

Predicting frequency distribution and influence of sociodemographic and behavioral risk factors of *Schistosoma mansoni* infection and analysis of co-infection with intestinal parasites

Carla V.V. Rollemberg,¹ Marília M.B.L. Silva,² Karla C. Rollemberg,¹ Fábio R. Amorim,¹ Nayanna M.N. Lessa,¹ Marcos D.S. Santos,¹ Acácia M.B. Souza,² Enaldo V. Melo,¹ Roque P. Almeida,³ Ângela M. Silva,¹ Guilherme L. Werneck,^{4,5} Mario A. Santos,¹ José A.P. Almeida,³ Amélia R. Jesus^{1,4}

¹Laboratory of Molecular Biology, University Hospital, Federal University of Sergipe; ²Post-doc Geography Unit, Department of Geography, Federal University of Sergipe; ³Department of Geology, Federal University of Sergipe; ⁴Research Institute in Immunology, National Institute of Science and Technology, Brazilian Research and Technology Council, São Paulo; ⁵Department of Social Medicine, Institute of Medicine and Health, Public University of Rio de Janeiro-Fundação Oswaldo Cruz, Rio de Janeiro, Brazil

Correspondence: Amélia Ribeiro de Jesus, Laboratory of Molecular Biology, University Hospital, Federal University of Sergipe, rua Claudio Batista s/n, Sanatório, Aracaju, Sergipe, Brazil. Tel: +55.79.21051806.
E-mail: jesus-amelia@uol.com.br

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Abstract

Geospatial analysis was used to study the epidemiology of *Schistosoma mansoni*, intestinal parasites and co-infections in an area (Ilha das Flores) in Sergipe, Brazil. We collected individually georeferenced sociodemographic, behavioral and parasitological data from 500 subjects, analyzed them by conventional statistics, and produced risk maps by Kernel estimation. The prevalence rates found were: *S. mansoni* (24.0%), *Trichuris trichiura* (54.8%), *Ascaris lumbricoides* (49.2%), Hookworm (17.6%) and *Entamoeba histolytica* (7.0%). Only 59/500 (11.8%) individuals did not present any of these infections, whereas 279/500 (55.8%) were simultaneously infected by three or more parasites. We observed associations between *S. mansoni* infection and various variables such as male gender, being rice farmer or fisherman, low educational level, low income, water contact and drinking untreated water. The Kernel estimator indicated that high-risk areas coincide with the poorest regions of the villages as well as with the part of the villages without an adequate sewage system. We also noted associations between both *A. lumbricoides* and hookworm infections with low education and low income. *A. lumbricoides* infection and *T. trichiura* infection were both associated with drinking untreated water and residential open-air sewage. These findings call for an integrated approach to effectively control multiple parasitic infections.

Introduction

Schistosomiasis and intestinal parasites are common in Asia, Africa and Latin America (Chitsulo et al., 2000; Hotez et al., 2010). In 2013, the World Health Organization estimated that there are 249 million people requiring treatment for schistosomiasis, while the actual number of people treated in 2012 was only 42.1 million (WHO, 2014). More than 1.3 billion people worldwide are infected by *Ascaris lumbricoides*, 1.25 billion by *Trichuris trichiura* (WHO, 2010) and 740 million by hookworm caused by the nematodes *Necator americanus* and



Ancylostoma duodenale (Da Silva *et al.*, 2003). Protozoal infections are also common problems in the developing countries with *Giardia lamblia* affecting nearly 33% of general populations, while *Entamoeba histolytica* prevalence often reaches 50% and is estimated to cause more than 100,000 deaths per year (WHO, 2010).

Polyparasitism represents a major health problem and affects a substantial proportion of the populations in the tropics (Hotez *et al.*, 2010). However, few studies address prevalence rates, the types of interaction that occur between different species of parasites, their spatial distributions, sociodemography and the behavioral factors associated with these infections. The ability to predict the distribution of co-infections at large geographical scales has important implications for the design of control programs for neglected tropical diseases in general (Brooker *et al.*, 2002; Brooker and Clements, 2009; Hotez *et al.*, 2010).

Due to the diversity of sociodemographic and development status among regions there is a need for large-scale parasitological surveys in Brazil. Such studies were conducted in the 1970s, while more recent studies have tended to be local and are, therefore, not capable of reflecting the situation in the country as a whole. However, a multicenter study of 7-to-14-year-old students in 10 Brazilian states recorded 55.3% intestinal parasites, such as *A. lumbricoides*, *T. trichiura* and in particular *G. lamblia* (Campos *et al.*, 2002). Spatial modelling of co-infections has largely been ignored in Brazil, but some studies have investigated the spatial distribution of co-infection between *Schistosoma mansoni* and hookworm (Bethony *et al.*, 2001; Gazzinelli *et al.*, 2001; Raso *et al.*, 2006, 2007).

We describe the prevalence of *S. mansoni* alone as well as co-infection with intestinal parasites, such as soil transmitted helminths (STHs) and protozoa in the municipality of Ilha das Flores, Sergipe, Brazil, known to have high rates of prevalence for these parasites (Rollemberg *et al.*, 2011). Using this rural community as a model, our objective was also to investigate the association of these infections with known sociodemographic and behavioral risk factors. The importance of this study was to point out and localize the main risk factors to be the target for interventions that could benefit affected populations. We used geographic information systems (GIS) with improved techniques for storage, query and analytical software designed to identify variables that do not only reveal disease distribution, but also the sociodemographic and behavioral factors influencing the disease distribution. Geo-localization was used to prove the influence of the surface water contamination by primitive sewage system in the higher transmission areas of Ilha das Flores. Although this study was primarily aimed at evaluating the local situation in this community, we feel that our approach can also be used as a tentative model for other parts of North-Eastern Brazil.

Materials and Methods

The present epidemiological study, combining a field study with geolocalization using GIS, was performed to improve our understanding of the sociodemographic, behavioral factors involved including the influence of surface water contamination on acquisition of *S. mansoni* and other parasitic infections.

Study area

The study took place in Ilha das Flores municipality located 135 km from Aracaju, the capital of Sergipe State, Brazil (Figure 1). This municipality is one of the major producers of rice in the Northeast and is situated on the banks of the São Francisco River, the main river irri-

gating North-Eastern Brazil. It has the geographic coordinates of 10°26'05"South and 36°32'21"West.

Ilha das Flores comprises four areas, *i.e.* the city center and the villages of Bongue, Serrão and Bolivar. In 2007, it had 8568 inhabitants, 85.4% of whom with access to potable water, but only intermittently. Thus, no one in the area has constant access to tap water, so people must use surface water for their daily activities. According to the Brazilian Institute of Geography and Statistics (IBGE) data from 2007, only 3.3% of the population has sanitation coverage (IBGE, 2007). There is an extensive but primitive irrigation system that was created for rice plantation and other purposes, taking its water from the local river through two pump stations, one located in the city center and the other in the village of Serrão. Water is returned through a stream leading back into the river. Local people use the irrigation canals for many different household activities and these canals also receive waste from open sewers. Additionally, the canals are infested by snails of the *Biomphalaria* species, the intermediate host of *S. mansoni* (Barboza *et al.*, 2012). The combination of contamination of surface waters with open-air sewage and the presence of *Biomphalaria* species are important determinants for the transmission of schistosomiasis.

Study design

This was a cross-sectional, epidemiological study in the rural areas of Ilha das Flores between September 2008 and May 2010. The infections tested for included *S. mansoni* and the STHs *A. lumbricoides*, hookworm and *T. trichiura*. The protozoal infections investigated were *E. histolytica*, the non-pathogenic *E. coli*, *G. lamblia*, *Enterobius vermicularis* and *Strongyloides stercoralis*. To understand the consequences of these infections for the individuals' health, symptoms related to these parasite infections were also evaluated.

The georeferenced database

Aerial photography from 2003 at the 1:25,000 scale was obtained from the State Planning Department (SEPLAN) in Sergipe. These aerial photographs were georeferenced through the acquisition of control points acquired with a Global Positioning System (GPS) instrument (Trimble) with a 2.5 m resolution after correction. A georeference database was created using Spring, v 5.2 (National Institute for Space

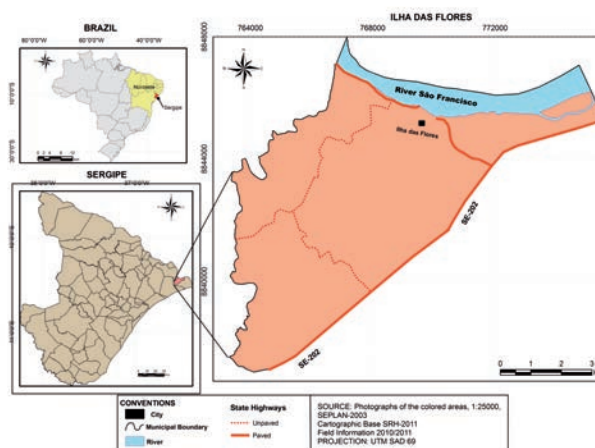


Figure 1. The study area and its localization in the state of Sergipe, Brazil.



Research). The urban network information plan was superimposed on the aerial photograph of the municipality by means of the vector editing section of the Spring software, while the households were mapped with GPS during home visits by the field team. Sociodemographic and behavioral data collected in epidemiological survey (described below) were entered into the ACCESS program database and exported to the georeferenced Spring database.

Data collection

According to data of the schistosomiasis control program (PCE) from 2007, Ilha das Flores had a 46.5% prevalence of *S. mansoni* infection (Rolleberg *et al.*, 2011). However, we observed that the health agents collected the parasitological data for the PCE from subjects living in areas of particular risk for infection, which could overestimate the prevalence, so we decided to use a prevalence of 30% to calculate our sample size, which was done by binomial analysis using Stata 7.0 (Stata, College Station, TX, USA), with a 95% confidence interval (CI) of 26.0 to 34.2. Based on that, our calculated sample size amounted to 500 individuals, or 100 families (considering an average of 5 persons per family).

Parasitological data regarding *S. mansoni* and intestinal parasites were obtained from 100 randomly selected families in order to exceed the calculated sample size. The total number of study subjects included 570 individuals proportionally distributed between the four localities that compose the municipality of Ilha das Flores. Stool samples were collected from each member of the household and microscopic examination was performed using two methods: i) two slides from a single stool sample were quantitatively examined according to Kato-Katz *et al.* (1972); and ii) in order to increase the sensitivity and to see protozoa, the three-fecal-test qualitative method (Gomes *et al.*, 2004) was used. This test is based on microscopic examination of three pooled fecal samples collected on three different days and preserved in formalin. The overall result was considered positive if at least one egg or cyst (protozoa) was detected by any of the methods.

The field team distributed a questionnaire with 87 questions to every resident. The variables analysed in the present study were a subsection consisting of age, gender, area of residence, place of birth and time of residence in the same (endemic) area, housing conditions and sanitation, *i.e.* water supply unadjusted, electricity, general sewage network and type of sewage system (open-air sewage or septic tank); degree of schooling (illiterate, elementary school, high school, or undergraduate); labour activities (current employment and/or other work activities); family income [translated into US dollars (USD) in this manuscript]; and behavioral risk factors for acquiring the diseases under study, such as exposure to surface water and/or soil (history, time, and location of water contact; hygiene habits, such as washing of hands and vegetables in relation to meals, and use of shoes). Clinical symptoms in the last year, such as diarrhea, blood and mucus in stool, were also evaluated. All members of the community testing positively in the parasitological examination were treated with praziquantel (50 mg/kg of body weight) for schistosomiasis, albendazole (400 mg single dose for children above 2 years old and adults) for the STHs and metronidazole for the intestinal protozoa, according to the type of parasite found (*E. histolytica*, 500 to 700 mg three times a day for 5 to 10 days) and for giardiasis (2 g once a day for 3 days).

Statistical analysis

All variables collected (questionnaire outcomes and the results of the parasitological examinations) were entered into SPSS Statistics, version 17 (IBM Corp., Armonk, NY, USA) and MIwiN, version 2.28 soft-

ware (Rasbash *et al.*, 2012) by two investigators. Descriptive data analysis was performed for calculation of the prevalence of all the parasitic infections and co-infections under study. The sociodemographic, and behavioral variables, in absolute and percentage frequencies, were organized in charts. We evaluated the associations between infections by the different parasites under study with the above mentioned sociodemographic and behavioral risk variables, calculating prevalence ratios including 95% CI using logistic regression for *S. mansoni* and chi-square or the Fisher exact test for the other parasite species. Periodically referred clinical symptoms in the last year, such as diarrhea, blood and mucus in stools were investigated for potential association with infection by *S. mansoni* and intestinal parasites by calculating prevalence ratios including the 95% CI using chi-square or the Fisher exact test. The accepted level of statistical significance was $P < 0.05$ for all tests carried out.

Spatial analysis

Mapping of the spatial distribution of schistosomiasis in the municipality was performed to evaluate the geographical variation in its occurrence to identify the distribution of risk and model its occurrence. The software Crime Stat III (<http://www.icpsr.umich.edu/CrimeStat/>) was used to develop a shapefile of a dual kernel, or kernel ratio for the four study locations (city center, Serrao, Bolivar, and Bongue). This was calculated from the ratio of number of positive individuals for schistosomiasis per household, by number of individuals in the household. The risk was expressed as the probability of occurrence with values ranging from 0 to 1. A circle with a radius of 4 m (the minimum distance between households) centred on positive individuals, was taken as the region of potential influence where nearby events could have contributed to the results. The thematic map from the results of Kernel density estimator was created in ArcView GIS version 3.1 (ESRI, Redlands, CA, USA), which is compatible to Crime Stat III. The Kernel density layer was superimposed on the thematic maps of urban areas that showed the location of the residences, from which the questionnaires and parasitological data had been collected by the field team. We also created cartographic maps of the distribution of the rice fields, urban area and surface water in ArcView GIS version 3.1, to analyze the proximity of the houses of the risk areas for *S. mansoni* infection.

Results

Out of the originally selected 570 individuals, 500 individuals completed the survey and participated in accompanying stool examinations, while seventy persons were excluded because they did not perform the parasitological tests. We found 120 individuals with positive stool examination for *S. mansoni* (24%). Among those infected, 34.8% were female with an age range from 9 to 73 (mean \pm SD=30.7 \pm 14.44 and median of 30); and 65.2% were male with an age range from 2 to 72 (mean \pm SD=23.6 \pm 13.68 and median of 19). Multiple parasitism was common in subjects from 11 to 20 years old.

Frequency statistics revealed that only 59 (11.8%) of all individuals did not present any co-infection, whereas 279/500 (55.8%) had three or more parasites simultaneously. Among the 120 schistosomiasis patients, only 13/120 (10.8%) were exclusively infected with *S. mansoni*. Table 1 shows the frequencies of *S. mansoni* infection and co-infections with other intestinal parasites.

We detected a positive association between *S. mansoni* and male gender, low-level education and low income. We also observed positive associations between *S. mansoni* infection and water contact (both in



the form of drinking untreated water and direct contact with surface water). With respect to profession, we found a strong association for rice farmer or fisherman. There were also associations between schistosomiasis and simultaneous trichuriasis and STH infection. Table 2 shows the association of STHs and protozoal infections with sociodemographic and behavioral risk factors. The STHs detected were *T. trichiura*, *A. lumbricoides*, hookworm, *E. vermicularis* and *S. stercoralis*. The protozoal infections detected were *E. histolytica*, *G. lamblia*, and the non-pathogenic *E. coli*. We found an association between open-air sewerage with *T. trichiura* and STH infection, association of drinking untreated water with infection by *A. lumbricoides* and *T. trichiura* as well as with STH in general, and monthly family incomes <USD 300 (the minimum salary defined by the Brazilian Government) associated with *A. lumbricoides* and hookworm infection and with STH in general. Diarrhea and blood in stool were both associated with *S. mansoni* infection, while diarrhea alone was commonly seen together with infection due to *A. lumbricoides* and *T. trichiura* (Table 3).

The spatial analysis is presented as descriptive maps showing raw prevalence estimates of *S. mansoni* infection with the kernel estimator. The highest risk areas were in the southern part of Serrão village, in the south-eastern part of Bolivar village, in the poorest area of the city center and along the river bank in Bongue village. The majority of the individuals (393/500, 78.6%) in these villages live in houses with septic tanks installed, while others (25/500, 5%) belong to a general sewage network or have open-air sewerage (55/500, 11%). A minority of the individuals (27/500, 5.4%) did not answer to this question. We observed that the majority of the septic tanks were not adequately built and therefore contaminated the surrounding soil. We also observed that there was a higher number of open-air sewerage/septic tanks than homes connected to a sewage network in the areas with higher risk for *S. mansoni* (Figure 2). We also observed in the cartographic maps a proximity of the rice field, surface water and the urban area (Figure 3).



Figure 2. (A) Risk areas for *S. mansoni* infection in the urban villages of Ilha das Flores, expressed as a probability of occurrence with values ranging from 0 to 1. (B) Each of the squares below shows a detail of the hot spot areas of the villages of Serrão, Bolivar, Main City, and Bongue, respectively. Types of sewage system from the houses marked in the map: houses with general sewerage network are painted in green; with septic tank in yellow and open air sewerage in red. The round dots around the houses are the individuals living in the houses.

Table 1. Prevalence of schistosomiasis and intestinal parasitic infections in Ilha das Flores.

Parasitic infections	No. of infections (Total tested=500)	Prevalence (%)
Parasite		
<i>Schistosoma mansoni</i>	120	24.0
<i>Ascaris lumbricoides</i>	246	49.2
<i>Entamoeba histolytica/dispar</i>	35	7.0
<i>Entamoeba coli</i>	128	25.6
<i>Enterobius vermicularis</i>	18	3.6
<i>Giardia lamblia</i>	25	5.0
Hookworm	88	17.6
<i>Strongyloides stercoralis</i>	4	0.8
<i>Tricuris trichiura</i>	274	54.8
Co-infection with <i>S. mansoni</i> and intestinal parasites		
<i>S. mansoni</i> + <i>A. lumbricoides</i>	61	50.8
<i>S. mansoni</i> + <i>T. trichiura</i>	79	65.8
<i>S. mansoni</i> +STH ^o	62	51.7
<i>S. mansoni</i> +protozoa [#]	10	8.3
<i>S. mansoni</i> +STH ^o +protozoa [#]	35	29.2
<i>S. mansoni</i> without co-infection	13	10.8

^oAll soil-transmitted helminths; [#]*G. lamblia* and *E. histolytica*.

Discussion

Schistosomiasis is a focal disease and it is important to study endemic regions to build a model to understand the dynamics of the sociodemographic and behavioral determinants of its transmission. However, this disease should not be investigated in isolation since, in most endemic areas, schistosomiasis is not the only chronic parasitic infection found. It is estimated that 26-68% of individuals with schistosomiasis are carriers of other helminth infections such as hookworm, *A. lumbricoides* or *T. trichiura* (Bundy *et al.*, 1991). Most of the endemic areas are prevalent ($\geq 10\%$) or hyperendemic (prevalence $\geq 50\%$) for STH infections. Due to the requirement of an aquatic snail intermediate host for transmission, areas endemic for schistosomiasis are commonly near perennial water reservoirs that, if contaminated with fecal matter, sustain the *S. mansoni* life-cycle. The contaminated water source also contaminates the soil and fresh food with a variety of helminth and protozoal parasites (Clements *et al.*, 2010).

In the present study, we studied a known endemic area where 89.2%

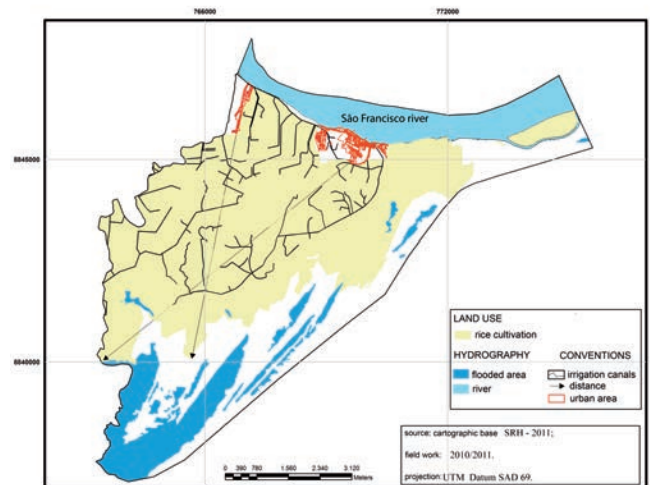


Figure 3. Land use and irrigation system in the study area.

Table 2. Associations of *S. mansoni* and other intestinal parasite infections with sociodemographic and behavioral factors and concomitant infections in Ilha das Flores.

Parasites/socio-economic factors	PR	95% CI	P
<i>S. mansoni</i>			
Age	2.2	1.39-3.64	0.008
Male gender	2.0	1.27-3.26	0.003
Education < elementary school	7.1	2.41-20.93	<0.001
Monthly income < USD 300.00	1.8	1.28-2.60	0.0005
Drinking untreated water	6.9	2.44-19.86	<0.001
Being a rice farmer	2.7	1.29-5.40	<0.001
Being a fisherman	3.3	1.39-7.69	<0.001
Contact with surface water sources	1.9	1.36-2.59	<0.001
Simultaneous <i>T. trichiuris</i> infection	1.8°	1.19-2.80	0.006
Simultaneous intestinal parasites	1.7°	1.00-2.70	0.056
<i>A. lumbricoides</i>			
Monthly income < USD 300.00	2.0#	1.4-2.9	0.02
Drinking untreated water	1.6#	1.1-2.3	0.02
<i>T. trichiura</i>			
Commonly walk barefoot	1.6#	1.1-2.4	0.02
Drinking untreated water	1.7#	1.1-2.4	0.02
Open-air sewage at home	1.6#	1.1-2.4	0.03
Hookworm			
Monthly income < USD 300.00	1.8#	1.1-3.0	0.02
Drinking untreated water	1.5#	0.9-2.5	0.01
STH°			
Monthly income < USD 300.00	1.9°	1.3-2.9	0.03
Drinking untreated water	2.6°	1.5-4.3	0.03
Open sewage at home	2.9°	1.9-4.6	0.04

PR, prevalence ratio (odds ratio interpreted as a PR); CI, confidence interval; USD, US dollars; STH, soil-transmitted helminths. °Fisher exact test; #logistic regression.

Table 3. Associations of intestinal parasitic infections and *S. mansoni* with clinical symptoms.

Parasites	Diarrhea		Blood in stool	
	PR	95% CI	PR	95% CI
<i>S. mansoni</i>	1.7°	1.1-2.6	1.7°	1.0-2.9
<i>A. lumbricoides</i>	1.7°	1.2-2.6	1.5°	0.9-2.3
<i>T. trichiura</i>	1.5°	1.0-2.2	1.4°	0.8-2.2
Hookworm	1.3°	0.8-2.0	0.9°	0.5-1.7
STH	1.9°	1.2-3.1	1.5°	0.8-2.6

PR, prevalence ratio; CI, confidence interval; STH, soil-transmitted helminths. °P < 0.05 according to Fisher exact test.



of the study population had concomitant parasitic infections, most commonly *A. lumbricoides* and *T. trichiura*. These STHs appeared frequently in this municipality, probably due to the association of water-borne contamination with their life cycles. The high frequency of these co-infections suggests an important focus maintaining transmission of these parasites, which are usually spread by fecal-oral routes (Veronesi and Focaccia, 2009).

The human host can harbor many different species of parasites at the same time and the fact that the external environment presents a high degree of contamination increases the probability of infection with multiple parasitic infections. By analyzing the distribution patterns of infected subjects in the community, it can be determined whether the observed events display a systematic pattern rather than being randomly distributed. Our data support the understanding that associations between various parasitic diseases are linked to these agents' similar mechanisms of transmission, which make these infections good indicators of dysfunctional social and sanitary conditions (and *vice versa*). Apart from helminth infections, the relatively high prevalence of intestinal protozoa in our material points to a high degree of interpersonal contamination due to poor hygiene conditions (e.g. not washing hands, unhygienic keeping of fresh food, drinking untreated water and walking barefoot) or poor sanitation (quality of the sewage system). Mapping the spatial distribution of co-infection is indeed an important way to determine the areas of priority and implement cost-effective measures of control programs (Raso *et al.*, 2006).

Da Silva *et al.* (2007) found that the prevalence and intensity of *S. mansoni* infection increased with increasing numbers of STH infections. They felt, however, that the strength of this association was not only because of socioeconomic or environmental conditions, but because of the interaction between the parasites as well and intrinsic host factors that increase susceptibility to several helminths (da Silva *et al.*, 2007). We agree with that conclusion, but identified in this study that also the intermediate determinants for infectious diseases, such as housing and sanitation (water supply and sewage type), hygiene, purchasing power and education, are very important determinants. Infection with multiple intestinal parasites was found to be common in the community of Ilha das Flores, particularly in 11-to-20-year-old individuals, because their behavior makes them vulnerable to disease transmission.

Sociodemographic and behavioral variables were found to be significantly associated with *S. mansoni* and STH infections. The association of the minimum monthly income (USD 300) with *S. mansoni* infection and intestinal parasites suggest that the influence of nutritional factors not evaluated in the present study may also be important disease determinants along with hygiene shortcomings related to housing conditions, such as the type of sewage used. We also found associations between drinking untreated water with *S. mansoni*, *A. lumbricoides* and *T. trichiura* infections. The former two parasites were associated with open-air sewages, while *S. mansoni* high-risk areas were found in households located near open-air sewages and septic tanks. As was observed and also recorded by IBGE (2007), the majority of the septic tanks in this area were not properly built suggesting that improved sanitation and measures leading to better personal economy are important steps when attempting to solve these health problems. Low educational level is also associated with *S. mansoni* infection. Education, when properly applied, leads people to acquire knowledge with respect to preventive measures that can help them to reduce the prevalence of parasitic diseases (Ferreira *et al.*, 2000).

The exploratory analysis of spatial density kernel estimator made it possible to identify individuals from the areas of greatest vulnerability with regard to schistosomiasis infection in Ilha das Flores. The kernel

estimator showed hotspots in places of the municipality where the population is poor, which was confirmed by the observation of a higher number of open-air sewage and septic tanks in the high-risk areas, together with the results of conventional statistical analysis which associated family income with infection. The proximity of the residential area of Ilha das Flores municipality with the rice field and the surface water, confirms the influence of these important determinants for *S. mansoni* infection.

Most specialized studies map snail infections or relate snail distributions to schistosomiasis prevalence with the objective of identifying high-risk areas, by studying human water contact sites (Barbosa *et al.*, 2004, 2014; Kloos *et al.*, 2004; Araujo *et al.*, 2007). It is clear that the ability to predict the spatial distribution of infections improves our understanding of co-endemicity and its distribution, which can be used as evidence base for the spatial orientation of large integrated control programs (Brooker and Clements, 2009). Sophisticated analyses of spatial data are useful for the future planning of epidemiological control strategies in diseases depending on vectors, because they can identify the spatial combination of sanitation and social factors mapping the potentially risk areas. Khormi and Kumar (2011, 2012, 2014) used a geostatistical model with a combination of environmental and socioeconomic variables to model areas at risk of dengue fever in Saudi Arabia, by Getis-Ord G_i^* statistics, while Bhunia *et al.* (2012) created distribution maps of visceral leishmaniasis in India to visualize the role of land use for disease transmission analyzed by a probabilistic approach. The georeferenced database created in our study can be used for future geostatistical analysis, using a combination of the data to map areas at risk for schistosomiasis.

Previous malacological studies by our group in this area have showed that the irrigation system impacts on the competitive selection replacing the native *Biomphalaria straminea* by *B. glabrata* (Barboza *et al.*, 2012) which is more sensitive to dehydration and therefore favored by the irrigation system (Michelson and Dubois, 1979; Barbosa *et al.*, 1993). *B. glabrata* is more easily infected by *S. mansoni* and this is probable one of factors influencing schistosomiasis transmission in this area (Barboza *et al.*, 2012). In the present study, we mapped land use and showed the proximity of rice fields to the residential areas as an additional risk besides the presence of open-air sewages and septic tanks in the areas with higher infection density. Our results suggest that the main contamination in Ilha das Flores occurs in the proximity of the houses of the inhabitants. In fact, during the raining season, the surface water overflows inside the houses in this municipality. These data suggest that it is important to improve the sanitation level of this municipality as a strategic move for control for *S. mansoni* transmission.

Conclusions

Poverty is strongly associated with *S. mansoni* as well as intestinal helminths and protozoal infection based on a combination of conventional statistical and geospatial analysis that identifies potential areas of transmission, where a set of social and behavioral features maintain these endemic diseases. The conditions of vulnerability to endemic diseases using kernel modelling, pointing to a set of possibilities for the occurrence of diseases, can contribute to building a system of monitoring, epidemiological surveillance, and hygiene-oriented measures to guide the actions of national schistosomiasis control programs. The georeferenced database created in this study will help future development of a geostatistical model that can include also water contact, vector distribution, houses with open-air sewage and septic tanks, *i.e.*

information relevant to regional planning efforts to effectively control these diseases.

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