CHAPTER NINE

Integrated Control Strategy of Schistosomiasis in The People's Republic of China: Projects Involving Agriculture, Water Conservancy, Forestry, Sanitation and Environmental Modification

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Abstract

Among the three major schistosome species infecting human beings, *Schistosoma japonicum* is the only endemic species in The People's Republic of China. Schistosomiasis is endemic in 78 countries and regions and poses a severe threat to public health and socioeconomic development. Through more than 60 years of hard work and endeavour, The People's Republic of China has made considerable achievements and reduced the morbidity and prevalence of this disease to the lowest level ever recorded, especially since the introduction of the new integrated control strategy in 2004. This review illustrates the strategies implemented by giving successful examples of schistosomiasis control from the different types of remaining endemic areas. The challenge to control or eliminate *S. japonicum* is analysed in order to provide useful information to policy makers and scientists.

1. INTRODUCTION

Major successes in the control of *Schistosoma japonicum* have been achieved in the last 60 years, yet infections due to this helminth parasite remain an important public health issue in The People's Republic of China (Chen, 2014). The current national control programme involves a comprehensive strategy, which is adapted to different socioecological settings, aiming at multiple transmission pathways. This chapter reviews the components of the integrated control strategy, summarizes our experience and understanding of the complexity of schistosomiasis control and paves the ground for future elimination of this disease, which has been a scourge for many millions of people in The People's Republic of China for thousands of years.

2. BACKGROUND

Schistosomiasis japonica remains a major public health issue and a significant cause of morbidity in The People's Republic of China (Utzinger et al., 2005; Xu et al., 2015; Yang et al., 2014; Zhou et al., 2005). Two features of the *S. japonicum* life cycle distinguish it from other forms of schistosomiasis: first, *Oncomelania hupensis*, the only intermediate host snail of *S. japonicum*, is amphibious (Li et al., 2016). These snails breed in water networks (canals and lakes), marshlands and a variety of microhabitats in hilly and mountainous environments, which complicates control. Second, more than 40 mammalian species, including dogs, pigs and cattle can serve as reservoir hosts, which greatly adds to the complexity of control and elimination (Liu et al., 2016; Wang et al., 2008b).

Although schistosomiasis is generally referred to as a neglected tropical disease, this is not the case in The People's Republic of China. During the past six decades, the control of this disease has been regarded as a top priority and the Chinese Government has launched a series of control programmes (McManus et al., 2010; Utzinger et al., 2005; Yang et al., 2014; Zhou et al., 2005). This sustained effort has resulted in a substantial reduction in the prevalence of human *S. japonicum* infection. By the end of 2004, the estimated human population infected with schistosomes was 726,000, compared to approximately 11.6 million infected in the early 1950s (Zhou et al., 2005, 2007a). The number of provinces in which this disease is still rampant has dropped from 12 to 7, with 5 formerly endemic provinces reaching the national criteria of transmission interruption in the last century (Xu et al., 2016; Zhou et al., 2007a). Despite this achievement and continued strong control effort, progress has stalled (Utzinger et al., 2005; Zhang et al., 2012b). Recent experiences warn that reductions in infection and morbidity may be transient. Resurgence of schistosomiasis infection was noted after the cessation of the World Bank Loan Project (WBLP) on schistosomiasis control in 2002 (Liu et al., 2013a; Seto et al., 2011; Zhang et al., 2012b). National surveys of schistosomiasis in The People's Republic of China show that the prevalence of *S. japonicum* in humans did not substantially change from 1995 (4.9%) to 2004 (5.1%) in the lake and marshland regions. The situation in other endemic areas of southern China is similar (Zhang et al., 2016a; Zhou et al., 2007a). More than 80% of current cases are found in the lake and marshland regions of Hunan, Hubei, Jiangxi, Anhui and Jiangsu Provinces with vast areas of *O. hupensis* habitats, where the control of schistosomiasis transmission has proven particularly challenging (Wang et al., 2009a). In the hilly and mountainous areas of Sichuan and Yunnan Provinces, *S. japonicum* has raged without limit for years (Liu et al., 2016; Spear et al., 2004). Compared to the other endemic provinces of The People's Republic of China, these regions are sparsely populated and underdeveloped. Although they also have lower snail population densities, the variable and intricate topography makes control difficult (Lu et al., 2013). The intractable situation here, in particular, underscores the urgent need to better understand the transmission dynamics following chemotherapy-based control so that re-emergence can be avoided and improvement in human well-being maintained (Zhou et al., 2005).

The past approach to reduce the rate of schistosomiasis infection through the use of simultaneous chemotherapy for humans and domestic cattle has only been temporarily effective as chemotherapy alone will not eliminate schistosomiasis (Bergquist et al., 2005; Colley et al., 2014; Useh, 2013; Zhou et al., 2007b). Reinfection contributes to a high proportion of cases of schistosomiasis in both humans and domestic animals and, besides, long-term repeated chemotherapy has led to poor compliance and decreased efficacy (Liu et al., 2014; Utzinger et al., 2005). In addition, the use of chemical molluscicides or modifications of *O. hupensis* habitats to control snail populations have resulted in environmental pollution and ecological damage (Colley et al., 2014; Lin et al., 2007). Other factors, such as the recent complex changes in the environment due to climate change, frequent flooding and population migration, have compromised recent efforts to control schistosomiasis. As a result, more residents have become infected and the habitats of *Oncomelania* snails have increased (Li et al., 2007; McManus et al., 2010; Zhou et al., 2008).

In 2004, the State Council of The People's Republic of China established two targets for the National Schistosomiasis Control Programme: (1) to reduce human infection prevalence by 2008 in all endemic counties to less than 5%, including 110 counties that had a prevalence exceeding 5%; and (2) to reduce human prevalence to less than 1% by 2015 (Utzinger et al., 2005; Zhou et al., 2007a). The Work Plan for the Mid-and Long-term of National Schistosomiasis Control Programme from 2004 to 2015 was released in the same year (Liu et al., 2013a). On the basis of experience and lessons from past schistosomiasis control practices with respect to the endemic status and zoonotic nature of *S. japonicum* in various and situations and ecologies, a new, comprehensive control strategy was developed aiming at interrupting the transmission pathways (Wang et al., 2009a) (Fig. 1). In line with the introduction of this new control strategy, the first pilot study was implemented in

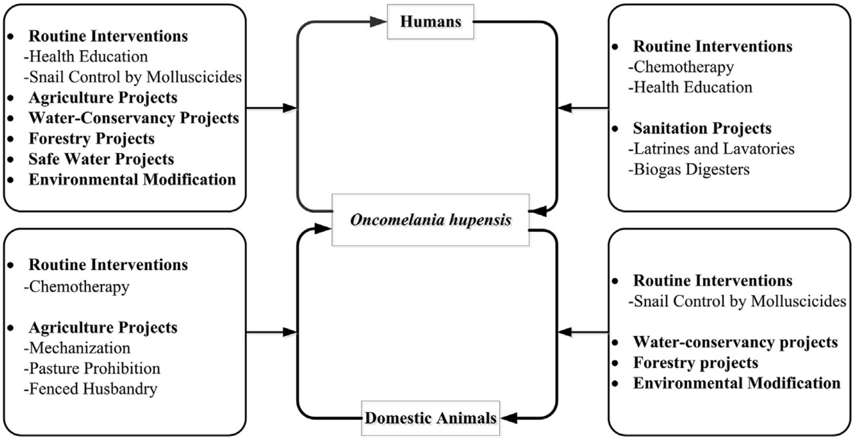

Figure 1 A sketch of *Schistosoma japonicum* transmission pathways and control projects included in the integrated control strategy in The People's Republic of China.

two villages in Jinxian County, Jiangxi Province, in 2005. Subsequently, the strategy was undertaken in another four pilot regions, ie, Anxiang County of Hunan Province, Hanchuan City of Hubei Province, Guichi District of Anhui Province and Puge County of Sichuan Province. After accumulating field-based evidence and further improving the strategy in light of gained experience, the new strategy was scaled up and recognized as the national control approach. It involves a multicomponent approach founded on routine interventions (ie, simultaneous chemotherapy of humans and cattle, snail control by molluscicides and health education). Apart from routine interventions, the comprehensive control strategy covers the following projects: agriculture (ie, removal of bovines and their replacement with mechanized equipment, special rules for pasture and fenced husbandry), water conservancy (ie, building of dam reservoirs, management of lakes, rivers and canals, etc.), sanitation (ie, provision of lavatories, latrines, biogas digesters, piped water/safe wells, etc.), forestry and land management. Successful establishment and implementation of this integrated approach means efficient intersectoral collaboration, especially between departments in charge of agriculture, water conservation, forestry, natural resources, communication, land and education (Utzinger et al., 2005; Wang et al., 2008b).

In this review, we summarize the various approaches on agriculture, water conservancy, forestry, sanitation and safe water and land environmental management describing five national pilot projects. We also provide a discussion about the challenges of the current control strategy of schistosomiasis in The People's Republic of China.

3. COMPONENT PROJECTS OF THE INTEGRATED CONTROL STRATEGY OF SCHISTOSOMIASIS

3.1 Agriculture

Current agriculture projects for schistosomiasis control comprise a battery of interventions, including removal of bovines and their replacement with mechanic equipment, rules for pasture, fenced husbandry and paddy-upland rotation, etc. Bovines are recognized as the main *S. japonicum* infection source in The People's Republic of China and they contribute to an estimated 75–90% of the egg contamination in the endemic areas (Cao et al., 2016; Hong et al., 2013a; Zhang et al., 2016b). Considering the fact that about 80% of snail infections originate from cattle, the reduction of this source of infection plays a key role in any integrated control strategy of *S. japonicum* (Gray et al., 2008; Wang et al., 2008b; Xu et al., 2015). Promotion of rearing livestock in pens, agricultural mechanization (phasing out water buffaloes tilling the earth for motorized equipment) and grazing prohibition in snail-infested grasslands are key ingredients of present schistosomiasis control strategies (Hong et al., 2013a; Wang et al., 2009a). Raising bovines behind fences and preventing domestic animals from grazing in close contact with *O. hupensis* snails would block the transmission from already infected livestock to the snails, thus interrupting the next step of the transmission of *S. japonicum* to humans. The introduction of farm machinery also reduces the human infection risk by lowering the likelihood of water contact. Pengshan County removed 97.6% of their bovines in 2006 and became the first bovine-free county in Sichuan Province. Due to this intervention, the rate of infection with *S. japonicum* in humans decreased from 3.7% in 2005 to 0.4% in 2006 (Min, 2008). Studies have shown that the prevalence rates in both humans and cattle decreased significantly after implementation of the measures described above together with mass drug administration using praziquantel of both villagers and bovines and molluscicide treatment of snail-infested areas (Cao et al., 2014; Chen et al., 2006, 2014; Hong et al., 2013a; Hu et al., 2010; Liu et al., 2013b; Xiang et al., 2013; Zhu et al., 2011). Yet, complete removal of bovines is hardly feasible since they play an important role in agricultural production and are major sources of income in the mountainous regions of the Sichuan and Yunnan Provinces (Zhong et al., 2011). In this situation, emphasis was focused on grazing prohibition in snail-infested grasslands and fenced husbandry. These simpler measures have also resulted in a declining trend of infection rates in humans (Li et al., 2012a; Yang et al., 2009; Yi Huo et al., 2009). To implement these interventions, local governments provide funding and subsidies for farmers to remove cattle from the grasslands and instead purchase mechanized farm equipment such as tractors (Wang et al., 2009a).

Additionally, in rice paddy fields, where *O. hupensis* is widely distributed, farmers cannot avoid contact with water contaminated with schistosome cercariae. Therefore, paddy-upland rotation adjusted to local conditions has been applied to reduce the snail habitats (Wang et al., 1997). Predators and biological competitors have also been used to control snail populations and been used together with construction of dykes and fish ponds (Colley et al., 2014; Rollinson et al., 2013; Yuan et al., 2005).

Increasing crop production through irrigation takes place across the globe at different scales. A close correlation between the distribution of *O. hupensis* and water canal systems has been observed in endemic regions and frequent human water contact occurs along the canals and ditches resulting in increased numbers of schistosomiasis patients (Yuan et al., 2005). If only water resource development and management could be combined with sound snail control measures (Dong et al., 2013; Huang et al., 2012; Xu et al., 2014), schistosomiasis control would yield twice the result with half the effort. Therefore, environmental considerations should be included in discussions at the very beginning when designing irrigation schemes (Xu et al., 2010).

3.2 Water conservancy

The role of water bodies (lakes, rivers of various size, artificial irrigation schemes, water reservoirs and canals) in the transmission of schistosomiasis cannot be overestimated (McManus et al., 2010; Seto et al., 2007; Steinmann et al., 2006). Water not only secures the survival of the intermediate host snails, but provides also the opportunity for *Schistosoma* cercariae to develop and eventually penetrate the human skin at water contact. Water bodies in endemic areas are frequently contaminated by the faeces of humans and other mammalian hosts infected with *S. japonicum* (Colley et al., 2014; Useh, 2013).

Construction of dam reservoirs for the generation of electricity and irrigation systems as well as for provision of drinking water attracts snails and expands their habitats and are therefore potential emerging schistosome transmission sites (Chen et al., 2010, 2013; Li et al., 2012b; McManus et al., 2010; Xu et al., 2010). For this reason, strategies to minimize such negative effects for schistosomiasis control should be integral parts in the planning and implementation of future water projects. The expansion of snail habitats can, to some extent, be controlled by health impact assessment and subsequent health risk management measures during the planning and design phases of water conservancy projects (Steinmann et al., 2006; Xu et al., 2010; Yuan et al., 2005). It is thus possible to manage water resources without increasing snail populations that would exacerbate the schistosomiasis situation.

Modification of rivers banks and lake shores has led to a remarkable improvement in schistosomiasis situation in The People's Republic of China (Chen et al., 2010; McManus et al., 2010). Both the banks of major rivers traversing the Chinese plains and those of the smaller streams of the hilly regions provide breeding spots for *O. hupensis*. The snails are confined to an area located approximately 1 m above and 1 m below the water level. Rivers and canals have been restructured by straightening, deepening and cementing the banks to discourage growth of aquatic vegetation and thus increase the water flow. Construction of small reservoirs and ponds in the hilly and mountainous regions has proved effective in snail control there (Dong et al., 2008b). Burying the snails under a thick layer of soil through hydraulic reclamation is highly effective and even more so when combined with the use of molluscicides. In addition, measures such as changing water levels and raising the land of islets by adding sand from the surrounding bottom reduce snail habitats and populations (Xu et al., 2010; Zhu et al., 2009).

There is no doubt that irrigation canals or ditches play a significant role in snail breeding, but the situation can be improved by concrete lining of ditch and canal banks, digging and dredging, including sinks and other facilities that block snail spread when new water ways are constructed (Huang et al., 2012; Su et al., 2004; Xu et al., 2010) (Fig. 2). Snail sinks slow down water flow and create suitable conditions for the deposition of *Oncomelania* snails so as to prevent their spread into irrigation systems (Ding et al., 2008; Jiang and Wang, 2012; Su et al., 2004; Zhu et al., 2014) (Fig. 3), while chemical molluscicides are used to kill snails that collect in the snail sinks (Jiang and Wang, 2012; Zhu et al., 2014). The use of concrete or tile drains reduces surface water and control snail habitats and populations in the irrigation systems in this way (Wei et al., 2004). Alteration of water levels through intermittent drying out of impoundments and irrigation canals or ditches would probably have an additional, beneficial effect. Although environmental management is useful, a lasting effect requires far-reaching changes and provision for maintenance of snail control facilities and

Figure 2 Concrete irrigation systems for environmental management preventing the establishment of *Oncomelania* snail habitats.

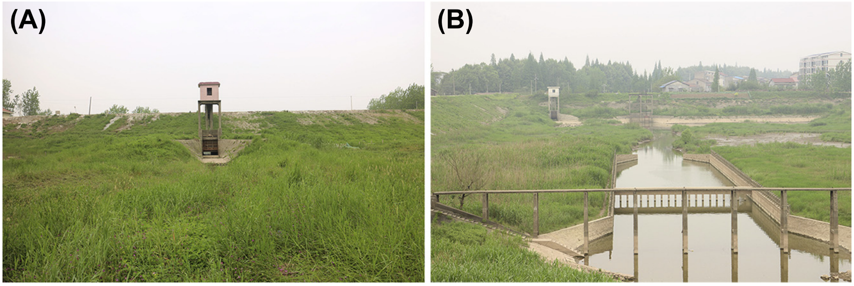

Figure 3 Restructured water connections (A) and pools (B) preventing snails to spread from the outside to the inside of embankments.

equipment (Li et al., 2016). In the absence of maintenance of instituted constructions, the intermediate host snails may reoccur with an increasing density, even in cemented ditches (Ding et al., 2013; Xu et al., 2010).

In general, environmental management does work in most settings, but constructions must be kept in good condition and adjusted to the local situation in order to guarantee permanent effects (Ding et al., 2013; Xu et al., 2010; Zhu et al., 2009).

3.3 Forestry

Snail control combined with forestry projects is an essential component of the integrated control strategy of schistosomiasis, both in the lake and marshland regions and the mountain areas in The People's Republic of China (Jiang et al., 2013; Liu et al., 2011; Zhang et al., 2006, 2012a). Places along lakes and rivers, where effective control of the water edge cannot easily be achieved, have attracted attention as they constitute risk areas. To deal with this situation, ecological engineering for snail control and schistosomiasis prevention has been instituted (Fig. 4). The practice of planting fast growing and adapting trees such as Chinese ash, Chinese tallow, poplar and willow, etc., leads to changes in soil temperature, humidity, pH values and vegetation density, which make the land less susceptible to *O. hupensis* (Zhang et al., 2006, 2013). Moreover, certain chemicals in the fallen leaves of these trees are toxic to *Oncomelania* snails (Sun and Peng, 2013; Yang et al., 2011; Zhang et al., 2006). Agroforestry or intercropping is a land management system in which crops are grown among lines of trees. It combines both agricultural and forestry technologies to create more diverse, productive and sustainable land-use programmes (Hong and Wang, 2012; Liu et al., 2011; Meng et al., 2012; Tang et al., 2011). Through a complex array of carefully selected trees and crops, these environmental management measures forge a forest ecosystem which counteracts the growth of *Oncomelania* snails, thus lowering the risk for schistosomiasis infection (Huang et al., 2011; Tang et al., 2011; Zhang et al., 2006, 2013). However, attention must be paid to the distance between lines of trees to make room for discharge of flood water and intercropping. A distance of approximately 10 m should be kept between the trees and the river banks in case of possible damage (Sun et al., 2006; Zhang et al., 2006) (Fig. 4). Both trees and crops

Figure 4 Environmental management involving forestation and cemented river banks reduce snail habitats. Fences have been installed to prevent animals from grazing in grasslands where *Oncomelania* snails are present.

should be chosen carefully according to environmental and climatic conditions. In addition, buffer areas surrounding the planted forests are designed to reduce human activities in heavily endemic areas. This reduces human and bovine water contact and risk for infection (Zhang et al., 2006). As for snail control in wetlands and wildlife as well as nature reserves, epidemic surveillance has been enhanced and facilities constructed to stop the diffusion of snails. Warning signs have been erected to warn people of the danger of schistosomiasis infection in endemic regions.

3.4 Sanitation and safe water

The provision of safe water supply, sanitation and hygiene (WASH) is a critical component of sustainable schistosomiasis control (Campbell et al., 2014). Human excreta are the main source of bacterial and viral agents causing diarrhoea through contamination of natural and artificial water bodies. Given the presence of the intermediate host snails, untreated human waste completes the schistosomiasis transmission cycle (Colley et al., 2014; Wang et al., 2009a). For this reason, an appropriately constructed sanitation infrastructure that ensures safe disposal of human and domestic animal excreta, especially bovine faeces, is vital for schistosomiasis control (Dong et al., 2008a; Gao et al., 2009). Household lavatories, latrines with triple compartment tanks (Fig. 5) and biogas digesters can stem contamination of freshwater sources by infected individuals and are therefore promoted and built in rural and endemic regions (Remais et al., 2009; Wang et al., 2009a) (Fig. 6). Biogas systems produce methane from human and animal waste providing access to clean and renewable energy, and studies have demonstrated that anaerobic biogas digesters can destroy *S. japonicum* eggs through chemical inactivation and removal through sedimentation (Carlton et al., 2012; Remais et al., 2009). Other benefits include reduced greenhouse gas emissions, improved air quality in rural kitchens and increased grain output through improving soil quality by organic fertilization (Lansing et al., 2008; Remais et al., 2009). Fishermen's boats have been equipped with containers for human waste, so that it can be disposed of on land instead of in the water (Gao et al., 2009; Wang et al., 2009a). These measures have received funding by local governments and the provision of improved sanitation by safe water projects and proper treatment of human and animal waste has proven effective in endemic regions in The People's Republic of China (Dong et al., 2008a; Gao et al., 2009; Zhang et al., 2005).

Indisputably, water is irreplaceable in the transmission of schistosomiasis (Useh, 2013). In rural and poor agricultural communities without piped

Figure 5 Triple compartment sewage facilities reduce schistosomiasis transmission by inactivating schistosome eggs.

Figure 6 A household biogas digester, an important innovation that prevents water contamination from infected individuals and domestic animals.

water, residents depend on local streams or natural pools for agricultural as well as recreational and sanitary needs, thereby exposing themselves to schistosomiasis infection (McManus et al., 2010; Utzinger et al., 2005). The contamination of natural water resources through untreated disposal of human and animal waste is part of the vicious circle that translates into higher risks for local schistosomiasis infection (Colley et al., 2014). Therefore, access to safe drinking water, especially in rural and endemic areas have received exclusive priority for schistosomiasis control in The People's Republic of China (Carlton et al., 2012). Not surprisingly, studies have shown that the prevalence rates of schistosomiasis are lower where access to safe water is available than in otherwise similar areas (Zhang et al., 2005). Provision of WASH has always been advocated for schistosomiasis control by the World Health organization (WHO), but it should be emphasized that this issue is only one part of a multicomponent control strategy (Campbell et al., 2014).

3.5 Environmental modification

Oncomelania hupensis, the sole intermediate host snail of *S. japonicum*, is vastly distributed in The People's Republic of China (Utzinger et al., 2005; Zhou et al., 2009). These snails can survive and breed in the water networks of lakes and marshlands in the plains as well as in the smaller streams in the endemic areas in the hills and mountains. Reduction of the snail-infected areas through sophisticated land modification projects has always been part of The People's Republic of China's national schistosomiasis control programmes due to the vast distribution of *O. hupensis*, which remains a strong impediment to the control and eventual elimination of *S. japonicum* to this day (Rollinson et al., 2013).

The projects on environmental modification consist of a series of snail control measures, including land management, amelioration of waterlogged fields and ecological land conservation, etc. (Hu et al., 2010; Xu et al., 2013) (Fig. 7). The original aim of these projects is to protect arable farmland and raise grain production to support the increasing population, but they also play an essential part in controlling snail populations in places where *S. japonicum* is still endemic (Utzinger et al., 2005). Chemical molluscicides often fail in waterlogged paddy fields with crisscrossing irrigation canals and ditches. Therefore, the waterlogged fields in these snail-breeding areas are drained by various measures, eg, by raising the land above the water table through construction of concrete ditches and embedded pipe drains. Much of the farmland in the lake and marshland areas has been obtained through construction of dykes and embankments to enclose lakes and rivers and the *O. hupensis* snails cannot survive in this environment (Huang et al., 2012). Another simple, yet very effective practice is to suffocate the snails by filling disused irrigation ditches with the freshly dug-out soil of new ones. Moreover, it is imperative to accept the last resort of relocating villages

Figure 7 Land modification projects combined with concrete lined irrigation ditches in an endemic area in The People's Republic of China.

where the epidemic situation of schistosomiasis is severe and the snail habitats cannot be controlled.

It has been shown that land modification, eg, filling in natural willow groves and levelling low-lying land has a significant effect on the density of *O. hupensis* snails (reduced from 33.2 per m^2 in 2010 to 0.1 per m^2 in 2012) at the banks and beaches of the Yangtze River after the flood season (Gao et al., 2013). Another longitudinal study in Hubei Province suggests that land consolidation, in conjunction with replacement of water buffaloes for tilling by motorized equipment, effectively reduces the snail-infested areas and interrupts transmission (Xu et al., 2013). In one high-risk region a reduction of the human schistosomiasis infection rate from 78.9% in 2012 to 0.5% in 2008 was recorded (Xu et al., 2013).

4. SUCCESSFUL COMMISSIONS: FIVE NATIONAL PILOT CONTROL PROJECTS

In 2005, five national pilots of integrated control strategy of schistosomiasis were designated to accumulate first-hand experience and evidence regarding the efficiency and feasibility of the strategy within various settings. The following areas were chosen: Guichi District in Anhui Province, Anxiang County in Hunan Province, Hanchuan City in Hubei Province, Jinxian County in Jiangxi Province and Puge County in Sichuan province. The findings are given in the following sections.

4.1 Guichi District, Anhui Province

4.1.1 Study area

Guichi District belongs to the lake and marshland region, is located in the middle and lower reaches of the Yangtze River in Anhui Province and has a population of 0.65 million out of which 0.40 million are at risk for *S. japonicum* infection. The Qiupu River basin, the Jiuhua River, the Yangtze River basin and the Shengjin Lake region comprise the endemic areas, which are moulded by the difficult terrain, fluctuating water levels, crisscrossing rivers and a vast distribution of *Oncomelania* snail habitats. This situation makes Guichi District a representative endemic focus of the lake and marshland regions. Historically, this district stands out as one of the most serious *S. japonicum*–endemic areas in the country. By the end of 2004, the infection rates of human and bovines were 3.9% and 7.7%, respectively, and there were approximately 29.8 km^2 of snail-infested areas (Wang et al., 2009c). Residents live by the rivers or lakes and they farm the grasslands, which are colonized by *Oncomelania* snails and usually also contaminated by human and cattle excreta. Frequent water contact and lack of decent sanitation make the locals vulnerable to schistosomiasis infections (Wang et al., 2006, 2008a; Zhou et al., 2011).

4.1.2 Interventions

In 2005, the Guichi District was designated as a national pilot area for schistosomiasis integrated control. The new strategy was implemented between 2006 and 2008 in 13 villages randomly selected from an original screen of 40 villages. Before initiation, routine measures had been used to control *S. japonicum* infection, including simultaneous chemotherapy with praziquantel for all villagers and cattle, snail control by molluscicides and health education programmes. Intensive health education, focused on the need to avoid snail-infested areas and associated water bodies, was carried out in all 13 villages among more than 90% of the residents.

Complementary efforts were made during the study period. All bovines, being the recognized infection source, were phased out and replaced with mechanized equipment with subsidies from local government. By February 2006, a total of 1131 bovines were removed from the Qiupu River basin and 738 farm machines purchased instead. By March 2007, 896 bovines were replaced with 806 farm machines in the basin of the Jiuhua and Yangtze Rivers. In November 2007, 227 pieces of farm equipment took the place of 1021 bovines in the Shengjin Lake region (Wang et al., 2009c). Other kinds of domestic animals were fenced in and improved sanitation was achieved by supplying piped water and lavatories/latrines, which were also funded by the local government. The number of household lavatories in the Qiupu River basin, the Jiuhua-Yangtze River basin and the Shengjin Lake region amounted to 5343, 1767 and 250, respectively. Safe water access was available for 84.4% of the households in the Qiupu River area and 92.5% in the Jiuhua-Yangtze River basin (Wang et al., 2009c). In addition, environmental management was undertaken to reduce the snail habitats (eg, crop changes to reduce water consumption in the snail-inhabited areas) (Chen et al., 2006; Wang et al., 2009c; Zhou et al., 2011).

4.1.3 Results

In the Qiupu River basin, compared to the situation in 2005, the average infection rate of residents, the density of infected snails and the infection rate of snails decreased by 68.6%, 96.0% and 96.0%, respectively, after the implementation of the integrated control strategy in 2008 (Fig. 8A). In the Jiuhua-Yangtze River basin, compared to 2006, the same parameters decreased by 51.6%, 71.2% and 69.0%, respectively (Fig. 8B), while in the Shengjin Lake region, compared to 2007, they decreased by 49.6%, 73.6% and 51.8%, respectively. In addition, the number of cases of acute schistosomiasis in all the areas investigated decreased significantly after implementing the comprehensive control strategy in 2008. Taken together, these results suggest that the new integrated control strategy can substantially reduce the burden of schistosomiasis, at least in the lake and marshland regions (Wang et al., 2009c).

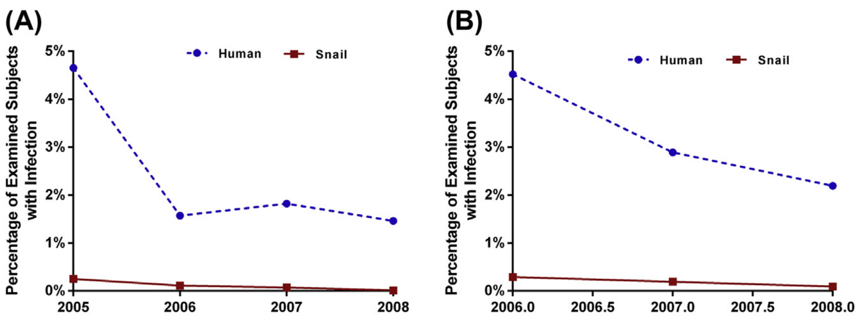

Figure 8 Rates of infection with *Schistosoma japonicum* in humans and snails in the Qiupu River basin (A) and in the Jiuhua-Yangtze River basin (B).

4.2 Anxiang County, Hunan Province

4.2.1 Study area

Anxiang County is located in the northwest of Dongting Lake in Hunan Province. It has a population of about 0.55 million, 0.43 million of whom still depend on farming, and the county's economy relies on animal husbandry. The 34 sluice gates, 172 km of embankments and vast marshlands crisscrossed by canals and rivers make Anxiang County another major *S. japonicum* focus in the lake and marshland regions, where the control of schistosomiasis transmission has proven particularly challenging. In 2005, Anxiang County became one of the national pilot study areas of the integrated control strategy (Zhu et al., 2011).

4.2.2 Interventions

Routine control measures were in force before the initiation of the new, integrated control strategy that has been undertaken since 2005. Chemotherapy with praziquantel has been available for all infected villagers in the autumn every year with selective treatment for high-risk populations including fishermen and herdsmen twice a year. The molluscicide niclosamide was used twice a year, while health education was carried out among residents focussing on provision of a good understanding of this particular disease and the behavioural changes needed to be implemented. These interventions continued in all villages (Li et al., 2013).

Additional interventions were included in parallel with the routine measures. First, 9583 bovines and 9504 sheep were removed from this county to eliminate this source of infection. Activities were carried out in a two-stage process. Removal of cattle and sheep were instituted in 50 villages in the first stage in 2005, a measure that was expanded to include all endemic villages in a subsequent second stage. All sheep were killed and most water buffaloes replaced with farm machinery ($n = 7841$) or transferred to nonendemic regions. Losses caused by the removal of bovines and sheep were well compensated. Second, tap water and lavatories were built to improve sanitation. As a result, access to safe water supply and household lavatories became available to 90% and 80% of all families, respectively. Biogas pools ($n = 11,563$) were constructed covering 80% of all local family residencies. Third, environmental management was implemented, including forestry and agricultural projects. A cumulative 254.3 ha of land were subjected to forestry projects and 32.0 km of ditches and canals were cemented to counteract snail habitats. Fourth, industrial restructuring was promoted to create employment opportunities for local people, who transferred from rural labour to this new environment (Li et al., 2013).

4.2.3 Results

The annual survey data on *S. japonicum* infection in humans, domestic animals and snails from 2004 to 2012 were collected and analysed. After the implementation of the comprehensive strategy to control the source of *S. japonicum* infection and *Oncomenania* snails, the percentage of villagers with schistosomiasis declined to 0.6% from 11.2% within the study period. The infection rate of livestock decreased from 17.1% to zero. The percentage of snails infected with *S. japonicum* fell to zero in 2012 compared with 1.1% in 2004 (Fig. 9). These results show that the comprehensive control measures instituted to reduce the transmission of *S. japonicum* infection from humans and cattle to snails are effective in the marshland and lake region (Li et al., 2013; Zhu et al., 2011).

4.3 Hanchuan City, Hubei Province

4.3.1 Study area

Hanchuan City is located in typical marshland along the lower reach of the Hanjiang River in central Hubei Province, The People's Republic of China. It has a population just above one million, 0.53 million of whom are in the danger of schistosomiasis infection. The Hanjiang River is the largest tributary of the Yangtze River, and vast marshland areas suitable as breeding sites for *Oncomelania* snails emerge each year following the monsoon season

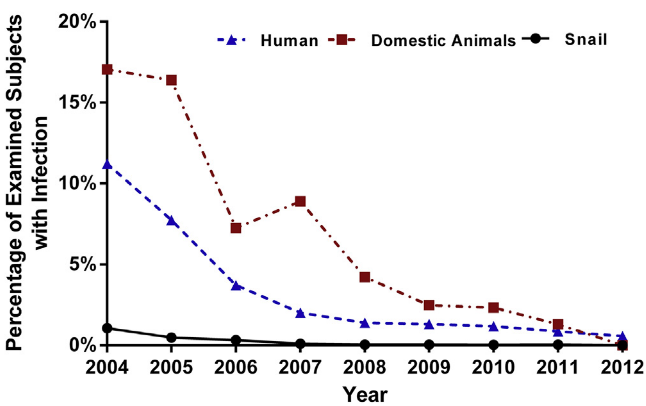

Figure 9 Rates of *Schistosoma japonicum* infection in Anxiang County 2004 through 2012.

flooding. Hanchuan City is highly endemic for schistosomiasis. In 2004, there were 367 endemic villages and approximately 22.1 km^2 of snail-infested area in this region. Ninety-seven cases of new infections and ten cases of acute schistosomiasis occurred in the same year. The prevalence of schistosomiasis in humans and bovines in 2004 was 6.9% and 8.8%, respectively (Xiang et al., 2014). From 2005 to 2013, the new, integrated control strategy was carried out in the marshland areas around this city.

4.3.2 Interventions

Prior to the new, comprehensive control strategy, routine control interventions, comprising simultaneous chemotherapy with praziquantel of villagers and bovines, mollusciciding and health education were implemented. These measures continued in all schistosomiasis-endemic villages with the additional interventions integrated. The pilot stage from 2005 to 2007 involved only five towns along the Hanbei River, a tributary of the Hanjiang River implementing the integrated strategy in all affected villages in Hanchuan. The new interventions included (1) removal of 11,800 bovines from 2005 to 2013 replacing them with 1441 farm machines, which was supported with government subsidies; (2) prohibition of grazing in the snail-infested grasslands coupled with promotion of rearing cattle and sheep inside fences (this approach covered 6377 livestock); (3) human and animal faeces was managed by building lavatories with three-cell septic tanks and biogas pools plus providing toilet containers for the fishermen's boats from 2005 to 2013 (approximately 40,000 lavatories and 24,000 biogas digesters were constructed reaching 85.0% and 80.7% coverage, respectively with another 15 latrines available at the fishermen's docking sites); (4) snail control interventions including agriculture, forestry, water conservancy, land management and infrastructure construction were instituted to reduce the snail habitats (Chen et al., 2014; Hong et al., 2013a; Wang et al., 2009b, 2010; Xiang et al., 2013, 2014).

4.3.3 Results

After the implementation of the comprehensive measures, the infection rates of human and cattle decreased from 6.4% to 8.1% in 2004 to 0.6% and zero in 2013, respectively (Fig. 10). There were no cases of acute schistosomiasis since 2007, no new infections since 2011 and no infected snails found since 2012. Compared with 2004, the average density of living snails dropped by 56.8% and 68.4%, respectively. In 2013, all the 367 endemic villages in 26 townships reached the criteria of transmission control (Xiang et al., 2014).

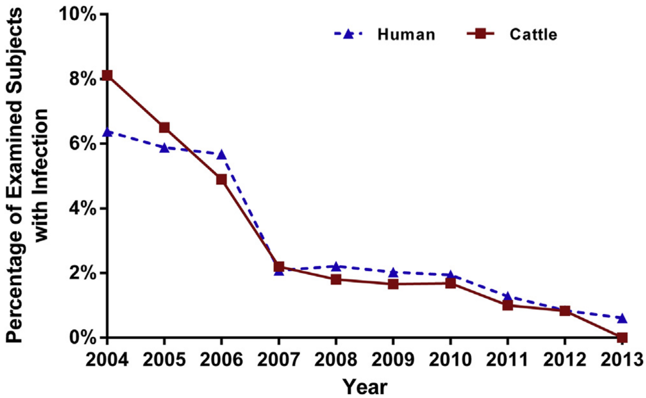

Figure 10 Rates of *Schistosoma japonicum* infection in humans and cattle from 2004 to 2013 in Hanchuan City, Hubei, The People's Republic of China.

Taken together, these results show that the integrated control strategy could control the schistosomiasis transmission effectively in the marshland and lake regions (Xiang et al., 2014).

4.4 Jinxian County, Jiangxi Province

4.4.1 Study area

Poyang Lake, the largest freshwater water body in The People's Republic of China, is located in northern Jiangxi Province. The surface area of the lake fluctuates dramatically between flood and dry seasons. Along with the Dongting Lake in Hunan Province, the Poyang Lake influences the schistosomiasis transmission strongly in the lake and marshland regions. Jinxian County has a population of just under 1 million people and was chosen as a national pilot area for comprehensive control of schistosomiasis in June 2005, involving three villages around Poyang Lake, in which *S. japonicum* is endemic, namely Xinhe, Aiguo and Guanghui (Wang et al., 2009d).

There is 13.3 km^2 of snail-infested grasslands long the embankment around the Poyang Lake where these three villages are situated. The local residents farm the grasslands and fish in lake near these grasslands. Both humans and cattle in this area are often infected with schistosomiasis with humans at particular risk due to frequent water contact through their daily activities such as fishing, cultivating crops, cutting weeds, pasturing and swimming (Hu et al., 2008; Wang et al., 2009a, 2012). In 2004, the prevalence of schistosomiasis in humans and bovines in this pilot was 9.3% and 11.0%, respectively (Wang et al., 2009d).

4.4.2 Interventions

In 2005, the comprehensive control strategy was implemented in the original three villages and expanded to all villages of the Sanli Township in Jiangxi Province the following year. Routine interventions, such as chemotherapy, mollusciciding and health education continued along the new measures. An intensified health education programme was carried out to promote a better understanding of *S. japonicum* with the aim of bringing about behavioural changes that would interrupt transmission. Additional health education sessions were provided to schoolchildren to create a schistosomiasis-free campus. The following new interventions were incorporated into this comprehensive strategy: (1) regulations were implemented to replace water buffaloes with small farm machines, thus eliminating them as an infection source. In all, 2156 bovines were removed and replaced with 489 farm machines in these three villages; (2) cattle grazing in the snail-infested grasslands was prohibited and warning signs were put up. Management staff was employed to ensure the measure was implemented; (3) safe water supply covering 60.3% of the local households was provided and well-designed household lavatories with three-cell septic tanks and methane pools were constructed in 1275 households accounting for 81.2% of the local families. All boats were provided with toilet containers so that human faeces could be brought ashore and treated. Besides, public latrines were installed at schools and docking sites, including four middle-large biogas pools; (4) crop and husbandry structure changes were advocated (eg, promotion of oilseed rape cultivation and poultry farming). To practically implement these comprehensive interventions, the government provided funding and subsidies to remove cattle from the grasslands and build public latrines, public methane pools, piped water and wells (Hong et al., 2013b; Liu et al., 2013b; Wang et al., 2009a,d).

4.4.3 Results

After the implementation of comprehensive interventions to control the source of *S. japonicum* infection, the percentage of infected villagers declined to 1.6% in 2006 from 9.3% in 2004. Compared with 2005, the density of infected snails had decreased by 97.2% 2 years later. In addition, human ascariasis and trichuris infections dropped by 59.1% and 48.2%, respectively. The overall results suggest that a multicomponent comprehensive control strategy of schistosomiasis is effective in the marshland and lake regions, which will remain a problem even after criteria for infection control are attained (Hong et al., 2013b; Wang et al., 2009d).

4.5 Puge County, Sichuan Province

4.5.1 Study area

Covering an area of 50.2 km^2 the town of Tezi is geographically large, but the population is only approximately 4000. However, the number of livestock, including cattle, sheep, horses and pigs, is more the double the human population. Tezi lies in the Northeast of Puge County, Sichuan Province and has a complex topography with mountains and valleys varying in altitude between 1000 and 2500 m above the mean sea level. It is a typical mountainous *S. japonicum*—endemic area. In spite of a snail-infested area of just above 1 km^2, the infection rates of humans and cattle have been recorded at 35.5% and 30.5%, respectively (Yi Huo et al., 2009).

Tezi is an underdeveloped region inhabited by the Yi people, an ethnic minority group in The People's Republic of China. They carve out their existence on the sides of steep mountain slopes far from the cities keeping a primitive way of life and depending on animal husbandry for their livelihood. Soil erosion and high mountains and steep slopes make agricultural production and transportation difficult, so cattle and horses are indispensable. Therefore, removal of cattle to control schistosomiasis might not be an option here as the locals sometimes even live under the same roof together with their livestock. In addition, lavatories, latrines or any other form of sanitation facilities are not only unavailable but also difficult to envisage in this dispersed situation. Both human and domestic animal faeces are left untreated. Residents of Tezi farm the grassland along the mountain streams that also provide pasture for their animals. These streams are colonized by the *Oncomelania* snails and as water contact is frequent, transmission of schistosomiasis involving both humans and livestock is rampant (Yi Huo et al., 2009).

4.5.2 Interventions

In April 2005, Tezi was designated a national pilot study area of the integrated control strategy of schistosomiasis, which was implemented in all villages between 2006 and 2013.

Simultaneous chemotherapy with praziquantel is routinely available for all residents 5—65 years of age and domestic animals in this area to reduce the morbidity due to *S. japonicum* and, in turn, to lower the snail infection rate through reduced faecal contamination of the environment. In addition, pasture in the snail-infested grasslands was prohibited and regulations were implemented to promote raising domestic animals in pens. Fifteen carefully selected, safe grazing pasture areas were established and faeces-treatment pools were built. Management staff was employed to ensure that the animal waste was properly disposed of and the following interventions were implemented to reduce humans as source of infection:

1. Household tap water was installed, 290 simple lavatories were constructed covering 98.7% of the households and 267 gas pools were built so that biogas from the septic tanks could be collected and used as fuel. Treated human and animal waste was used as organic fertilizers.
2. Repeated mollusciciding was used to reduce the snail populations and environmental management aiming at eliminating snail habitats, including paddy-upland rotation, cementing the ditches, etc., were instituted.
3. An intensified health education programme, adjusted to local conditions, was carried out among the residents to promote a good understanding of the *S. japonicum* life cycle and better compliance for chemotherapy as well as awareness of the importance of proper treatment of human and cattle sewage.

To reach all local people, billboards and publicity materials were written bilingually in Chinese and the Yi language (Chen et al., 2016; Liu et al., 2014; Yi Huo et al., 2009).

4.5.3 Results

After the implementation of the comprehensive interventions described above, the percentage of infected villagers decreased by 97.7% to 0.3% in 2013 compared to 2005. The infection rate of livestock dropped by 96.0% to 0.4% in 2013 compared to 2005 (Fig. 11) and the area of snail-infested grasslands shrunk by almost a third. No infected snails were found after 2007. Household lavatories are now available for 98.7% of the local families. In general, the results suggest that the multicomponent comprehensive antischistosomiasis strategy is even effective in the mountainous regions, which are notoriously difficult to control for this disease (Yi Huo et al., 2009).

5. CHALLENGES

Although The People's Republic of China has achieved great success of schistosomiasis control based on a programme that has been active without interruption since the early 1950s, there are still considerable challenges (Zheng et al., 2013). One is the ongoing process of implementing the new, comprehensive control strategy, consolidating the achievements made and reaching the goals set by 'Work Plan for the Mid-and Long-term of

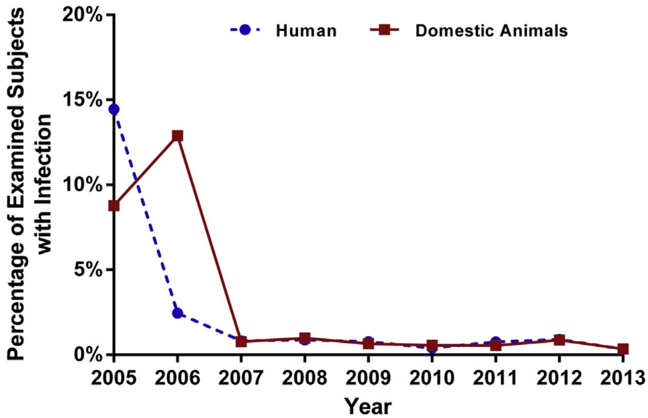

Figure 11 Rates of *Schistosoma japonicum* infection in humans and domestic animals based on data from 2005 to 2013 in Puge County, Sichuan, The People's Republic of China.

National Schistosomiasis Control Programme', which has yet to be finalized (Lei and Zhou, 2014a,b; Zhou et al., 2005, 2012).

Political commitment and provision of finance are critically important in finalizing the work plan and obtain sustainable and effective control of the schistosomiasis (Wang et al., 2008b, 2014). However, local governments may not be able to bear the financial burden of large investments in projects involving the full spectrum of activities that involve agriculture, water conservancy, forestry, sanitation and environmental modification. As for major water resource projects, allocations from The People's Republic of China's Central Government budget cover 30% of total amount of investment, while the remaining 70% must rely on local financial support. Small projects constitute the full responsibility of local governments (Xu et al., 2010; Zhu et al., 2016). Promotion of replacing cattle with mechanized equipment, construction of sanitation facilities, including latrines, biogas systems and forestry programmes are held back by lack of government fiscal subsidies. The full effect of the control efforts is jeopardized by inadequate and inequitable government investments, which contributes to lack of service of agricultural machines and poor operation and maintenance of abovementioned approaches. It is therefore imperative that strong policy programmes and financial support be undertaken by the The People's Republic of China's Government without delay to ensure continued successful and sustainable schistosomiasis control (Lei and Zhou, 2014a,b).

Intersectoral collaboration between the health sector and other governmental sectors, prominently the agriculture, education, water resources and forestry sectors, have a key role in the efforts to reach successful and effective comprehensive control of schistosomiasis (Lei and Zhou, 2014a,b). Although the new control strategy is integrated with other society development efforts, such as rural energy development and construction of a new rural, trans-department communication system, planning and coordination should be enhanced to leverage and direct existing intersectoral funding to the schistosomiasis-endemic areas (Lei and Zhou, 2014a,b; Remais et al., 2009). Also, efforts may be compromised, as the professional teams, especially at the primary level, are greatly weakened by shrinking investment for schistosomiasis control that results in long-term expert staff retiring without adequate replacements, reduced staff mobility, inadequate facilities and lack of training (Lei and Zhou, 2014a,b). Further, the role of each project in the integrated control strategy of schistosomiasis, which is primarily aimed at reducing the source of infection, remains largely ignored without national-scale evaluation. The five national pilot studies summarized here do not necessarily involve all the interventions of the comprehensive control strategy. These combinations are driven by differences in socioecological conditions. In the context of outcome related to the interventions in endemic areas, a scientific and systematic assessment of the effects and benefits of this multicomponent control strategy of schistosomiasis in various settings is currently unavailable. While extensive control efforts in endemic areas have greatly decreased infection intensity and prevalence, current surveillance methods and diagnostic tools would lead to underestimation of the endemic status in areas with low prevalence (Xu et al., 2015; Zhou et al., 2005, 2012). Moreover, there is a strong need to determine what level and/or coverage of this new integrated control strategy are required to have a favourable effect on schistosomiasis transmission and, in the longer perspective, elimination.

6. THE WAY FORWARD

Over the past six decades of endeavour, The People's Republic of China has made remarkable progress in schistosomiasis control with strong reduction of transmission achieved in most endemic areas (Chen, 2014; Collins et al., 2012). The pilot studies presented here show that control of schistosomiasis is an achievable goal, which requires an integrated strategy adapted to different eco-epidemiological settings. To achieve further advances in schistosomiasis control, sustainable financial resources and political commitment need to be assured. Moreover, the comprehensive control strategy requires collective and multidisciplinary efforts. Intersectoral collaboration, especially between the Departments of Health, Finance, Land and

Resources, Water Resources, Agriculture and Forestry, should be strengthened to facilitate the national programme of schistosomiasis control in The People's Republic of China.

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