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The effects of irrigated agriculture on the transmission of urinary schistosomiasis in the Middle and Upper Valleys of the Senegal River basin

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The importance of the increase in irrigated land on the perimeters of the Middle and Upper Valleys of the Senegal River basin, on the prevalence and intensity of urinary schistosomiasis, was investigated. Surveys were conducted, in May–June 1997, to determine the prevalence and intensity of *Schistosoma haematobium* infection among 1445 children aged 7–14 years: 1011 in 10 villages near Matam, and 434 in four villages near Bakel. Macrohaematuria was present in seven of the study villages (four near Matam and three near Bakel), whereas microhaematuria was present in all the villages, with prevalences of 10%–73%. A second survey, conducted, in June 1999, on 755 children from nine of the study villages near Matam, demonstrated significant increases in the prevalences of both micro- and macro-haematuria in three of the villages, all of which were adjacent to the Senegal River and practising irrigated agriculture. None of the other study villages re-surveyed was irrigating any of its agricultural land.

A longitudinal survey was also carried out, between May 1997 and November 1998, on about 10% of the population (2272 subjects) of Nguidjilone, north of Matam; selective treatment with praziquantel (40 mg/kg) was given in May 1997, and mass treatment in May 1998. The data analysed were those

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relating to the 125 individuals who provided samples at each survey. Very severe infections (> 1000 eggs/10 ml urine) were seen in five subjects in May 1997. One year later (i.e. 1 year after the selective treatment), the prevalence of urinary schistosomiasis had increased in every age-group. Although prevalence had decreased slightly by November 1998 (6 months after the mass treatment), the intensity of the infections seen had increased in every age-group.

At the end of the dry season (May–June 1997), *Bulinus truncatus* infected with schistosome cercariae were recovered from the Senegal River. However, immediately after the next rainy season (November 1997), no snails were found at any collection site on the river.

The epidemiology of schistosomiasis has been extensively studied in the Lower and Middle Valleys of the Senegal River basin (SRB; Vercruysse *et al.*, 1985, 1994; Talla *et al.*, 1992; Stelma *et al.*, 1993; Verlé *et al.*, 1994; Picquet *et al.*, 1996; Shaw *et al.*, 1999). Since the construction of the dams at Diama in Senegal (1985–1986) and Manantali in Mali (1988–1989), there has been a very large increase in the prevalence of human infection with *Schistosoma mansoni* around Lac de Guiers, in the Lower Valley. Although the first case of infection with *S. mansoni* in this area was only recorded in 1988, the annual number of cases has since increased very rapidly (Talla *et al.*, 1992; Stelma *et al.*, 1993). By 1995, all the villages surveyed around Lac de Guiers were infected (Picquet *et al.*, 1996), and recent results indicate that the situation is getting even worse (De Clercq *et al.*, 1999). *Schistosoma haematobium* foci, in the Lampsar area of the Lower Valley and the Podor area of the Middle Valley, were described by Vercruysse *et al.* (1985). The Lower-Valley focus of urinary schistosomiasis, caused by *S. haematobium*, has apparently extended upstream since 1989 (Verlé *et al.*, 1994) while the focus of intestinal disease, caused by *S. mansoni*, has extended downstream, creating foci of mixed infections (Ernould *et al.*, 1999). Seven years after the completion of the dam at Manantali, increases in the prevalence and intensity of human infection with *S. haematobium* were recorded in the Podor area (Shaw *et al.*, 1999), although the intensities remained low–moderate compared with the high *S. mansoni* worm burdens.

The epidemiology of *S. haematobium* over much of the Upper Valley of the SRB, between Matam and Bakel, is unknown. The objective of the present survey was to determine if the recent increases in the area of land under irrigation in this region had affected the local prevalence and intensity of urinary schistosomiasis. *Bulinus pfeifferi*, and therefore *S. mansoni*, are not believed to be present in this region (unpubl. obs.).

SUBJECTS AND METHODS

Study Area

The Middle Valley of the SRB stretches east, for a distance of 500 km, from the town of Richard Toll to the town of Matam (see Fig.). Upstream of Matam, the river extends, south–east to south, in a relatively narrow and deep basin, termed the Upper Valley, in which the town of Bakel is situated. The region is typical sahelian, with a short rainy season, between July and September, followed by a long dry season. Annual rainfall varies between about 300 mm in the Lower Valley to approximately 500 mm at Bakel. Villages in the SRB are categorized according to their source of water: those using wells and temporary, rain-fed pools are classified as '*diéri*' (with rain-fed agriculture) whereas those using river water are classified as '*walo*' (with floodwater-recession agriculture). The '*walo*' villages lie between the main east–west road and the river, whereas the '*diéri*' villages are to the south of the east–west road. Between 1984 and 1996, the area of land under irrigation in the districts of Matam, Bakel and Podor increased two-fold (from 3037 to 7097 ha), three-fold (from 635 to 2097 ha) and four-fold (from 4288 to 17 793 ha), respectively (unpubl. obs.). Between 1996 and 1998, however, only another 500 ha in the area around Matam and 100 ha in Bakel went under irrigation (unpubl. obs.).

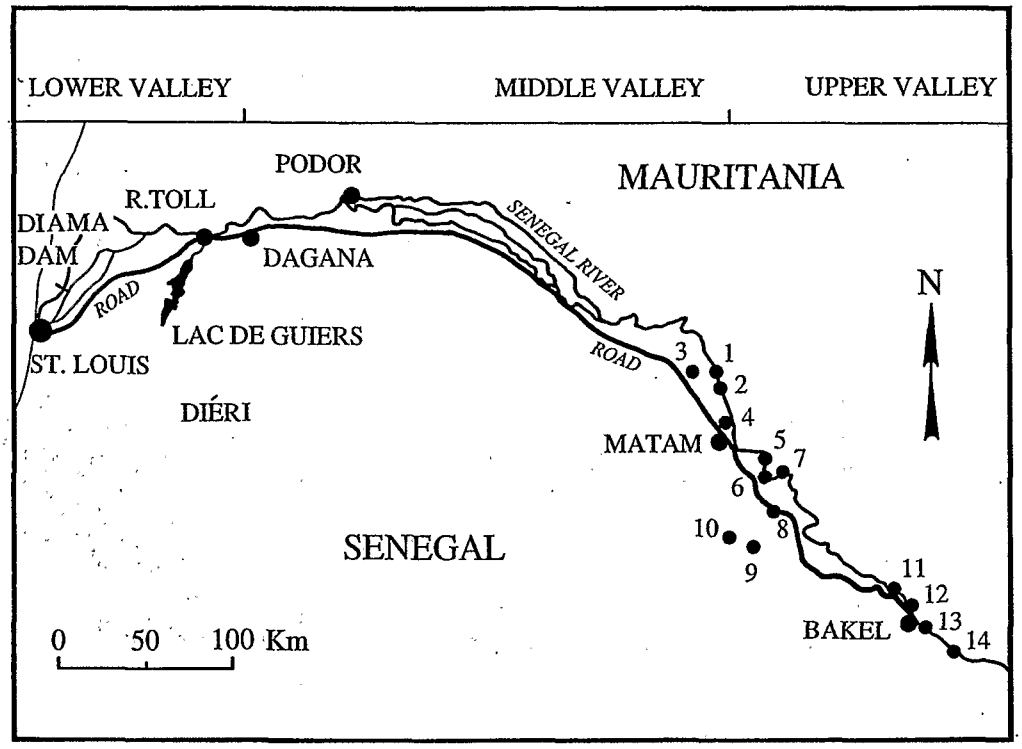

Fig. Sketch map of the Senegal River basin, showing the positions of the villages investigated in the study: Nguidjilone (1); Oudourou (2); Ranoua (3); Tiguéré Siré (4); Garli (5); Dolol (6); Ngano (7); Amadi Ounaré (8); Kellol (9); Andieri (10); Galladé (11); Manael (12); Kounghani (13); and Aroundou (14).

Study Sites

Fourteen villages (see Fig.) were selected (geographically at random) in the districts of Matam (which has approximately 268 000 inhabitants) and Bakel (which has approximately 54 000 inhabitants): eight '*walo*' villages (Ranoua, Nguidjilone, Oudourou and Tiguéré Siré north of Matam, and Garli, Dolol, Ngano and Amadi Ounaré south of Matam, with all but Ranoua and Amadi Ounaré next to the Senegal River); two '*diéri*' villages west of Matam (Kellol and Andieri); two villages north of Bakel (Galladé and Manael, both adjacent to the Senegal River); and two south of Bakel (Kounghani and Aroundou, both close to the border with Mali and both adjacent to the Senegal River).

Study Design

In May–June 1997, in each of the study villages, about 100 schoolchildren aged 7–14 years were each asked to provide one morning sample of urine, so that the prevalence of micro- and macro-haematuria could be determined. A second survey, using the same methodology but restricted to nine of the study villages near Matam, was conducted 2 years later (June 1999). The presence of transmission sites (irrigated fields, river, temporary pools) in or near each village was noted at each survey and the changes in transmission sites occurring between the surveys were also recorded.

Nguidjilone, which is situated to the north of Matam, was selected for a longitudinal

TABLE 1

The prevalences of micro- and macro-haematuria observed, in 1997 and 1999, in the districts of Matam and Bakel, Senegal

Region and village	Adjacent to:*		1997			1999		
	Senegal River?	Irrigated land?	No. of subjects	% with: Microhaematuria	% with: Macrohaematuria	No. of subjects	% with: Microhaematuria	% with: Macrohaematuria
MATAM								
Nguidjilone	Yes	Yes	116	60	25	100	80	36
Oudourou	Yes	Yes	100	46	2	100	81	21
Ranoua	No	No	98	30	0	72	28	0
Tiguéré Siré	Yes	No	100	10	0	106	14	0
Garli	Yes	Yes	100	13	0	100	81	13
Dolol	Yes	No	116	35	<1	101	28	2
Ngano	Yes	Yes	61	51	2	73	68	14
Amadi Ounaré	No	Yes	153	73	14	ND	ND	ND
Kellol	No	No	69	17	0	50	16	0
Andieri	No	No	98	28	0	53	11	0
BAKEL								
Galladé	Yes	No	129	36	<1	ND	ND	ND
Manael	Yes	Yes	104	32	5	ND	ND	ND
Kounghani	Yes	Yes	101	46	4	ND	ND	ND
Aroundou	Yes	Yes	100	49	7	ND	ND	ND

* Temporary pools were present in every village investigated.
ND, Not determined.

parasitological study (because of the high prevalences of micro- and macro-haematuria and good compliance observed during the initial sampling survey). Approximately 10% of the whole population of 2272 were selected at random from the files provided by the chief of the village, enrolled in the study, and asked to provide urine samples on three occasions (May 1997, May 1998 and November 1998). Following the guidelines of the World Health Organization (WHO, 1985), the residents of the village who were aged 7–14 years were all treated with praziquantel (40 mg/kg) in May 1997, and all residents were similarly treated in May 1998.

Parasitological Parameters

Urine samples with visible blood were recorded as positive for macrohaematuria. The presence of microhaematuria was determined using reagent strips (Hemastix; Bayer). The urine samples collected during the longitudinal survey were filtered (through Nytrel filters) so that any *S. haematobium* eggs present could be counted under the microscope; if a sample was negative, a second sample from the same donor was examined the following day.

Malacological Surveys

Malacological sampling was carried out during the dry season (May–June 1997) and after the rainy season (November 1997) in all 14 study villages in the environs of Matam and Bakel. Potential transmission sites were sampled for snails by two people searching for 15 min at each water-contact point. Any snails found were identified and examined for cercarial shedding. In June 1999 all the study villages around Matam except Amadi Ounaré were re-investigated in this way.

RESULTS

Table 1 shows the prevalence of micro- and macro-haematuria in the villages investigated in 1997 and 1999. At the first survey (of 14 villages), when 1011 children were examined in the district of Matam and 434 in the district of Bakel, macrohaematuria was observed in seven villages: four in Matam district (Amadi Ounaré, Nguidjilone, Ngano and Oudourou) and three in Bakel district (Aroundou, Koughani and Manael). Microhaematuria was present in all 14 villages, at prevalences of 10%–73%. At the second survey (of nine villages), when 755 children were examined, the prevalences of both micro- and macrohaematuria were found to have increased in Nguidjilone, Oudourou, Garli and Ngano. These four villages are all located next to the Senegal River and all practise irrigated agriculture. The prevalence of macrohaematuria was highest in Oudourou and Nguidjilone (north Matam), which had developed new irrigation schemes on their perimeters in 1997 and 1998, respectively. In the two other villages with evidence of increased transmission, Garli and Ngano (south Matam), there has been no increase in the area of land under irrigation since 1997. Among the villages where no increase in prevalence was observed, Dolol and Tiguéré Siré (both situated by the Senegal River) and Ranoua [located next to a temporary pool (*marigot*) called Diamel] have no irrigated land, and only temporary pools were seen in the two '*diéri*' villages (Kellol and Andieri).

The final analysis of the results of the longitudinal survey was confined to the 125 individuals of all ages (61 of whom were aged <15 years) who gave samples at all three sampling times. Table 2 shows the overall prevalence and intensity of infection before treatment in Nguidjilone, according to age. The highest prevalences and intensities of infection were observed in the subjects aged ≤ 29 years. Very severe infections (i.e. >1000 eggs/10 ml urine) were seen in three 8-year-old children and two 17-year-old adolescents.

One year after selective treatment, the prevalences of infection observed in every age-group were greater than those seen pre-treatment (overall prevalence = 68%). Although the overall intensity of infection had only decreased by 15%, no very severe infections were observed. Six months after the mass treatment, prevalence was slightly reduced (58%) but egg counts were higher in

TABLE 2

Age-related prevalences and intensities of infection with Schistosoma haematobium *among the residents of Nguidjilone, before treatment*

Age (years)	*No. of subjects examined*	*Prevalence (%)*	*Geometric mean intensity (eggs/10 ml urine)*	*% of subjects with:*	
				> 50 eggs/10 ml	*> 1000 eggs/10 ml*
1–14	95	40	19.3	14	3
15–29	57	47	15.3	12	3.5
30–44	40	22	8.5	2.5	0
45–59	21	19	4.5	0	0
> 60	20	30	2.9	0	0
Any	233	36	12.7	9	2

every age-group, with an overall increase in egg counts of about 40%. Very severe infections were again observed (1.6%), in one child and one 18-year-old adolescent.

At the end of the dry season (May–June 1997), *B. truncatus* were present in the Senegal River next to two of the study villages north of Matam (Nguidjilone and Oudourou) and in two villages near Bakel (Kounghani and Galladé), albeit at very different levels (Table 3). *Bulinus truncatus* infected with *Schistosoma* sp. were found in Nguidjilone (north Matam) and Galladé (Bakel). All temporary pools were dry at this time and most of the irrigation schemes were not functioning.

No snails were found in the sampling sites on the Senegal River after the rainy season (November 1997); the *Bulinus sp.* had probably been washed away during the heavy rains. Uninfected *B. senegalensis* were found in the rice fields and temporary pools in the Matam area, and uninfected *B. truncatus* and *B. senegalensis* were also found in temporary pools in the Bakel area. In June 1999, some *B. truncatus* infected with schistosomes were collected in the irrigation canals in Ngano (south Matam).

DISCUSSION

The Situation Before and after the Dams were Constructed

Although the Middle and Upper Valleys of the SRB were known to be endemic areas for *S. haematobium* (Chaine and Malek, 1983), detailed information on the infection in this region is scarce. In 1977–1978, Chaine and Malek (1983) examined two Senegalese villages (Navel and Diamwely) in the upper Middle Valley (between Matam and Bakel) and found prevalences of human infection of 1.3%–6.7%. Surveys in 1984–1985, before the construction of the dams in the Bakel area, revealed prevalences of 6.8% in Aroundou and 29.6% in Diawara (Diallo *et al.*, 1991). A survey performed in two villages (Sadel and Navel) in 1991 (Diallo *et al.*, 1991), 2 years after both dams had become operational, revealed very low prevalences (around 1%) of *S. haematobium* infection in the Matam area, whereas the prevalences in Aroundou and Diawara, both in the Bakel area, had risen substantially from those recorded in 1984–1985, to 50.5% and 47.5%, respectively.

In the present study, the prevalences of haematuria observed in the dipstick-based survey in 1997 indicated an overall prevalence of *S. haematobium* infection of about 40%, which is comparable with those recently seen in the district of Podor, in the Middle Valley (33%–54%; Picquet *et al.*, 1996). The 1997 data indicate that, since 1991, the pattern of infection has stabilized in the Bakel region, but not in the Matam area. The reason(s) for the differences remains enigmatic, although irrigation may play an important role: there is 3.5-fold more land irrigated in the Matam area than in the Bakel area. Immigration of infected personnel to the Matam area and

TABLE 3

Potential transmission sites investigated in the districts of Matam and Bakel, and details of the collected snails

*Region and village**	*Transmission site*	*Snail species collected*	*No. of snails collected*	*% of snails infected*	*Sampling period*
MATAM					
Amadi Ounaré	Temporary pool	*B. senegalensis*	25	0	November 1997
Nguidjilone	River	*B. truncatus*	104	10.6	May 1997
	Rice fields	*B. senegalensis*	4	0	November 1997
Ngano	Irrigation canal	*B. truncatus*	27	7.4	June 1999
Oudourou	River	*B. truncatus*	6	0	May 1997
BAKEL					
Aroundou	Temporary pool	*B. forskalii*	41	0	November 1997
		B. truncatus	10	0	
Kounghani	River	*B. truncatus*	4	0	June 1997
Galladé	River	*B. truncatus*	12	16.6	June 1997
	Temporary pool	*B. senegalensis*	14	0	November 1997
		B. truncatus	10	0	

* No snails were collected in the other study villages.

changes in the local micro-environment may have favoured increases in the infection and size of snail populations, leading to an increase in levels of transmission.

Transmission in 1997

Visually detectable haematuria was shown to be a good marker of heavy infection and, therefore, of the risk of morbidity in areas where *S. haematobium* is endemic (Lwambo *et al.*, 1997). Of the six villages in Matam district where no cases of visual haematuria were observed in 1997 (Ranoua, Tiguéré Siré, Garli, Dolol, Kellol and Andieri), only Garli practises irrigated agriculture, using an old but still functioning system. In contrast, the four villages (Nguidjilone, Oudourou, Ngano and Amadi Ounaré) where children with macrohaematuria were seen all practise irrigated agriculture, and three of them are located near the Senegal River. Similarly, in the district of Bakel, the three villages (Manael, Kounghani and Aroundou) where macrohaematuria was observed all practise irrigated agriculture and are next to the river. As a transmission site, the Senegal River seems less important than irrigated land, since high prevalences are not observed in every village by the river and, in the Middle Valley, *S. haematobium* is transmitted primarily by *B. senegalensis* (Vercruysse *et al.*, 1994), which is only found in temporary pools and irrigation canals. The results of snail-infection experiments revealed a total incompatibility between isolates of *S. haematobium* from the Lower and Middle Valleys and laboratory-bred *B. truncatus* (Southgate *et al.*, 1985). It is, however, important to note that urinary schistosomiasis would increase in the whole of the area if a *B. truncatus*-borne *S. haematobium* strain were to be introduced into the SRB from the Upper Valley, across the border in Mali (Rollinson *et al.*, 1997). Indeed, recent infection experiments have demonstrated for the first time that isolates of *S. haematobium* from the environs of Podor, Matam and Bakel demonstrate some compatibility with *B. truncatus* (Southgate *et al.*, 2000). The importance of these observations, in relation to the epidemiology of *S. haematobium* in the SRB, has been confirmed by M. Sène (unpubl. obs.), who has recently found *B. truncatus* from the Middle Valley naturally infected with *S. haematobium*.

Changes between 1997 and 1999

After a period of 2 years, the prevalences of children with micro- and macro-haematuria in Matam remained stable in five out of the nine villages investigated in the second survey. None of these five villages (Ranoua, Tiguéré Siré, Dolol, Kellol and Andieri) practise irrigated agriculture, although two are near the Senegal River. Increases in both micro- and macro-haematuria were observed in each of the other four villages (Nguidjilone, Oudourou, Garli and Ngano), all of which practise irrigated agriculture and are situated near the river. In Oudourou and Nguidjilone, the two villages where the area of irrigated land increased between 1997 and 1999 (by 80 ha in Oudourou and by an unknown amount in Nguidjilone), the prevalence of macrohaematuria had increased by 1999, to $>20\%$. This increase in prevalence was probably a result of the additional land coming under irrigation, and the new potential breeding sites for *B. senegalensis* so created.

The present results indicate that heavy *S. haematobium* infections (as indicated by visible blood in urine) are more likely to occur in villages practising irrigated agriculture than in the other villages. In Mali, similarly, the prevalence of heavy infection only exceeded 5% in areas with irrigation, and the risk of schistosomiasis was found to be six times greater in irrigated areas than in savanna settlements without any irrigation programmes, and three times greater than in villages near natural water bodies (Brinkmann *et al.*, 1988). Further, longitudinal, malacological studies may add information on the impact of water-development programmes on snail abundance. Such an impact has been clearly observed in the delta of the SRB (Ernould *et al.*, 1999). In northern Cameroon, however, rice cultivation and irrigation did not lead to any increase in the prevalence of schistosomiasis over a period of 6 years (Audibert *et al.*, 1990), as there were concomitant improvements in sanitation and decreases in rainfall.

The Situation in Nguidjilone, near Matam

The first survey and the selective treatment in Nguidjilone were conducted in May 1997, at the end of the dry season when transmission is at a low level. The prevalence of *S. haematobium* infection observed 1 year later was actually higher than the pre-treatment values. In the Middle Valley, near Podor, prevalences returned to pre-treatment levels in villages where only individuals positive for eggs had been treated (Shaw *et al.*, 1999). Although Shaw *et al.* (1999) found mass treatment more effective, re-infection following the mass treatment investigated in the present study was extremely rapid (< 6 months), particularly in the youngest age-group (in which the prevalence of heavy infection and egg counts were the highest observed). This indicates that transmission pressure in the Nguidjilone area was high after the mass treatment, probably reflecting the increasingly large area of local land under irrigation (and therefore, the large number of potentially infective water contacts).

Conclusions

The present data clearly indicate that, since the construction of the dams in the area, focal transmission of urinary schistosomiasis has increased in the area between Matam and Bakel, with some dramatic cases of severe infections which have not been observed elsewhere in the SRB. Irrigated agriculture is practised in all the villages where the prevalence of severe infection was seen to increase during the present study. In order to reduce morbidity significantly, it has been recommended that all the school-age children in areas where the prevalence of microhaematuria exceeds 20% are treated once a year (Savioli *et al.*, 1997). It seems justified that such control measures be implemented in the appropriate areas of the SRB.

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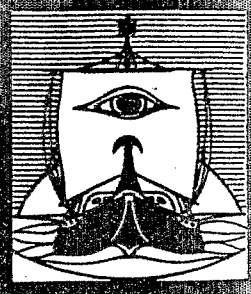

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