IMPACT OF ENVIRONMENTAL CHANGE AND SCHISTOSOMIASIS TRANSMISSION IN THE MIDDLE REACHES OF THE YANGTZE RIVER FOLLOWING THE THREE GORGES CONSTRUCTION PROJECT

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Abstract. With the construction of the Three Gorges high dam on the Yangtze River in China in mind, a serious of ecological environmental factors that might affect the transmission of *Schistosoma japonicum* in Jian Han Plain were investigated by means of data collection, field surveys and observation in Hubei Province. Several ecological factors including water level of the Yangtze River; riparian water table, annual rainfall and yearly evaporation were investigated in relation to the prevalence of schistosomiasis. The results suggest that after the dam construction, middle water level flows (*ie* between flood flows and dry-weather flows) will persist in the flood season due to a rise in the water table. The investigation indicated that snail distribution and human schistosomiasis prevalence differed significantly between years which had typically high, middle and low typical water levels in the Yangzte. Moreover, the prevalence of the disease showed a significant linear regression relationship with density of snail intermediate hosts, water table, annual rainfall, yearly evaporation and ground altitude in the survey area. Systematic and careful monitoring and surveillance is necessary to investigate the impact of the environmental changes brought about by the dam construction on schistosomiasis transmission.

INTRODUCTION

Water resources development is essential for a wide range of human activities. In particular it is needed so that demands for energy and food can be met. During the past ten years however, certain adverse effects of such development have received considerable attention. The prospect of environmental degradation in the face of development was examined by the World Commission on Environment and Development (WCED, 1987). The health impact of this degradation was also emphasised in the report of the WHO Commission on Health and Environment, Our Planet, Our Health (WHO, 1992a). This report noted that environmental factors might have an important effect on schistosomiasis transmission following the Three Gorges Construction (TGC) on the Yangtze River in central China.

TGC is a major project to manage the Yangtze River, in order to control flooding and boost social economic development in China. To mitigate some of the environmental effects created by building a high dam, investigations of factors related to the distribution of *Schistosoma japonicum* at sites upstream of the proposed dam have been carried out in China since 1980. This upstream area (the reservoir area) is a non-endemic area for *S. japonicum*, but the geographic situation and temperature are suitable for the intermediate host snail (*Oncomelania*) to survive and reproduce. This is a serious potential risk factor because only 40 km downstream from the dam is the most serious endemic area of schistosomiasis in China and 500 km upstream from the dam, in Sichuan Province, the disease is prevalent. The snails could be attached to floating carriers and drift downstream for 300 kms and also could spread upstream either by their own efforts, or by carriers such as humans or boats (Gu *et al*, 1987; Xu and Fang, 1988; Xu *et al*, 1989, 1993). It has been suggested that the major ecological environmental change concerns water level and silt in the Yangtze River and the water table along the riverside following the TGC (Cai *et al*, 1987; Cheng and Cao, 1987; Gong *et al*, 1987; Zhen, 1988). It is unknown, however, whether these changes would promote or inhibit *S. japonicum* transmission in the middle reaches of the Yangtze River.

There are several reports concerning the relationship between large irrigation projects and the transmission of schistosomiasis. For example, after the construction of the Aswan High Dam in Egypt, there was enhanced schistosomiasis transmission;

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factors included changes in water level and flow velocity, concentration of suspended particles in the silt and aquatic plants that favored the survival of *Biomphalaria*, but not *Bulinus* snails. There was a decrease in *S. haematobium* and an increase in *S. mansoni* (Abdel-Wahab, *et al*, 1979, 1993; El Almy and Cline 1977; Gilles, 1973; Van du Schalie,1974; Malek, 1975; Saif *et al*, 1978; Webbe and El Hak, 1990). Other examples include Lake Kariba in Zambia, the Volta reservoir in Ghana and the Sennar Dam in Sudan. All of these impoundment projects appear to have promoted transmission of schistosomiasis (Hunter *et al*, 1993; Kongs, 1994; Mahmoud, 1990; Talla *et al*, 1990).

The purpose of the study was to understand and analyse the potential impact of environmental change on the transmission of *S. japonicum* following the TGC, by presenting information related to snail distribution, the prevalence of the disease, the water level of Yangtze River, water table, annual rainfall, yearly evaporation and altitude.

Hubei Province is located at the middle reaches of Yangtze River in China. The topography comprises mountain and hill areas to the northwest and southeast separated by the Jiang Han Plain. Rivers and canals dissect the plain which is dotted with lakes. The major farm product is cotton and rice in rural areas. Hubei Province has 52 counties in which schistosomiasis is endemic, 35 of which are distributed on the Jiang Han plain. The basic epidemiological features of schistosomiasis in this area are:-

1) the water level in the rivers and canals oscillates, favoring snail survival.

2) widespread irrigation means that snail dispersion has developed from foci on the lakeside to canals and ditches. Furthermore, by the opening of irrigation floodgates, snails can be spread from areas of high population density in rivers. This increases the problems of snail control.

3) because area of human habitation near infected snail habitats, people and cattle contact infected water frequently and it is easy to become infected or reinfected by the parasite. Currently, more than 95% of infected people are distributed on the Jiang Han Plain and consequently, it is important to control the transmission of *S. japonicum* in the area.

MATERIALS AND METHODS

Based on the physical features of geographic condition and rivers system on the Jiang Han Plain, four survey areas in four endemic cities were selected (Jing Zhou City, Qian Jiang City, Hong Hu City and Han Chuan City); the basic endemic situation of the four cities is shown in Table 1.

Data collection

Hydrological and meteorological data were collected from 1970 to 1995. The data include water levels of the Yangtze River, water table, rainfall and evaporation in a survey area.

Data on epidemiological information was collected from 1970 to 1995. The data include the number of infected people, infection rate, the distribution of the snail intermediate host *Oncomelania hupensis* in varied situations and altitudes, the density of the snails and the rate of snail infection in the survey area.

Field survey

Snail survey: a snail distribution survey was carried out in different habitats and altitude in the survey area from 1996 to 1997. All of the snails on the surface of mud within a 0.11 m^2 quadrate were collected by tweezers and average density/m^2 was calculated. (Mao, 1990). The relationship between snail distribution and hydro-meteorological factors

Table 1
Basic situation of schistosomiasis in study area.

Study area (city)	No.of total population (people)	No.of infected people (person)	Rate of infected person (%)	No.of infected cattle (cattle)	Rate of infected cattle (%)	Area of snail habitats (ha)
Jing Zhou City	489,987	1,399	5.5	190	4.01	88.93
Qian Jiang City	916,113	16,859	6.5	1,004	3.61	1,852
Hong Hu City	775,300	11,960	4.16	388	4.77	784.53
Han Chuan City	992,613	10,512	6.08	665	2.8	2,116.67
Total	3,174,013	40,730	5.11	2,247	3.49	4,842.13

Table 2
Monthly average value of water level of the Yangtze River and the water table on the Jiang Han Plain (m).

Month	Jing Zhou City		Hong Hu City	
	Water level of Yangtze River	Water table at riverside	Water level of Yangtze River	Water table at riverside
January	32.12	29.4	22.3	20.92
February	31.48	29.12	23.6	21.17
March	31.72	29.4	23.81	21.87
April	33.51	30.19	24.01	22.22
May	34.42	31.2	25.23	23.54
June	38.74	32.02	28.46	25.87
July	40.89	33.61	31.45	26.23
August	39.58	33.69	29.41	25.69
September	38.26	33.27	27.63	24.77
October	36.59	32.55	25.76	22.33
November	34.32	31.22	23.84	21.85
December	32.62	30.2	22.25	21.2

Notes: Standard water level is based on Wusongkou chart data in Shanghai.

was investigated by correlation and regression.

Case finding: people in the survey area were screened by the cellophane fecal thick-smear method and miracidal hatching techniques (Mao, 1990; WHO, 1993). The relationship between disease prevalence and hydro-meteorological factors was investigated by correlation and regression.

Water table measurement: six wells were selected in the survey area in order to observe the daily fluctuation of the water table (Ministry of Water Electricity in China, 1965). A correlation analysis on the water table with the water level of the Yangtze River was performed. Meanwhile, seventeen snail habitat sites were selected randomly to determine any possible relation between depth of water table and snail density.

Data analysis

Based on the features of typical water-level-years in the Yangtze River, high (1974), middle (1984) and low (1986) water-level-years were selected. Epidemiological data for these years were also collected and analysed. All data were analysed using Excel and SPSS programs.

RESULTS

The relationship between the water level of the Yangtze River and the water table

The water level of the Yangtze River and the depth of the water table were observed and recorded all year round. The monthly water level of Yangtze River at two hydraulic stations (Jing Zhou City and Hong Hu City) and monthly water table at the two counterpart sites were compared with correlation analysis. The results showed correlation coefficients of $r = 0.86$ ($p<0.05$) in Jing Zhou City and $r = 0.91$ ($p<0.05$)in Hong Hu City, respectively. The fluctuation of water table along the riverside appeared to reflect the water level of the Yangtze River (Table 2).

Relationship between the Yangtze River and the water table

Based on a long term observation by the Hydrogeological Unit in Hubei, the middle water level of the Yangtze River lasts for a longer period in the flood season. This might result in greater reduction and fluctuation of the water table in the area below the dam following TGC completion. This situation might potentially enlarge the area of marshy land and also increase the snail habitats on the Jian Han Plain. It has been confirmed that the range of the water table is affected within 15 km along with the Yangtze River in the flood season and 7 km in the low-water season. The most sensitive area was the riparian area within 2 to 3 km of the river (Sun *et al,* 1989). On the basis of this observation, epidemiological data on schistosomiasis on the Jiang Han Plain of Hubei Province were collected. The results estimate that there are in Hubei Province 69,931 hectares of snail habitats and 219,945 schistosomiasis patients. Of the 35 counties on the Jiang Han Plain, 25 are distributed along the Yangtze River.

Table 3
The distribution of schistosomiasis of the Jiang Han Plain in Hubei Province.

Note	Size of total human population (persons)	No. of townships (unit)	No. of villages (unit)	No.of human population in endemic area (persons)	No. of snail habitats (ha)	No. of infected people (persons)
a	34,971,106	348	16,849	8,269,263	69,931	219,945
b	33,827,018	338	13,206	7,885,407	19,232	219,930
c	96.70%	97.10%	78.40%	95.40%	99.30%	99.70%
d	19,650,697	211	8763	4,947,446	42,704	140,226
e	56.20%	60.90%	52%	59.80%	61.10%	63.70%
f	5,332,418	134	2,526	2,931,934	29,562	69,494
g	15.20%	38.50%	14.90%	35.50%	42.30%	31.80%

Note:
a: Whole state of Hubei Province
b: 35 counties in Jian Han Plain
c: Percentage of b/a
d: 25 counties bordering the Yangtze River
e: Percentage of e/a
f: 15 km zone in 25 counties
g: Percentage of f/d

Table 4
t value of the average density of the snail in different typical water levels of the Yangtze River.

Snail survey year	Mean of snail	SD	t value	p value
(high)1974	1.0019	2.1340	74 *vs* 84 is 2.6311	<0.05
(middle) 1984	0.5704	1.1341	74 *vs* 86 is 2.6768	<0.05
(low) 1986	0.5360	1.0406	84 *vs* 86 is 0.3406	>0.05

Of the total population of Hubei Province, 95.4% live in schistosomiasis affected counties, and 59.8% live in counties bordering the Yangtze River (Table 3).

The relationship between water table and the density of snails

Seventeen snail habitat sites were randomly selected to identify whether there was a relationship between depth of water table and snail density. The result showed a curvilinear relationship with r = 0.90. The multi-regression equation was $Y= -0.1052+0.069x-0.0009x^2$. These data suggest that snails are mainly distributed at depths equivalent to water table depths of 20 to 45 cm. Few snails could be found at water table depth equivalents of less than 1 cm or more than 75 cm. This result could offer a theoretic basis for snail control measures in lowland areas where snail habitats are influenced by the water table (Fig 1).

Relationship between the average density of snails and the different typical water level year of the Yangtze River

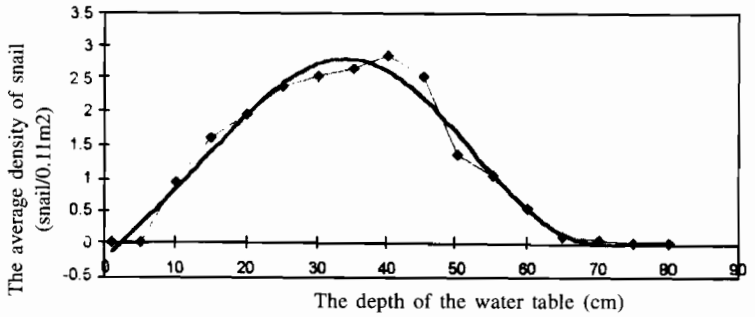
Data for snail distributions in 217 sites were collected for corresponding high, middle and low typical water level years (1974, 1984, 1986). The results demonstrated that the average density of snails was significantly different in the high water level year compared with middle and low water level years ($p<0.05$). It appears that the distribution of snails was influenced by the high water levels in the Yangtze River (Table 4).

Relationship between human prevalence of infection and different typical water-level years of the Yangtze River

Data on human prevalence of infection were collected for corresponding water-level years. x^2 tests suggest that prevalence is different between different water level years. The high water level (1974) differed from middle water level (1984) $x^2 = 180.5$ and from low water level (1986) $x^2 = 24.9$, ($p< 0.01$). Prevalence of the disease was markedly different between different water-level years.

Relationship between endemicity and hydrometeorological factors

Hydrometeorological data related to rainfall, evaporation and water table were collected from 1985-1995 in four counties. A correlation of monthly water table depth with monthly rainfall was r = 0.95 and



$y = -8E\text{-}10x^6 + 2E\text{-}07x^5 - 1E\text{-}05x^4 + 0.0003x^3 - 0.0031x^2 + 0.1179x - 0.228$

$R^2 = 0.9761$

Fig 1–The relationship between average density of the snail and the depth of the water table.

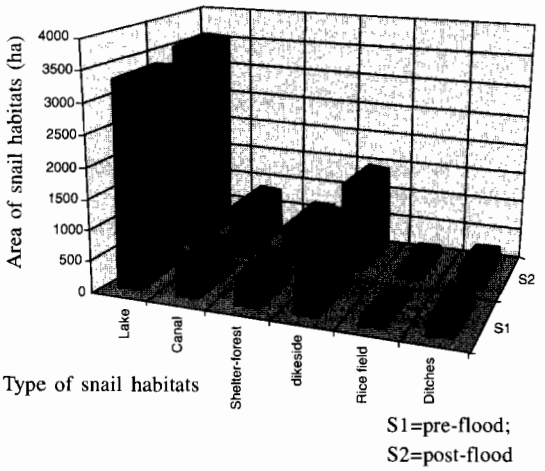


Fig 2–Area of snail habitats pre-and post-flood.

the correlation of water table depth with the monthly evaporation was r = 0.93. Meanwhile, a correlation of annual rainfall on human infection rate and snail habitat gave r values of 0.88 and 0.94 respectively. Hydrometeorological factors appear to be closely related to endemic conditions in the survey area.

Effect of flood on schistosomiasis prevalence

1974 was a typical high-water level year for the Yangtze River. In this year, annual rainfall (1,927 mm) was the highest since 1949. The Jiang Han Plain was flooded not by the Yangtze, but as a result of heavy rain. When the excessive rainfall stopped, a snail survey demonstrated that the area of snail habitats had increased by 19.32%, and the average density of live snails and the density of infected snails had increased by 120% and 91% respectively. The number of acute cases had also increased by 30% and 55.6% and many schoolchildren were infected. It appears that this event had a serious negative impact on schistosomiasis control (Fig 2).

The relationship between the endemic condition and ground altitude

Data on the ground altitude (GA), average density of snails (ADS) and infection rate of people (IRP) were collected for 237 villages in the survey area. A regression analysis gave an equation of R = 4214.15 + 114.078 GA + 1132.389 ADS in which the p values for GA and ADS were < 0.001.

DISCUSSION

Ecosystem changes around large water projects may favor the introduction of parasitic diseases. In particular, intermediate snail hosts of schistosomiasis may be introduced by fishermen, farm workers, or domestic animals and even by birds (Hunter *et al*, 1993). At present the catchment upstream from the Three Gorges is a non-endemic area for *S. japonicum*, but the geological situation and temperature are suitable for the intermediate host snail (*Oncomelania*) to survive and reproduce. There is a serious potential risk, because natural and artificial factors could introduce the snail into the reservoir area and then into indigenous mammals including humans and water buffalo. Hence long term monitoring is necessary in this area.

Water resource development does not occur in isolation. The construction of a dam creates changes in both the upstream and downstream areas. Previous investigations have shown that fluctuation of the water level of the Yangtze River can affect the rise and fall of the water table. After construction of the dam, the middle water level of the Yangtze River will last a longer period in the flood season, which might result in less fluctuation and increased detention and extent of the water table in the area below the dam. This situation might enlarge the area of marshy land and the area of snail habitats as well. This extension of the water table and possible entrenchment of schistosomiasis transmission on the Jian Han Plain is a key issue for further monitoring and surveillance following completion of the project.

There was a linear regression relationship between the depth of the water level and the density of the snail in the survey area. The results of the snail survey demonstrated that snails were mostly distributed at the sites where depth of the water table ranged from 20 to 45 cm. These results could provide a theoretical basis for snail control measures in lowland area with a full water table.

Snail distribution and prevalence of human schistosomiasis infection significantly differed between a typical high water level year and middle and the low water level years of the Yangtze River. In particular, when heavy rain and flood condition were contemporaneous, snail area and density markedly increased and the human infection rate increased quickly. The results also indicated that monthly rainfall, evaporation and water table depth had a linear regression relationship with snail distribution and the number of infected people on the Jian Han Plain. Thus hydrometeorological change could be a crucial environmental factor in the entrenchment of transmission of *S. japonicum* in this area. Given the current problem of frequent flood disasters on the Jiang Han Plain, strategies to control snail dispersal and the disease are urgently needed. The Three Gorges Dam should be able to control the water level of the Yangtze River in the flood season. It is hoped that as the problem of flood damage is solved for the Jian Han Plain, the transmission of *S. japonicum* might also be controlled.

The Jiang Han Plain is an important commercial grain and food oil growing area, as well as being one of the most serious epidemic areas of *S. japonicum* in China. Since the Plain is located in the area downstream of the proposed dam, there is a series of potential ecological environmental changes that might take place. These issues are being addressed both in and out of China. (Davis, in preparation 1999; Sleigh and Jackson 1998; Xu *et al* 1998). However, further multilateral participation to investigate and mitigate adverse health impacts is needed. Systematic and carefully monitored surveillance of environmental change could be performed and preventive strategies against schistosomiasis could be developed.

CONCLUSION

Through data collection and field observation and investigation, environmental factors that might potential influence the transmission of *S. japonicum* following TGC were investigated. These factors included water level of the Yangtze River, the water table along the riverside, annual rainfall and yearly evaporation. The results indicated that the fluctuation of the water level of Yangtze River could affect the water table both upstream and downstream of the Jian Han Plain. More than half of the human population, snail habitats and the number of people infected with schistosomiasis in the whole province are distributed in this area. Moreover, the infection rate and snail density were significantly different between typical high, middle and low water level years. Hydrometorological and ecological environmental factors also have a close relationship with the transmission of *S. japonicum* in this area. These results contribute to our undersatanding of the future of schistosomiasis transmission in the area and may contribute to future control strategies after completion of the Three Gorges Dam.

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