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Infectious Diseases of Poverty

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The Three Gorges Dam: Does it accelerate or delay the progress towards eliminating transmission of schistosomiasis in China?

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Abstract

The Three Gorges Dam, located in the largest endemic area of schistosomiasis in China, is one of the world's largest hydroelectric projects to date. Some large-scale hydro projects have resulted in schistosomiasis emergence or re-emergence. Therefore, the dam's potential impact on the transmission of *Schistosoma japonicum* has raised concerns from medical researchers worldwide. A systematic literature review, coupled with an analysis of data on the water level and snail density in the Yangtze River was conducted to assess the impact of the dam on schistosomiasis transmission after more than 10 years of operation. The dam has significantly altered the water levels in the Yangtze River according to different seasons. These changes directly impact the ecology of the schistosome snail host. Due to the dam, there has been a reduction in the density of *Oncomelania* snails and/or changes in the distribution of snails. The prevalence of infection with *S. japonicum* has decreased in the downstream areas of the dam, including in the Dongting and Poyang Lakes. The prevalence of infection with *S. japonicum* in humans has decreased from 6.80 % in 2002 (before the dam began operating) to 0.50 % in 2012, and the number of people infected with *S. japonicum* have decreased from 94 208 in 2002 to 59 200 in 2011 in the Poyang Lake region. The presence of the dam does not seem to affect snail breeding or the prevalence of schistosomiasis in the Three Gorges Reservoir. Overall, the Three Gorges Dam has significantly contributed to changes in hydrology after more than 10 years of the dam operating. The changes caused by the dam, together with integrated control of schistosomiasis, might be accelerating the progress towards eliminating the transmission of *S. japonicum* in the middle and lower reaches of the Yangtze River. Despite the positive effect the dam is having in controlling *S. japonicum* transmission, continued surveillance is required to monitor the future ecological impacts of the dam over the long term.

Keywords: Three Gorges Dam, Schistosomiasis, *Schistosoma japonicum*, *Oncomelania hupensis hupensis*, Elimination, China

Multilingual abstracts

Please see Additional file 1 for translations of the abstract into six official working languages of the United Nations.

Background

The Three Gorges Dam, the world's largest dam, is located in the upper reaches of the Yangtze River, the longest river in Asia and the third longest in the world. The middle and lower reaches of the Yangtze River are the largest endemic area of schistosomiasis in China (see Fig. 1) [1]. The two largest lakes in China (Poyang Lake in Jiangxi Province and Dongting Lake in Hunan Province), which are located along the middle and lower reaches of the Yangtze River, constitute a shallow lake group unique in the world that extensively exchanges water with the river. The two lakes are endemic areas of schistosomiasis. The water level elevates substantially following the monsoon season. *Oncomelania hupensis hupensis* snails, the intermediate snail hosts, are distributed strictly in the Yangtze River basin due to its so-called 'winter-land, summer-

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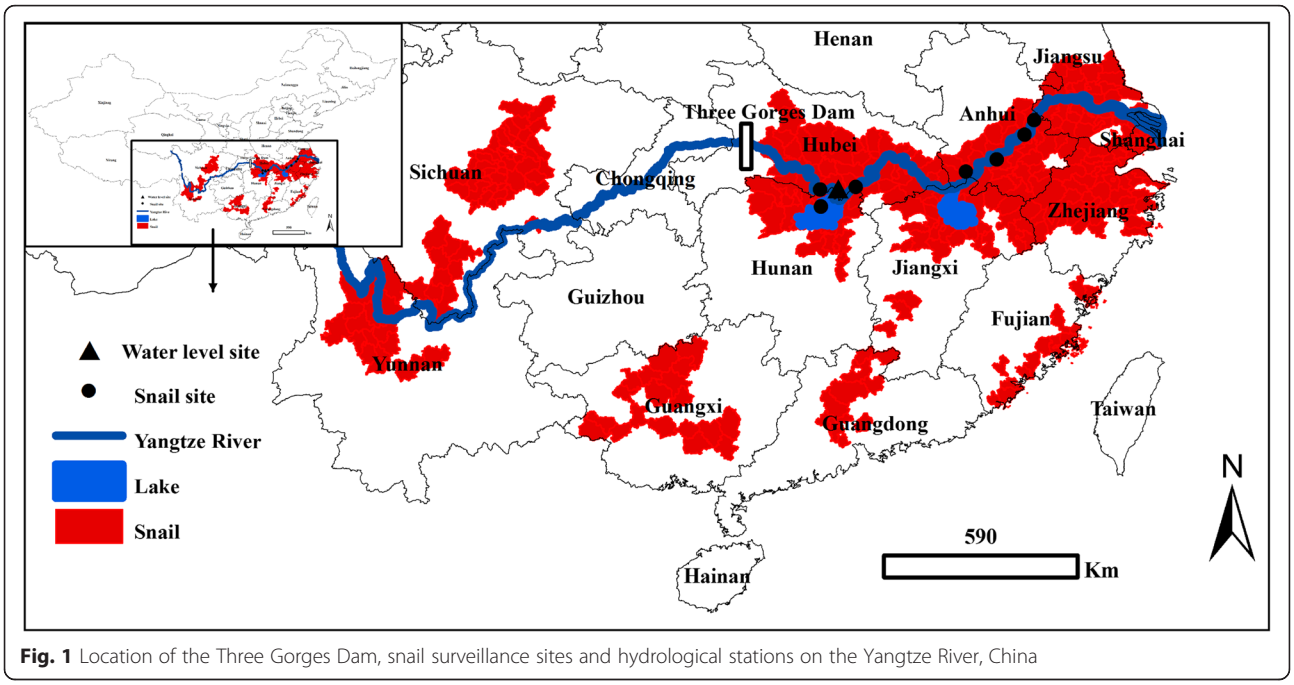

Fig. 1 Location of the Three Gorges Dam, snail surveillance sites and hydrological stations on the Yangtze River, China

water' ecohydrological condition that is favoured by the snails [2, 3].

The filling of the Three Gorges Reservoir began in June 2003, and its water level rose to 135 metres by the end of 2003, to 156 metres in 2006 and 172 metres in 2008. Since 2009, the water level has been maintained at 175 metres throughout November and December, and is lower in the other months.

It has previously been reported that some large-scale hydro projects (e.g., the Sudanese Gezira-Managil Dam, the Egyptian Aswan High Dam and the Ethiopian Melkasadi Dam) have resulted in schistosomiasis emergence or re-emergence [4–9]. Hence, the potential impact of the Three Gorges Dam on the transmission of *Schistosoma japonicum* in the Yangtze River basin has raised concerns from researchers worldwide [10–18]. Over the past decades, numerous studies have been carried out to forecast or assess the impact of the dam on the distribution of *O. h. hupensis* snails and the transmission of *S. japonicum* [19, 20].

Through a systematic review and an analysis of data on the water level and snail density, we assessed the dam's impact on *S. japonicum* transmission after more than 10 years of operation. In this paper, we also discuss the potential implications for national strategies to control and eliminate schistosomiasis.

Methods

Search strategy

We conducted a systematic literature review by searching all relevant articles, published up to September 2015, which examined the impacts of the Three Gorges Dam on the transmission of schistosomiasis. Relevant studies were identified from the following electronic databases: PubMed, Science Citation Index Expanded™, China National Knowledge Infrastructure, Wanfang Data, China Science and Technology Journal Database and SINOMED. The following keywords and any combinations thereof were used: "Three Gorges Dam" in combination with "schistosomiasis", "*Schistosoma*", "snail" and "*Oncomelania hupensis*". No language restrictions were applied.

Article selection

Two reviewers independently checked the titles and abstracts of all identified articles for inclusion eligibility. We excluded the following: (1) review articles, (2) dissertations, (3) conference abstracts and presentations, and (4) non peer-reviewed reports. For eligible publications, full papers were retrieved and reviewed by the same two reviewers. They were then grouped into two categories: field simulation studies or prediction studies that were carried out before the dam started operating and therefore did not include data on the impact of the dam on schistosomiasis transmission in the study period; and observational or monitoring studies that were implemented after the dam started operating and were able to include data on the impact of the dam on schistosomiasis transmission in the study period.

Data on changes in the water level and snail density

Daily data on the water level (above sea level, 8:00 AM) at the Chenglingji Hydrological Station (located at the

junction of the Yangtze River and Dongting Lake) were collected from 1995 to 2013. In 2005, seven snail surveillance sites (villages) along the Yangtze River were set up to monitor the changes in the density of snails in the bottomland areas of the middle and lower reaches of the Yangtze River (see Fig. 1). In these snail surveillance sites, molluscicides for snail control were either not used or used very sparingly. These bottomland areas were surveyed using the traditional Chinese method of systematic sampling (20 m × 20 m) done annually in the spring [21]. Data on snail density (snail/0.11 m^2) were collected from the seven snail surveillance sites from 2005 to 2013.

Calculating the time of how long snail habitats are inundated with water

O. h. hupensis snails are distributed mainly in marshlands that are 25–28 metres in elevation in the Dongting Lake area close to the Chenglingji Hydrological Station [22]. Therefore, we calculated the time of 25 metre, 26 metre, 27 metre and 28 metre elevated marshes being inundated with water. If the water level in a day was higher than the elevation of the marsh, we regarded that marsh to be inundated with water. We estimated the link relative ratio of the days the marshes were inundated with water. The link relative ratio refers to the comparison between the days the marshes were inundated with water in a year and the days they were inundated with water in the previous year. For example, the days a marsh was inundated in 1996 are divided by the days it was inundated in 1995, thus achieving the link relative ratio of 1996.

Results

Included articles

A total of 626 articles were identified from six electronic databases (33 from PubMed, 37 from Science Citation Index Expanded™, 190 from Wanfang Data, 205 from China National Knowledge Infrastructure, 121 from China Science and Technology Journal Database and 40 from SINOMED). Due to duplication or irrelevance, 520 studies were excluded after the titles were screened. By screening the abstracts and full texts of the remaining 106 papers, it was determined that 51 articles would be excluded for they were not relevant to the topic, or they were review articles, dissertations or conference presentations, and 55 papers would be included in this study. The decision tree for the inclusion or exclusion of papers is illustrated in Fig. 2.

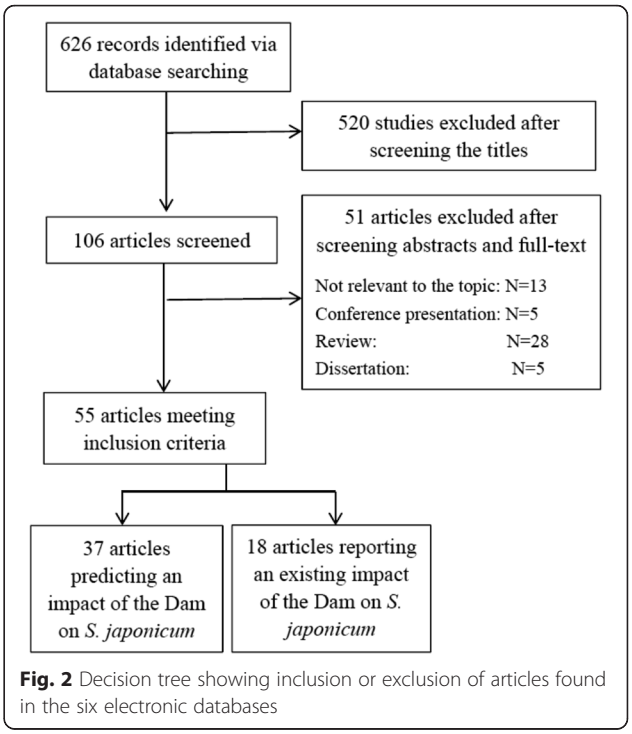

Fig. 2 Decision tree showing inclusion or exclusion of articles found in the six electronic databases

Predicted impact of the dam on schistosomiasis transmission

A series of studies have been conducted predicting the potential impact of the Three Gorges Dam on the distribution of *Oncomelania* snails and transmission of *S. japonicum*. For the regions below the dam (i.e. along the middle and lower reaches of the Yangtze River), most of the studies consistently reported that the Three Gorges Dam would decrease the probability of flooding and cause changes in the water level in these areas of the Yangtze River; that is, upon completion of the dam, the water level would rise during the first part of the year and decrease during the last two or three months of the year (see Table 1). Most of the studies also consistently predicted that the decreased the probability of flooding due to the Three Gorges Dam would limit the dispersal of the snails and reduce the chance of human and livestock making contact with water that is infested with the cercariae of *S. japonicum*. However, most of the prediction studies we assessed reported that changes in the water level would increase the probability of human and livestock becoming infected with schistosomes, but that the epidemic status of schistosomiasis would be minimally affected in the Jiangxi segment of the Yangtze River (see Table 1). The predictions on the impact of the changes in the water level on *Oncomelania* snails were different in the different segments of the Yangtze River. For example, it has been predicted that some new habitats for *Oncomelania* snails would be created in the Hubei [23] and Anhui segments [24] of the river, but that the density of snails would decrease in the Jiangsu segment [25] after the completion of the dam (see Table 1). Some studies predicted that changes in the water level caused by the dam would not affect the reproduction or distribution of *Oncomelania* snails or increase the density of the snails [17, 20], but

Table 1 Predicted impact of the Three Gorges Dam on the distribution of *Oncomelania* snails and transmission of *S. japonicum*

Segment of Yangtze River	Water level rising		Water level decreasing		*Oncomelania* snails	*S. japonicum*	Refs.
	Height (m)	Months	Height (m)	Months			
Hubei (Jianghan Plain)	0.06–1.5	Jan – May	1.8–2.4	Nov, Dec	New habitats for *Oncomelania* snails would appear.	The probability of humans and livestock becoming infected would increase.	[17, 20, 23, 24]
Hunan (Dongting Lake)	0.06–1.5	Jan – May	1.6–2.6	Nov, Dec	The distribution of snails would not be significantly affected, however, the reproduction of snails would be effectively curbed.	The probability of humans and livestock becoming infected would increase and schistosomiasis epidemics would worsen.	[17, 20, 23, 25]
Jiangxi (Poyang Lake)	0.11–0.90	Jan – Mar	0.07–0.13	Dec	The reproduction and distribution of snails would be unaffected or the density of snails would increase, or the density of snails would decrease in the autumn.	The epidemiology of schistosomiasis would be very limitedly affected.	[17, 20, 23, 58, 59]
Anhui	0.14–0.76	Jan – Apr	0.06–1.26	Oct – Dec	The distribution of snails would not be significantly affected, however, some new habitats for snails would appear.	The probability of humans and livestock becoming infected would increase.	[17, 20, 24, 27, 60–62]
Jiangsu	0.15–0.40	Feb – Apr	0.32–0.75	Oct, Nov	The distribution of snails would be not affected and the density of snails would decrease.	The incidences of schistosome infections in people and livestock would increase.	[17, 20, 25, 27, 58]

another study reported that changes in the water level would decrease the density of *Oncomelania* snails in the Jiangxi segment in autumn [13]. In addition, Cai et al. [26] reported in 2000 that the Three Gorges Dam would considerably reduce silt entering the Dongting Lake from the Yangtze River in the 50 years following the construction of the dam and that this would effectively limit the reproduction of snails.

Before the dam started operating, the Three Gorges Reservoir (see Fig. 1) was free for *Oncomelania* snails and *S. japonicum* for Yangtze water in the region was rapid following and collides with the cliffs, sandbars and precipices that flank the river [27]. Some studies reported that great environmental changes (e.g., sedimentation and formation of marshlands) resulting from the dam could form potential habitats for *Oncomelania* snails [27–29], whereas some simulated studies reported that *Oncomelania* snails could survive and breed in the Three Gorges Reservoir [30–34]. Some researchers reported that both *Oncomelania* snails and transmission sources of schistosomiasis might have been introduced into the Three Gorges region due to the dam [35–37]. However, other studies reported that the Three Gorges Reservoir would not be an ideal location for the reproduction of *Oncomelania* snails, as the dam's 'winter-water, summer-land' operation cycle contradicts with the snails' 'winter-land, summer-water' breeding cycle [38, 39].

Dam's impact on the water level

After the Three Gorges Dam started operating, various studies have reported on the dam's impact on the water level in the regions below the dam [40–46]. The results of these studies are consistent with or similar to each other: they report that the dam has effectively controlled floods and because of it, an early-flooded bottomland occurs in the spring and earlier water recessions occur in the autumn along the middle and lower reaches of the Yangtze River. For example, Li et al. [43] reported that the mean water level between January and March 2012 rose by 0.41 metres in the Jiangsu segment of the Yangtze River, and that from April to December 2012, it decreased by 0.32 metres, compared with the levels in 2002. These results are similar or consistent with the results from monitoring the Chenglingji Hydrological Station. Figure 3 shows that the peak water level decreased and the lowest water level rose in the Yangtze River from 1995 to 2013. During the first 10 years of the dam's operation, the water levels were above 32.5 metres (warning line) in only three of the years and the water levels were above 33.0 metres (dangerous line) in only two of the years, compared with seven years and six years, respectively, during the nine years before the dam started operating (1995–2003).

The time that the snail-harbouring marshlands were inundated with water changed more frequently and in a wider range after the completion of the dam. Such changes in the time were marketed in 2006 that the time the snail habitats were covered with water was very short (see Fig. 4a) with a high link relative ratio (see Fig. 4b).

Dam's impact on schistosomiasis transmission

During the last several years, some studies have reported on the Three Gorges Dam's impact on the distribution of *Oncomelania* snails and transmission of *S. japonicum*

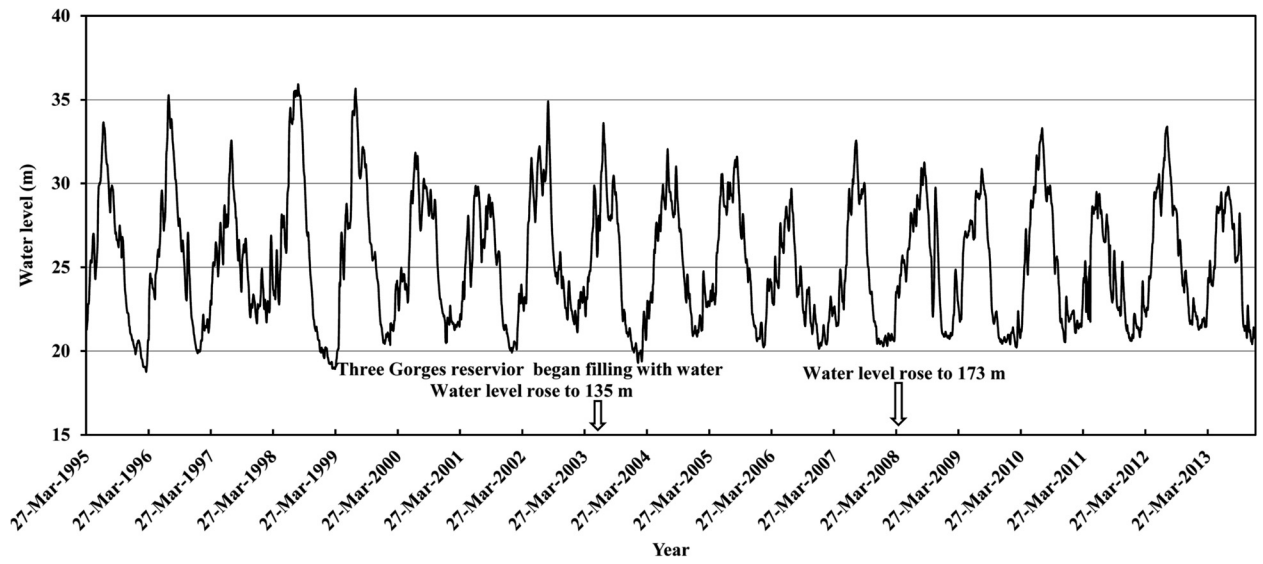

Fig. 3 The daily water level above sea level (8:00 AM) at the Chenglingji Hydrological Station located at the junction of Yangtze River and Dongting Lake, from 1995 to 2013

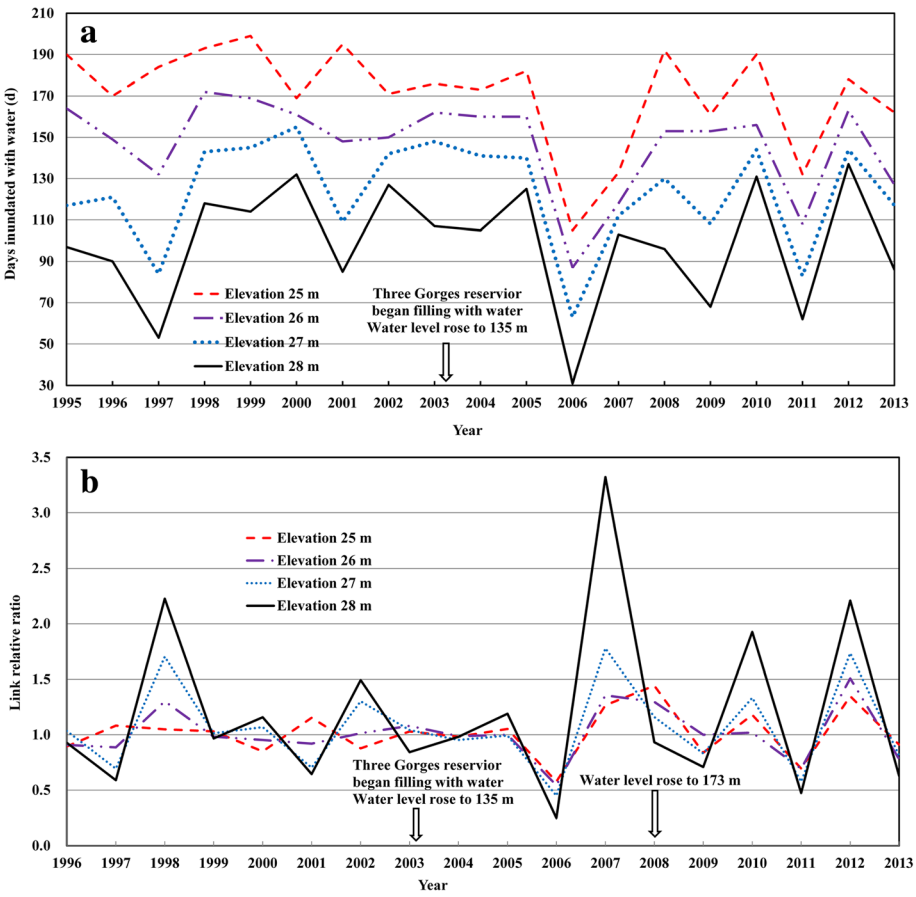

Fig. 4 The number (**a**) and link relative ratio (**b**) of days that snail-harbouring marshland are inundated with water in the Dongting Lake region, from 1995 to 2013

after the dam operating. Most of these reports revealed that the Three Gorges Dam has contributed to a reduction in the density of *Oncomelania* snails and/or changes in the distribution of *Oncomelania* snails in the downstream areas of the dam, including the Dongting and Poyang Lakes [19, 40, 42, 44–48]. This was consistent with the monitoring results. Figure 5 shows that the density of *Oncomelania* snails in the bottomland areas of the middle and lower reaches of the Yangtze River has decreased notably from 2005 to 2013. Some studies reported that both the prevalence of infection with *S. japonicum* and the number of individuals infected with *S. japonicum* have decreased significantly after more than 10 years of the dam's operation [40, 41, 43, 45]. For example, Chen et al. [45] reported that the prevalence of infection with *S. japonicum* in humans decreased from 6.80 % in 2002 (before the dam started operating) to 0.50 % in 2012. They also reported that the number of individuals infected with *S. japonicum* decreased from 94,208 in 2002 to 59,200 in 2011, and that the number of acute *S. japonicum* cases decreased from 128 in 2002 to one in 2012 in the Poyang Lake region. Meanwhile, Zhang et al. [40] reported that the number of individuals infected with *S. japonicum* reduced from 54,304 in 2002 to 25,378 in 2012, and that the number of acute *S. japonicum* cases reduced from 251 in 2002 to two in 2012 in Anhui Province. However, other studies reported that the dam had virtually no immediate impact on the transmission of schistosomiasis [11, 49] and some other studies showed that the Three Gorges Dam does not definitely affect snail breeding and the prevalence of schistosomiasis in the Three Gorges Reservoir, as the dam operates in a so-called 'winter-water, summer-land' cycle. That is, the water levels rising in the winter and falling in summer in the reservoir contradict with the *Oncomelania* snails' 'winter-land, summer-water' breeding stimulation. In particular, *Oncomelania* snails struggle to survive in high water levels in the winter, which is the situation due to the dam [38, 50, 51].

Discussion

The construction of the Three Gorges Dam commenced in 1994 after decades of research and fierce debate. Benefits of the dam, such as flood control and power generation, are indisputable and the dam has lived up to these expectations. However, this study found that the dam's impact on the transmission of *S. japonicum* is different to previous forecasts (see Table 1). Overall, this study found that the changes in hydrology caused by the Three Gorges Dam might be favourable for the control of *S. japonicum* transmission, based on the results from the observational and monitoring studies [19, 40–50].

There might be several reasons for this. Firstly, the dam has effectively controlled floods and deterred the dispersal of *Oncomelania* snails, and thus curtailed the infection to humans and animals [52, 53]. For example, some studies reported that the number of patients infected with *S. japonicum* reduced significantly, and especially that acute *S. japonicum* cases were rarely seen in the middle and lower reaches of Yangtze River after more than 10 years of the dam's operation [40, 41, 45]. Secondly, during the first few months of the year, the presence of the dam leads to the production of an early flooded bottomland [43], and this not only can result in the death of adult *Oncomelania* snails or reduce their survival rate and oviposition, but is also not a favourable environment for embryo development of *Oncomelania* eggs [25]. Moreover, after the dam started operating, it has been observed that in the summer, many snail-harbouring marshlands are either not flooded or only flooded for a very short period of time. This is also not favourable for the development of juvenile snails, as *Oncomelania* snails have to live in water during the early stages of their development [54]. Some studies, together

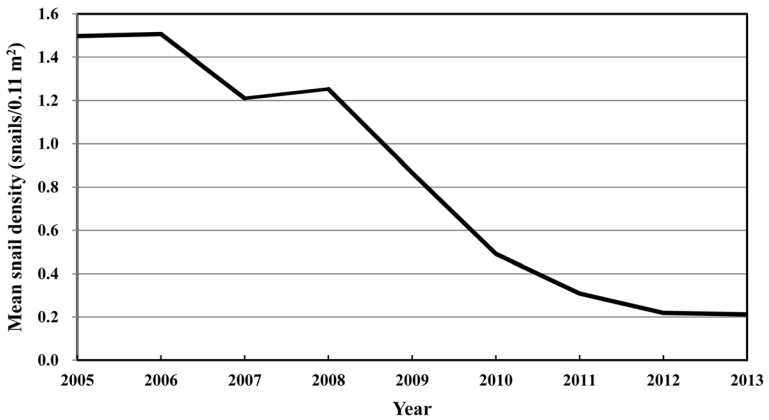

Fig. 5 The density of *Oncomelania* snails in the bottomland areas of the middle and lower reaches of the Yangtze River, from 2005 to 2013

with our monitoring results, showed that the density of *Oncomelania* snails decreased significantly in many snail-harbouring marshes in the downstream areas of the dam [40, 45–48]. Thirdly, earlier water recessions in the autumn caused by the dam have advanced the exposure time of snail-harbouring marshes, thus they may be suitable for early planting of crops such as wheat and rapeseed. Currently, some of these marshlands have begun to be planted and this has resulted in a significant decrease in the density of *Oncomelania* snails [55]. Although some farmers spend a longer period of time working on the marshlands and therefore have a higher chance of coming into contact with cercariae-infected water, other people and livestock such as bovines, the primary infection source of *S. japonicum* transmission in China, are kept away from these marshlands, meaning that the probability of most humans and livestock becoming infected with *S. japonicum* decreases. In addition, many studies predicted that advanced water recessions in the autumn would lengthen the amount of time humans and livestock spend on the marshlands and increase the incidence of schistosome infections for both humans and livestock [17, 20]. However, an integrated control programme, aiming to reduce the roles of bovines and humans as infection sources, has been implemented in China since 2005 [56]. The control programme consists of agricultural mechanisation, fencing bovines, chemotherapy for humans and bovines, health education, provision of clean water and improved sanitation [57]. Hence, the programme has led to a reduction in the amount of time that humans and livestock spend on marshlands. Up until now, there have been no reports of increased incidence of schistosome infections due to earlier water recessions in the autumn. Fourthly, the dam operates in a so-called 'winter-water, summer-land' cycle, which contradicts with the *Oncomelania* snails' 'winter-land, summer-water' breeding stimulation. In particular, *Oncomelania* snails struggle to survive in high water levels in the winter, which is the situation due to the dam [38, 50, 51]. Although both *Oncomelania* snails and human transmission sources for schistosomiasis may have been introduced from schistosomiasis endemic areas into the Three Gorges Dam region [20], no local sites of *Oncomelania* snails or locally infected people have been identified so far [19].

The changes in hydrology caused by the Three Gorges Dam may have an important implication for the Chinese national control strategies that aim to eliminate schistosomiasis. For example, tractors should plant crops such as wheat and rapeseed in the snail-harbouring marshlands that are suitable for early planting of crops due to early water recessions in the autumn. This can reduce the density of *Oncomelania* snails or even eliminate snails, as well as increase the income of farmers. Of course, farmers should be educated about how to avoid contact with cercariae-infected water when planting on these snail-harbouring marshlands.

Our study had some limitations. Although a large number of articles were found in the course of the systematic review, most of these were excluded due to duplication or irrelevance, and only 55 papers reporting the relationship between the Three Gorges Dam and the transmission of schistosomiasis were included in the study. Most of the included articles were simulation or forecast studies, or used only routine monitoring data to assess the dam's impact on the transmission of schistosomiasis. Hence, it was difficult for us to systematically and quantitatively analyse the impacts of the Three Gorges Dam on the transmission of schistosomiasis. In view of this limitation, the relationship between the dam and the transmission of schistosomiasis outlined in this study should be interpreted with caution.

Conclusion

There have been significant changes in hydrology since the Three Gorges Dam started operating in 2003. These changes, together with the integrated control programme currently implemented in China, might be accelerating the progress towards the elimination of *S. japonicum* transmission in the middle and lower reaches of the Yangtze River. Continued surveillance is needed to monitor the longer-term ecological impacts of the dam on the transmission of schistosomiasis.

Additional file

Additional file 1: Multilingual abstracts in the six official working languages of the United Nations. (PDF 747 kb)

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Availability of data and materials

The data supporting the findings in our paper can be found in Center for Tropical Disease Research, Fudan University.

Authors' contributions

YBZ and SL contributed to the literature search, YBZ and QWJ conducted the monitoring studies, YBZ and QWJ analysed the data, YBZ, SL, YC and QWJ contributed to the writing of the paper. All authors approved publication.

Competing interests

The authors declare that they have no competing interests.

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