Susceptibility and Infection Risk of Schistosomiasis Disease

An Zhao[1,2], Shuming Bao[2], Peng Gong[3]

[1]Institute of Geographic Sciences and Resources Research, CAS, Beijing 100101;
School of Geography and Environmental Science, Jiangxi Normal University, Nanchang 330022, P.R.China
E-mail: zhaoa.04b@igsnrr.ac.cn, sbao@umich.edu
[2]The Key Lab of Poyang Lake Ecological Environment and Resource Development, Jiangxi Normal University, Nanchang 330022
[3]State Key Laboratory of Remote Sensing Science, Jointly Sponsored by the Institute of Remote Sensing Application, Chinese Academy of Sciences and Beijing Normal University, Beijing 100101
and Department of Environmental Science, Policy and Management, University of California, Berkeley, CA 94720-3114
E-mail:penggong@berkeley.edu

Abstract

The environment of schistosomiasis epidemic areas in China is complex with various forms of geomorphologies. The spatial distribution of schistosome (*Schistosoma japonicum*) and parasitic hosts is random. It is often difficult to eradicate snails(*Oncomelania* snails) and cercaria, and to avoid interactions with schistosomiasis-susceptible areas for livestock and humans. Rapid, efficient and timely determination of schistosomiasis-susceptible area holds significant importance. This paper first introduces the initial origin and various definitions of schistosomiasis-susceptible area. We present a new definition according to the key parameters that influence the epidemic and transmission of schistosomiasis. Secondly five study aspects of schistosomiasis-susceptible area are summarized in light of the factors that have influences on the formation of schistosomiasis- susceptible area. Problems, drawbacks and causes in different concepts and study methods of schistosomiasis-susceptible area are introduced. Perspectives of historical medical-geography study of schistosomiasis-susceptible area are reviewed. We present spatial simulation and modeling approaches that are based on remote sensing and geographic information systems(GIS) and data-driven models and knowledge-driven model. They represent an important area of new applications of remote sensing and GIS in health related problem solving. Finally, we suggest to import the concepts in hazard/risk analysis into the schistosmiasis epidemiology. This allowed us to put forward two new concepts: susceptibility level and infection risk, for which a primary calculation framework and internal relation is established. We hope to use them as the base for future studies of chistosomiasis-susceptible areas.

Keywords

schistosomiasis-susceptible areas, theoretic definition, study methods, geographic modeling, conceptional framework of hazard/ disaster study

I. INTRODUCTION

The ecological environment of schistosomiasis-epidemic areas is complicated and their natural boundaries are difficult to discern. Especially for the epidemic type of lacustrine marshland, the epidemic areas distribute broadly and continuously to large extents, where snails spread haphazardly and randomly. It is almost impossible to determine the regional distribution of infected snails, the relation between upper and lower reaches often switch over. This is particularly true during flood seasons. These make it difficult for us to determine the order of timing for extinguish snails and cercaria, resulting in less effective results for the given huge amount of money and resources invested in suppressing the resurgence of snails. Correspondingly the spatial distribution of cercaria density has not been studied quantitatively before. This makes local residents difficult to effectively stay away from schistosomiasis-epidemic areas in their daily life and social economic activities. Thus it is difficult to break the vicious cycles of infection and re-infection thorough control efforts. Rapid and effective determination of schistosomiasis-epidemic area can provide decision support for formulation of effective prevention measures and pertinently carry out the work of snail and cercaria extinguishing on one hand. On the other hand, it facilitates to pinpoint and set up warning boards, to remind residents of high risks of schistosomiasis-epidemic areas to achieve the objectives of reducing contact with contaminated waters, knocking-down contracting rate, alleviating and slowing down the overall situation of schistosomiasis transmission in China. Therefore rapid and effective determination of schistosomiasis-epidemic area is significant both theorectically practically.

In this paper we make a theoretic exploration and review the concepts, criteria, study methods of schistosomiasis-epidemic area based on present research achievement in the field. We then make some suggestions on the direction of future studies in this field.

II. CONCEPT OF SCHISTOSOMIASIS-SUSCEPTIBLE AREA

A common perception of schistosomiasis-susceptible area is the risky zone that has high probability for people and livestock to become infected. Such zones include grass beaches, water-

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land transitional zones and contaminated waters that contain high-density cercaria and has infection ability. The distribution of susceptible area has something to do with various environmental factors such as snails, infected snails, human and animal feces, ponds and pits, and meteorological factors (wind speed and direction) and hydrological factors(flow speed and direction)(Zhong et al., 1994). Given that schistosomiasis-susceptible area is related to geographic space on earth surface that has potential infection thread to human and livestock, strictly speaking the concept of schistosomiasis-susceptible area is not a generic concept of preventive medicine but belongs to a concrete concept in epidemiology. To be more precisely, a major issue in medical geography of schistosomiasis transmission.

The concept of schistosomiasis-susceptible area emerged in the early 80s. It was initiated by the Schistosomiasis Control Office of the Chinese Central Government which defined it as areas where there are frequent human activities, severe cercaria contamination and more chance of infection (Hua, 1994). Though this concept has come into being for more than twenty years, the grading criteria and study methods have not been standardized in academia. Zhang et al (1990) gave his definition of schistosomiasis-susceptible area, and categorized it into three grades, or susceptible area, less susceptible area and non-susceptible area. Concrete criteria are: susceptible area refers to grass beaches with the density of infected snails > $0.005/0.11M^2$ and acute patients are reported; less susceptible area refers to grass beaches with the density of infected snails <$0.005/0.11M^2$, or snail density >$2/0.11M^2$, but no or very few acute patients occur; non-susceptible area refers to areas with no infected snails, or snail density <$2/0.11M^2$, no infected or acute patients occur. Wu (Chen, 1995) gave a comprehensive classification of schistosomiasis-susceptible area according to the geographic environment, topography, inundation period, vegetation, frequency of epidemic water contact and infection index of human/livestock. Zhu(Chen, 1995) regarded schistosomiasis-susceptible area as areas with snails that are close to local life and social economic activities, and used risk index to determine susceptible area. First-grade susceptible area has an index >2, second-grade susceptible area has an index of 1-2, and non-susceptible area has an index <1. Xie et al (2005) carried out cercaria survey by means of mouse-infection and used the cercaria density in the snails and epidemic water to demark high-risk susceptible area and guide prevention and control work of schistosomiasis. Chen et al (1995) took areas with infected snails for schistosomiasis-susceptible area, and furthermore suggested to annihilate the snails in the marshlands that are within 500 meters around residential areas. Gao et al (1995) found moisture, feces pollution, contact frequency and period in water are the main factors of forming schistosomiasis-susceptible area.

Based on different definitions of susceptible area mentioned above, we could reduce the factors related to susceptible area to the following: feces pollution, density of infected snails, cercaria density, contact intensity with contaminated waters (including frequency and period), disease nosography (including acute patients) and environmental factors including the geographic environment, altitude, inundation period and vegetation. These almost covered all related factors in the transmission process. As a matter of fact, the most important parameter that influences prevalence and transmission of schistosomiasis are density of infected snails (the origin of cercaria) and density of cercaria in water, which directly dictates the extent and susceptibility of contaminated water area. Contact intensity with contaminated waters does not belong to the susceptibility concept, but belongs to the concept of infection risk, which can only take effects in areas of certain susceptibility. Disease nosography depends on the spatial combination of susceptibility and infection risk. Therefore, we suggest here that schistosomiasis-susceptible area is the spatial distribution and dynamics of waters containing cercaria that have infecting capability to human, livestock and other mammal. Such water bodies include continuous lake water, shallow water on the marshlands, ponds and pits, dew on branches and leaves. The susceptibility is the overall infection level that is related to the density of cercaria with infecting power.

III. METHODS FOR DETERMINING SCHISTOSOMIASIS-SUSCEPTIBLE AREAS

Due to inconsistency in the meaning of schistosomiasis-susceptible area and susceptibility, and the nature of multidisciplinarity in the study of schistosomiasis-susceptible area, in addition to the confinements of researchers themselves (geographers are short of medical knowledge, persons in charge of disease control lack skills in spatial analysis), the existing methods in determining schistosomiasis-susceptible area are based on field survey of single or several factors of a particular location. We can divide the methods into five aspects according to the different factors as following:

A. Determination of schistosomiasis-susceptible area based on feces pollution

Chen et al (1992) found feces pollution is dominated by animal cattle, pigs and human in their selected 30 villages in Dongting lake region from 1987–1994. The closer to the levees, the higher the pollution. Cattle feces constitute the majority in areas of different distances, the farer to the levees, the higher the proportion of cattle feces. Pig feces are mainly distributed within 300 meters to the levees. Human feces appear sparsely around the area. The conclusion is that areas within 300 meters from levees have infected snail density > $0.005 /0.11m^2$, belonging to first-grade susceptible area. Infected snail density is linearly related to feces density.

Wan (2004) found from their experiment that snail life longevity is normally less than one year. If we can disrupt the pollution source of snails and waters, that is the infected people and livestock no longer excrete eggs into the marshlands, the quantity of infected snails will surely fall down. Subsequently, the infection source-cercaria will drop down accordingly. Therefore, ban ning of animal grazing in the grasslands is an effective measure for the purpose of disruption of schistosomiasis transmission. In the context of difficulties of eliminating snails in the Poyang lake region, banning of animal grazing in the grasslands can reduce the biological pollution that will eventually reduce the infection level of water areas.

B. Determination of schistosomiasis-susceptible area based on infected snails

Zhuo et al (1991) found from 1987–1989 field survey that infected snails distribute continuously in patterns of strips along levees in four selected villages and an island in the Dongting Lake region. There is no obvious pattern for spatial unit demarking. The width of the zones of infected snails and alive snails is related to the width of snail extent, vegetation types, relief, speed of water flow, kind of pollution sources. The width of susceptible area dominated by cattle feces as the major pollution source is relatively wide, the polluted areas from levees could reach 1000 meters; pollution from pig sources reaches a distance of 100 meters with a few cases reaching 400 meters; for pollution of human feces, the width of this kind of susceptible area is relatively narrow with the polluted areas mainly distributed near levees or abandoned levees that harbor boats. For the factor of altitude, the altitute range of infected snails is usually narrower than or similar to that of live snails.

Wang et al(2002) conducted a study for three consecutive years on the relation between the coverage of vegetation and the snail growth, annual variation of schistosomiasis infection in six selected grasslands of Duchang county in the Poyang lake region. They found that for grasslands of altitudes ranging from 13 to 16 meters, the longer the inundation period, the lower the vegetation coverage. The snail growth has positive relation with vegetation coverage. This relation holds for the same grassland in different years or different seasons in the same year. The bigger the snail (the shell is longer), the higher is the infection. The annual variation of schistosomiasis infection is not related to vegetation coverage, but to pollution sources, depth of ponds and pits, and the strength of control measures.

C. The relation between cercaria and schistosomiasis-susceptible area

Xie et al (2000) used "C-6 Film" method and "Conventional Mesh Capture" method during the flooding period in the Dongting lake region from May to October to capture cercaria monthly in order to have an understanding of the distribution of schistosomiasis-susceptible area in two selected water areas each with 100 meters ×120 meters along the levees. They found that cercaria can be captured anywhere in the selected water areas. However, the concentration is 83.78% and 78.48% when the distance is within 60 m from the levee for the two selected water areas. They also found that the most cercaria can be captured when the weather is good and sunny, air temperature is 26℃–28℃, the water temperature is 18℃–26℃ and the wind is from the south with a strength of grades 3–4.

Xie et al (2005) used "mouse infection" method to detect the infection capability of contaminated waters in two geographic environments in 2003 and 2004. The infection rates were 100%. Approximately 0.1%–0.2% cercaria in flowing water can infect mouses, indicating the epidemic waters in Nanjing city along the Yangtze river is extensive and the cercaria density is high. During the flooding season, floods could revert river flow spreading cercaria to go upstream to cause infection upstreams leading to expanding of schistosomiasis transmission.

D. Relation between contact frequency with water and schistosomiasis-susceptible area

Yuan (1990) suggested to use density of infected snails, density of snails and number of acute infection patients as indices to discriminate the levels of susceptibility on the marshlands where farmers live within a relatively independent natural unit, or to use density of infected snails, density of positive feces and contact frequency in a clustering algorithm to make zonations of susceptible area.

Wu (1991) selected 24 study sites to study on the relationship between the habitant behaviors and prevalence. He created four zones from the levee with <200 m as the first zone, 200–500 m as the second zone, 500–1000 m as the third and above 1000 m away from levees as the fourth. He found that contact frequency with water was decreased with the distance away from levees. The positive kato-katz checks decrease gradually too.

E. Relation between human/livestock infection and schistosomiasis-susceptible area

Zhong et al (1994) conducted a survey of schistosomiasis patients in the Poyang Lake region from 1987 to 1990. They found the number of acute patients in the region has a tendency of spatial clustering, mainly distributed in the susceptible area that was classified as the first-grade marshlands close to residential areas. The reason might be that human/livestock traveled and worked frequently around those marshlands that happen to be polluted by positive feces. As a result, they became infected leading to be acute patients. Yuan (1994) focused his work on sources of schistosomiasis. He found that the residential infection rate was higher when the inhabitant was at closer distances around epidemic sources.

As a matter of fact, the above factors do not take effect individually but worked collectively to constitute a schistosomiasis-susceptible area. In addition, the environmental factors have close relationship to schistosomiasis-susceptible areas. They often co-influence the susceptibility in a mixed way with other factors. For instance, Zhang (1990) thought schistosomiasis-susceptible area does not mean an administrative township or village, but a concrete marshland/grassland or a local area in a big snail-infested marshland/grassland. The infected snail densities are high in some areas of special topography, posing high risks, but such an area could be small in size.

IV. BASIC UNDERSTANDING ON VARIOUS STUDIES OF SCHISTOSOMIASIS-SUSCEPTIBLE AREA

A. Significance of schistosomiasis-susceptible area studies

Studies on schistosomiasis-susceptible area provide pertinent information for decision-support of extinguishing snails and cercaria to achieve maximum control effect with limited resources. On the other hand it will help find the extent and level of susceptibility in vast grasslands/marshlands to allow warning boards to be established to remind local residents of high-risk susceptible areas of schistosmiasis infection. Thus, the goal of reducing contact with contaminated water can be better achieved, decreasing infection rates.

B. Parsing the concepts of schistosomiasis-susceptible area

The concept of Schistosomiasis-susceptible area defined as "areas of frequent activities of human/livestock, severe pollution and enormous chance of infection" was initiated in the early 1980's by the Schistosomiasis Control Office of the Central Government of China. This is a qualitative concept that can reflect basic connotation, but is not very accurate and lacks quantitative indexing. There could be exceptional cases in real life. For example, some places may have little human/livestock activities and pollution comes from neighborhood places (eggs, miracidia, cercaria could move along with flows and winds), but the chance of infection is rather high. In other places, human/livestock activities are intensive and the pollution is severe, but the snail density is so low. Therefore, the chance of human/livestock infection is low instead.

The definition and categorization indices of schistosomiasis-susceptible area by Zhang et al (1990) can reflect susceptibility to a certain degree in Schistosomiasis transmission, but have some drawbacks as well. First, the density of infected snails can only reflect the original seedbed of cercaria that have infection power, but cannot objectively map the nature of activity, spatial distribution, density and potential infection of cercaria. Cercaria could shift downstream in conditions of flows and winds to reach far places from infected snails. They have a tendency of gathering along the banks, resulting in spatial shift of original seedbeds and infecting areas. Second, groups of acute schistosomiasis patients could reflect the susceptibility in areas nearby, but could generate some errors. For instance, some acute patients could be infected at other places even though they are from lower-susceptible areas. To the contrary, in some high-susceptible areas, the infection rates could be low if protection measures are carefully taken. Therefore, the above mentioned categorization indices can hardly reflect the actual susceptibility of schistosomiasis transmission.

The definitions of Zhu et al (Chen et al., 1995) and Chen et al (1995) have similar problems of spatial shift of seedbed of pathogeny-cercaria and infection locations. The density of infected snails does not always have positive relation with the density of cercaria. On the other hand, contact strength with contaminated water considered by Zhu et al (Chen et al., 1995) is, as a matter of fact, not an issue of schistosomiasis susceptibility, but an issue of infection risk which will be discussed later.

Gao et al (1995) studied the main factors of schistosomiasis-susceptible areas, which are not strictly meaningful definition in fact. They found that there existed close relations between schistosomiasis-susceptible factors and water conditions, human/livestock feces pollution, contact frequency and period with contaminated water. A similar problem existed in their study that messed-up the susceptibility and infection risk. We agree with Xie (2005) in using examination result of cercaria from snails and contaminated water to indicate highly susceptible areas.

C. Comparison of methods for determining schistosomiasis-susceptible areas

After parsing the concepts of schistosomiasis-susceptible area and reviewing different methods, we reached the following understandings. First, incomplete examination of factors influencing the determination of schistosomiasis-susceptible areas lead to the exaggeration of certain factors while ignoring certain other important factors. Second, some methods did not use the key factors related to schistosomiasis-susceptible area, but focused on indirect or original source factors that do not support the initial definition of schistosomiasis-susceptible area. Third, a majority of methods used in-situ survey results that may not be well designed to represent the real spatial variation. Therefore, such data do not fully support the exploration of spatial relation between factors that are field surveyed and schistosomiasis transmission, preventing information on the spatial distribution and levels of susceptibility of schistosomiasis transmission from being produced.

It can be seen that existing theoretical studies on schistosomiasis-susceptible area (including extents and susceptibility) rest on qualitative and conceptual levels while practical studies are limited at the analysis of a few factors collected in field survey in limited areas. Not much progress has been made towards extensive and quantitative studies and spatial simulation. The causes could be related to the following two aspects. First, any study on schistosomiasis-susceptible area needs both medical knowledge on schistosomiasis and geographical analysis skills (including point interpolation to form plane representation, spatial relation analysis and cartographic visualization, etc.). Because less attention has been paid to true interdisciplinary collaboration between these two fields, the progress of schistosomiasis-susceptible area is slow. Second, the elements of different life phases of schistosomiasome and parasite hosts have respective activity spaces and internal relations. It is usually difficult to find a relatively close region to allow quantitative relationship to be established between schistosomiasome transmission and the environment. The conceptual model proposed by Xu et al (2006) is an exception but their model has not been validated. Thus a commonly acceptable framework for assessing schistosomiasis-susceptible area has not been established.

V. DETERMINATION OF SCHISTOSOMIASIS-SUSCEPTIBLE AREA WITH A MEDICAL GEOGRAPHY APPROACH

In order to make an in-depth study of schistosomiasis-susceptible area determination, it is necessary to integrate biological knowledge of schistosomiasis transmission, knowledge and methods of medical geography, GIS and remote sensing in the development of schistosomiasis transmission models. There are approximately two ways for consideration to achieve the integration. First, as discussed above, spatial variation can be studied with field survey data collected on such factors as those of meteorology, hydrology, soils and vegetation etc. Based on these factors we determine the schistosomiasis susceptible areas. Second, a process-based model can be built that is based on environmental monitoring and spatial modeling (including the susceptibility and infection risk) of schistosomiasis transmission. The later consists of three aspects. The first is the study on spatial variation of schistosomiasis transmission conditions in large-scale spatial extents by remote sensing and GIS (Zhou et al., 1998; 1999a; Seto et al., 2002). This is good in providing rapid and approximate forecast of prevalence extents and intensities in a large area. The second one is the use of remote sensing to identify snail-infested schistosomiasis-epidemic water areas from other environments (Jiang et al., 2002; Zhou et al., 1999b) and the monitoring of grasslands/marshlands conditions (snails-breeding areas) (Brooker et al., 2001; Kristensen et al., 2001; Guo et al., 2002; Lin et al., 2002). The third is the comprehensive modeling of the entire schistosmiasis transmission process (Liang et al., 2002; Xu et al., 2006).

The most important factors in schistosomiasis prevalence and transmission are densities of positive snails and cercaria in the contaminated water. They are the constructive factors of the susceptibility and infection risk. Remote sensing and human naked eyes cannot differentiate infected snails from non-infected snails, contaminated water from safe water. However, there are some relationship between infected snails, cercaria densities and snail distribution, spatial-temporal nature of human./livestock activities, sanitary establishment, awareness and measures taken of self-protection. We can make relational analysis and geographic modeling to simulate the spatial distribution of infected snails and cercaria densities by integrating other spatial data (meteorology, hydrology, DEM, landcover, infrastructure, etc) and ground survey data. In the same grassland/marshland, areas around outlets of villages, areas that harbor boats, areas near paths and roads of human/livestock, areas surrounding livestock sheds, areas contiguous to pitches, ponds, depression and pits, are belts of high-density infected snails. They have clear properties of spatial clustering and stability.

Therefore, effective integration of large scale remote sensing data with GIS data and local ground survey data has strong potential in determination of schistosomiasis-susceptible areas. Application of remote sensing, GIS technology and geographic modeling by exploring data-driven models and knowledge-driven models (Bonham-Carter, 1994) in spatial simulation and risk grading of susceptible areas and infection risk assessment of schistosomiasis transmission is an important direction of further research.

VI. CONCEPTUAL FRAMEWORK OF HAZARD/RISK STUDY IN SCHISTOSOMIASIS-SUSCEPTIBLE AREA

If we import the concepts of hazards and risks in the natural hazard theory into the study of schistosomiasis-susceptible area, we could derive two new concepts that are susceptibility (Levels) and infection risk. In hazard theory, hazard is the spatial distribution of natural phenomena that are detrimental to human kind. Risk is level of losses human being suffers from a disaster of certain hazard happened due to spatial variation of human activities and property safety (vulnerability). In a GIS, if we treat hazards and risks as different layers of data, the spatial distributions of the two layers do not necessarily coincide with each other. That is the disaster risk is not surely high in the high-hazard region if proper prevention measures are taken. To the contrary, the disaster risk is high in the low-hazard region if proper prevention measures are not taken. Similarly, we could define schistosomiasis susceptibility as the spatial distribution, dynamics and activation situation of cercaria density in the contaminated water bodies. That is the infection threat to human/livestock existing in natural conditions before actual contact with the contaminated water by human/livestock is made. Infection risk is the degree of human/livestock infection with schistosomiasis in conditions of human/livestock activity and spatial pattern under certain spatial distribution of given schistosomiasis susceptibility. It depends on the spatial overlapping relations of human/livestock activity and susceptibility. We could adopt the formula "infection risk = susceptibility * contact index" where contact index is the water contact intensity by human/livestock. A generic formula is "contact index=contact time * contact area * contact frequency", that can take effect only in conditions of certain cercaria density. Of course, different groups of human/

livestock could have appreciably different infection results under conditions of the same susceptibility and infection risk due to age difference, constitutional difference and difference of the acquired immunity of an individual. Therefore, we could use density of infected snails (source of pathogeny) in the zone along the water-land boundary, the density of cercaria (congregation of pathogeny) to reflect susceptibility, overlapped by spatial distribution of human/livestock activities to produce the infection risk.

VII. CONCLUSIONS

In this paper, we analyzed the initial origin, different definitions, study methods of schistosomiasis-susceptible area. These helped us to form some basic understandings in this field. We propose two concepts for future studies on shistosomiasis-susceptible areas. These are the susceptibility (levels) and infection risk of schistosomiasis transmission. By integrating field survey, remote sensing scaling up, GIS data, geographical modeling, we can generate quantitative measures to describe the two concepts.

Schistosomiasis is an epidemic disease caused by parasites. Individual factors in the transmission process have direct and indirect relationships with geographic elements making the application of remote sensing, GIS technology and geographic modeling valuable tools in the study of schistosomiasis transmission. Occurrence, multiplication and transmission of schistosomiasis have close relations to the suitability of the natural and social environment that are suitable for the pathogeny and parasite hosts to grow. The intermediate host - snail, need proper environmental factors (temperature, moisture, sunshine, inundation frequency, water depth, water level, vegetation and soil) to breed, miracidia and cercaria in the life cycle of schistosomiasis have direct relations to water temperature, sunshine, wind speed and direction, flow speed and direction, content of sand and silt in water. The behavior, activity, sanitary infrastructure of the terminal host-human/ livestock directly determine the survival of schistosome and infection/re-infection degrees. The susceptibility is mainly dependent on the density of cercaria in water bodies. The infection risk is mainly dependent on the spatial-temporal pattern of human/livestock activities under the conditions of certain susceptibility. Many aspects of environmental aspects can be directly or indirectly obtained by remote sensing technology. Other factors could be acquired through GIS spatial modeling assisted by other thematic data and ground survey data.

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