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Schistosomiasis transmission and control in China☆

Lan Zou[a], Shigui Ruan[b,*]

[a] Department of Mathematics, Sichuan University, Chengdu, Sichuan 610064, PR China
[b] Department of Mathematics, University of Miami, Coral Gables, FL 33124-4250, USA

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ABSTRACT

In the last 60 years, great progress has been made in controlling and preventing schistosomiasis in China. However, due to the ecosystem changes caused by the construction of the Three Gorges Dams and the South-north Water Conversion Project, the effects of climate change, the scarcity of a highly sensitive surveillance and response system, schistosomiasis is still considered as a major public health problem and is listed among the top infectious diseases in the country prioritized for control and elimination. Based on the epidemiological pattern of schistosomiasis and ecological characteristics of the vector snail, endemic areas of schistosomiasis in China were categorized into three types: (i) plain region with waterway networks, (ii) mountainous and hilly regions, and (iii) marshland and lake regions. China aims to reach the criteria of transmission control threshold of less than 1% in the lake and marshland provinces and reach transmission interruption threshold in hilly provinces of Sichuan and Yunnan by the end of 2015. The purpose of this article is to use the deterministic model proposed in our earlier study in (Chen et al., 2010) to simulate the schistosomiasis infection data from other lake and marshland provinces, including Hunan, Jiangxi and Anhui. Our simulations demonstrate that the model can reasonably mimic the schistosomiasis infection data from these lake and marshland provinces. Thus, similar control and prevention measures can be designed and proposed for these provinces. We will also try to use the model to simulate the schistosomiasis infection data from Sichuan and Yunnan provinces in the mountainous and hilly regions where cattle farming is not as popular and important as in the lake and marshland provinces and find out that different control and prevention strategies are required.

1. Introduction

Schistosomiasis is an acute and chronic disease caused by parasitic worms *Schistosoma*. It is the second most socioeconomically devastating parasitic disease after malaria (The Carter Center). Globally, at least 249 million people required preventive treatment for schistosomiasis in 2012 (WHO, 2014). Six parasite species have been reported to be able to infect humans, including *Schistosomiasis haematobium, Schistosomiasis japonicum, Schistosomiasis mansoni, Schistosomiasis intercalatum, Schistosomiasis mekongi and Schistosomiasis malayensis* (Wang et al., 2013). These parasites live in certain types of freshwater snails (intermediate hosts). The infectious and larval form of the parasite, known as cercariae, emerge from the snail, hence contaminating water. Humans and other mammals (definite hosts) can become infected when their skin comes in contact with contaminated freshwater. The transmission cycle continues when definite hosts suffering from schistosomiasis contaminate freshwater sources with their excreta containing parasite eggs which hatch in water.

Schistosomiasis japonica is mainly prevalent in China, the Philippines, and parts of Indonesia. One feature of the life cycle of this parasite, which distinguishes it from the other human schistosome species, is that a wide spectrum of potential definitive hosts, including over 40 species of domestic and wild mammals (cattle, buffaloes, swine, goats and rats, whereas sheep, rabbits, and horses (Chen and Feng, 1999)) are suspected of being potential reservoirs, which complicates transmission patterns. The second characteristic of *S. japonica* is that the intermediate host snail *Oncomelania hupensis* is amphibious rather than aquatic. Effectively controlling schistosomiasis or even eradicating it in some areas does not necessarily mean that it cannot re-emerge, because of its complicated transmission process (Liang et al., 2006).

S. japonica has existed in China for more than 2100 years (Mao and Shao, 1982; McManus et al., 2010). In 400 BC, there were descriptions of schistosomiasis in "*Zhouhou Beiji Fang* (Handbook

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* Corresponding author.
E-mail address: ruan@math.miami.edu (S. Ruan).

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of Prescriptions for Emergency)", which was the first handbook of clinical first aids in China. In 1977, *S. japonicum* eggs were identified in a female corpse dating back to the Western Han dynasty (206 BC–9 AD), which was exhumed in Changsha, Hunan Province, where schistosomiasis still persists today. In 1978, *S. japonicum* eggs were also found in another corpse buried 100 years earlier in Jiangling County, Hubei Province, which is also an endemic area of schistosomiasis now.

In the first half of the 20th century, the epidemics of schistosomiasis in some areas of China were so bad that the disease wiped out some towns and villages entirely. An investigation in Gengtou Village, Baifu Township, Fengcheng County, Jiangxi Province, in 1954, showed that only two persons were left alive, while in the middle of the 19th century, there were approximately one thousand households in the big village according to the record of the township. Approximately 90% of the deaths were supposed to be due to schistosomiasis (Chen and Feng, 1999). In the 1950s, *S. japonica* was epidemic throughout 12 provinces in China. Over the past 60 years, China has made tremendous progress in treating and controlling schistosomiasis and the disease was successfully eradicated in some provinces. By 1995, five provinces (Guangdong, Shanghai, Fujian, Guangxi, and Zhejiang) had blocked the transmissions of *S. japonica* (National Institute of Parasitic Diseases). However, transmissions still occur in Hunan, Hubei, Jiangxi, Anhui and Jiangsu provinces along the Yangze River, and Sichuan and Yunnan provinces in the mountainous and hilly regions.

Although great achievements have been made for controlling schistosomiasis in China, there are still many major challenges such as the existing extensive snail habitats with complicated environments, ecosystem changes caused by the construction of the Three Gorges Dams and the South-north Water Conversion Project, the effects of climate change, the scarcity of a highly sensitive surveillance and response system, and the access of infected persons to health care (Collins et al., 2012). Today, schistosomiasis is still considered as a major public health problem and is listed among the top infectious diseases (along with HIV/AIDS, tuberculosis, and hepatitis B) in the country prioritized for control and elimination (Ross et al., 2013; Wang et al., 2008). By the end of 2011, a total of 454 counties (cities, districts) were endemic with schistosomiasis, of which 103 reached transmission control threshold and 274 reached transmission interruption threshold. China aims to reach the criteria of transmission control threshold of less than 1% in the lake and marshland provinces and reach transmission interruption threshold in hilly provinces of Sichuan and Yunnan by the end of 2015 (WHO Representative Office China).

Based on the epidemiological pattern of schistosomiasis and ecological characteristics of the vector snail, endemic areas of schistosomiasis in China were categorized into three types: (i) plain region with waterway networks, (ii) mountainous and hilly regions, and (iii) marshland and lake regions (Mao and Shao, 1982). In Chen et al. (2010), we proposed a deterministic model to describe the human-cattle-snail transmission dynamics of schistosomiasis and used the model to simulate the schistosomiasis infection data from Hubei Province which is in the lake and marshland regions. The purpose of this article is to further use the deterministic model in Chen et al. (2010) to simulate the schistosomiasis infection data from other lake and marshland provinces, including Hunan, Jiangxi and Anhui. Our simulations demonstrate that the model can reasonably mimic the schistosomiasis infection data from these lake and marshland provinces. Thus, similar control and prevention measures can be designed and proposed for these provinces. We will also try to use the model to simulate the schistosomiasis infection data from Sichuan and Yunnan provinces in the mountainous and hilly regions where cattle farming is not as popular and important as in the lake and marshland provinces and find out that different control and prevention strategies are required.

2. Mathematical modeling

Let $S_H(t)$ and $I_H(t)$ denote the density of susceptible and infected human population, $S_C(t)$ and $I_C(t)$ denote the density of susceptible and infected cattle population, and $S_S(t)$ and $I_S(t)$ denote the density of susceptible and infected snail population at time t, respectively. The schistosomiasis model is a system of six ordinary differential equations (see Chen et al., 2010):

$$\begin{cases} \dfrac{dS_H}{dt} = -\beta_{SH} S_H I_S + r_H I_H, \\ \dfrac{dI_H}{dt} = \beta_{SH} S_H I_S - r_H I_H, \\ \dfrac{dS_C}{dt} = b_C(S_C + I_C) - \beta_{SC} S_C I_S + r_C I_C - d_C S_C - k_C S_C(S_C + I_C), \\ \dfrac{dI_C}{dt} = \beta_{SC} S_C I_S - r_C I_C - d_C I_C - k_C I_C(S_C + I_C), \\ \dfrac{dS_S}{dt} = b_S(S_S + I_S) - \beta_{HS} S_S I_H - \beta_{CS} S_S I_C - d_S S_S - k_S S_S(S_S + I_S), \\ \dfrac{dI_S}{dt} = \beta_{HS} S_S I_H + \beta_{CS} S_S I_C - d_S I_S - k_S I_S(S_S + I_S). \end{cases} \tag{1}$$

The parameters are described as follows:

β_{SH} – transmission rate from infected snail to human;
r_H – recovery rate of infected human;
b_C – natural birth rate of cattle;
β_{SC} – transmission rate from infected snail to cattle;
d_C – death rate of infected cattle;
$(b_C - d_C)/k_C$ – carrying capacity of cattle;
r_C – recovery rate of infected cattle;
b_S – natural birth rate of snail;
β_{HS} – transmission rate from infected human to snail;
β_{CS} – transmission rate from infected cattle to snail;
d_S – death rate of infected snail;
$(b_S - d_S)/k_S$ – carrying capacity of snail.

The basic reproduction number, defined as the expected number of secondary infections produced by an index case, is defined as follows (Diekmann et al., 1990, 2010; van den Driessche and Watmough, 2002):

$$R_0 = \sqrt{\frac{b_S - d_S}{b_S k_S}\left(\frac{\beta_{SH} N_H \beta_{HS}}{r_H} + \frac{\beta_{SC}\beta_{CS}(b_C - d_C)}{k_C(b_C + r_C)}\right)}, \tag{2}$$

which is composed of two parts: the influence of infectious humans and infectious cattle.

In Chen et al. (2010), we used the model to simulate the schistosomiasis infection data from Hubei Province from 2005 to 2007. By carrying out sensitivity analyses of the basic reproduction number on various parameters, we noticed that the transmission of *S. japonicum* between cattle and snails plays a more important role than that between humans and snails in the endemicity of schistosomiasis in Hubei Province. In the following, we will use the model to simulate the schistosomiasis infection data from other provinces in China. We will classify these provinces as marshland and lake regions, mountainous and hilly regions, and plain regions with waterway networks, and discuss some useful and effective schistosomiasis control measures in these provinces.

3. Marshland and lake regions

Marshland and lake regions including the areas on the banks of the Yangze River and surrounding lakes of different sizes in Hunan, Hubei, Jiangxi, Anhui, and parts of Jiangsu provinces. The human