average weight of 24 h stools was 130 g for the two children and 194 g for the three adults.

Figure 5.1A shows the association between individual egg counts and miracidial output after hygienic washing for 13 volunteers. Ten out of the 13 samples (77%) produced miracidia. Eggs in the peri-anal region hatched not only for people with high egg counts, but also for those who had relatively light infections. Linear regression of log [number of miracidia + 1] and log [epg] resulted in a slope that did not differ significantly from 1. Therefore, the overall association between miracidial count (y) and egg counts could be assumed to be proportional: y = 0.12 epg (90% CI 0.038–0.37; $P < 0.01$). The association between egg counts and miracidial counts for fresh stools showed less variability (Figure 5.1B). Here, 10 out of the 12 samples (83%) produced miracidia, and miracidial counts showed a clearly increasing trend with egg counts. Again, the overall statistical association could be assumed to be proportional: y = 0.13 epg (90% CI 0.052–0.34; $P < 0.01$). For both associations, age and sex of the host had no significant effect (data not shown).

From the values above, it can be calculated that this population of nearly 1,000 individuals releases approximately 30,000 miracidia per day due to hygienic bathing (Table 5.1). Direct deposition of a single complete stool into the water would result in approximately 2,500 miracidia. Thus, overall around 12 (= 30,000/2,500) complete stools should reach the water every day in order to contribute to transmission in the same order of magnitude as hygienic bathing. For children (5-14 years), one complete stool would result in about 1,300 miracidia, mainly due to the smaller size of their stools. In that case, as many as 23 stools would be needed to match up with the number of miracidia produced after hygienic washing.

Sensitivity analysis revealed that the variability of the statistical association between miracidial count and egg counts (Figure 5.1A) has the biggest impact; the 90% CI corresponds to a range of 4 to 37 complete stools, matching the population miracidial output through hygienic bathing. Using the daily stool production as observed in the study in St Lucia (Bundy *et al.* 1987) resulted in a slightly higher average (14 stools instead of 12).

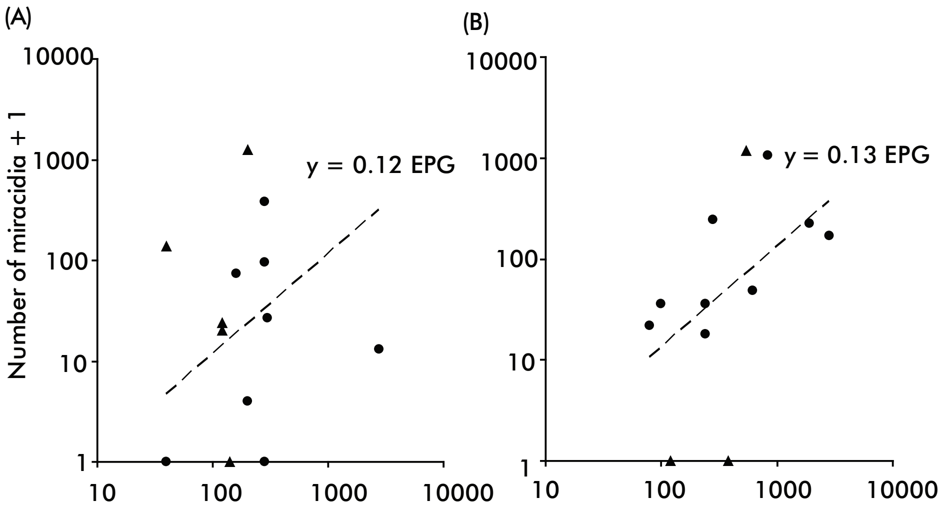

Figure 5.1 Association between number of miracidia, measured by hatching, and the intensity of *Schistosoma mansoni* infection, measured by Kato-Katz fecal smear. The fecal material for hatching came from: (A) hygienic washing by 13 volunteers and (B) random samples of 2 g fresh stool from 12 volunteers. Triangles and dots represent females and males, respectively. The curves were based on linear regression of log [number of miracidia + 1] against log [epg], assuming a proportional association.

Table 5.1 Calculation of the *Schistosoma mansoni* miracidial production for the village of Thiago, Northern Senegal, comparing contamination of the water through hygienic washing with (possible) direct of stools

Age group (years)	Epidemiological study		Questionnaire study			Miracidial output (thousands)	
	N_E* (a)	Arithmetic mean epg (b)	N_Q*	No. defecations per day (c)	Hygienic washing after defecation (%) (d)	Through hygienic washing per day (e)†	Through direct deposition of one stool (f)‡
5–9	300	257	70	1.9	51.4	9.0	1.1
10–14	193	289	40	1.6	53.0	5.7	1.5
15–19	168	423	25	1.4	48.0	5.7	3.8
20–29	118	638	42	1.6	42.4	6.1	5.0
30–39	89	133	20	1.3	41.6	0.8	1.3
≥40	123	373	21	1.2	33.4	2.2	3.9
Total	991	340	218	1.6	46.9	29.5	
					Weighed mean (all age groups):		2.5
					Weighed mean (5–14 years):		1.3

* N_E and N_Q represent the number of individuals in Thiago for the epidemiological and questionnaire study, respectively.

† The value of (e) = 0.12 (a).(b).(c).(d)/100, where 0.12 followed from Figure 1A.

‡ The value of (f) = (0.13/2).*W*.(b)/(c), where 0.13 followed from Figure 1B, and *W* is the weight of 24 h stools: i.e. on average 130 g for children (5–14 years) and 194 g for adults (≥15 years).

5.5 Discussion

In the majority of the individuals infected with *S. mansoni*, we could demonstrate active miracidia in the water they used for hygienic washing. This confirms that the infection can indeed be transmitted through this route. The overall population miracidial output through hygienic bathing matched with not less than four and on average 12 complete stools deposited directly in the water every day. Given the common practice of using streams for hygienic washing in this population in Northern Senegal, it may thus play a major role in the continuous and efficient transmission of *S. mansoni*.

We appreciate that our calculations of population miracidial output are based on small numbers of subjects, which allow for semi-quantitative results at most. It was not possible to recruit more individuals on a voluntary basis. Nevertheless, our finding that hygienic bathing by a whole population results in considerably more miracidia than a single stool deposited in the water is robust to a range of alternative assumptions, as demonstrated by the sensitivity analysis. More precise estimates of population miracidial output through different modes of transmission should follow from other, more extensive studies in different settings.

The importance of hygienic washing becomes intuitively clear from the following calculation. Figure 5.1 shows that a full anal wash and 2 g of stool result in about the same average number of miracidia for an individual with a given epg. To arrive at the population miracidial output, the anal wash result is multiplied by around 720, i.e. 1,000 individuals × 1.6 times defecating per day × 0.45 times hygienic washing. The result for 2 g fresh stool is multiplied by 60 to arrive at the average stool weight of about 120 g (note that the reported values of 130 g and 194 g represent 24 h stools). The ratio of 720/60 is exactly the value of 12, which resulted from the more detailed calculations using information from Table 5.1. Another conclusion that could be drawn from Figure 5.1 is that the amount of stool adhering to the peri-anal region after defecation is about the same as that of a fresh stool sample, thus 2 g. Differences in viability or concentration of eggs (Yu *et al*. 1998) may cause slight deviations, however. The exact amount of stool adhering to the peri-anal region, and the incorporated number of viable schistosome eggs, can only be obtained from additional studies.

Husting (1965) was the first to suggest that hygienic washing in streams is a probable route of contamination of water bodies with *S. mansoni* eggs. Also, Chandiwana (1986) reported that eggs remaining around the peri-anal region could be a major factor in the transmission of schistosomiasis mansoni, which would explain the continuation of transmission in the hot dry period in Zimbabwe. Furthermore, Cheesmond & Fenwick (1981) considered the transfer of eggs through bathing and washing of hands an evident way of contamination of water bodies in Egypt. We are the first to have experimentally demonstrated the validity of *S. mansoni* transmission through hygienic bathing.

As surface waters are common goods for drinking and other domestic activities, defecation into streams is not accepted and prohibited in traditional societies such as in Northern Senegal. This was confirmed by regular observational studies on water contact behavior in the same study area throughout a period of 3 years, which never resulted in a single observation of direct defecation into the water, even by children (unpublished data). We are aware that the presence of an observer may have resulted in more desirable behaviors, but even if people occasionally defecate directly into the water, it is very unlikely to have happened to an extent of a dozen of complete stools in the water every day in a population of about 1,000 individuals. Fecal material may also reach the water through accidental events, such as animals walking through defecation sites and carrying human feces into the water. However, there is no written evidence of such events, and the amount of fecal material transferred would probably be limited. Moreover, it has been shown that eggs in naturally deposited feces lose their viability within a couple of hours, certainly in a hot and dry climate as is usual in Northern Senegal (Kassim & Gibertson, 1976; Upatham *et al*. 1976). Furthermore, the role of an animal reservoir in the transmission of *S. mansoni* is usually considered negligible (Adewunmi *et al*. 1991; Duplantier & Sène 2000). These observations, in combination with our study results, suggest a major role for hygienic bathing after defecation in the transmission of *S. mansoni*, at least in the absence of rainfall (i.e. >90% of the days in Northern Senegal).

This finding probably applies to many more African populations endemic for schistosomiasis mansoni. It is, however, questionable whether this will contribute to new or better means of control. In Senegal, as in many parts of Africa, washing or bathing after defecation (and also after urination) is an important cultural practice, more than a religious one (Sow *et al*. 2004). Given this longstanding tradition, the introduction of alternative options would require substantial and possibly insurmountable behavioral changes. For example, latrines, as an alternative to defecation in the field, have rarely shown to be effective in traditional communities (Mertens *et al*. 1992; Vu Nguyen *et al*. 2006). Even putting an end to hygienic washing in streams may not yield the expected positive outcome, because remnants of fecal material of infected people may still be able to contaminate the water during playing or swimming, especially when considering that the eggs may survive for a long time in a moist environment such as the peri-anal region. The likelihood of this possibility can easily be tested using the same methodology as presented in the current study.

Last but not least, dissuading hygienic bathing as a control measure may even be detrimental, as the advantages of good hygienic practices could outweigh the disadvantages caused by schistosomiasis.

In conclusion, our study suggests that hygienic bathing after defecation is a major factor in the transmission of *S. mansoni*. It remains to be seen whether alternatives to hygienic washing in streams are successful or even desirable at all.

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Chapter 6

Low awareness of intestinal schistosomiasis in Northern Senegal after 7 years of health education as part of intense control and research activities

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6.1 Summary

We evaluated the awareness of and knowledge about intestinal schistosomiasis in a highly infected rural community of Northern Senegal where a variety of health information and education activities had taken place for 7 years as a component of different research and control programmes. As the infection had been introduced only recently, an initial ‘zero’ knowledge can be assumed. Most of the health education activities had been performed with adapted messages through local health and community workers. By a questionnaire, 566 individuals were asked simple questions on symptoms, mode of transmission, the sources of information and health-seeking behavior. About 86% of the respondents stated that they knew what schistosomiasis was, and 92% that in case of illness they would seek treatment at the health centre. However, only half of the people accurately quoted symptoms associated with intestinal schistosomiasis: diarrhea, abdominal pain and bloody stools. The majority of respondents realized that the disease was somehow linked with water and (lack of) hygiene, but only 44% of respondents reported water contact as the source of infection. Ultimately, only 30% of the respondents gave adequate answers about both symptoms and mode of transmission. We conclude that even intense and long-lasting education efforts for a specific and straightforward problem as schistosomiasis are not enough to have profound impact on the knowledge of rural traditional communities.

6.2 Introduction

After the construction of the Diama dam (completed in 1986) in the delta of the Senegal River Basin, the area experienced an unexpected epidemic of intestinal schistosomiasis (Talla *et al.* 1990, 1992). The first cases with *Schistosoma mansoni* infection were found in the city of Richard Toll (Northern Senegal) in 1988 and thereafter the number of cases rose dramatically in all the surroundings. The lack of safe water supply, poor sanitation, intense human water contacts and high density of the vector host (*Biomphalaria pfeifferi* snails) resulted in a very intense transmission. Subsequent epidemiological studies conducted in the area revealed extremely high prevalences and intensities of *S. mansoni* infection (Stelma *et al.* 1993; Gryseels *et al.* 1994). Since 1992, the number of cases with schistosomiasis disease that reported in the health system has risen dramatically (Sow *et al.* 2002).

Over the past decade, we conducted in-depth epidemiological studies in one traditional community village in the epicentre of the epidemic, Ndombo, situated near the city of Richard Toll and along the same canal (Gryseels *et al.* 1994). A wide variety of cross-sectional and longitudinal studies took place, ranging from immuno-epidemiological and ultrasound-based clinical studies to a 3-year long, village-wide water contact study (Stelma *et al.* 1993, 1994, 1997; Gryseels *et al.* 1994; Kardorff *et al.* 1996; Van Dam *et al.* 1996; Guissé *et al.* 1997; Thomas *et al.* 1997; Yazdanpanah *et al.* 1997; Burchard *et al.* 1998; Van Lieshout *et al.* 1999).

At least half of the population was examined and treated in clinical and parasitological surveys; all inhabitants had access to diagnosis and treatment in the local health centre. Each study was accompanied by extensive information and education campaigns, through various public channels: schools, religious meetings, community meetings and the local health services. Most of these activities were assured by the district and village health and community workers in the local language (Wolof) with appropriate messages. Several survey team members actually lived in the village. Investments were made in specific matters, e.g. a new sound system for public and religious messages, film evenings and strengthening of the local health centre. Apart from the treatment offered to survey participants, the health centre was provided with drugs and training to treat or refer patients.

In 1994, a regional schistosomiasis control programme was launched which also covered Ndombo, based on health education, strengthening health services and the distribution of praziquantel through intensified passive case detection and targeted community actions. Through various ways of information – billboards along roads, posters in villages (Figure 6.1), radio and television messages, community meetings, training of local health and community staff, activities of the local health centre – people with symptoms associated with schistosomiasis were encouraged to visit the local health services to be tested and treated. A recent evaluation showed that the level of training, equipment and supplies in the health centres had been satisfactory and the programmes successful in this respect (Van der Werf *et al.* 2002). The current study aimed at assessing the perception and measuring the level of knowledge about intestinal schistosomiasis in the general population.

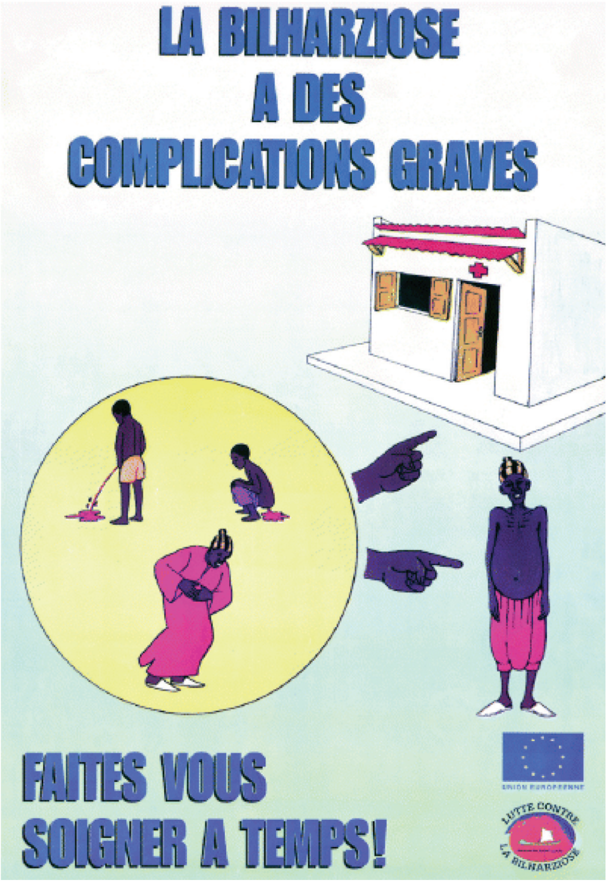

Figure 6.1 Poster used by the health education programme in health facilities in Northern Senegal to explain that schistosomiasis (intestinal and urinary) has severe consequences: 'Get cured in time!'.

6.3 Materials and methods

Study area and population

The study was carried out in Ndombo, situated along the Taouey canal, which at the nearby city of Richard Toll joins the Senegal River with an inland lake (Lac de Guiers). The canal and a meandering marshland are the main sources of water supply for this population. The village is endowed with a functional and well-equipped health centre run by a competent nurse and community health workers. The study was performed in 1998 during an evaluation phase of the control programme.

School children were recruited from the single primary school existing in the village. During the study, 240 were present of 300 pupils enrolled in the school. Initially, the same number of adults were randomly selected from the general population, but due to social sensibilities we interviewed more than planned (326 instead of 300) adults. In contrast to the children, most adults were illiterate.

The questionnaire survey

A simple questionnaire was developed about the perception and awareness of intestinal schistosomiasis, which largely responded to the messages, conveyed through the health education programmes. Open-ended questions were asked about the knowledge of intestinal schistosomiasis, its symptoms and mode of transmission, the source of information about the disease, the perception of its severity, and general health-seeking behavior. Respondents were not prompted with possible answers, and multiple answers were allowed for symptoms and mode of transmission. In the local school, the school teachers administered the questionnaire to their pupils, after proper explanation. The school teachers were not interviewed themselves. For the adults, the questionnaire was administered in local language by properly trained interviewers with at least secondary school education, recruited among the villagers.

For analysis, the responses were stratified into: ‘adequate’ when the answers were consistent with the health education messages; ‘incorrect’ when no answer was given or when it had nothing to do with intestinal schistosomiasis; ‘unclear’ when they combined adequate and incorrect answers. Chi-square tests were used to test age and sex differences on reporting.

6.4 Results

About 86% (484/566) of the respondents reported that they knew what intestinal schistosomiasis was, in the vernacular language called *Bilaadios*. This was reported more often by adults than by children (90% *vs.* 80%, $P < 0.001$), and more by males than by females (90% *vs.* 81%, $P = 0.002$). Most people cited other sources of information than the regional health education programme tools, with the majority of respondents reporting to know about schistosomiasis through the research project (64%) or friends and relatives (12%). Only few people referred to media (4%), and none mentioned the billboards or posters as a source of information. The remainder (20%) did not remember the source of information. The disease was regarded as severe by almost all (95%) interviewees; 2% answered that malaria was more severe and 3% considered the disease to be benign. Concerning health-seeking behavior, the large majority (92%) of the interviewees reported that, if they had schistosomiasis, they would seek treatment at the local health centre. Only few mentioned other medical facilities, such as self-healing (4%) and traditional healer (3%).

The symptoms to which people referred varied considerably. Of 798 answers given, abdominal pain (223 times, 28%), diarrhoea (216, 27%) and bloody stools (116, 15%) were most often mentioned. Various symptoms usually not associated with schistosomiasis (and not part of the health education messages) were also reported (30%): fever (84 times), fatigue (34), bloated stomach (30), headache (29), vomiting (29), weight loss (22), itching (11) and constipation (4). While about half (54%) of the respondents gave an adequate answer (diarrhea, abdominal pain or bloody stools), many added one or more non-schistosomiasis related symptoms (15%). Thus, 69% could mention at least one correct symptom. The remainder gave only incorrect answers (10%) or could not mention any symptom at all (21%). Males gave more often adequate answers than females (60% *vs.* 48%, $P = 0.004$) and there was no significant difference between age groups (58% for children *vs.* 51% for adults, $P = 0.094$) (Table 6.1).

The 456 answers on mode of transmission could be grouped into three main categories: 'water contact' (271 times), 'drinking of dirty water' (53) and non-water-related sources of infection such as 'presence of garbage' or 'flies' (132). Less than half of the respondents reported water contact as the only mode of transmission (43%), together with some who added an incorrect answer (4%). The other respondents gave only incorrect answers (28%) or no answer (24%). Adults gave more often an adequate answer on mode of transmission than children (57% *vs.* 25%, $P < 0.001$) (Table 6.1). Within the children this pattern was also visible, with 35% of the oldest group (11–16 year, $n = 109$) giving an adequate answer compared with 17% of the youngest group (7–10 year, n = 131) (P = 0.005). There was no gender-related difference for any of the age groups (P = 0.813).

Only 30% of the population sample (20% of children and 37% of adults) gave adequate answers on both symptoms and mode of transmission (Table 6.1). Similarly, 41% gave at least one correct (so, adequate or unclear) answer to each of both questions. This was 28% of children and 50% of adults.

Table 6.1 Reported knowledge about intestinal schistosomiasis, its symptoms and mode of transmission in Ndombo (Northern Senegal). Values are in percentages (%). Between brackets the number of persons interviewed. Knowledge 'unclear' means that both adequate and incorrect answers were given. See the main text for a listing of various incorrect answers.

	Children		Adults		
Reported knowledge	**Male (151)**	**Fem. (89)**	**Male (138)**	**Fem. (188)**	**All (566)**
'Ever heard of schistosomiasis'	86.1	68.5	94.2	86.7	85.5
Symptoms					
Adequate*	60.9	53.9	59.4	45.2	54.2
Unclear	15.2	6.7	17.4	16.5	14.8
Incorrect	23.8	39.3	23.2	38.3	30.9
Mode of transmission					
Adequate†	26.5	22.5	63.0	52.7	43.5
Unclear	6.6	1.1	7.2	2.1	4.4
Incorrect	66.9	76.4	29.7	45.3	52.1
Symptoms and mode of transmission combined					
Both adequate	19.9	19.1	40.6	34.0	29.5
Both adequate or unclear	31.8	21.3	59.4	43.6	40.8

* 'Diarrhea', 'abdominal pain' or 'bloody stools'
† 'From the water' or 'from the stream'

6.5 Discussion

The present investigation does not pretend to be an in-depth sociological study, nor a formal evaluation of a well-planned health education campaign. In fact, this study was initiated as part of an internal assessment, but the results are striking enough to be presented to a wider audience. No pre-intervention study was performed; however, as the infection and the disease were not at all known or present in the area before 1990, the initial knowledge can be assumed to have been virtually non-existent.

Irrespective of above considerations, we can safely conclude that a large part of the target population has not acquired an appropriate level of knowledge about schistosomiasis symptoms and mode of transmission, in spite of many years of efforts in control and research. As the village of Ndombo has experienced most and quite intense educational efforts, the situation in the rest of Northern Senegal can only be less satisfactory. The 30% with adequate knowledge about both symptoms and mode of transmission is much less than the initial 86% who answered yes to the question: 'Have you ever heard of intestinal schistosomiasis?'. As it often happens in questionnaire surveys, answers may be given to please the interviewer or to prevent a suggestion of ignorance. In this light, we should also not be too optimistic about the fact that the large majority of the respondents declared to seek treatment at the local health centre when having schistosomiasis.

Many of the information and education activities had focused on health-seeking behavior (Figure 6.1), rather than behavioral changes, as it was believed that as long as water supply and sanitation were not improved, such messages would not be useful. In this respect, 54% adequately reporting symptoms (or 69% reporting at least one correct symptom) are perhaps better – and more optimistic – measures of how well the health education messages came across. Nevertheless, transmission was extensively explained and related advice was always given. Indeed, a large proportion of the respondents realized that the disease is somehow linked with water and (lack of) hygiene, but their comprehension of the mechanism of transmission was muddled. Ndamba *et al.* (1989) reported similar findings in Zimbabwe. Reporting water as mode of transmission did increase with age. This may represent an increase in specific knowledge about schistosomiasis, but it may also, more generally, reflect a rising experience with or awareness of health risks associated with water. It is also interesting to note that many school children in our study reported the presence of garbage or flies as mode of transmission. This may very well be explained by the fact that garbage collection was a main concern and political item in the community during the period of interviews. Poor knowledge on sources of transmission among children is considered a factor of concern, as in this group water contact behavior and infection rates are generally highest (Schall, 1998; Useh & Ejezie, 1999).

As follows from the reported sources of information, the epidemiological research project which has operated in the area since 7 years before the interviews has played a crucial role in increasing the knowledge on schistosomiasis, although its aim was not to perform health education. The health education messages by radio spots, video films, billboards and posters appeared to have had a minor impact on the community. Perhaps the messages were not gripping enough. This puts forward the limited impact of general messages, hence, intensive community-based actions are more effective. Some of the respondents acknowledged that information on schistosomiasis was conveyed to them through family members or other persons. This indicates that community social organizations may act as a good intermediary to deliver health education messages. The school teachers can also be associated in health education training in school programmes and through community social infrastructure. In communities with high illiteracy rates, school children can act as agents for the diffusion of health education messages (Schall *et al.* 1987; Schall, 1987). In Brazil, Uchoa *et al.* (2000) found in a sociological survey that school was also reported as a source of information on schistosomiasis.

Despite sustained control efforts and intensive research actions, intestinal schistosomiasis is still an unclear disease for many residents of Ndombo. The weak awareness of intestinal schistosomiasis in a focus where it is part of daily life is intriguing, but it shows the limits of schistosomiasis control through the classical health education model. Moreover, knowledge and perception do not necessarily lead to behavioral change: e.g. even if the awareness about the risk of infection with schistosomes is improved, people still resort to streams for their domestic water supply if no alternative is presented (Kloos *et al.* 1986; Kloos, 1995; Yuan *et al.* 2000). Hopefully, the more acceptable level of knowledge of the symptoms may lead to health-seeking behavior and early treatment at health care facilities, thereby contributing to morbidity control (Andrade & Bina, 1985; Taylor *et al.* 1987; Polderman & De Caluwé, 1989; Butterworth *et al.* 1991; Mehanna *et al.* 1997). Regarding the outcome of our study, the acquired basic notions of schistosomiasis are fairly small, but they may improve as the epidemic and control efforts go on. Also, the socio-economic upgrading due to the dam (which initially caused the epidemic) and subsequent agricultural development, may further raise the overall educational level of the population.

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Chapter 7

General discussion

7.1 Answering the research questions

1. What is the impact of water resources development projects in Northern Senegal on the epidemiology of water-related diseases?

The construction of the Diama dam in Northern Senegal led to an outbreak of intestinal schistosomiasis, but did not have an effect on other water-related diseases, such as malaria, diarrhea, dysentery, and urinary schistosomiasis.

In Chapter 2 we measured the public health impact of the Diama dam (completed in 1986) through a documentary study, based on annual numbers of clinical cases of malaria, urinary and intestinal schistosomiasis, diarrhea and dysentery over the period 1982 (4 years before the dam) to 1996 (10 years after) as reported in medical records of four districts in Northern Senegal. After adjusting for contemporary trends in reported morbidity, e.g. due to population growth or increases in health service use, we observed an enormous increase in the number of intestinal schistosomiasis cases, which in Richard Toll since 1990 even approximated that of endemic malaria. No other adverse health effects were reported after the completion of the dam.

Despite the high *S. mansoni* infection rates observed in the area (Gryseels *et al*. 1994; Stelma *et al*. 1994), intestinal schistosomiasis was merely known as a mild disease (characterized by bloody diarrhea, abdominal pain) at the early stage of the epidemic (Kardoff *et al.* 1996; Lanuit *et al.* 1996; Thomas *et al*. 1997). However, since 1998 a growing number of patients reported to the health system with advanced hepatic pathologies, such as hepato-splenomegaly, liver fibrosis and/or signs of portal hypertension, i.e. hematemesis (vomiting blood). This was unexpected given the intense control efforts carried out in the region, but also because severe schistosomiasis morbidity generally develops only after many years of continuous exposure to the disease (Silverry-Lemos *et al*. 2008; King & Dangerfield-Cha, 2008; Zhou *et al*. 2007). Although this trend was closely followed for only a few years and has since then not been officially confirmed, it illustrates the severe public health consequences due to the water resource development projects in Northern Senegal, as well as the shortcomings of the control measures taken (see also Chapter 6).

The construction of the Diama dam has certainly had positive socio-economic impacts, as foreseen by some pre-dam health assessment studies. These were rated above potential health hazards, while an outbreak of intestinal schistosomiasis was never even anticipated. This warrants the need of post-dam impact studies and the implementation of adequate and timely preventive measures during the pre and post dam era.

2. What is the pattern of water contact behavior in the Senegal River Basin and can it explain the high *Schistosoma mansoni* infection rates?

Water contact patterns and levels in Northern Senegal were not exceptional and cannot explain the extremely high infection rates.

After the outbreak of the *S. mansoni* epidemic in Northern Senegal, extremely high infection rates were observed, while infection intensities had similar age-related patterns as in conventional endemic situations in sub-Saharan Africa, i.e. with egg counts and antigen levels increasing to a peak in adolescents and strongly declining in adults (Stelma *et al*. 1993; Polman *et al*. 1995). Our detailed water contact observations in a village in Northern Senegal during the first years of the *S. mansoni* outbreak to determine the role of human water contact in the epidemic revealed that the observed extremely high infection levels were not due to intense exposure levels (Chapter 3).

An explanation for the extremely high intensity levels would be the absence of acquired immunity in this recently exposed, supposedly non-immune community, but this is in contrast with the observed endemic-like age-related infection patterns, as well as with the strongly decreasing ratio of infection intensity to water contact with age that we found in women, suggesting some level of age-related resistance. Possibly, hormonal or other age- and or sex-related factors, such as skin permeability, may play a role (Gryseels *et al*. 1994; Polman *et al*. 2002; Scott *et al*. 2003; Fulford *et al*. 1998).

It should be noted that water contact measurements only provide an indirect measure of true exposure, i.e. exposure to infectious cercariae, which is impossible to determine from human behavior only (Fulford *et al*. 1996). The possibility will therefore always remain that our conclusions as well as those of other investigators are based on an inadequate understanding of how water contact translates into exposure. Thus, further research is needed with respect to the translation of water contact data into actual exposure, as well as the relation between exposure and actual acquisition of new *Schistosoma* infections at the individual level. In particular, studies focusing on cercariometry (e.g. patterns in the number of cercariae per m^3 water) are relevant.

Our extensive database on water contacts can be further exploited by relating individual egg counts to individual water contact. Through Poisson regression we can try to estimate the impact of factors that may influence the relation between water contact and infection, such as hour of the day or time of the year (both reflecting differences in cercarial densities) and type of activity (associated with area of body exposed). These factors may then be used to develop a more reliable exposure index than only frequency and duration, as used in Chapter 3.

3. What is the contribution of hygienic practices to the contamination of the water with schistosome eggs?

Hygienic bathing after defecation plays a major role in the contamination of water with S. *mansoni eggs.*

Our investigations concerning the determination of the pattern of fecal contamination of water bodies have clearly associated personal hygienic behavior to contamination of streams and ponds. Many school-aged children reported to defecate near streams, despite the presence of latrines in the community (Chapter 4). We have proven for the first time that the traditional practice of hygienic bathing after defecation results in miracidia in the water, and our quantifications suggest that this mode of contamination introduces a large amount of viable schistosome eggs in the streams, resulting in many more miracidia per day than by an accidental direct deposition of a complete stool in the water (Chapter 5). Other modes of contamination – such as stools being washed into the water by heavy rains or animals walking through defecation sites and carrying human fecal material in their hooves – are not very likely, as in a dry country such as Senegal, eggs in stools do not remain viable for a long time (see also Chapter 7.3). This implies a dominant role of hygienic bathing in the transmission of intestinal schistosomiasis.

It should be noted that the scale of our studies was small. More studies need to be conducted to confirm and refine our quantifications. It would be particularly interesting to do comparative studies in communities where hygienic bathing is not or less often practiced. Still, regular swimming and playing in the water with some remnants of feces adhering to the peri-anal region, especially of children, may result in miracidia in the water, be it to a lesser extent. If this proves to be the case, then fully functioning sanitation services, which have often been suggested as the ultimate solution to intestinal schistosomiasis, may still not lead to a complete interruption of the transmission cycle after all.

4. What is the impact of behavioral interventions on the reduction of schistosomiasis transmission in Northern Senegal?

Intense and prolonged health education appears to have little impact on the knowledge and awareness concerning schistosomiasis in Northern Senegal and would therefore not result in a reduction of schistosomiasis transmission.

We evaluated the awareness and knowledge of intestinal schistosomiasis in a highly infected rural community in Northern Senegal where a variety of health information and education activities had taken place as a component of research and control programs (Chapter 6). As the infection had been introduced only recently, initial knowledge could be assumed to be 'non-existing'. After 7 years of health education and other control efforts however, intestinal schistosomiasis still appeared a vague disease for many residents. In particular the lack of awareness of intestinal schistosomiasis in a focus where the disease is part of daily life is surprising, and shows the limitations of the classical health education model.

It should be noted that more knowledge and perception do not necessarily lead to behavioral change. Even with greater awareness about the risk of *Schistosoma* infection, people will still resort to streams and other potentially infected water sources if there are no alternatives (Kloos *et al*. 1986; Yuan *et al*. 2000). One of the village chiefs illustrated this very clearly by stating that "we rather have rice and schistosomiasis than no rice and no schistosomiasis". For this reason, many of the information and education activities focused on health-seeking behavior, rather than on behavioral changes. In this respect, health education seemed more successful (69% reported at least one correct symptom, and 92% stated that in case of illness they would seek treatment at the health center), but knowledge on symptoms and risk factors was still poor.

Similar findings have been reported in Zimbabwe (Ndamba *et al*. 1989), but there are also examples of actual behavior change consecutive to health education programs such as in Egypt (Abdel Salam *et al*. 1986), in Ghana (Aryeetey *et al*. 1999) and in Brazil (Schall, 1998). The main message is that efforts to change behavior should be specific for the geographic and cultural context. Schistosomiasis is not acquired by unavoidable, random exposure to vectors or germs, but by an 'act of will' to enter the water. Therefore, control by behavioral change is possible, but again, health education can improve knowledge about the disease and health care seeking, but may have little impact on behavior if no adequate alternatives for water contact are available.

7.2 Direct versus indirect water contact studies

Over the last decades, many water contact studies have been carried out to explore transmission determinants and quantify the relationship between water exposure and schistosome infection (Gazzinelli *et al*. 2001; Friedman *et al*. 2001; Bethony *et al*. 2001). As explained in Chapter 7.1 (question 2), exposure to water is not the same as actual cercarial exposure, so that water contact studies provide a proxy of exposure to infection at most. Water contact studies have been based on various methods, such as diaries, bimonthly interviews or self reported interviews. Here, we will consider the two most widely used methods: indirect questionnaire surveys and direct observations.

Questionnaires are the standard methodology used in water contact studies in Brazil (Barbosa & Barbosa, 1998; Barreto, 1993; Coura-Filho *et al*. 1994; Da Silva *et al*. 1997; Lima et Costa *et al*. 1987, 1998; Moza *et al*. 1998; Firmo *et al*. 1996; Ximenes *et al*. 2001). In depth interviews have been less commonly used (e.g. El Katsha & Watts, 1998). Questionnaires are simple and cheap and are widely used to measure water exposure, symptoms of infection, and knowledge, attitude and practice regarding schistosomiasis. Regarding water exposure, they are particularly convenient to measure average duration and frequency of water related activities.

Direct observation has been the most frequently used method for water contact studies in Africa (Bundy & Blumenthal, 1990; Coulibaly *et al*. 2004; Dalton & Pole, 1978; El Katsha & Watts, 1997a, 1997b; Fulford *et al*. 1996; Kabatereine *et al*. 1999; Kloos *et al*. 1983; Kvalvig & Schutte, 1986; Ofoezie *et al*. 1998; Tayo *et al*. 1980; Watts *et al*. 1998; WHO, 1979; Woolhouse *et al*. 1998). The advantage of using direct observations is that observers can record the performed activities and their duration on the spot. Direct observation of water contact can also provide empirical data on intensity of exposure, location and characteristics of the water contact sites. Moreover, observers have a better view on the nature of activities. Modern computer-assisted devices can further ameliorate the recording of individual water contacts in the field, and improve the data management and analysis.

Both direct observations and questionnaires have inherent strengths and weaknesses and vary in labor intensity and costs. Direct observation methods cannot provide information on activities taking place outside the limits of observation sites (in time and place), nor can they gather information retrospectively. They are also regarded as labor intensive and expensive (Kloos *et al*. 2006). Methodological weaknesses are the so-called ‘observer effect’ and ‘observer boredom’ (WHO, 1979). The observer effect can be reduced by the use of binoculars, shelters and local observers. Observer boredom can be avoided by cutting the number of hours worked at a stretch, adequate supervision, etc. Direct observation is less efficient in rural agricultural areas characterized by dispersed water contacts over large areas (Kloos *et al*. 1998; Watts *et al*. 1998). Questionnaire surveys can overcome most of these limitations but cannot reliably identify the location of water contacts and the intensity of exposure parameters, and may fail to identify temporal exposure patterns. Also, questionnaires depend on individual recall and for water contact this may be rather biased. The questionnaire survey conducted in Northern Senegal (Scott *et al*. 2003) may also have suffered from the low level of education in the rural communities, causing difficulties in the comprehension and interpretation of the questions. This and other limitations inherent to questionnaires may explain the extremely high duration of water contacts observed in the study by Scott *et al*. (2003), which are in contrast with our findings (Chapter 3) and those observed in most other areas of Africa.

Recognizing the different merits of direct observation and questionnaires, some investigators have tried to develop combined methodologies (Bethony *et al*. 2001, 2004; Gazzinelli *et al*. 2001). The combined methodology might require local adaptation to the environmental, water contact and socio-economic situation. The higher cost (about double) of direct observations as compared to questionnaire surveys (Kloos *et al*. 2006) makes the combined methodology only feasible in small studies.

Exposure measurement involves the evaluation of cercarial densities in studied water contact sites. Laboratory bred (shaved) rodents can be used to determine the extent of cercarial infection in natural habitats. Another method consists of direct recovery of cercariae in flowing streams, by catching cercariae in cloth with mesh filter size of 30 μm – 50 μm. Disadvantages are the workload involved in raising large numbers of rodents and managing them before they can be examined (i.e. perfused), and the low sensitivity of direct cercarial recovery. Still, these techniques are useful by giving information about the factual presence of the parasite.

7.3 Possible role of different modes of contamination of water bodies with fecal material

Our studies on hygienic practices (Chapter 4) and hygienic bathing after defecation (Chapter 5) were motivated by our interest to determine the ways by which water bodies are contaminated with stools containing parasite eggs, one of the most poorly understood steps in the transmission of *S. mansoni*. To achieve this, several small and preliminary studies involving different approaches were carried out in Thiago and surrounding villages (Northern Senegal). In addition to the studies in Chapters

4 and 5, we performed or planned observational studies of human defecation behavior, mapping defecation sites and estimating the risk of stools reaching the water, and assessing the role of animal reservoirs in transmission. Below we report the preliminary findings.

The study of defecation behavior consisted of three days of discrete observation of individuals visiting so-called ‘defecation sites’ in each of five rural villages along the Senegal River. The majority of defecation sites were located near a stream, since the available vegetation offered the necessary privacy for the visitors. We recorded age, sex, time of defecation, distance of the deposited stools to the water, and the activities performed before and after the act of defecation. When the defecation had taken place, the result was confirmed shortly after the person had left, and the place of defecation was plotted on a sketch map.

In total 143 acts of defecation were observed (Table 7.1). The majority of people observed to be defecating were in the age group of 5-20 years for both males and females. Males were overrepresented with 68% of the observations, and most acts of defecation were performed in the afternoon between 2 and 4 p.m.. Almost one third of the stools were deposited between 0 – 5 meters of the water, which is similar to what was found in studies in Egypt (Farooq & Mallah, 1966), Zimbabwe (Husting, 1965; Chandiwana, 1986) and Nigeria (Akogu & Akogun, 1996). Direct defecation into the water was not observed.

Table 7.1 Observation of defecation behavior in 5 communities along the Senegal River.

Age (years)	N	Distance of defecations from the river		
		< 5 meters	5 - 10 meters	> 10 meters
0 - 9	18	5 (28%)	9 (50%)	4 (22%)
10 - 19	67	21 (31%)	38 (57%)	8 (12%)
20+	58	11 (19%)	19 (33%)	28 (48%)
Total	143	37 (26%)	66 (46%)	40 (28%)

Knowledge of the activities that take place before and after defecation is important if health education is to be implemented to prevent people from contaminating the environment. In the areas studied, the most important activities observed both before and after defecations were respectively walking along the river, bathing and crossing. Only bathing was observed as a post-defecation activity with a hazard of contamination. As discussed in Chapter 5, hygienic bathing entails a risk of *S. mansoni* eggs reaching the water, but discouraging such behavior remains questionable.

The course of stools deposited was traced by using maps of defecation sites in three ecologically different settings along the Senegal River (see Figure 7.1 for an example). The number of stools deposited each day was followed, and their distance to the water measured during a whole week. Each observation day, the sites were visited and it was checked whether the stools were dry, eaten by animals, (partly) destroyed by animals walking through, or flooded.

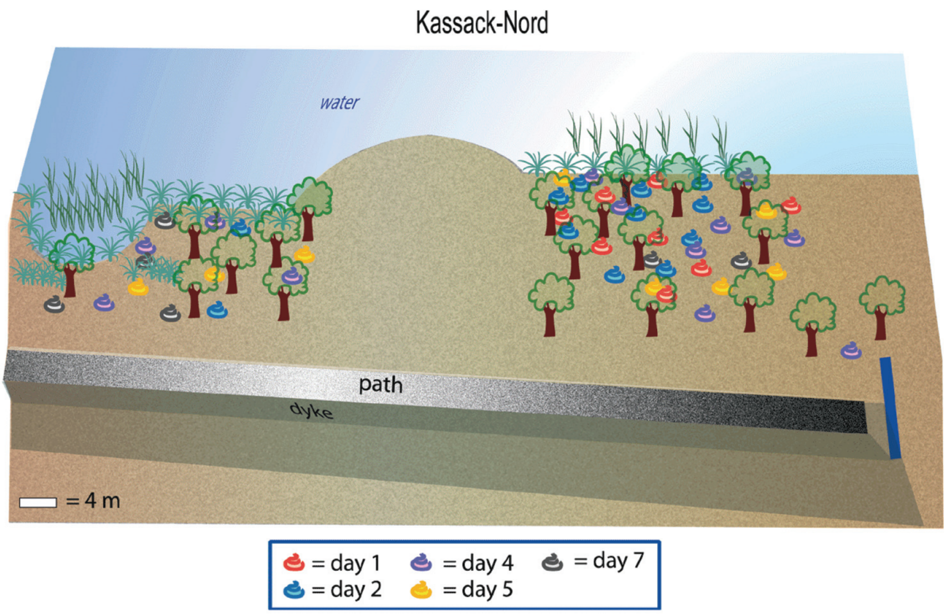

Figure 7.1 Map of stool deposits along a natural water body. Day indicates the moment of deposition during the week of observation.

The preliminary results of this small investigation showed that the mean distance between the human defecations and the water was about 1.2 meters. The stool closest to the water was deposited at a distance of 65 cm, while the one furthest away was situated at 42 meters. During our observations, only six stools disappeared and none was destroyed by animals.

Another small study focused on the viability of eggs in fresh stools in natural conditions over time. It has been reported that in warm climates the viability tends to quickly decrease over time as the stools dry out (Husting, 1965; Upatham *et al*. 1976). Figure 7.2 shows that the viability of schistosome eggs gradually decreases over time, closely following an exponential decay function. In general, there are hardly any viable eggs in the stool within half a day (12 hours), and no viable miracidia were found in samples taken one day after production of the stool. Added to our observation of no prints of hooves or animal feet in the mapped stools, this makes contamination of water bodies with *S. mansoni* eggs by animals walking through human stools highly unlikely. In addition, the impact of flooding appears to be limited as well, since most stools washed into the water by heavy rains may thus not be fresh enough to contain viable eggs.

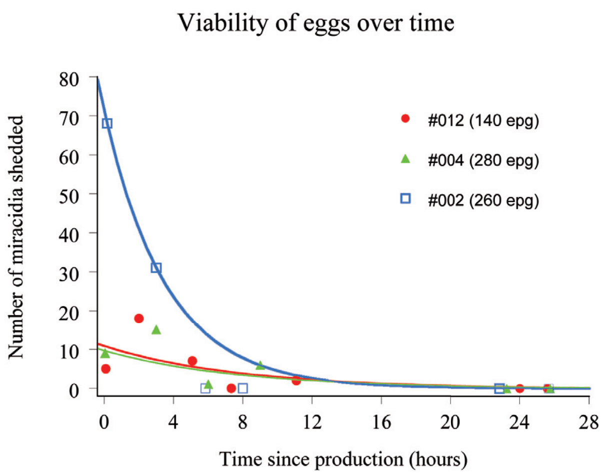

Figure 7.2 Number of miracidia shedded in 2 mg samples of stool taken over time from three stool specimens. The stool specimens were exposed to natural conditions. The lines represent the best fitting exponential curve for the observations with the same color. Epg is eggs per gram feces.

The studies above emphasize the important role of hygienic bathing in the transmission of *S. mansoni* in a warm and dry country such as Senegal. The only other potential mode of contamination of water bodies could be through reservoir hosts (Modena *et al*. 2008; Gentile *et al*. 2006). In Senegal, naturally infected rodents were found in the vicinity of human foci. However, these infections were thought to be of very little importance in transmission foci (Duplantier & Sène, 2000). Future studies should consider detailed observations of the role of various rodent species towards infecting water, for instance, by capture-recapture studies to assess their densities, by perfusion to determine infection levels, and by remote sensing devices to follow their daily movements.

7.4 Conclusions

1. The water resources development projects in the Senegal River Basin have caused a considerable burden of intestinal schistosomiasis, but not of other water related diseases.
2. The patterns of water contact in Northern Senegal were not exceptional and did not mirror the high infection levels observed in the *S. mansoni* outbreak.
3. In a dry country like Senegal, fecal remnants in the peri-anal region of an infected individual may be the most important source of contamination of water with *S. mansoni* eggs.
4. The health education control strategy adopted in Northern Senegal has failed to enhance satisfactory behavior change regarding schistosomiasis infection.

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Summary

Schistosomiasis is a parasitic disease caused by blood flukes (worms) transmitted by snails. Schistosome eggs leave the body with human feces (for *Schistosoma mansoni*) or urine (for *S. haematobium*), and they hatch when getting into contact with fresh water. The released larva (miracidium) can infect an intermediate snail host, which then produces thousands of larvae (cercariae) that infect humans who are in contact with water while bathing or doing other activities in streams and ponds. The infection is endemic in many parts of Africa and often constitutes a threat to health as an adverse effect of water resource programs. In Northern Senegal, prior to the construction of two dams in the Senegal River Basin, intestinal schistosomiasis (caused by *S. mansoni* infection) was unknown. Two years after the completion of the Diama dam in 1986, an unprecedented outbreak struck the area eventually resulting in a staggering 90% prevalence in the surroundings of the city of Richard Toll, the epicenter of the epidemic.

In the presence of this exceptional epidemiological situation in Senegal, we aimed at complementing current knowledge about aspects of schistosomiasis transmission related to human behaviors with the final purpose of recommending appropriate control measures. To attain this objective, we first provided an overview of the increase of water related diseases, including intestinal schistosomiasis, in the post dam era. We then performed a series of field studies to assess patterns of water contact, human sanitary practices and the impact of health education campaigns in the outbreak area.

In **Chapter 2**, we measured the public health impact of the dams in the human population through a health documentary survey, based on reported clinical cases in the medical records, in four districts in Northern Senegal. The number of clinical schistosomiasis cases has risen dramatically since 1988, and in Richard Toll even approximated that of endemic malaria. Our conclusion was that the unexpected emergence and spread of intestinal schistosomiasis as well as the increase of urinary schistosomiasis (caused by *S. haematobium*) have aggravated the public health situation in the Senegal River Basin.

In **Chapter 3**, we described the results of water contact studies in the village of Ndombo. The daily water contact behavior of the whole population was observed from 6 a.m. till 7 p.m., seven days each month in a two-year period. This resulted in over 120,000 recorded water contacts for 1651 subjects. Bathing was the main activity, followed by household activities. Frequency and duration of water contact depended on age and sex rather than season, with women and adolescents showing the highest levels. Still, the water contact levels were not exceptionally high and

cannot explain the extremely high infection intensities as observed in Northern Senegal. Comparison with fecal egg counts in the respective age and sex groups further revealed that water contact levels did not correspond with infection levels, indicating that other factors than exposure primarily determine intensity of infection.

Chapters 4 and **5** provide more insight into how feces containing *S. mansoni* eggs can reach surface water such as streams and ponds. The degree of contamination of natural habitats with infected stools is difficult to assess due to the privacy that characterizes the act of defecation. In **Chapter 4**, we investigated defecation behavior of children in relation to latrine use in the pilot village of Kassak-Nord (Northern Senegal) using a simple questionnaire. The survey demonstrated that 24% of children defecated in the bush, particularly near the streams where the nature offers hideouts. Many respondents declared that they clean themselves after defecation, but this was mainly done by using plants and sticks, suggesting that fecal material with parasite eggs may easily remain adhering to the peri-anal region. Furthermore, latrines were present but not adequately used for various reasons.

In **Chapter 5**, we demonstrated for 10 out of 13 *S. mansoni* infected volunteers that feces trapped in the peri-anal region after defecation contained eggs that lead to miracidia after hygienic washing. This means that those who bathe in water bodies immediately after defecation can introduce viable *S. mansoni* eggs into the water. We calculated that a population of nearly 1000 individuals releases about 30 thousand miracidia per day due to hygienic bathing, while direct deposition of a single complete stool into the water would result in about 2500 active miracidia. Thus, overall about 12 complete stools should reach the water every day to contribute to transmission in the same order of magnitude as hygienic bathing, which is unlikely considering the taboo on defecating directly into the water. This suggests that hygienic washing after defecation may be an important mode of transmission.

Chapter 6 describes the evaluation of various health education efforts as part of regional control programs in the outbreak area. We interviewed 566 persons (adults and children) about their perception of schistosomiasis and level of knowledge regarding its spread and control. They were asked simple questions about symptoms, mode of transmission, the sources of information, and health-seeking behavior. The great majority of the respondents stated that they knew what schistosomiasis was and that in case of illness they would seek treatment at the health center. However, only half of the people accurately quoted symptoms associated with intestinal schistosomiasis: diarrhea, abdominal pain or bloody stools. The majority of respondents realized that the disease was somehow linked with water and (lack of) hygiene, but only 44% of respondents reported water contact as the source of infection. We concluded that even intense and long-lasting health education efforts for a specific and straightforward problem as schistosomiasis are not enough to have profound impact on the knowledge, attitudes and practices of rural traditional communities.

Chapter 7.1 provides an overview of the main research findings. **Chapter 7.2** gives some more background about the two main ways to study water contact behavior of populations in schistosomiasis endemic areas: observational studies *vs.* use of questionnaires. **Chapter 7.3** provides further information about the routes by which schistosome eggs may reach natural water bodies. In **Chapter 7.4** we list the main conclusions, which are as follows: (1) The water resources development projects in the Senegal River Basin have caused a considerable burden of intestinal schistosomiasis, but not of other water related diseases; (2) The patterns of water contact in Northern Senegal were not exceptional and did not mirror the high infection levels observed in the *S. mansoni* outbreak; (3) In a dry country like Senegal, fecal remnants in the peri-anal region of an infected individual may be the most important source of contamination of water with *S. mansoni* eggs; (4) The health education control strategy adopted in Northern Senegal has failed to enhance satisfactory behavior change regarding schistosomiasis infection.

Samenvatting

Schistosomiasis is een infectieziekte die wordt veroorzaakt door parasitaire wormen die op de mens worden overgedragen via slakken. De eieren van de worm verlaten het lichaam met de ontlasting (bij *Schistosoma mansoni*) of urine (bij *S. haematobium*) en komen uit als ze in contact komen met water. De vrijgekomen larven (miracidia) kunnen de tussengastheer - een zoetwaterslak - infecteren, die vervolgens duizenden larven (cercariën) produceert. Deze kunnen mensen infecteren die zich in het water bevinden bijvoorbeeld om te baden. De infectie is in grote delen van Afrika en vormt vaak een bedreiging voor de gezondheid als een negatief gevolg van watermanagement programma's. Zo was intestinale schistosomiasis (veroorzaakt door *S. mansoni*) voor de bouw van twee dammen in de Senegal Rivier onbekend in Noord Senegal, maar vond er twee jaar nadat de Diama dam gereed was gekomen in 1986, een ongekend grote uitbraak in de regio plaats. Hierdoor raakte maar liefst 90% van de bevolking in de omgeving van de stad Richard Toll geïnfecteerd.

Uitgaande van deze uitzonderlijke epidemiologische situatie in Senegal hadden wij tot doel de huidige kennis rond gedragsaspecten bij de overdracht van schistosomiasis te verbeteren, om uiteindelijk tot aanbevelingen voor geschikte bestrijdingsmaatregelen te komen. Hiertoe hebben we eerst een overzicht gemaakt van de toename in watergerelateerde ziekten, inclusief intestinale schistosomiasis, in de periode na de bouw van de dam. Daarna hebben we een serie van veldstudies uitgevoerd om watercontactpatronen, sanitaire gebruiken en het effect van campagnes met betrekking tot gezondheidseducatie in het uitbraakgebied te bestuderen.

In **Hoofdstuk 2** hebben we de impact van de dam op de volksgezondheid vastgesteld op basis van het aantal gerapporteerde klinische gevallen in de medische archieven van vier districten in Noord Senegal. Het bleek dat het aantal klinische gevallen van schistosomiasis enorm was toegenomen vanaf 1988, in Richard Toll zelfs bijna tot aan het niveau van endemische malaria. Onze conclusie was dat de onverwachte opkomst en verspreiding van intestinale schistosomiasis, evenals de toename van urinaire schistosomiasis (veroorzaakt door *S. haematobium*), de volksgezondheidssituatie rond de Senegal Rivier heeft verslechterd.

In **Hoofdstuk 3** hebben we de resultaten beschreven van watercontact studies in het dorp Ndombo. Hier werden van de gehele bevolking alle contacten met oppervlaktewater geobserveerd van 6 uur 's ochtend tot 7 uur 's avonds, zeven dagen per maand, gedurende een periode van 2 jaar. Dit resulteerde in meer dan 120 duizend gerapporteerde watercontacten voor 1651 mensen. Baden bleek de belangrijkste bezigheid in het water, gevolgd door huishoudelijke activiteiten. De frequentie en duur van het watercontact was afhankelijk van leeftijd en geslacht, meer dan van seizoen, waarbij de hoogste waarden bij vrouwen en adolescenten gemeten werden. Echter, de uiteindelijke niveaus van watercontact waren niet uitzonderlijk hoog en kunnen daarom geen verklaring vormen voor de extreem hoge infectiegraden die in Noord Senegal zijn geobserveerd. De vergelijking met eitellingen in de ontlasting van de respectievelijke sekse- en leeftijdsgroepen liet verder zien dat watercontacten niet gerelateerd zijn aan infectieniveau, wat aangeeft dat andere factoren dan de blootstelling aan water een sleutelrol vervullen in het bepalen van de intensiteit van infectie.

Hoofdstukken 4 en **5** verschaffen meer inzicht in hoe ontlasting besmet met *S. mansoni* eieren oppervlaktewater zou kunnen bereiken. Het is lastig de mate van besmetting van de natuurlijke omgeving met geïnfecteerde stoelgang vast te stellen vanwege de privacy die gepaard gaat met deze activiteit. In **Hoofdstuk 4** hebben we op basis van een eenvoudige vragenlijst het defecatiegedrag van kinderen in het dorp Kassak-Nord onderzocht, met name met betrekking tot het gebruik van latrines. De studie liet zien dat 24% van de kinderen hun behoefte in de openlucht doen, vooral nabij waterstromen waar de begroeiing natuurlijke beschutting biedt. Veel respondenten gaven aan zichzelf na de ontlasting te reinigen, maar dan vooral door het gebruik van planten en stokjes, wat suggereert dat er gemakkelijk enige ontlasting met parasitaire eieren in de anale streek zou kunnen achterblijven. Verder bleek dat latrines wel aanwezig waren maar om diverse redenen amper werden gebruikt.

In **Hoofdstuk 5** hebben we bij 10 van de 13 met *S. mansoni* geïnfecteerde deelnemers aangetoond dat ontlasting die in de anale streek is achtergebleven eieren kan bevatten die miracidia opleveren als men zich wast met water. Dit betekent dat degenen die meteen na de ontlasting het water opzoeken om zich te wassen levensvatbare *S. mansoni* eieren naar het water kunnen overbrengen. We hebben berekend dat een bevolking van ongeveer 1000 mensen ongeveer 30 duizend miracidia per dag kan opleveren ten gevolge van dit ‘hygiënisch wassen’, terwijl een complete stoelgang die rechtstreeks in het water gedeponeerd zou worden 2500 miracidia zou opleveren. Dit betekent dat elke dag in totaal 12 complete stoelgangen het water zouden moeten bereiken om hetzelfde resultaat te bereiken als door hygiënisch wassen, wat zeer onwaarschijnlijk is gezien het taboe dat rust op het rechtstreeks deponeren van ontlasting in het water. Dit suggereert dat hygiënisch wassen wel eens een heel belangrijke bron in de overdracht van intestinale schistosomiasis zou kunnen zijn.

Hoofdstuk 6 geeft een evaluatie van een reeks activiteiten op het gebied van gezondheidseducatie als onderdeel van bestrijdingsprogramma’s in het uitbraakgebied. Hiertoe werden 566 mensen (volwassenen en kinderen) ondervraagd over hun perceptie van schistosomiasis en over hun kennis met betrekking tot de verspreiding en bestrijding ervan. Eenvoudige vragen werden gesteld over symptomen, manieren van overdracht, informatiebronnen en hulpzoekgedrag. De overgrote meerderheid van de respondenten gaf aan dat ze wisten wat schistosomiasis was en dat ze in geval van ziekte een gezondheidspost zouden bezoeken. Echter, slechts de helft van de mensen was in staat om de juiste symptomen van intestinale schistosomiasis te noemen: diarree, buikpijn of bloed in de ontlasting. De meesten wisten dat de ziekte op de een of ander manier te maken had met water en (gebrekkige) hygiëne, maar slechts 44% van de respondenten noemde watercontact als een bron van infectie. We concludeerden dat zelfs intensieve en langdurige educatieve inspanningen niet genoeg zijn om een significant effect te hebben op de kennis, attitude en gebruiken van traditionele rurale gemeenschappen met betrekking tot een specifiek en relatief eenvoudig probleem als schistosomiasis.

Hoofdstuk 7.1 geeft een overzicht van de onderzoeksbevindingen. **Hoofdstuk 7.2** biedt meer achtergrond over de twee belangrijkste manieren om gedragsstudies met betrekking tot watercontact uit te voeren in gebieden met schistosomiasis: rechtstreekse observaties versus vragenlijsten. **Hoofdstuk 7.3** verschaft meer informatie over de verschillende manieren waarop *S. mansoni* eieren het oppervlaktewater zouden kunnen bereiken. In **Hoofdstuk 7.4** geven we een opsomming van de belangrijkste bevindingen: (1) De waterontwikkelingsprojecten in en rond de Senegal Rivier hebben een aanzienlijke ziektelast veroorzaakt door intestinale schistosomiasis, maar niet door andere watergerelateerde ziekten; (2) De watercontactpatronen in Noord Senegal waren niet uitzonderlijk, en konden de hoge infectieniveaus die zijn waargenomen in het *S. mansoni* uitbraakgebied niet verklaren; (3) In een droog land als Senegal zou achtergebleven ontlasting in het gebied rond de anus van een geïnfecteerde persoon wel eens de belangrijkste manier van besmetting van water met *S. mansoni* eieren kunnen zijn; (4) De toegepaste strategieën met betrekking tot gezondheidseducatie in Noord Senegal zijn er niet in geslaagd om gedragsverandering ten aanzien van schistosomiasis te bewerkstelligen.

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Curriculum Vitae

Seydou Sow was born in January 31, 1956 in Dakar (Senegal). In 1977, he passed his secondary school exam at the Lyceum Faidherbe of St Louis (Northern Senegal). In 1978, he began studying social sciences at the University of Dakar. In the following year, he obtained a grant to study Economics at the University of Donetsk (Ukraine, former USSR). He simultaneously followed courses on Philology and Sociology. In 1985, he obtained his MSc degree with the grade *magna cum laude*. After some years of working on farming project management, he started in 1991 as a supervisor of different field teams within the Schistosomiasis Research Network in Northern Senegal. During that period, he familiarized himself with Health Sciences and actively participated in several epidemiological studies in the field of Parasitology. In 1996, he was appointed as a research fellow at the Institute of Tropical Medicine (ITM) in Antwerp, Belgium. At the same time, he followed courses on Development Studies at the College of Developing Countries of the University of Antwerp. He subsequently obtained a Diploma in Development Policy and an MSc in Public Administration and Management. In March 1999, he started a PhD project in collaboration with the ITM and the Department of Public Health, Erasmus MC, University Medical Center Rotterdam. For a period of 5 years, he travelled between Senegal, Belgium and The Netherlands to collect and analyze the data described in this thesis. In 2005, he returned to Senegal, where he continued the collaboration with the above mentioned institutions through regular scientific correspondence that resulted in the scientific papers presented in this thesis. He is now working as a free-lance consultant for development projects and also as a scientific editor for some health consultancy offices.

Publications

Sow S, de Vlas SJ, Stelma F, Vereecken K, Gryseels B, Polman K (2009). The contribution of water contact behavior to the high *Schistosoma mansoni* infection rates observed in the Senegal River Basin (*Submitted*).

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ERASMUS UNIVERSITEIT ROTTERDAM

PhD Portfolio Summary

Summary of PhD training and teaching activities

Name PhD student: Seydou Sow **Erasmus MC Department:** Public Health	**PhD period:** 1999-2009 **Promotor:** Prof. J.D.F. Habbema **Supervisors:** Dr. Sake J. de Vlas, Dr. Katja Polman

PhD training	Year	Workload (Hours)
General courses		
Laboratory Animal Science (Laboratory of ESPOIR In Senegal)	2003	28
Statistics	2001	8
Diploma in Development Policy (University of Antwerp, Belgium)	1998	
MSc Public Administration and Management (University of Antwerp)	1999	
Specific courses		
Quantitative Methods for Tropical Diseases Control (NIHES, Erasmus MC)	2001	40
Seminars and workshops		
International Workshop on Integration of Schistosomiasis in Mali, Senegal, Zimbabwe and Morocco; ITM, Antwerp, Belgium	2001	16
Weekly seminars on epidemiology (2 hours per week at ITM*)	2000-05	80
(Inter)national conferences		
International Conference of the Schistosomiasis Research Project; Cairo, Egypt	1998	40
VII International Symposium on Schistosomiasis; Rio de Janeiro, Brazil	1999	40
International Colloquium: Moving Targets: Parasites, Resistance and Access to Drugs; ITM	2000	40
International Colloquium: Promoting Growth and Development of Under Fives; ITM	2001	40
International Colloquium: Health Care for All; ITM	2001	40
International Colloquium: Integration and Disease Control; ITM	2002	40
Cerebrospinal Fluid Analysis in Tropical Neurology; ITM	2002	40
International Colloquium: European Science and Training for the Promotion of Health in Developing Countries: "Networking the Networks"; ITM	2002	40
Uniting Streams Conference; NVTG, Amsterdam, The Netherlands	2003	40
VI European Conference of Tropical Medicine; Lisbon, Portugal	2003	40
International Conference on Pathogenic Helminths; Dakar, Senegal	2007	40

* ITM = Institute of Tropical Medicine, Antwerp, Belgium