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Irrigation and Schistosomiasis in Africa: Ecological Aspects

Eline Boelee and Henry Madsen

International Water Management Institute

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Cover photograph by Henry Madsen shows laundry and other water uses, including snail sampling, in the "Office du Niger," Mali.

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Contents

SUMMARY

This research report discusses ecological aspects of schistosomiasis transmission and options for its control in irrigated areas in Africa through environmental measures. Human schistosomiasis is endemic in 46 African countries. After being infected by larvae emerging from human excreta and urine deposited in the water, freshwater snails act as intermediate hosts. They, in turn, produce larvae that enter through the skin of people who are exposed to the contaminated water. Many surface irrigation systems in Africa create favorable snail-breeding conditions that facilitate the transmission of schistosomiasis. This process is illustrated with examples from different agro-ecological regions, including Morocco, Mali, Sudan, Cameroon, Egypt, Burkina Faso, Kenya and Zimbabwe.

The presence and density of snails differ much among sites and vary within irrigated areas and over seasons, often subject to local circumstances, for example, inadequate water management and system maintenance that result in water stagnation and weed growing. These are common features in African irrigation systems along with increased human population densities and lack of sanitation and domestic water supply.

Snail-control can be an important component of integrated campaigns against schistosomiasis transmission. Chemicals (molluscicides) can be effective in the control of snails on the short term, but not as a long-term measure as they are too expensive, eco-toxic and unsustainable. Environmental control of schistosomes' intermediate hosts (freshwater snails) offers good alternative approaches, especially when they reduce man-water contact as well. The main options available are adapted system design, adequate water management and proper maintenance.

Irrigation and Schistosomiasis in Africa: Ecological Aspects

Eline Boelee and Henry Madsen

Introduction

There are numerous examples that substantiate the fact that the establishment of irrigation projects and other water resources development projects have increased transmission of schistosomiasis and other water-related diseases (see reviews by e.g., Deacon 1983; Oomen et al. 1988 and 1990; Talla et al. 1990; Bolton 1992; Hunter et al. 1993; Grosse 1993; Steele et al. 1997; Hervé and Brengues 1998; Ofoezie 2002). Schistosomiasis and other water-related diseases, while expected to remain public health problems of significance may become more acute as a result of the growing human population, and the ensuing demands on energy and food that will lead to expanded and intensified exploitation of water resources in Africa. It is, therefore, important that health considerations are addressed when evaluating potential benefits of new irrigation schemes, and that measures are taken to minimize health problems related to the new ecological settings (Tiffen 1991). Clearly, the potential health risks of water resources development are related to problems already present in the area. However, the possibility of new diseases being introduced or existing diseases reaching epidemic proportions (as was seen in the Richard Toll area of Senegal — e.g., see Gryseels et al. 1994; de Clerq et al. 2000; Sow et al. 2002), cannot be ruled out.

This research report discusses distribution patterns of the intermediate host snails in irrigation and environmental aspects of schistosomiasis transmission. Many examples are presented to illustrate the variability among different irrigation schemes in Africa in order to provide a better understanding of the ecological aspects of schistosomiasis transmission. These cases are primarily based on the authors' personal experiences, supplemented with data from literature to encompass a greater part of the wide spectrum of irrigation schemes encountered in the African continent. After the case studies, options for control of schistosomes' intermediate hosts are discussed with emphasis on ecological and engineering measures of snail and transmission control.

Schistosomiasis

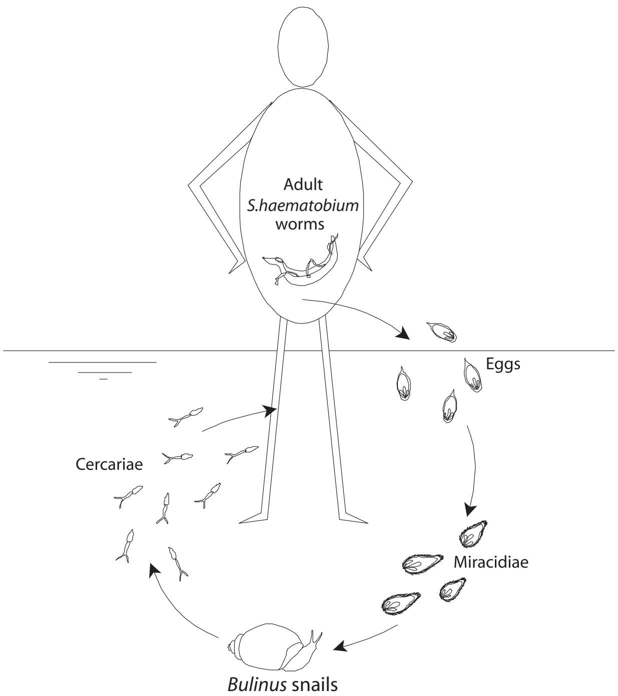
Schistosomiasis is a chronic, debilitating parasitic disease caused by blood flukes of the genus Schistosoma. Freshwater snails, after being infected by schistosome "miracidiae," (larvae that emerge by the hatching of eggs found in human excreta, deposited in the water) act as intermediate hosts. The infected snails produce other larvae called "cercariae," which infect humans by entering the body through the skin during water contact (figure 1). The disease, also known as "bilharzia," is endemic in 74 countries in Africa, South America and Asia. Worldwide, an estimated 200 million people are infected, of which 20 million is assumed to suffer from more or less a severe form of the disease creating 4.5

million DALYs[1] lost (WHO Expert Committee 2002). Schistosomiasis is endemic in 46 out of the 54 countries in the African continent (table 1, figure 2). The disease may cause damage to various tissues (the bladder, liver or the intestines) depending on the species, and lower the resistance of the infected person to other diseases. There are 16 different known species of *Schistosoma (S)*, of which 5 are infective to man -- *S. mansoni, S. haematobium, S. intercalatum, S. japonicum* and *S. mekongi.* The species differ according to their snail intermediate hosts, egg morphology, final location of the adult worms in the human body, resulting symptoms, and their geographical distribution (Doumenge et al. 1987). The most common forms of the disease in Africa are: intestinal schistosomiasis, which is caused by *S. mansoni;* and urinary schistosomiasis, which is caused by *S. haematobium.*

In sub-Saharan Africa, approximately 393 million people are at risk of infection from *S. mansoni,* of which 54 million are infected. Those numbers for *S. haematobium* are estimated to be as high as 436 million at risk, of which 112 million are infected (van der Werf et al. 2003).

The intermediate hosts of schistosomes in Africa are freshwater pulmonate snails, which belong to the "Planorbidae" family. The species belong to two genera, namely *Biomphalaria,* host for *S. mansoni,* and *Bulinus,* host for *S. haematobium* and *S. intercalatum* (Sturrock 1993). Both *Biomphalaria* and *Bulinus species* prefer water velocities below 0.3 m/s, gradual changes in the water level, a slope of less than 20 m/km, firm mud substrate, little turbidity, some organic pollution, partial shade and optimal water temperature between 18° C and 28° C (Birley 1991). Under these conditions, aquatic vegetation and algae, which are the main sources of nutrition for aquatic snails, flourish creating favorable habitats for intermediate snail hosts.

FIGURE 1.
Transmission cycle of urinary schistosomiasis.

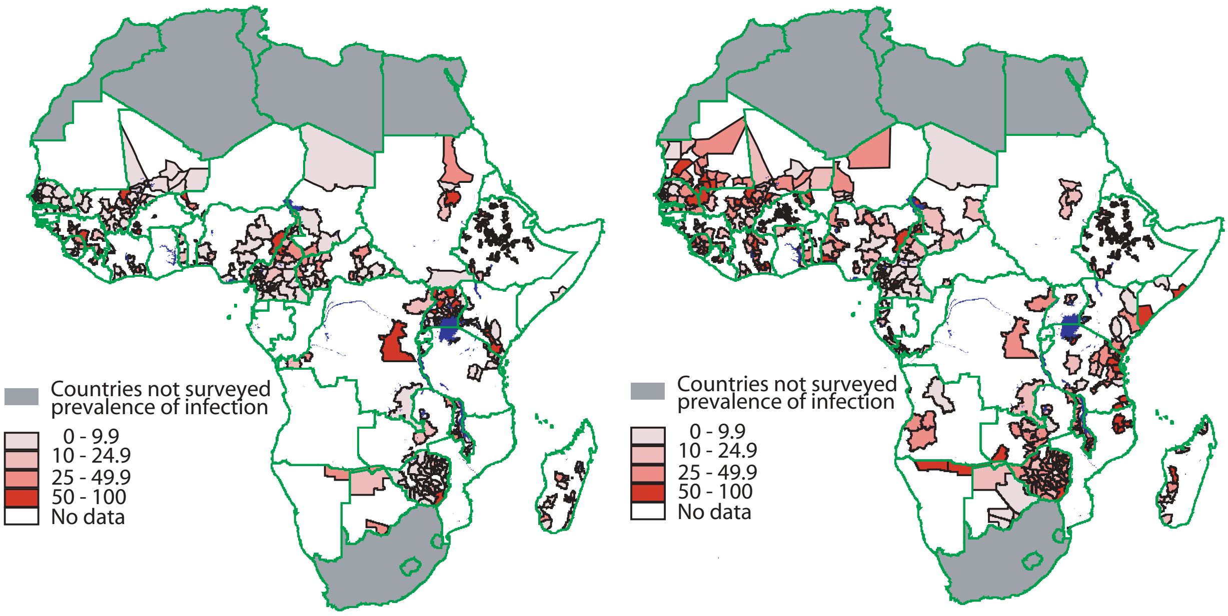


Source: Boelee 1999

Transmission can take place in almost any type of habitat e.g., from large lakes and rivers to small seasonal ponds and streams. Although transmission may be intense in both natural and man-made water bodies, the latter seems particularly important as the human population density is often high near these. Within irrigation schemes transmission is focal and is primarily due to much localized contamination of habitats with human excreta or urine containing schistosome eggs and, also because of the high incidence of human water contact at a few points. Schistosome transmission usually is seasonal, primarily due to the variation in temperature and the irrigation cycle. Local circumstances influence both time and place of transmission, which should be taken into consideration when designing ecological measures to control the snail population.

[1]DALYs: disability-adjusted life years, an indicator that allows comparison between acute and chronic diseases. DALYs for a disease or risk factor are calculated as the annual sum of the years of life lost due to premature death in the population plus the years lived with the disability multiplied by a weighing factor accounting for the degree of morbidity. As clinical symptoms are often not reported, the calculated 4.5 million DALYs lost on account of schistosomiasis is widely believed to be a significant underestimation (WHO Expert Committee 2002).

FIGURE 2.
Prevalence of schistosomiasis caused by *S.mansoni (left map)* and *S.haematobium* (right map) in sub-Saharan Africa by district.



S. mansoni *S. haematobium*

Source: Maps provided by Simon Brooker, Department of Infectious Disease Epidemiology, Imperial College School of Medicine, London (see also Brooker et al. 2000)

Snail Distribution

Generally, presence and density of snails differ highly among sites, and their variability within irrigated areas, in most instances, is related to the canal type, distance of sites from the canal off-take, and the composition and density of aquatic vegetation (Appleton 1978; Madsen 1996a; Khallaayoune et al. 1998a). A major part of this variability, however, is also due to specific local conditions such as (temporary) water stagnation, water depth, shading, and density and composition of aquatic vegetation. All these can be influenced by human interventions, e.g., cleaning and maintenance works, removing the aquatic macrophytes, the application of pesticides and temporary drying out of canals and structures. This may affect snail populations in a manner that is not always predictable. Irrigation schemes are dynamic agro-ecosystems that can transport snails a long way along the canals and where local events can either provide habitat-friendly conditions or inhibit snail populations (Laamrani et al. 1998). Although intermediate hosts can survive long periods of continuous desiccation, intermittent irrigation may dry out snails regularly and arrest their reproduction. This is likely to create a negative effect on the snail population density as well. Intermittent irrigation can also promote the passive transport of snails, as these may be attached to loose debris when irrigation resumes. Often there is a relationship between waterflow velocities and the location of breeding sites in an irrigation system. For instance, more snails are found at sites with low-flow velocities. Often very high densities of snails can be found at the starting point of low-order canals (Boelee et al. 1997). This could be due to snails being washed into such canals and their subsequent upstream migration. The flow conditions around the off-take might also be favorable to the snails, especially in terms of aeration of the water and food availability.

TABLE 1.
Regional distribution of schistosomiasis by species. In some countries only one of the two species is present.

Region	Countries		Countries with schistosomiasis	Presence of *S.mansoni*	Presence of *S.haematobium*
Northern	Algeria, Egypt, Lybia, Morocco (incl. Western Sahara) and Tunisia	(5)	5	2	5
Sudano-Sahelian	Burkina Faso, *Cape Verde, Chad, *Djibouti, Gambia, Mali, Mauritania, Niger, Senegal, Somalia and Sudan	(11)	9	8	9
Gulf of Guinea	Benin, Côte d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone and Togo	(9)	9	9	8
Central	Angola, Cameroon, Central African Republic, Congo, DR Congo, *Equatorial Guinea, Gabon, *Sao Tome and Principe	(8)	6	4	6
Eastern	Burundi, Ethiopia, *Eritrea, Kenya, Rwanda, Tanzania and Uganda	(7)	6	6	5
Islands	Comoros, Madagascar, Mauritius, *Reunion and *Seychelles	(5)	2	1	2
Southern	Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe	(9)	9	9	9
Total		54	46	39	44

Source: Adapted from WHO Expert Committee 1993 and Van der Werf et al. 2003

Note: Division of countries according to FAO 1995; countries with prevalence <0.5% are excluded; countries where the number of schistosomiasis cases is reported as zero or where only a very low prevalence was found, are denoted with an asterisk

Schistosomiasis Control

In countries where schistosomiasis is endemic, control is aimed at reducing morbidity and arresting symptoms of the disease. These measures are put in place either through a specific control program or through the primary healthcare system (Mott 1984; Chippaux 2000). Making available a vaccine to immunize people, still seems a distant prospect (Gryseels 2000; Hagan et al. 2000). Luckily, safe and effective drugs such as "praziquantel" are available to treat infected people (Crompton et al. 2003; Hagan et al. 2004). Nevertheless, experience shows that reinfection following treatment can be very fast (Tchuem Tchuenté et al. 2001). Moreover, not all countries have adequate health systems to reach the population at risk (Chitsulo et al. 2000). Therefore, minimizing morbidity can be effectively supported through parallel preventive measures i.e., reducing the contamination of water with schistosome eggs, and at the same time preventing exposure of humans to schistosome-infested water (WHO Expert Committee 1993, 2002). Unfortunately, health education, water supply and sanitation programs have only a marginal impact on the youngsters playing in and around water bodies and on people, whose occupation involves water contact. Therefore, snail control is an important preventive measure in an integrated approach to control schistosomiasis transmission (Madsen and Christensen 1992; Sturrock 2001). Snail control may be achieved through chemical, environmental or biological means, where environmental measures often have additional controlling effects on the transmission cycle.

The most effective method of achieving significant reductions in snail population density is the use of molluscicides such as "niclosamide," which are pesticides specifically made to terminate aquatic snails. Focal molluscicide application, which is implemented seasonally according to the transmission pattern, is the most recommended approach to snail control (Klumpp and Chu 1987). However, the high cost of niclosamide and its negative environmental impact i.e., primarily toxicity to fish, make it necessary to opt for new approaches to snail control. This is even more important in areas where irrigation water is used intensively for fishing, livestock, domestic purposes and even drinking (see e.g., Yoder 1983; van der Hoek et al. 1999, 2001, 2002a; Boelee and Laamrani 2004; Nguyen-Khoa et al. 2005). Alternative approaches include not only modified techniques and strategies for molluscicide application, but also environmental control measures and biological interventions to reduce the application of niclosamide and to provide more long-lasting effects.

The use of plant molluscicide is considered as an alternative way to control snail populations. In Ethiopia, berries of endod *(Phytolacca dodecandra)* were formerly used extensively as soap for washing laundry. Experiments are under way to determine how the reintroduction of Endod in snail-infested locations can contribute to schistosomiasis control (Wolde-Yohannes et al. 1999). However, the production of sufficient material for large-scale use would be problematic. In a study in Egypt, application of the nontoxic floating *Azolla* weed to create shading and, thereby reduce the growth of submerged plants was successful in diminishing snail densities for a short period, but the effect of vegetation clearing led to a much longer impact on snails (Allam 2000). The shade caused by *Azolla* reduced the growth of aquatic plants, especially algae, the preferred food source of aquatic snails, to a certain extent. However, the removal of vegetation diminished the food resources for snails to a higher degree. In addition, as vegetation once removed takes a long time to re-grow, it had a direct impact in minimizing snail populations. Another aspect of clearing vegetation is that along with it aquatic snails attached to the vegetation were also removed (Allam 2000).

There are only few examples of successful biological control of schistosome intermediate hosts, and they too have been applied only on a limited scale (Pointier and Giboda 1999). The focus of biological control has been on the introduction of a nonsusceptible snail species that may act as competitors of the intermediate hosts (Madsen 1990, 1996b and references therein).

However, increasing awareness of the importance of protecting biodiversity makes this approach become less attractive (Kristensen and Brown 1999). At present, there is no method of biological control that could be recommended for general use.

The starting point of all programs to control the intermediate host snails should be: (i) a profound knowledge of their distribution patterns; (ii) their population dynamics; and (iii) an understanding of factors affecting these patterns. This, however, cannot always be achieved and, as such, in cases where elaborate studies are not possible, either snail control should be replaced by other approaches to control schistosomiasis transmission or general principles of snail ecology in irrigation should be applied. We, the authors, hope that this document will help you to understand how this can be achieved. The following discussion relates to distribution patterns of the intermediate hosts and the biological aspects of transmission. This ecological variability is illustrated as evidenced in different irrigation schemes in Africa.

Irrigation in Africa

Food production can be increased by augmenting the area under cultivation or by intensifying the utilization of areas already under cultivation and, thereby increasing the yield per surface area. In many areas, this requires an increased and reliable water supply, which often can be ensured only through irrigation. The African continent, in particular, has very high spatial and temporal variability in rainfall compared to other continents (Walling 1996; FAO 2003). FAO (1995) grouped the 53 African countries into 7 regions based on geographic and climatic homogeneity, which has a direct influence on irrigation (figure 3). Table 2 shows the variety in water resources and withdrawals for each of the regions. For the African continent as a whole, approximately 85 percent of water withdrawals are directed towards agriculture, but this figure varies considerably from one region to the other. For example, in the relatively humid central region, only 43 percent of the water withdrawals is used for agriculture because of the high potential in the area for rain-fed agriculture. Nevertheless, in the Sudano-Sahelian region and on the islands, 94 and 99 percent of the water withdrawals, respectively, are used for agriculture (FAO 1995).

TABLE 2.
Regional distribution of water resources.

Region	Area (1,000 km²)	Rain (km³/yr)	Internal renewable resources (km³/yr)	Total withdrawals (km³/yr)	Withdrawals / resources (%)
Northern	5,753	411	50	76	152
Sudano-Sahelian	8,591	2,878	170	24	14
Gulf of Guinea	2,106	2,965	952	6	1
Central	5,329	7,621	1,946	1	0
Eastern	2,916	2,364	259	7	3
Islands	591	1,005	340	17	5
Southern	4,739	2,967	274	19	7
Total	30,025	20,211	3,991	150	4

Source: Adapted from FAO 1995

FIGURE 3.
Regional division of Africa.

Source: FAO 1995

TABLE 3.
Regional distribution of irrigated area. Irrigation includes full or partial control, river flood irrigation and modified wetlands, which comprises cultivated wetlands, valley bottoms and flood recession cropping. The figures represent a slight underestimation since the following countries are not included: Cape Verde, Djibouti, Gambia (Sudano-Sahelian region), Equatorial Guinea, Sao Tome and Principe (Central region), Comoros, Mauritius, Reunion, Seychelles (Islands), but these are all countries with very little irrigation.

Region	Irrigated area		
	Potential (1,000 ha)	Realized (1,000 ha)	Percentage realized (%)
Northern	7,194	5,872	82
Sudano-Sahelian	5,019	2,041	41
Gulf of Guinea	7,416	523	7
Central	13,730	94	1
Eastern	5,843	517	9
Islands	1,517	935	62
Southern	6,360	1,922	30
Total	47,079	11,904	25

Source: Adapted from Aquastat 2005 and FAO 1995

The extreme variety in climatic conditions, topography, size of the area, and financial inputs create a very heterogeneous geographical distribution of irrigation, in keeping with the water withdrawals (table 3). Almost half (49 percent) of the African continent's irrigation takes place in the North, where agriculture without irrigation is hardly possible. In Equatorial Africa (Central and Gulf of Guinea regions), where precipitation is high, rain-fed agriculture is dominant and irrigated areas form less than one percent of the cultivated land (FAO 1995). Irrigation is used here at a much smaller scale for a second crop, rice cultivation, to secure special high-value crops, or in home gardens.

Surface irrigation is the most widely used technique in Africa. About 4.4 million hectares, roughly one-third of the total irrigated area in Africa, almost all of it in the northern region, are irrigated through a system of open irrigation canals, which are usually fed from a retention lake created by a dam. Surface systems vary in size and can have either earth canals or concrete-lined canals, but usually have earth drains. Roughly, one million hectares are irrigated through sprinkler systems, while less than 150,000 hectares are by drip irrigation. More than half of the irrigated area in Africa is irrigated differently, e.g., by traditional techniques such as flood irrigation or wetland management (FAO 1995).

Most irrigation systems in Africa create specific conditions that may favor establishment of schistosome intermediate hosts and the subsequent transmission of schistosomiasis, especially where drainage is not always adequate (Tanji and Kielen 2002). Improper drainage can create stagnant water locally with ample aquatic vegetation, thus providing ideal breeding habitats for snails. Nevertheless, as the population does not intensively use most drains, water contact is minimized and the transmission of schistosomiasis is low. The situation, however, is completely different in systems where drains bring return flow back to the canals and irrigation schemes, which are further downstream e.g., as in Egypt. Under a situation like this the risk of contamination with fecal matter and urine increases, while enhancing the prospect of intermediate hosts and schistosomiasis being transmitted farther.

In addition to the storage of water in a large dam, most surface irrigation systems require an appropriate system for water storage within the scheme to facilitate flexibility in water distribution. Sometimes (night) storage ponds are constructed, and canals are frequently "over-dimensioned." Often water-related diseases are linked to water storage structures within the irrigation system. For instance, the stagnant or slow-flowing water in these water bodies favors the growth of aquatic plants, which creates favorable breeding conditions for the intermediate host snails. Because water is present almost continuously, such habitats easily become the more popular sites for human water contact and, thus schistosomiasis transmission is established. Clearly, if one wants to control snail populations in an irrigation scheme through environmental measures, a detailed knowledge of the site-specific conditions favoring transmission of schistosomiasis is required for each scheme. This kind of information is needed, as realistic options to control schistosomiasis transmission are very much dependent upon the specific conditions prevalent within the scheme.

Examples of Schistosomiasis in African Irrigation

In this section, four cases of schistosomiasis ecology in irrigation are discussed, including options for, or experiences in, environmental control measures. This is followed by a more limited description of case studies based on the literature.

Morocco: Tessaout Amont (northern region)

In Morocco, the transmission of urinary schistosomiasis increased with the development of modern open canal irrigation systems (Mahjour 1993). The Ministry of Health was able to counteract this expansion with an effective National Schistosomiasis Control Program (Laamrani et al 2000c). However, the risk of transmission prevailed until recently because of the abundance of breeding sites for the intermediate host *Bulinus truncatus* in many irrigation systems (Laamrani et al. 2000b).

In Central Morocco, the Tessaout Amont irrigation system is a case in point, how the construction of a large modern open canal irrigation system introduced urinary schistosomiasis into the Haouz plain. It is a plain that has had a long tradition of irrigation. The Tessaout Amont irrigation system has a typical Moroccan layout with upstream flow control, and is entirely gravity-fed. Open trapezoidal lined primary canals supply water from the Moulay Youssef dam to the elevated semi-circular concrete secondary and tertiary canals, which in turn feed unlined field canals. At road crossings and at canal outlets, inverted siphons have been constructed to convey water below a road or track. These siphons consist of two concrete boxes connected by an underground pipe.

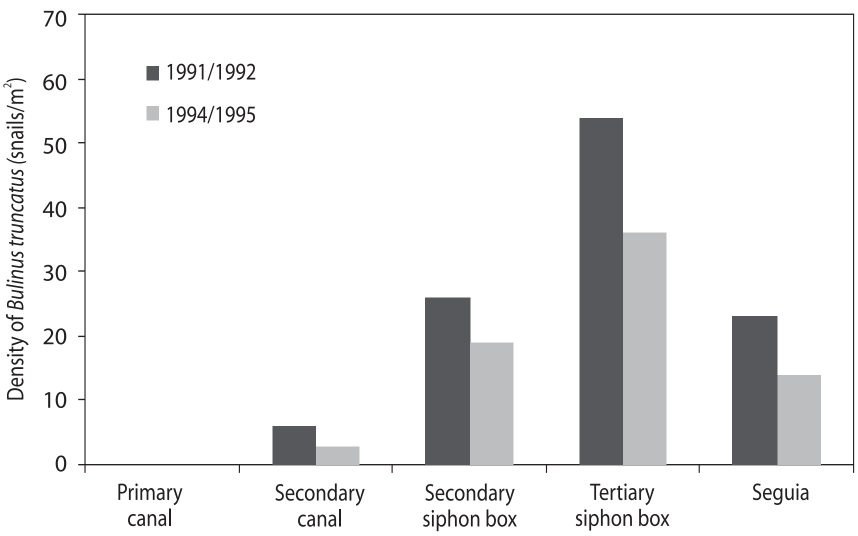
A rotational water distribution causes an almost permanent low flow in the secondary canals and an intermittent flow in the tertiary canals. These canals completely dry out between irrigation turns, but most hydraulic structures remain filled with water. In the absence of other sources, this standing water is used for all kinds of agricultural (e.g., livestock) and domestic purposes by the local population, inducing frequent water contact. The water level in siphon boxes fluctuates considerably; depending on the time elapsed since the last irrigation period, temperature and water use (Laamrani and Boelee 2002). These siphon boxes are the main transmission sites of *S. haematobium* (Khallaayoune and Laamrani 1992). Schoolchildren frequently use canals and siphon boxes for recreation and habitually urinate therein.

Cross-sectional snail surveys in the Tessaout Amont irrigation system showed that *B. truncatus* was common all over the area in all habitats, but was only sporadically (0.06%) infected with *S. haematobium* (Boelee 1999). High densities of intermediate snail hosts were most frequently found in the numerous tertiary inverted siphons (figure 4), especially near the tail end of the canals and in the downstream boxes. The preference of *B. truncatus* for tertiary siphon boxes could be explained by the relative stability of this habitat and the availability of food resources in the form of microscopic algae, which are stimulated by long periods of water stagnation. The siphon provides a good starting point for focussed environmental schistosomiasis control to reduce snail host populations, water contact and water contamination.

In this irrigation scheme, in 1993, three methods for snail control in these siphon boxes were assessed (Khallaayoune et al. 1998b). Molluscicide (niclosamide) application resulted in a pronounced reduction in the snail population density, but snails started to recolonize the sites a few months later. Regular brushing of the inner sides of the siphon boxes and covering the siphon boxes with concrete lids to prevent light entering caused a significant reduction in the number of snails. The latter two methods were not as effective as the application of molluscicide. However, long-term application of molluscicides is not sustainable because of its high cost and negative environmental impacts.

Three more environmental control options were studied (Laamrani et al. 2000a). The first option: Regular emptying and cleaning of siphon boxes had a limited effect on densities of *B. truncatus* snails and eggs. The intervention could not suppress the snail population for long. More frequent emptying would require repeated inputs from a community that perceives no immediate benefit from these efforts. The second option: Creating a dark environment by covering the siphon boxes with iron plates proved to be much more effective in reducing *B. truncatus* populations. Some of the covers were equipped with moveable lids in order to make the water accessible to the villagers (figure 5). Covering boxes was very effective in reducing densities of *B. truncatus* populations. Human water contact too was reduced in the village and so was the contamination of the water. Meanwhile, the water in the boxes remained accessible. Three years after the intervention, most covers were still in place, while another year later, when schistosomiasis

FIGURE 4.
Average density of *Bulinus truncatus* in different habitats in the Tessaout-Amont irrigation system as found in cross-sectional snail surveys in 1991/1992 and 1994/1995.



Source: Boelee 1999

FIGURE 5.
Detail of an iron plate cover with a moveable lid on a tertiary siphon box to allow for the withdrawal of water in the Tessaout Amont irrigation system, Morocco.

had disappeared completely from the region, the covers were all removed and marketed (personal observations 2000 and 2001).

The third option: This concerned measures to increase the vertical waterflow velocity in siphons by reducing the inner dimensions of the siphon boxes, and thereby increase the instantaneous and average waterflow velocity. However, experiments carried out using such small siphon boxes revealed that *B. truncatus* quickly repopulated the siphons after the boxes were made smaller. Better results might be achieved by further reducing the inner dimensions, but this would result in overtopping of the canal and would generate higher energy losses. Consequently, such small siphons can only be applied in a layout where access to the fields is guaranteed through the construction of simple bridges over the drains, which would significantly reduce the number of required siphons (Boelee 1999).

Mali: Office du Niger (Sudano-Sahelian region)

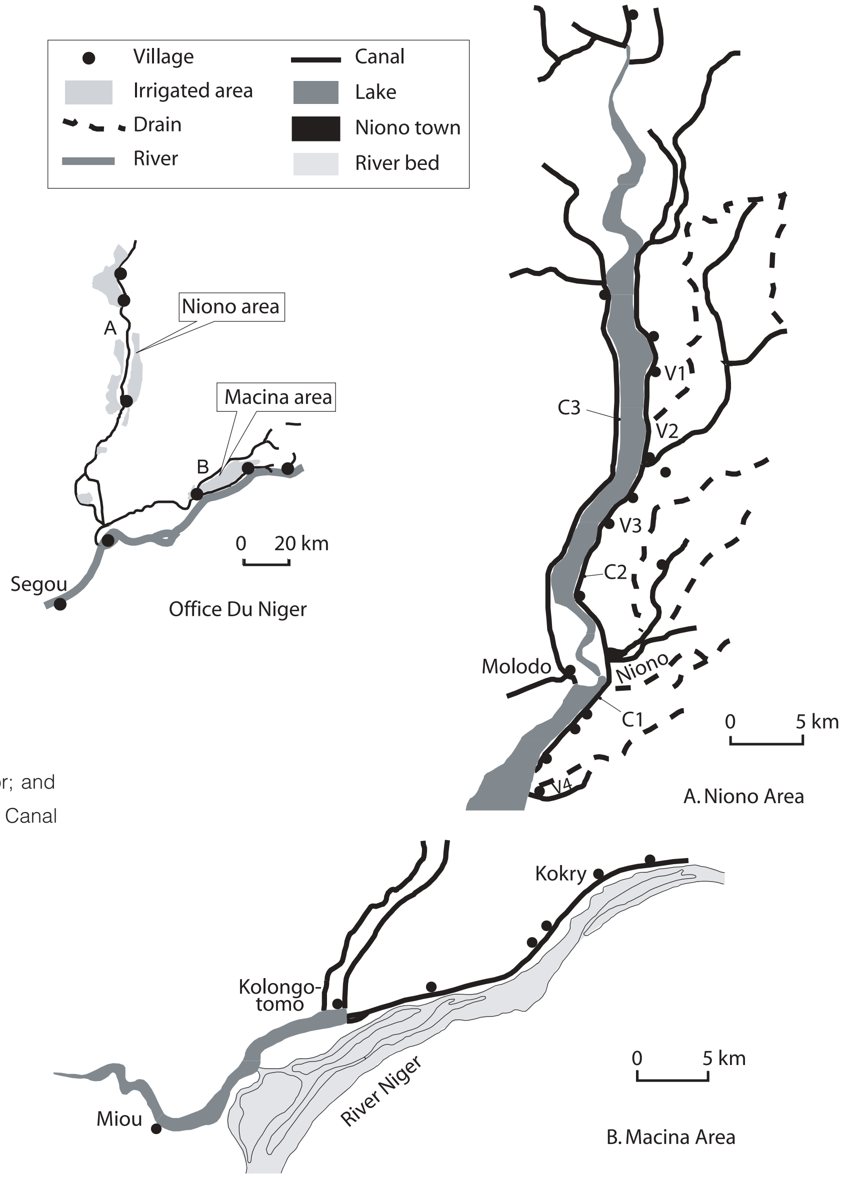
This extensive irrigation scheme, which was established in the late 1930s, is one of the most conducive areas for the transmission of schistosomiasis in Mali (Madsen et al. 1987; Traoré 1995b). The scheme is watered from the River Niger. Shortly after the off-take, the canal divides into two main canals to the Niono and Macina areas, which partly function as water storage lakes (figure 6). Principal canals take off at various points from the lakes and feed the large distributors. The main wet-season crop is rice, and during the dry season, which is from January to May, vegetables are grown.

The scheme-area covers the district of Niono, where 165,000 people from different ethnic backgrounds live in villages, which are scattered in a vast flat land surrounded by irrigation canals and drains. Extensive use is made of the canals for most water-related economic, domestic and recreational activities (Traoré 1995a). The prevalence of schistosome infections varies considerably among the villages. Data summarized in Doumenge et al. (1987) show that 10 to 97 percent of the population was infected with *S. haematobium* and 3 to 84 percent with *S. mansoni,* in both Ké-Macina and Niono. Currently, the common overall infection rates for each schistosome species are 60 percent and above.

The only intermediate hosts of human schistosomiasis found in the Office du Niger were *Biomphalaria pfeifferi* and *Bulinus truncatus* (Madsen et al. 1987). Both snail species were very common in the two lakes, in the large (principal and distributor) canals as well as in the small canals (“arroseurs”), but were rarely found in the field ditches. The intermediate hosts were focally distributed and to some extent associated to human water contact activities. Some human water contact sites in the lakes and large canals had very high snail densities, which caused a high incidence of schistosome infections in the locality.

Since the early 1980s, part of the scheme has been subjected to more intensive cropping i.e., two annual rice harvests with vegetable cultivation in between. Hence, there is one rice crop cultivated during the main agricultural season, which is from June to December—covering the rainy season and the first part of the dry season—and a second rice crop in the off-season, which is from January to May—covering the dry season (Coulibaly et al. 2004). This means that the large canals are filled to full capacity throughout the year. A survey conducted to compare schistosome transmission between areas with double and single cropping failed to demonstrate any clear-cut differences in snail population dynamics and schistosome transmission patterns between the two areas (Coulibaly et al. 2004). Infected snails are found not only in the large canals but also in the lower order canals. However, most human water contact occurs in the larger canals making them responsible for most of the schistosome transmission within the scheme.

FIGURE 6.
The "Office du Niger" irrigation scheme in Mali.



Note:
Canals:
C1. Canal Grüber;
C2. Siengo Distributor; and
C3. Molodo Principal Canal
Villages:
V1. Ringandé;
V2. N'Débougou;
V3. Bagadadji; and
V4. N'Gallamadian

Source: Madsen et al. 1987

A key factor for the high density of snails and subsequent intense transmission of schistosomiasis in these large canals, is the abundance of aquatic plants (figure 7), especially the submerged species. Usually, water in these canals is very clear, especially during the dry season, which is also the most significant transmission season (Coulibaly et al. 2004). Generally, the snails are found within the bottom vegetation, which is not cut as it is assumed to protect the canal banks against erosion.

In many large canals in Office du Niger, in Mali, concrete steps are constructed to provide easy access to the users of water for washing and laundry, and to protect the canal banks from erosion. These steps contribute to a concentration of water use activities in their vicinity. If snails could be effectively controlled in the large canals, there would be fewer invasions by the intermediate hosts into the lower order canals, thereby reducing schistomiasis transmission. Most of the snails are found on aquatic vegetation and, as such, cutting the plants might be more effective in controlling them than other measures like water level fluctuations. In addition, removal of vegetation does not interfere with irrigation water deliveries and it helps to expose the snails to predatory fish.

In recent years, the Office du Niger has become a very promising example of how large-scale irrigation can bring multiple benefits to farmers in sub-Saharan Africa. When a general evaluation of this area for the past 10 years was done, schistosomiasis was not mentioned as a major problem (Bonneval et al. 2002).

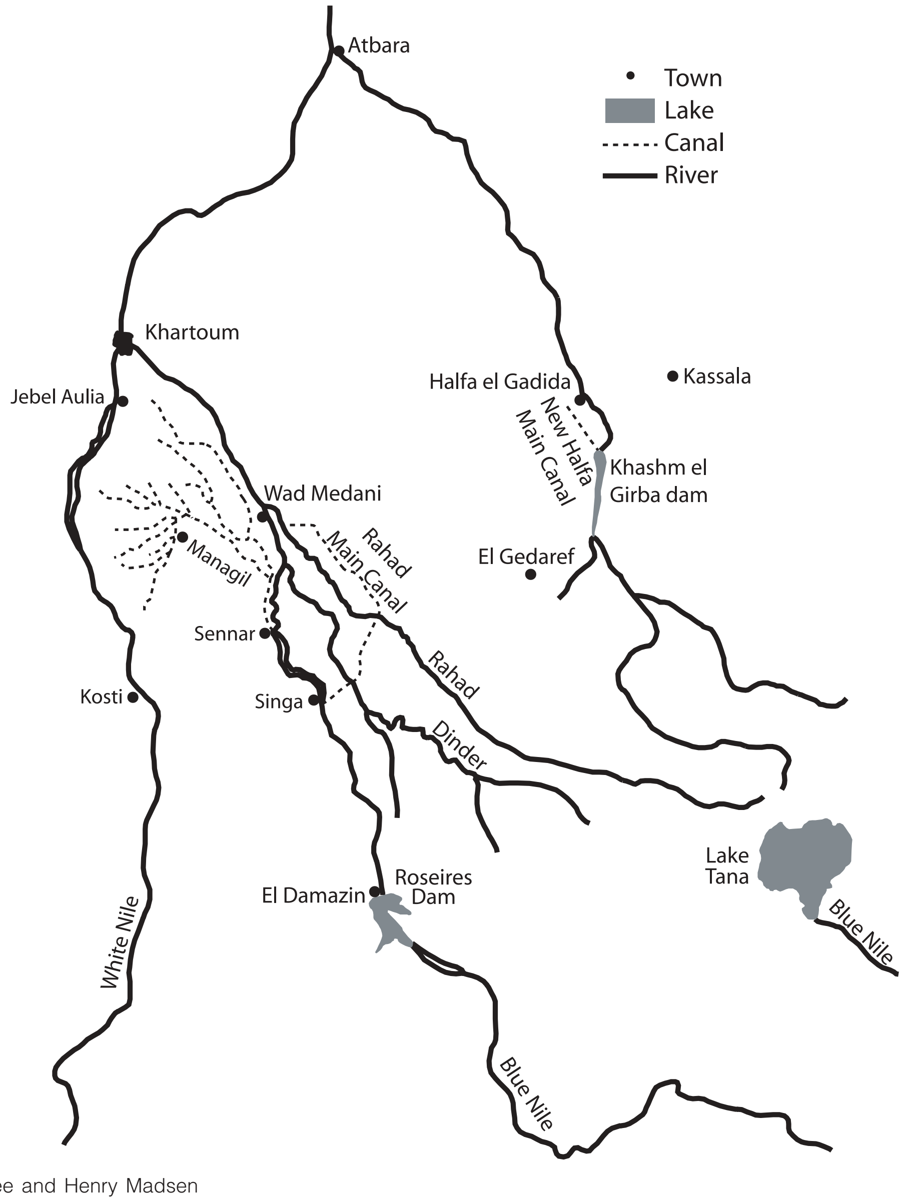
In Mali, other areas with water resources development projects such as Manantali, Sélingué and Dogon plateau constitute important areas for schistosome transmission (Brinkman et al. 1988; Traoré 1995b). At the Dogon plateau, the construction of small dams since the 1960s resulted in an increased schistosome transmission, with the prevalence of *S. haematobium* reaching up to 55 percent while the presence of *S. mansoni* remained low (De Clercq et al. 1994).

FIGURE 7.
Laundry site at a large canal in the Niono area of the “Office du Niger,” Mali.

Sudan: Gezira-Managil (Sudano-Sahelian region)

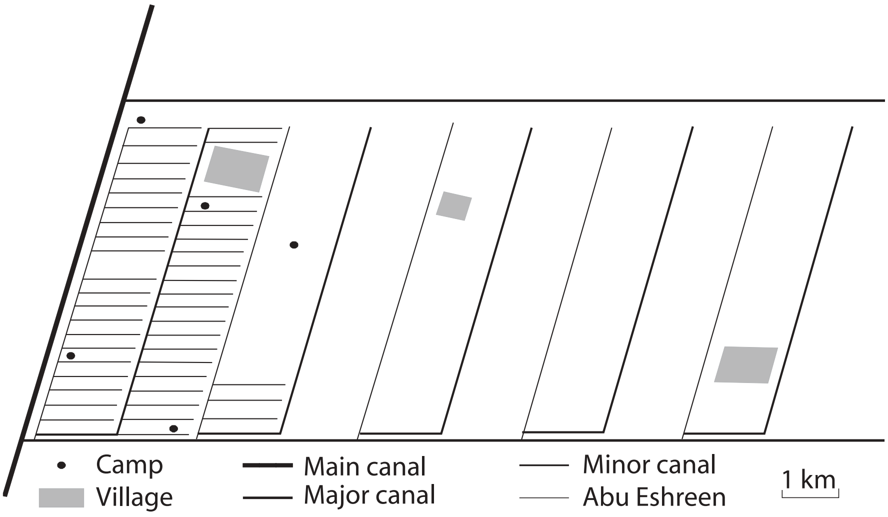
The Gezira irrigation scheme, which was started in 1924, had its Managil extension opened in 1963 (El Gaddal 1985). Together, the scheme now encompasses an area of approximately 840,000 hectares. The scheme is irrigated from the Sennar dam on the Blue Nile through two main canals, one for the Gezira and the other for the Managil (figure 8). The open earth-lined and gravity-fed irrigation canals are designed to distribute water sequentially from the main canal through branch canals, major canals, minor canals, field canals (Abu Eshreen), farm canals (Abu Sitta), and plot ditches (figure 9). Minor canals are 1.4 kilometers apart and take off in pairs from the major canals. Each field has one field canal, which takes water from the minor canal through a pipe that can be sealed when not needed. The fields are divided into 4-hectare holdings by farm canals.

FIGURE 8.
The major irrigation canals in central Sudan.



Source: Eline Boelee and Henry Madsen

FIGURE 9.
The irrigation canals in the Gezira-Managil scheme, Sudan.



Source: Eline Boelee and Henry Madsen

The prevalence of intestinal schistosomiasis is high in the Gezira Agricultural Scheme, while that of urinary schistosomiasis is variable but generally low (El Gaddal 1985). However, urinary schistosomiasis, which affected less than one percent of the population before World War II, increased in the 1950s to affect almost a quarter of the adult population and half the population of children. The number of people affected by intestinal schistosomiasis increased even more, especially among children (Oomen et al. 1988). Another vulnerable group was the canal cleaners, who stayed for long hours in the infested water on a daily basis (Fenwick et al. 1982).

In the 1970s the communications and control systems in the main canals broke down. Combined with heavy growth of aquatic plants (due to inadequate maintenance), this led to the situation where all canals had to be fuller to deliver water to the crops (Oomen et al. 1988). An abundance of *Biomphalaria pfeifferi* and *Bulinus truncatus* was present in all types of canals (Madsen et al. 1988).

In the main canal, fairly high densities of both *B. pfeifferi* and *B. truncatus* may occur upstream of sluice gates, where water is relatively calm close to the banks. Minor canals (up to 10 meters wide) are used for water storage within the scheme, thus making them suitable as snail habitats and for human activities. Snails were widely distributed within these canals, which is in marked contrast to the focal distribution of snails in the large canals in the Office du Niger in Mali. With high snail densities and intensive water contact, the minor canals are probably the most significant transmission sites in Gezira.

In the nearby Rahad irrigation system, which had its first agricultural season in 1978, a program of integrated schistosomiasis control was initiated in 1980 to prevent outbreaks similar to those in Gezira-Managil. This program, called the "Blue Nile Health Project," focused on village water supplies. In addition, it facilitated chemical snail control and medical treatment of infected people. In 1981 and 1982, in Rahad, 7 and 10 percent of the population, respectively, were infected. In the same years, the population infected in Gezira-Managil was 51 and 61 percent, respectively (Tameim et al. 1985). However, making further control efforts in the Rahad scheme became a problematic exercise. Specific problems related to low school attendance rates limited treatment opportunities for the children, as the medication against schistosomiasis was distributed at schools. This combined with the limited efficacy of the focal snail control approach, may be responsible for the control program implemented in Rahad to be unsuccessful in effectively controlling transmission (Elias et al. 1994).

Cameroon: Lagdo (central region)

The Lagdo hydroelectric dam on the Benue river in northern Cameroon, which was completed in 1988, created a 700-square-kilometer artificial lake. An area of 1,000 hectares is irrigated from the reservoir through a 3-kilometer open unlined main canal that divides into two concrete-lined principal canals. All other canal types are open and unlined, except at intakes and road crossings, where canals and drains are concrete-lined and provided with regulating gates (Tsafack 1997). Water flows almost continually in all canals and rice fields during the irrigation season, and year-round in the primary canal (Slootweg et al. 1993).

Schistosome infections were prevalent among the local population even before the introduction `of irrigated agriculture. Previous studies showed that in 1968, 15 percent of the population in the area was infected with urinary schistosomiasis (Doumenge et al. 1987). In 1986, one year before the creation of the scheme, 43 percent of the population in 15 fishing villages located around the lake was infected with *S. haematobium,* and 16 percent with *S. mansoni* (Robert et al. 1989). A recent epidemic of bloody diarrhea in Bessoum was attributed to *S. mansoni.* When the schoolchildren were examined, 61 percent was found to be infected (Cunin et al. 2000).

Surveys conducted between March 1994 and December 1995 showed 13 snail species, out of which 5 were potential schistosome intermediate hosts: *Bulinus globosus, B. truncatus, B. forskalii, B. senegalensis* and *Biomphalaria pfeifferi* (Tsafack 1997). *B. truncatus* was limited to the lake area and the irrigation system, where it occurred in all types of canals and rice fields. Schistosome infected *B. truncatus* was collected both in the lake and in the drains. *B. globosus* was common in temporary water bodies such as rain puddles and small pools within and around the irrigation scheme. In addition, *B. globosus* was also established in some irrigation canals.

Density fluctuations of the intermediate hosts were irregular due to the fluctuating water levels in the canals. The aquatic vegetation densities were high in irrigation canals and drains due to their poor maintenance (figure 10). Water was present throughout the system, almost permanently, due to a lack of synchrony in rice cultivation between farmers. Therefore, snail

FIGURE 10.
Principal canal with abundant vegetation in the Lagdo-area, northern Cameroon.

Photograph by Henry Madsen

populations became more abundant and present almost year round. If all the farmers would conform to the original rice-growing calendar and plant at the same time, canals would fall dry outside the season and be a deterrent to the year-round presence of snails (Tsafack 1997).

Literature Case Studies

Egypt (northern region)

Throughout Egypt, schistosomiasis has been present since the age of the Pharaohs. In the Egyptian Nile Delta, all villages are situated either next to canals or drains, which form an integral part of the daily life of the rural population. The canals are used for daily activities such as laundry, bathing, washing of household utensils, swimming, watering animals, bathing animals, ablutions before prayer, washing grains, making dough, cooking and washing vegetables, while the same water courses are used also for the disposal of untreated sewage, garbage and dead animals (Boelee and Gryseels 1995). Especially women, boys and young men, through their respective domestic, recreational and professional activities, are highly exposed to schistosomiasis (Abdel-Wahab et al. 2000; Gabr et al. 2000).

The Nile dams in Sudan contributed effectively to the existing transmission of schistosomiasis related to the dams of Upper Egypt and to its impact throughout the country. In the 1930s, the conversion from traditional flood irrigation to perennial irrigation after the construction of the low Aswan dam led to high human population densities, intensive agricultural practices and frequent prolonged water contact. Infection with urinary schistosomiasis increased from less than 11 percent of the population in 1934 to rates as high as 75 percent in 1937 (Hunter et al. 1993).

The main schistosomiasis control strategy in Egypt is proper diagnosis and prompt treatment of cases. While this method has been highly effective in reducing the disease, transmission is still prevalent. Over time, possibly, but not necessarily because of changes in the Nile's hydrology, *Bulinus* snails have been replaced by *Biomphalaria* in the Delta (Grosse 1993) and in other parts of Egypt as well (Yousif et al. 1998). As a result, the prevalence of urinary schistosomiasis has decreased, while infection rates of intestinal schistosomiasis have increased (Cline et al. 1989). This is reported not only in the Delta (Gabr et al. 2000) but also in the Fayoum (Abdel-Wahab et al. 1993), and in the newly reclaimed areas east of the Delta. Near the Suez canal, the prevalence of *S. mansoni* has increased from 10-20 percent in the 1980s to 40-50 percent in the 1990s, while *S. haematobium* infections in the area dropped from around 10 percent to a much lower percentage (El-Sayed et al. 1995). Recent analyses confirm that in Lower Egypt, north of Cairo, *S. mansoni* has now almost completely replaced *S. haematobium,* while it is also spreading to Upper Egypt, south of Cairo (El-Khoby et al. 2000).

Bulinus and *Biomphalaria* snails are present in most of the canals, which are mainly associated with dense aquatic vegetation, and not so much in the drains (Yousif et al. 1998).

Valley of Sourou, Burkina Faso (Sudano-Sahelian region)

In Burkina Faso, the presence of urinary schistosomiasis is more pronounced in the drier North than in the more humid South, while intestinal schistosomiasis is mainly present in the South and West of the country (Poda et al. 2004b). Within the main climatic zones of Burkina Faso, the heterogeneity in the transmission pattern of schistosomiasis is closely linked to the water systems (Poda and Traoré 2000). In general, irrigation systems and small permanent water bodies are preferred breeding sites for the snail hosts, and are the principal points of contact between people and the parasite (Poda 1996).

In the Valley of Sourou, several epidemiological and malacological studies have been carried out in the 1990s, comparing villages with irrigation schemes built 30, 20 and 3 years ago (Poda et al. 2001). The older irrigated areas invariably had much higher transmission of both urinary and intestinal schistosomiasis, with prevalences varying from 5-10 percent before the introduction of irrigation to 60-80 percent in the old schemes several years after the introduction of irrigation (Poda et al. 2003). Similar results were found a few years later (Dianou et al. 2004). Intermediate snail hosts for both types of schistosomiasis were found throughout the irrigation systems (Dianou et al. 2003). This means that over the different seasons in the semi-arid environment of Burkina Faso, the snails can always find suitable habitats, which are at the same time concentration sites for intensive water contact (Poda et al. 2004a).

Rice Cultivation in the Inland Valleys (Gulf of Guinea)

Over the past few decades, there has been an increased focus on the development of swamp rice farming in the West African inland valleys as it is more productive than the traditionally grown upland rice. Swamp rice farming usually involves the removal of the original vegetation and the construction of an ordered series of water-filled rice fields, which are drained into a central channel at the bottom of the valley. By damming at the head of the swamp, the water is made to flow through the peripheral channels and re-enter the central channel via the rice fields. In some valleys, storage ponds may be constructed at intervals along the central channel, which often become sites for washing and bathing, especially when they are positioned close to the villages.

In Côte d'Ivoire, three intensities of inland valley cultivation were compared: (i) R0 without rice; (ii) R1 with absence of or partial water control and with one rice crop per year; and (iii) R2 with partial or full water management and with two rice crops per year (Yapi et al. 2005). Distance to the nearest inland valley was a risk factor for schistosomiasis, both in the savanna and the forest villages, probably because of the increased water contact. In the savanna zone, prevalence of *S. haematobium* was 0.7 percent in R0; 2.3 percent in R1; 4.8 percent in R2; while in the forest zone, it was 1.7 percent in R0; 4.4 percent in R1; and 0.9 percent in R2. A significantly higher risk of infection was prevalent only in the valleys of the forest zone that had one rice crop. The authors conclude that rice cultivation might bring a marginal risk of being infected by *S. haematobium* since a significant positive association was found with the surface area of rice fields. However, in the case of intestinal schistosomiasis it was a different situation. In the savannah zone, intestinal schistosomiasis was more prevalent in the rice cultivating agro-ecosystems (11.9% for R1 and 16.1% for R2), than in the control system (2.1%). Intensity of the infection was related to the amount of rice cultivation and not to the amount of naturally occurring surface water. Both in the savannah and in the forest zone, the prevalence and intensity of *S. mansoni* infection was higher in double cropping villages (with full or partial water control) than in single cropping villages (with limited water control). In the forest zone, however, inland valley rice cultivation did not increase the risk of being infected by schistosomiasis. Nevertheless, intestinal schistosomiasis had a higher prevalence in the rice cultivating agro-ecosystems (46.6% in R1 and 51.3% in R2) than in uncultivated villages (17.5%), but the intensity of infection was not related to the amount of rice cultivation but to the amount of naturally occurring surface water. It can be concluded that in the forest zone, inland valley rice cultivation does not increase the risk of being infected by schistosomiasis, while in the savana areas rice cultivation definitely contributes to an increase in the transmission of *S. mansoni* (Yapi et al. 2005), which confirms the earlier findings by Cadot et al. (2000).

Previous studies in the region in spite of not having many clear results provide interesting background reading, e.g., Kazura et al. (1985) for Liberia and Gbakima (1994) for Sierra Leone.

Several inland valleys have been transformed into small reservoirs to meet the water requirements of livestock, domestic supplies and irrigation. In Cameroon, the development of hundreds of small agro-pastoral dams led to a rapid spread of schistosomiasis (Ripert and Raccurt 1987). Similar results have been reported from Côte d'Ivoire (Le Guen 2000; Cecchi in press), Ghana (Hunter 2003) and Burkina Faso (Poda and Traoré 2000; Poda et al. 2003). Since these dams usually do not have distinct irrigation systems comprising canals, hydraulic structures and drains, they will not be discussed further in this report.

Kenya: Mwea (eastern region)

The Mwea scheme, which was developed between 1952 and 1957, is one of the economically most important irrigation systems in Kenya. The 6,000 hectares of irrigated land in the scheme produce 90 percent of the country's total rice production, and are inhabited by 35,000 people (Clayton 1981). The first case of schistosomiasis in the region occurred in 1959, and within 10 years after the implementation of the irrigation system, 12 percent of the adult population and 60 percent of schoolchildren were found infected with *S. mansoni* (Waiyaki 1987). In 1987, this had spread to the rest of the population. Despite the entire irrigation system being treated with snail-killing chemicals (niclosamide), in some villages more than two-thirds of the inhabitants tested positive for *S. mansoni.* Ngunnzi (1977) suggests that it is impossible to eradicate the snails because of the presence of overgrown habitats and seepage from canals and drains. An integrated schistosomiasis control project, implemented between 1983 and 1988 by the Kenya Medical Research Institute in collaboration with the National Irrigation Board, included improvement of water supply, construction of bathing sites and latrines. Chemotherapy and health education were two other key focus areas of the project (Katsivo et al. 1993). Unfortunately, 50 percent of the children between 5-19 years got reinfected within 12 months of treatment (Muthami et al. 1995). The Mwea scheme was rehabilitated with Japanese support between 1990 and 1992. Further expansion of smallholder irrigation is expected. This kind of expansion in irrigation will attract migrants such as pastoralists, farm workers and merchants, leading them to more frequent water contact and expose them largely to schistosomiasis (Mutero 2001).

Zimbabwe: Mushandike (southern region)

In Mushandike, Zimbabwe, integrated schistosomiasis control measures determined, to a large extent, the final design of smallholder irrigation systems (Draper and Bolton 1986; Chimbari et al. 1991). Villages were located as far as possible from potentially infected water bodies. Tubewells with hand-pumps were constructed near each village. However, tubewell water being too hard, it was seldom used for laundry. The latrine-program, which included building instructions and the provision of cement for the construction of latrines, too was not successful, because of the hard bedrock. Consequently, the main environmental control measures consisted of interventions in the concrete-lined irrigation system (Bolton 1988). Hydraulic structures such as sluice gates, weirs and outlets had an adapted design to prevent standing water. In the operation of the system measures such as regular drying of canals, water level fluctuation in night storage reservoirs, regular maintenance and routine cleaning contributed to the continuous control of the intermediate snail host (Chandiwana et al. 1988). A uniform cropping pattern of maize and cotton in the summer, followed by wheat and vegetables in winter, maximized synchronicity in water use. Infection rates were monitored and people were provided with appropriate medication. Snail hosts remained present but in too low populations to sustain transmission. Despite continuous water contact and poor sanitation, the reduction in schistosomiasis was significantly more evident in the villages with the adapted irrigation design, than in villages where only treatment was given. The low transmission rates of intestinal and urinary schistosomiasis in Mushandike, Zimbabwe, can almost entirely be attributed to the adapted design (Chimbari et al. 1993).

Environmental Control of Schistosomiasis in Irrigation

As explained in the introduction, snail control and environmental management are important complementary strategies in the fight against schistosomiasis. While medication will help to reduce morbidity and break the transmission cycle of schistosomiasis, complementary measures are needed to make the environment less suitable for intermediate hosts, limit exposure and make the control efforts more sustainable (WHO Expert Committee 2002; Engels and Chitsulo 2003). Irrigation systems, as man-made environments *par excellence,* in particular, offer unique opportunities for planners, engineers and water managers to collaborate with disease and vector experts and create transmission-hostile areas. Irrigation structures are artificial water bodies that are usually managed actively. Hence, it is more feasible to modify or manipulate these systems than to change the stable natural habitats outside the irrigation schemes. In this section environmental measures will be discussed, based on the recommendations made by the World Health Organization (WHO 1999; WHO Expert Committee 2002) to reduce breeding of the intermediate host snail, and to prevent both water contact and contamination in irrigation schemes (table 4).

Planning

From many of the case studies discussed above it is clear that while the establishment of irrigation often results in the creation of excellent habitats for schistosomes' intermediate hosts, this in itself does not necessarily lead to an increase in transmission of schistosomiasis. The presence of the final hosts, the human beings, is equally important. Settlements being in close proximity to irrigation structures enhance the contamination of snail habitats with schistosome eggs, thus creating a favourable environment for the efficient and effective transmission of schistosomiasis. Water usage by people in settlements close to canals can be intense and cause more frequent water contacts and pollution. This organic contamination of the water may further stimulate the growth of snail populations. The combination of high human population density and high snail density in nearby habitats can lead to an extremely intense schistosomiasis transmission. In large irrigation schemes, it is difficult to avoid villages being located within the scheme. But, in the case of small-scale irrigation, the schemes should preferably be located at some distance from the villages.

Obviously contamination of the water with schistosome egg also occurs during field work, as workers do not have proper toilet facilities. This situation arises when the fields are distant from where proper toilet facilities are available. Establishment of pit latrines within the fields, as attempted in Mushandike in Zimbabwe, may not be financially feasible in most schemes. Nevertheless, health and hygiene education could help to change, for example, defecation habits to a location further away from the water. Preventing contact with infested water is possible by providing safe water supplies or, in situations when no other sources of water are available, by equipping the canals or (storage) structures with simple pumping devices. Provision of hygienic communal washing places in close proximity to where the pumps are installed will also reduce water contact. Including a safe rural water supply in the design of an irrigation system reduces the cost of adding a separate system later on, and also prevents the risk of schistosomiasis transmission at the water collection point. In addition to water for drinking, these facilities should also include laundry basins and cattle troughs (van Koppen et al. 2006).

In the last few years there has been a renewed attention on water and sanitation, especially through several initiatives aimed at reaching "Target 10" of the Millennium Development Goals. This target-10 aims at halving, by 2015, the proportion of people without sustainable access to safe drinking water and

TABLE 4:
Some suggested environmental measures for schistosomiasis control in irrigation systems.

Issue	Target	Measures
Contaminated water	Reduce pollution	Sewage system connected to drains, not canals; properly constructed and located latrines; health education; changed behaviour; solid waste disposal system
Snail breeding	Reduce stagnant and slow-flowing water	Repair leaking canals; drain or fill puddles, ponds, borrow pits as well as agricultural fields; redesign hydraulic structures into free-draining ones; cement line canals; clear canals, structures and drains of vegetation and silt; avoid (night) storage reservoirs; promote rotational flows; alternative irrigation techniques (sprinkler and drip)
Contamination with schistosomiasis	Reduce water contact	Crossings for canals and drains; laundry and bathing sites; piped water supply; safe children's swimming pools; fences
Low resistance to disease	Improve food intake	Allow free crop choice; educate on proper diet
General well-being	Increase socioeconomic status	Facilitate water use for other (productive) purposes such as livestock and pottery

Source: Adapted from McCartney et al. Forthcoming. Partly based on WHO 1999

basic sanitation (UN 2005). These efforts in providing drinking water and sanitation, especially when they are linked to schistosomiasis control programs, have the potential to reduce and possibly eliminate transmission of the disease in the long term, more than any other method of intervention (Utzinger et al. 2003). This impact will be even more compelling when incorporating the felt water needs of people in an integrated way, be it in the irrigation or water and sanitation sector (van Koppen et al. 2006).

It is crucial to collaborate with the health sector at the planning stage of a water resources project to ensure that efforts are aligned and developed in close coordination. Hence, in large-scale schemes health facilities should be up-graded to cater for the migrant laborers as well as for the new settlers therein. People coming from schistosomiasis-endemic areas should be screened, and those infected should be treated. It is of paramount importance that all settlers are made aware of the schistosomiasis transmission cycle and that well-planned sanitary measures are put in place (Birley 1995).

The use of geographical information systems for disease-risk assessment is under continuous development as in the case of malaria. However, this usage has not been applied to the risk assessment of schistosomiasis. The first risk map for *S. haematobium* that is based on remote sensing has been made for Tanzania by Brooker et al. (2001). Maps, as the one mentioned above, could be improved by combining schistosomiasis data with the information derived by mapping irrigated areas. GIS and modeling could be very useful to ascertain the health impacts of water resources development including schistosomiasis (Bergquist et al. 2000; Brooker et al. 2002).

Water Storage

As mentioned before, water storage is important in irrigation to increase flexibility and security for the farmers. Especially in irrigation systems where water supplies are irregular and unpredictable, farmers prefer to store any water that is accessible when it is available as they do not wish to be dependent totally on an unreliable supply. Then the water will be available for their use whenever it is needed. However, whether the water is stored in reservoirs, canals or other structures, storage can create ideal conditions for snail-breeding as well as water contact. This is mainly due to these waters being stagnant or slow–flowing, fostering permanent habitats.

Adapted design (e.g., with steep slopes) and proper operation and maintenance can reduce plant growth, thereby inhibit snail-breeding. Often storage reservoirs are used for other activities as well, e.g., fishing. The construction of piers would help reduce water contact, hence minimize the risk of transmission in fishing communities.

Design

Analyses of case studies have led to the identification of certain key factors i.e., characteristics of irrigation systems that promote the development of intermediate host snail populations (e.g., Oomen et al. 1990; Cooper-Weil et al. 1990; Tiffen 1991; Grosse 1993; Hunter et al. 1993; Slootweg 1994; Jobin 1999). Most of these key factors lead to the creation of water bodies with stagnant or slow-flowing water, which are ideal breeding sites to most intermediate host snails. Our report has shown that with more detailed analysis and additional field-data, it is possible to go beyond these rather superficial conclusions. At a closer look there appears to be substantial knowledge on how exactly and to what extent the transmission mechanisms of schistosomiasis will be influenced when the key factors are modified. In a world where vertical control programs are increasingly abandoned and local health systems are often found lacking the capacity and resources to effectively control chronically endemic infections such as schistosomiasis; environmental measures are a welcome supplement of case detection and treatment (WHO Expert Committee 2002). Moreover, it is relatively easy to adapt the design of a new irrigation system and make a schistosomiasis-hostile environment. This requires hardly any additional resources when done at the initial planning stage. However, once the system is constructed it is rather complicated to change the technical features of the system.

High waterflow velocities are well tolerated in cement-lined canals. If the flow is rapid, the high velocity thus created would scour the silt and transport it to the fields, thereby reduce the need for cleaning. This design principle is often applied in covered canals or buried pipelines (Van Bentum and Smout 1994). The main disadvantage of this option is the extremely high cost of constructing concrete canals as opposed to earth canals. Hence, most of the concrete canal systems in Africa are found in the middle-income countries such as Tunisia and Morocco. One of the essential requirements in the construction of cement-lined canals is to ensure they have a sufficient slope to drain the water fast and dry quickly after an irrigation turn.

In some irrigation systems, where the canals are lined and no rice or sugarcane is cultivated, at first sight it may seem there is no risk factor to be concerned of (Birley 1991), but the hydraulic structures therein may pose problems as they hold stagnant water for long periods of time. Once these are identified as main transmission sites, appropriate intervention measures can be defined. Check structures can be improved for free draining, e.g., duckbill weirs could have a small hole in the bottom of the weir and drop structures could have baffle blocks instead of a deep box to dissipate energy (Chimbari et al. 1991, 2001; Laamrani et al. 2000a).

While drains may contain slow-flowing or stagnant water and very dense vegetation covers, as pointed out earlier, these are hardly considered as important transmission sites because of the very limited water contact. On the contrary, systems without proper drainage may lead to problems with waterlogging and high snail densities in poorly drained fields. In general, irrigation systems with drainage networks, especially when properly designed and well maintained, are less likely to contribute to an increase in schistosomiasis transmission than systems that do not have proper drainage. In the case of the latter, inadequate drainage facilities may lead to waterlogging, thus creating a suitable environment for schistosomiasis transmission.

Almost all irrigation systems in the world, especially those in Africa are used not only for organized field irrigation but for other purposes as well, e.g., bathing, laundry, water collection, fishing, recreation and diversion of water to other activities (van Koppen et al. 2006). Accommodating these activities into the design of new systems by providing cattle crossings, laundry steps and other facilities not only serves the local communities and helps to reduce health risks, it also prevents damage to canals and other structures. Separate swimming pools can be added to a system without much extra cost. If these are well designed and attractive alternative locations, children themselves can play a role in keeping these sites free from vegetation and intermediate hosts.

Irrigation Water Management

In existing irrigation systems, canals and other structures cannot easily be modified to prevent snail breeding. Changing the water management in an existing irrigation system has consequences for the layout and vice versa. Moreover, if canals, drains and structures are to be modified, in addition to the high investment requirement, the irrigation system may be out of production for several months due to the entailing redesign and construction works. However, since most irrigation schemes, after a period of 20 – 30 years, are due for major rehabilitation often involving reconstruction of canals and structures, this offers an excellent opportunity to incorporate environmental disease-control measures in the system.

The main options to control snail breeding and schistosomiasis transmission are in maintenance and water management. The cost of implementing environmental measures for disease control may be beyond the budget of the health sector in most African countries, but as part of the capital or recurrent cost for irrigation systems, it would be easily affordable. Moreover, most environmental measures have benefits that go beyond vector control, e.g., increased water delivery efficiency and increased access to water for other purposes. Unfortunately, these benefits are very difficult to assess (Protection of the Human Environment 2000).

In any case, collaboration of the irrigation agency, water users' organization and local communities is crucial (Laamrani et al. 2001). Appropriate cleaning and preventive maintenance of all irrigation infrastructures such as canals, structures and drains will reduce the breeding of intermediate host snails, and improve irrigation performance (Pike 1987). The engineering measures given below are described principally for surface irrigation, which is a common feature in most African irrigation systems (FAO 1995). Although the introduction of sprinkler or drip systems would reduce the creation of favorable snail habitats considerably, it is not always feasible because of the high cost involved. However, this situation is changing rapidly with many development organizations introducing affordable systems for smallholders (see e.g., Kabutha et al. 2000; Blank et al. 2002; Penning de Vries et al. 2005).

Increased Waterflow Velocity

Intermediate host snails, in general, are not found where the waterflow velocity exceeds 0.3 m/s except when aquatic vegetation provides them refuge from the current. Higher waterflow velocities would also change the composition of the silt layer in the canals and the hydraulic structures, thereby would stifle the growth of aquatic vegetation. Moreover, depending on the silt layer and the material of the canal itself (e.g., concrete, sand, clay, and grass cover), heightened waterflow velocity for snail control may result in the erosion of canal banks.

Irrigation canals and structures are designed to convey a certain range of waterflows with their accompanying velocities. Hence, in existing irrigation systems it is not possible to change waterflow velocities without changing either the discharge or the infrastructure itself. Both are difficult to achieve in practice. Water discharges in canals are but one aspect of the complex water management in an irrigation system. Water scheduling to meet crop water requirements is a complicated process, especially when conflicting interests between higher water use efficiencies and farmers demanding flexibility have to be taken into account. If snail control measures have to be observed as well, water scheduling becomes an almost impossible task.

A constant low-flow could be changed to an intermittent high-flow by replacing the existing continuous delivery with rotation of the waterflow. However, effecting such a change in the waterflow would give rise to significant changes in relation to water delivery and water use. With water flowing in the canals continuously, farmers can irrigate their crops whenever they want to. But, with rotation, the flow has to be divided over specified time periods between (groups of) users, demanding a high level of organization, from farmers, who have to be at the right time at the right place to divert the water before their turn is over, and irrigation agencies, which have to implement the complicated water schedules. In addition, the flow required for rotation might be such, that modifications in the design would be required, for instance, bigger size canals and structures.

Another suggestion for the control of snail populations in irrigation canals is to periodically flush canal sections between the check structures. The high water velocity not only removes snails by washing them away or leaving them stranded high on the canal banks, it also scours silt deposits. However, this is only possible under certain conditions, for instance, when the canal is large enough to have special structures installed in its bed. Perhaps, comparable to a large earthen canal is the small river in Tanzania, where a special weir had been installed, especially for schistosomiosis control. As a result of installing this weir, snail populations were flushed away or stranded on the riverbanks; hence, they were not able to repopulate the riverbed (Fritsch 1993).

Water Level Fluctuations

Implementing water level fluctuation in large canals can be difficult, especially when these canals are used for water storage. The fluctuations could be important in small canals. In a water distribution system with rotational flow, water levels in the lower order canals fluctuate with the flows. The canals may completely dry out between irrigation turns, as witnessed in many lined systems in northern Africa. Rotational flow in systems with a high level of control of the agricultural cycle might enable water level fluctuations to occur even in large canals. The benefits from completely drying out canals would be that, at least for some time no transmission would occur. Moreover, even short periods of desiccation would cause mortality among the intermediate host snails. An additional benefit from drying canals would be facilitating the removal of aquatic plants. However, in canals with clear water and submerged plants, such as in the “Office du Niger” in Mali, this would have little impact and might even concentrate snails and infective *Schistosoma* larvae at the water contact sites. These relatively few sites, where water contact is high and intermediate hosts thrive, have to be kept under close surveillance for regular removal of silt and vegetation, possibly combined with the use of molluscicides.

A prerequisite for the use of water management as a tool to combat schistosomiasis is that water supply should be reliable and be controlled effectively. Otherwise, farmers may be inclined to store water in canals, hydraulic structures and on their fields to be used during times of water scarcity, despite the risk of such storage providing ideal conditions for intense schistosomiasis transmission (Van de Laar 1993).

Removal of Aquatic Vegetation and Silt

Intermediate host snails are often associated with aquatic plants, especially the submerged species, as these provide ideal surfaces for snails to graze and to deposit their egg masses. At the same time, the aquatic vegetation provides protection for these species against high waterflow velocities and against predators such as fish. Thus, removal of aquatic plants would affect snails directly and, under certain circumstances, expose them to predators.

The periodic removal of aquatic plants from canals also reduces friction to the waterflow and thus increases conveyance efficiencies in the irrigation system. In Egypt and Sudan, control of aquatic plants in canals has been applied as an effective method of snail control. Removal of aquatic plants is a very labor intensive and recurrent activity. In addition, the practice itself can become a health hazard, as was shown above for Gezira, Sudan. However, doing the manual canal cleaning during early hours of the day greatly reduces the risk of infection (Tamein et al. 1985).

In earth canals, removal of aquatic plants might lead to increased erosion of canal banks, which may be a problem to the irrigation agencies. In this case, the methods chosen for removal of aquatic plants should ensure that the roots of these plants are not destroyed. Unfortunately, leaving the roots intact stimulates rapid re-growth of plants. Hence, this practice may not be of much value for snail control unless repeated frequently. By controlling floating plants, such as water lilies and *Azolla* sp. that clog the canals and hydraulic structures, light penetration is increased, thus stimulating the growth of submerged plants.

Canal maintenance to facilitate the improvement of irrigation performance should normally consist of periodic removal of silt deposits and vegetation as discussed for Gezira. The need for routine maintenance increases in older irrigation systems, where the reservoir has silted up. Also in systems with year-round irrigation, siltation becomes a problem if irrigation takes place when the silt load of the water is high, notably in the rainy season. Generally, regular maintenance of canals and structures is less frequent than what would be desirable for snail control.

Conclusion

In this report, a number of measures have been identified that can be taken to reduce the risk of schistosomiasis transmission in irrigation. As pointed out repeatedly, it is unlikely that any single method will provide an effective means of controlling snails, let alone reduce schistosomiasis transmission. Even well-designed irrigation canals and structures can become snail-breeding sites if they are not well maintained. If water contamination is to be reduced effectively, the installation of appropriate sanitary facilities and educating the people on health risks should be done simultaneously.

On the other hand, opting for engineering approaches to overcome the problem of schistosomiasis will bring about other benefits, which improve irrigation performance and, thus make these approaches attractive to be incorporated into rehabilitation plans. Obviously, what can be implemented in a certain area depends on the physical characteristics of that specific irrigation scheme and the institutional setting.

For the African continent as a whole, there is high potential for the extension of irrigation. The area under irrigation (12.2 million hectares) is less than 30 percent of the estimated irrigation potential (42.5 million hectares). However, over 60 percent of the potential is located in humid regions, where the potential for rain-fed agriculture is high as well and the method of irrigation is mainly of a supplementary nature. In the regions where irrigation is most important for agriculture, 60 to 100 percent of the potential area is already irrigated. Out of the 12.2 million hectares currently considered under irrigation, it is estimated that almost half of it needs to be rehabilitated if they are to be managed to their maximum potential (FAO 1997). This is where real possibilities for environmental snail control occur: canals may be lined for higher flow velocities, hydraulic structures could be adapted for free draining, canal beds can be leveled to eliminate the formation of pools, reservoirs could be deepened and provisions be made to allow rotational flow or even flushing instead of continuous flow. For expansion areas, innovative appropriate irrigation techniques such as bucket and drip irrigation, adapted to African smallholders, might be very promising. Techniques like these do not create additional water bodies; on the contrary, these techniques may reduce water contact, especially occupational exposure of farmers in canals or field ditches.

When investing in water resources development and irrigation in Africa health impacts such as increased schistosomiasis transmission should also be taken into consideration. Research into sound investment strategies and evaluation of environmental control should be continued (WHO 1998). New research initiatives on controlling intermediate hosts could focus on methods of aquatic plant removal, structural changes of irrigation canals or reservoirs for snail control, better strategies of water management and control, and whether changed agricultural practices could have an impact on snail populations. Moreover, already available options for integrated schistosomiasis control should be made use of and tested at a large-scale level. Integrated development of water resources in Africa, which caters to all uses of water in a sustainable way with the objective of maximizing benefits and minimizing negative health impacts, offers an excellent opportunity for the incorporation of schistosomiasis control measures. This will contribute to a significant improvement in the health of rural communities in irrigated areas.

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