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The role of field irrigation canals in the transmission of *Schistosoma mansoni* in the Gezira Scheme, Sudan

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*This study was carried out to determine the importance of small field irrigation canals (*abu eshreens*)—of which there are over 22 000 in the Gezira Scheme— in the transmission of schistosomiasis. The observations were made during a 12-month period, November 1976–November 1977. The results indicated that during the 4-year crop rotation the* abu eshreens *supported snail populations in only two seasons, when they were irrigating crops of either cotton or groundnuts. Thus, when agricultural labourers built temporary dwellings on the* abu eshreen *banks during these periods, the probability of finding infected snails was high. The maximum risk periods occurred during vegetable harvesting (including groundnuts) (October–December) and in the cotton picking season (January–April). Certain special situations lead to some* abu eshreens *playing an even greater and more predictable role in transmission. These occur when* abu eshreens*: (a) irrigate eucalyptus or fruit trees; (b) irrigate a block inspector's garden; or (c) are situated very close to permanent villages. Possible control measures to reduce the transmission potential of* abu eshreens *are discussed. These include improved maintenance and the use of either focally sprayed or slow-release molluscicides.*

The Gezira Irrigation Scheme was started in 1924 with the completion of the Sennar Dam on the Blue Nile, and with the addition of the Managil Extension, which was opened in 1963, it now compromises 800 000 hectares. The scheme is situated to the south of Khartoum, between the Blue Nile and the White Nile.

The land is farmed by about 100 000 Arab tenants who live with their families and other nontenant Arabs in villages throughout the area. The permanent Arab population is estimated at 1.5 million of which perhaps 50% are infected with *Schistosoma mansoni* (1–3). The prevalence of *S. haematobium* varies from village to village.

Outside of the Arab villages there is a scattered population of over 0.5 million people made up of Gezira Board employees, irrigation workers, labourers from west Sudan, and Nigerian immigrants. The first two categories are well housed by the Government, but the Sudanese and Nigerians live either in temporary housing in the fields or in semi-permanent unregistered villages with no services. The rate of *S. mansoni* infection in the field workers and their families is over 50% (*3*).

During the annual cotton picking season there is a further influx of over 0.5 million people who stay, camped in the fields, from January until May or June. These migrants come either as bachelor labour from the far west of Sudan, or in family, and sometimes village groups from outside the boundaries of the Scheme. Among the migrants who visit the Scheme on a regular basis, the infection rate is again in the region of 50% (unpublished data, 1978).

The Gezira irrigation network consists of a series of open, mud-lined, gravity fed canals distributing water in the following sequence: from the main canal, to the major canal, then to minor canals, and finally to field irrigation canals called *abu eshreens*. All these canals, but particularly the minor ones, form excellent habitats for the snails *Biomphalaria pfeifferi* and *Bulinus truncatus*, which are the intermediate hosts of *Schistosoma mansoni* and *S. haematobium*, respectively. In 1974 a routine snail control regimen was introduced, which consisted of 5 aerial sprays with the molluscicide trifenmorph over the main, major, and minor canals in the most northerly 80 000 hectares (*4*,

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5). The regimen was continued for 3 years and its effects were regularly monitored by surveillance and sampling for snails, and parasitological examinations in preschool and school age children. The results suggested that the objective of keeping the minor canals virtually snail free had been achieved, but the incidence data gave equivocal results (*6*) since in some villages there was evidence that transmission was as high as in a nearby untreated area.

It was these results that led us to carry out the present study to determine under what conditions the field canals (*abu eshreens*) might act as snail habitats and transmission sites. Since the aerial spray method of molluscicidal application cannot affect snails in those *abu eshreens* that are closed on the day of spraying, one possible reason for the continuing transmission in villages near minor canals that were regularly treated may have been the persistence of snails in some *abu eshreens*.

The experimental area (Fig. 1)

This study focused on Toba minor canal, which is 4.8 km in length, and is flanked by 17 fields on each side (south bank: A_1–Q_1; north bank: A_2–Q_2) (Fig. 1). Each field has its own *abu eshreen* that takes its water from the minor canal through a 30-cm diameter pipe, which can be sealed by a flange or mud plug when not required. The fields are divided into 4-hectare holdings by *abu sitta* canals that run the 300 m from the *abu eshreen* across the breadth of the field.

Fig. 2 shows the crops on each of the fields at the time of the study and the position of any human dwellings, however temporary, that were built during the observation period. There were 2 permanent villages in fields A_2 and B_2 that housed agricultural labourers and their families. In T17 there were 114 people of Nigerian origin, and in T16 there were 60 people from the Fur tribe and 60 people from the Tama tribe—both from West Sudan. In field H_2 there was a field inspector's house in a 2-hectare garden.

The scattered dwellings were mostly temporary huts built either by migrant cotton pickers or by residents of T16 who preferred to camp near to the fields in which they were working. The camp labelled CP was erected in January 1977 by villagers from the east of the Blue Nile who stayed picking cotton and grazing stock until June 1977 when they returned home.

The Arab tenant farmers whose holdings were in the study area lived either in Angado village (Fig. 1) or in another village 2 km to the east of Talbab major canal.

Of the 34 *abu eshreens*, 4 were excluded from the study because they did not take water from the Toba minor canal. Fields C_1, D_1, and E_1 were irrigated by water from Koa minor canal to the south, and field L_2 was irrigated by water from Gad el Ain minor to the north.

Of the 30 *abu eshreens* included in the study, all except A_1, B_1, and A_2 followed the normal crop rotation of cotton–wheat–groundnuts/sorghum–fallow. Since the relatively low-lying land at the tail of the canal was prone to flooding, the Gezira Board allocated 2 fields to eucalyptus for fuel and building and left field A_2 for fodder and casual cultivation by the T16 and T17 labourers.

MATERIALS AND METHODS

This study was carried out during the 12 month period from November 1976–November 1977, i.e. the latter half of one agricultural year and the first half of the next.

Once a week—except when heavy rainfall closed the roads during August and September—the area was inspected by driving slowly in a Land Rover alongside the Toba minor canal from its offtake to its tail, stopping to take notes at every *abu eshreen*, using a sketch map. The following observations were recorded:

(*a*) Water levels, turbidity, flow rate, and vegetation in both the minor canal and in every *abu eshreen*.

(*b*) Any human water-contact activities—such as, bathing, swimming, washing, drinking, fording, irrigating, fishing, and collecting water in tins.

(*c*) Any human activities in the fields, for example, irrigating, planting, weeding, harvesting, house-building, shepherding, or defaecating. There was no identification of the individuals involved—but where possible, tribe, sex, and estimated age were noted.

(*d*) The state of all the crops on each field.

Snail sampling

Forty potential snail sampling sites were selected from the map: the headwater pools of 30 *abu eshreens*, 7 *abu eshreen* sites opposite dwellings, and 3 *abu eshreen* sites near to dwellings.

Some of these sites were dry and some never supported snail populations. Others supported snails for only part of the observation period. The aim was to examine each water-containing site at least once a month; sites of special interest were, in fact, visited more frequently.

At each site visit, snail sampling was "exhaustive", that is, scooping was continued until the number of snails captured per scoop was much lower than at the start and usually took one man 30 minutes. For example, snail recoveries might drop from over 30 snails per scoop to 2 or 3 per scoop, or in a less densely populated site from 2 or 3 per scoop to zero.

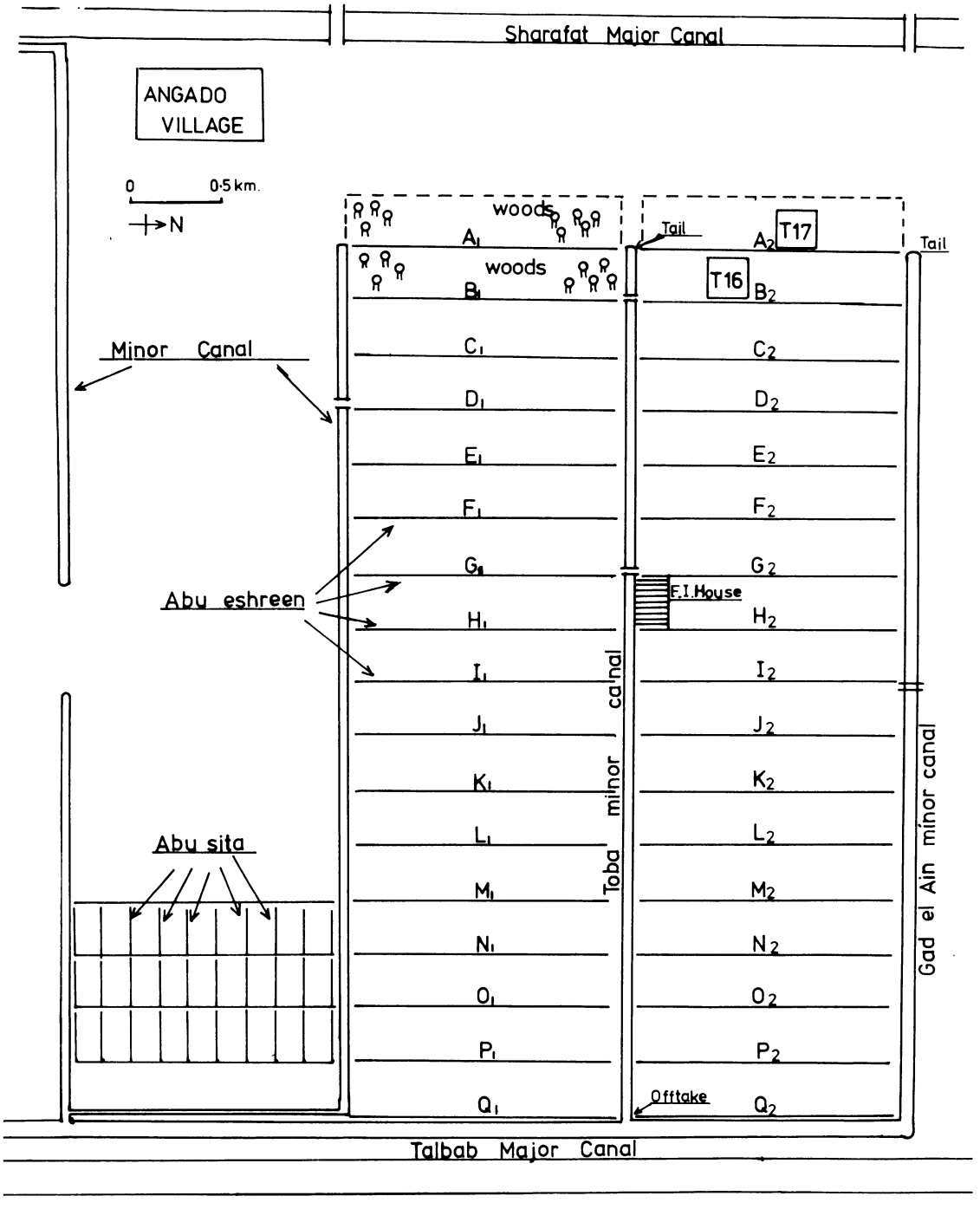

Fig. 1. The study area and the Gezira irrigation system.

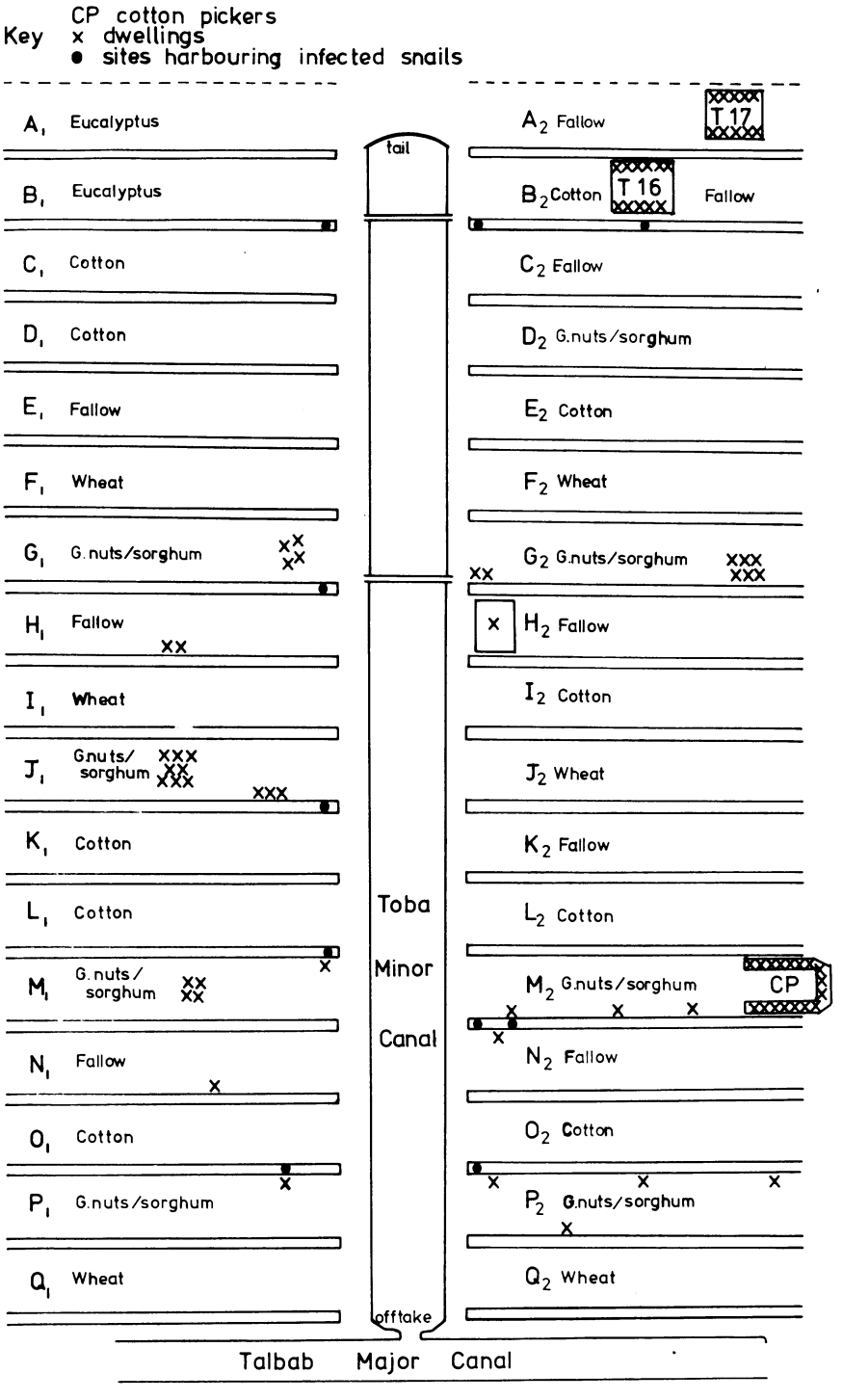

Fig. 2. Crops, dwellings, and infected snails within the experimental area.

Collections were made in the evenings (16 h 00–18 h 00) and early morning (05 h 00–07 h 00). The collected snails were then examined (between 07 h 00 and 11 h 00) for patent trematode infection in the field laboratory. This was done by separating the snails into species and screening all *Biomphalaria* and *Bulinus* in groups of 10, in clean water, in 74 mm x 25 mm glass tubes exposed to sunlight. Any tubes containing cercariae were quickly emptied and the snails were rinsed in clean water before being re-exposed individually to identify the infected specimen(s).

The number of snails of each species in each collection, was recorded and the maximum shell width of the *Biomphalaria pfeifferi* was measured to the nearest millimetre.

After examination, all snails were returned to the site from which they had been collected. No snails were crushed to determine the prevalence of immature trematode infections.

On some occasions snails were carefully dried and then marked with nail varnish prior to returning them to their original site, in an attempt to estimate the stability of snail populations.

RESULTS

Abu eshreens *as habitats for snails*

The *abu eshreens* can be classified according to the current crop being cultivated on the field they irrigate, which in turn determines the irrigation requirements for a 12-month period. Fig. 3 shows when an *abu eshreen* should contain water, and the months when they are expected to contain snails.

Table 1 shows the actual drying out date in relation to the crops being cultivated, for the 30 *abu eshreens* under observation:

Cotton. Only 2 of the 7 were dry by the end of April, 4 by end of May, and 2 (LM_1 and OP_2) did not dry out during the summer.

Wheat. All six followed the expected pattern of November opening, and closure by the following April/May.

Groundnuts/Sorghum. Only 1 out of 8 was dry by January, and 4 were allowed to remain wet into April.

Fallow. Two of the 7 were never completely dry because AB_2 acted as an overflow for Toba minor canal, while HI_2 was open to irrigate the garden of the field inspector's house.

Eucalyptus. Both *abu eshreens* were allowed to dry out in March so that the trees could receive their annual thinning.

These results indicated that in addition to the months when snails might be expected to populate *abu eshreens*, inefficient water management could cause a delay in the drying out of *abu eshreens* and consequently in snail deaths. Cotton *abu eshreens* should be dry by late March and groundnut *abu eshreens* should be dry by late December. If they are not, their snail populations will not be completely decimated.

Table 1. *Abu eshreens* on Toba minor canal. Periods of dryness in relation to crop

Cotton			Wheat			Groundnuts/dura			Fallow			Eucalyptus		
Field	Abu eshreen	When dry	Field	Abu eshreen	When dry	Field	Abu eshreen	When dry	Field	Abu eshreen	When dry[c]	Field	Abu eshreen	When dry
B_2	BC_2	March	F_1	FG_1	April	D_2	DE_2	Jan.	A_2	AB_2	Feb.[a]	A_1	AB_1	March
E_2	EF_2	April	F_2	FG_2	May	G_1	GH_1	Feb.	C_2	CD_2	Dry	B_1	BC_1	March
I_2	IJ_2	May	I_1	IJ_1	April	G_2	GH_2	Feb.	H_1	HI_1	Dry			
K_1	KL_1	May	J_2	JK_2	May	J_1	JK_1	April	H_2	HI_2	May[b]			
L_1	LM_1	Never dry	Q_1	Q_1/M	April	M_1	MN_1	April	K_2	KL_2	Dry			
O_1	OP_1	June	Q_2	Q_2/M	May	M_2	MN_2	April	N_1	NO_1	Dry			
O_2	OP_2	Never dry				P_1	PQ_1	April	N_2	NO_2	Dry			
						P_1	PQ_2	March						

[a] AB_2 acted as an overflow to Toba minor.

[b] HI_2 was wet only at the head. It irrigated the field inspector's garden.

[c] Dry means that the *abu eshreen* was bone dry for the season.

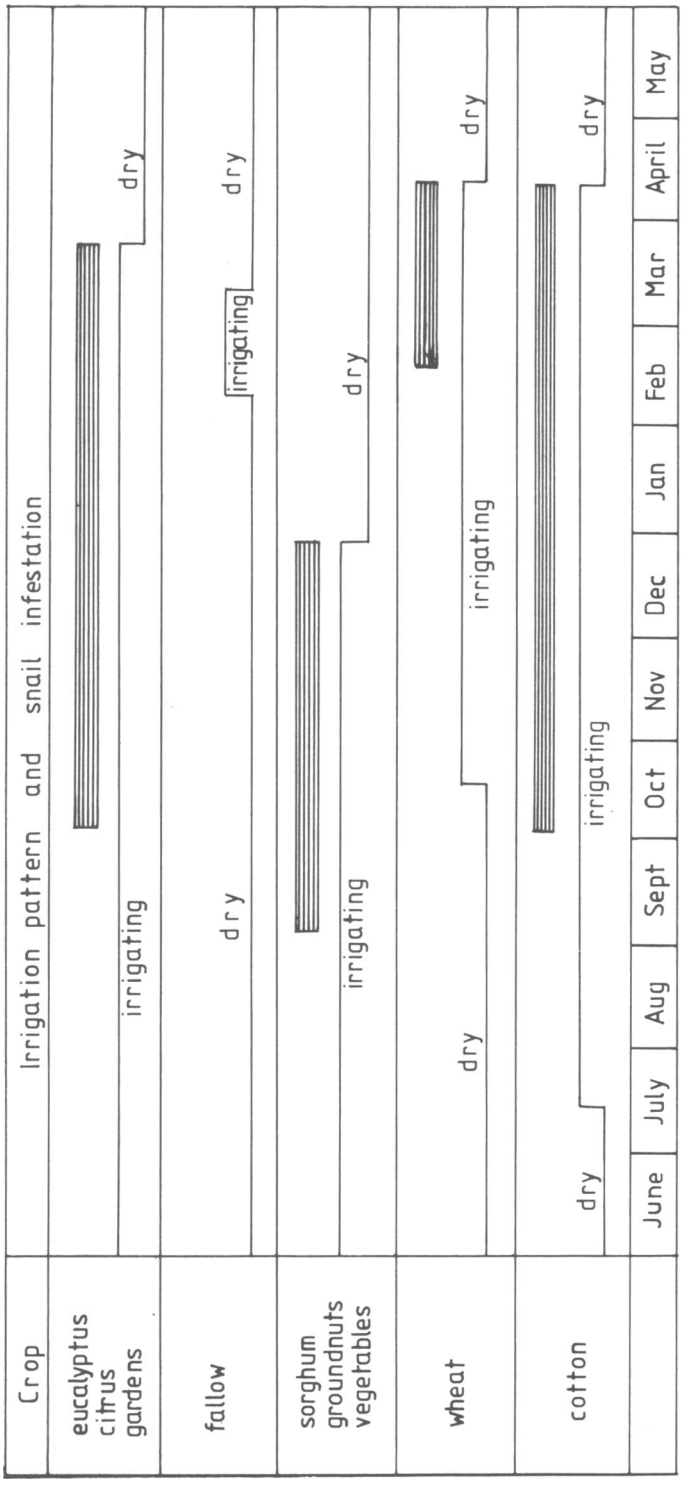

Fig. 3. The 4-year cycle of a Gezira *abu eshreen*.

However, with efficient water management, the periods when snails would be found in *abu eshreens* would be limited to the months of October–March for cotton and eucalyptus, September–December for sorghum/groundnuts, and March–April for wheat.

Abu eshreens *as transmission sites*

Table 2 shows the results of the snail sampling and screening and indicates the relationship between the presence of infected snails and the presence of dwellings (see also Fig. 2). The 2 sites, BC_1 and BC_2, although not strictly adjacent to the dwellings in T16, were the nearest water-contact sites to T16 in February and March when *abu eshreen* BC_2 was dry.

The transmission pattern in Gezira *abu eshreens* can be defined as follows:

Cotton abu eshreens. By November *Biomphalaria pfeifferi* snails populated the cotton *abu eshreens*. Their numbers increased in proportion to the weed growth from December to March, but once the *abu eshreen* was closed the snail population was greatly reduced by dessication.

Dwellings were built on the banks of some of these *abu eshreens* by sorghum harvesters (as with OP_1) in November, by groundnut harvesters (OP_1, OP_2) in December, or by cotton pickers (LM_1) any time between January and May. In such cases there was considerable water contact, as the temporary residents used the *abu eshreen* water for drinking, cooking, laundry, and washing.

After dwellings had been erected, infected snails were found in LM_1, OP_1, and OP_2. Infected snails were found also in BC_2 near the permanent village T16.

In those cases where no dwellings had been built on the banks of the *abu eshreens*, water contact—and hence potential contamination—was much reduced. However, there was always the possibility of infected faeces being deposited in or near an *abu eshreen* by a passer-by; but in fact no infected snails were found in any cotton *abu eshreen* without a nearby dwelling.

Wheat abu eshreens. Since the wheat *abu eshreens* were opened only after dredging in October they remained weed and snail free until March/April and dried out soon afterwards. Therefore they are unlikely to have been important as transmission sites.

Sorghum/groundnut abu eshreens. The presence of snails in these *abu eshreens* coincided with the November/December harvesting season. During these two months the *abu eshreens* supported aquatic weeds, emergent grasses, and many snails. These snails survived until the canal finally dried out but this process was delayed by the thick vegetation. Field workers built huts on the banks of the *abu eshreens* both to protect harvested crop and to be nearby for harvesting (JK_1, GH_1, MN_2, PQ_2).

Again water contact by the residents of these huts was regular and the resulting contamination led to the presence of infected snails. Thus the potential for transmission existed in every sorghum *abu eshreen*

Table 2. Patterns of snail sampling and infection rates in *abu eshreens* in the study area

Abu eshreen	Total snails examined	Snails infected	Month infected	Crop	Nearby huts
BC_1	5 640	4	November	Eucalyptus	T16
BC_2 (head)	713	2	November	Cotton	T16
BC_2 (T16)	128	4	February March	Cotton	T16
GH_1	189	1	November	Groundnuts	Tama
JK_1	219	2	June	Groundnuts	Tama
LM_1	522	1	June	Cotton	Tama
MN_2 (huts)	1 247	4	November January	Groundnuts	Tama
MN_2 (head)	1 206	3	February March	Groundnuts	Tama
OP_1	2 252	5	November February March	Cotton	Tama (groundnuts)
OP_2	1 948	3	March July	Cotton	Tama
17 Other sites	8 422	0			Nil
Total	22 486	29			

from October until December or until it dried out.

Fallow abu eshreens. Once the sorghum/groundnut *abu eshreens* were dry, they remained dry for 15 months before being redug and opened to pre-irrigate the cotton fields. Therefore they can be ignored as transmission sites except when they are opened in special situations such as for the field inspectors' gardens.

Eucalyptus, citrus and special situations. There are three situations in which the 4-year cycle is not applicable and *abu eshreens* are opened on an annual basis from June to March—or remain open throughout the year: when the crop in the field is either eucalyptus or citrus; or when there is a block inspector's or field inspector's house, office, or garden, within the 36-hectare field.

Snails may be found from October to March and sometimes all the year round. Infected snails may be found at any time of year. The *abu eshreens* are not usually near trees and these attract people because they provide both shade in which to rest and privacy, which makes them popular sites for defaecation, with subsequent washing in the *abu eshreen*.

At the block and field inspectors' offices in Gezira, farmers are regular visitors on business and the *abu eshreen* banks provide shady meeting places. Therefore contact and contamination in these *abu eshreens*, with or without permanent residents, are greatly increased. The main activities are drinking, washing, ablution, and bathing.

In October, as repopulation took place after the dry period, the sample collected from *abu eshreen* BC_2 yielded 4 infected *B pfeifferi* out of 34. Fifteen days later 57 snails were collected from the same site but none were infected. Indeed only one of the previous 34 (which had been marked with nail varnish before release) was recollected in this later sample. Although water contact contamination took place in BC_1 infection was detected only once. Thus, the more regular flow in these special *abu eshreens* may have a controlling effect on both miracidial penetration and the stability of the snail populations, although these *abu eshreens* are still potentially very important as transmission sites.

Distribution of infected snails

The overall picture illustrated by Fig. 2 and Table 2 shows that all 27 *abu eshreen* sites yielded snails in at least one visit and of these, 10 sites (Fig. 2) supported at least one infected snail. Of the 22 486 snails collected over the year, only 29 (0.13%) were found to be shedding *S. mansoni* cercariae, and they were all in sites near dwellings where water contact contamination had been observed. Of the 10 infected *abu eshreen* sites, 5 were irrigating cotton, 4 were irrigating groundnuts, and 1 was irrigating eucalyptus trees.

Control of transmission in abu eshreens

From Fig. 4 it can be seen that the normal Gezira *abu eshreen* should contain water for only 24 months in every 4 years and is likely to harbour snails for only 13 of those months. Transmission is most likely from October to December when the crop is sorghum/groundnuts and from October to April with cotton.

When snails are present and dwellings are constructed near to the *abu eshreens*, infection of snails will probably occur. The results also showed that incorrect water management may increase the period when transmission can take place.

In the Gezira, some 6000 fields are planted annually with cotton, 6000 are planted with sorghum, groundnuts, and vegetable plots, and there are about 1000 extra *abu eshreens* near block inspector's, field inspector's premises, citrus gardens, or eucalyptus trees, i.e., about 13 000 potential transmission sites.

Of 30 *abu eshreens* fed by the Toba minor canal, 29 infected snails were recovered from 10 sites. This is not a high rate of infection compared with recoveries from the water-contact sites in minor canals (e.g., 50 infected *B. pfeifferi* were found in one Toba minor site in December out of 1259 collected) but as limited foci with a high transmission potential they should be included in any control planning. The following action could be taken to minimize *abu eshreen* transmission:

(*a*) *Improved water management.* As soon as the *abu eshreen* has completed its function for the season it should be closed and drained immediately. This requires the cooperation of the field inspectors, water guards, and farmers, and proper delegation of responsibility. The water guard should be instructed to see that the outlet pipe is well sealed and the canal drained to speed up the natural drying process in December (for groundnuts) and April (for cotton).

(*b*) *Redigging.* Scouring the dry *abu eshreens* in February for cotton crops and in October for wheat crops removes weeds and appears to delay snail repopulation. If the wet *abu eshreens* could be cleaned by machine at intervals during the high risk periods some degree of snail control should result.

(*c*) *Focal molluscicding.* Efficient treatment with focal molluscides requires an enormous number of applications at a large number of sites.

A possible alternative control measure would be the suspension of a slow release formulation of a molluscide inside every *abu eshreen* pipe. This possibility will be tested in the Gezira in the near future.

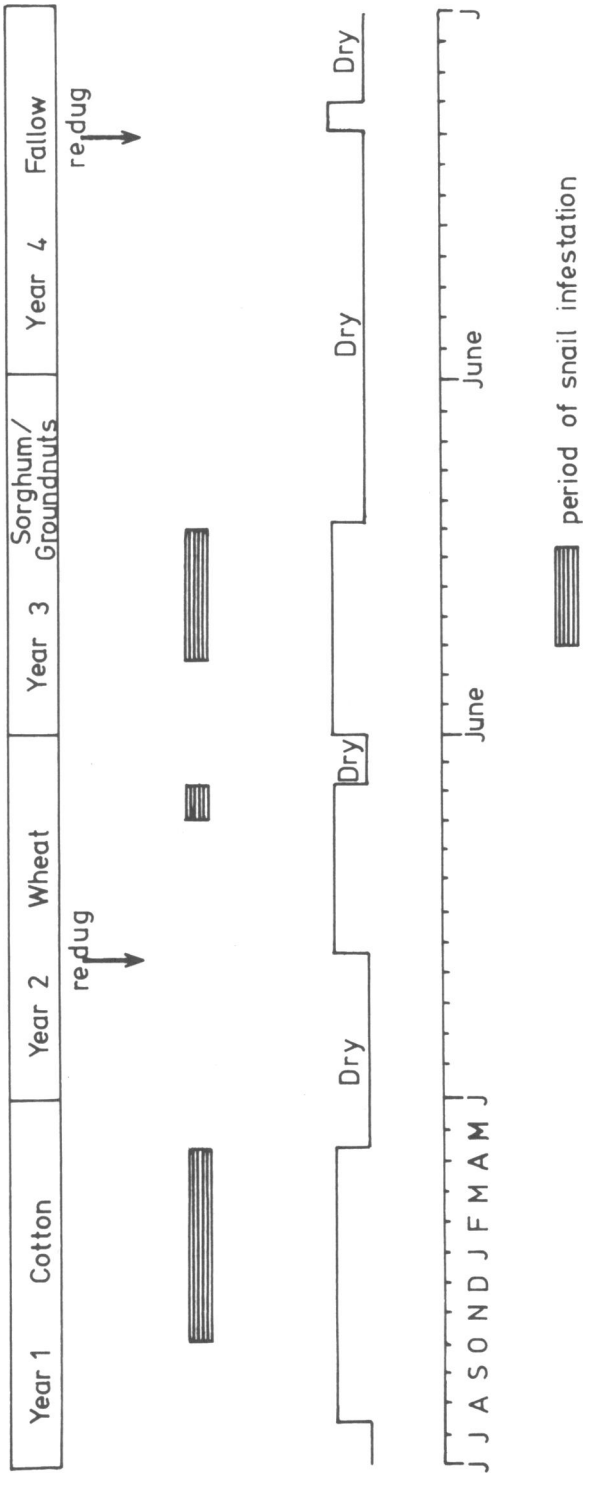

Fig. 4. *Abu eshreen* irrigation pattern and probable snail infestation according to the current crop growing in the field.

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RÉSUMÉ

RÔLE DES CANAUX D'IRRIGATION DANS LA TRANSMISSION DE *SCHISTOSOMA MANSONI* DANS LA ZONE DU PROJET DE GÉZIREH, SOUDAN

Dans la zone irriguée de Gézireh, au Soudan, vit une population arabe autochtone d'environ 1,5 million de personnes, auxquelles il faut ajouter 0,5 million de non autochtones composés essentiellement d'ouvriers agricoles, plus un apport saisonnier de plus de 0,5 million de cueilleurs de coton. Le taux d'infection général par *Schistosoma mansoni* dépasse 50%, et les efforts de lutte contre la schistosomiase au moyen d'applications généralisées de molluscicides n'ont pas donné jusqu'ici de résultats satisfaisants.

La poursuite de la transmission de l'infection dans les villages où les canaux mineurs proches sont régulièrement traités s'explique peut-être par la présence de populations de mollusques dans les canaux des champs (*abu eshreens*). On a donc entrepris une étude des *abu eshreens* pour déterminer la mesure dans laquelle ils jouent un rôle dans la transmission. On a observé les contacts de la population avec l'eau dans une zone expérimentale englobant un canal mineur et 34 *abu eshreens* et parallèlement on a procédé à l'examen d'échantillons de mollusques et au dépistage des cas d'infection manifestes.

Il ressort de l'étude que les *abu eshreens* contiennent en effet des mollusques, mais qu'au cours de leur cycle quadriennal d'irrigation régi par la rotation des cultures, il n'y a que deux grandes périodes de transmission possibles: lorsque les *abu eshreens* sont utilisés pour l'irrigation des arachides et des légumes, de septembre à janvier, puis lorsqu'ils sont utilisés pour l'irrigation du coton, d'octobre à avril. Les chances de trouver des mollusques infectés dans les *abu eshreens* au cours de ces deux périodes augmentent considérablement lorsque les ouvriers agricoles ou les cueilleurs de coton se construisent des logements provisoires dans les champs au bord même des *abu eshreens*. On pense que l'application focale de molluscicides, c'est-à-dire l'introduction régulière de petites quantités de niclosamine dans les *abu eshreens*, le premier jour de chaque mois par exemple pendant la saison de transmission, serait une mesure de lutte pratique que pourrait appliquer les travailleurs eux-mêmes conformément au principe d'auto-assistance.

Une gestion plus stricte des eaux, en particulier en ce qui concerne la fermeture des canaux, une fois terminé leur fonction d'irrigation pour la saison, contribuerait également à la lutte contre l'infection.

Pour certains *abu eshreens* (jusqu'à 1000), le cycle quadriennal d'irrigation n'est pas respecté pour des raisons spéciales. Dans certains cas, en effet, les *abu eshreens* restent ouverts presque en permanence pour irriguer les plantations d'eucalyptus ou pour fournir de l'eau pour les bureaux ou les jardins des inspecteurs de bloc et des inspecteurs de terrain. Dans ces *abu eshreens*, on a pu trouver des mollusques en permanence et le contact accru avec l'eau qu'entraine l'existence de jardins et d'arbres a provoqué une augmentation de la transmission. L'application focale régulière de molluscicides par les occupants des bureaux est suggérée à titre de mesure de lutte.

L'étude a montré que les 22 000 petits canaux d'irrigation des champs dans la zone de Gézireh jouent un rôle important dans la transmission, mais elle indique que les périodes de transmission sont prévisibles, de sorte que des mesures de lutte pourraient être mises en œuvre par la population elle-même, une fois celle-ci dûment informée des aspects sanitaires de la question.

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