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Mapping the risk for transmission of urban schistosomiasis in the Brazilian Northeast

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Abstract

This is an analysis of the risk of schistosomiasis transmission in the city of Recife in the Northeast of Brazil based on the number of schistosomiasis cases (*Schistosoma mansoni*) registered for the period 2007-2017 together with data resulting from active search of breeding sites of the *Biomphalaria* snail intermediate host. The analyses were performed using Kernel Density Estimation (KDE), SaTScan and Map Algebra methodology using human socio-demographic data and biotic and abiotic data from the snail breeding sites. Investigating 44 breeding sites resulted in a total of 3.800 snails, 31.8% of which were positive for *S. mansoni* DNA. These data were considered in relation to total of 652 schistosomiasis cases. The KDE showed two high-risk and two medium-risk clusters, while three significant clusters were identified by SaTScan. Combining these data with the Map Algebra methodology showed that all high-risk neighbourhoods had breeding sites with snails positive for *S. mansoni*. It was concluded that schistosomiasis transmission cannot be controlled without basic sanitation and sewage management in the presence of *Biomphalaria* snails. The technique of Map Algebra was found to be fundamental for the analysis and demonstration of areas with a high probability of schistosomiasis transmission.

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Introduction

Schistosomiasis, caused by various species of the genus *Schistosoma,* is one of the main parasitic infectious diseases in the tropical world. According to the World Health Organization (WHO), the transmission of this helminth infection currently occurs in 78 countries, 52 of which requires preventive therapy, but due shortages of drug administration only 97.2 million of the 290.8 million needing drug treatment with praziquantel received it as late as 2018 (WHO, 2020). In addition, it is estimated that schistosomiasis is globally responsible for more than 200,000 deaths annually (WHO, 2020). According to the Pan American Health Organization (Organização Pan-Americana da Saúde, OPAS) about 46 million children in Latin America including the Caribbean live in places at high risk of infection or reinfection with helminths transmitted by soil and 25 million people suffer from schistosomiasis (OPAS, 2017).

In Brazil, the number of reported cases of this disease has been increasing in urban areas, such as Belo Horizonte, Salvador and Fortaleza (Guimarães *et al*., 1993; Guimarães and Tavares-Neto, 2006). It is estimated that in the north-eastern and south-eastern regions of the country, schistosomiasis affects about 1.3% and 2.4% of the population, respectively, and that 25 million humans are exposed to the risk of contracting the disease in the country (Moh, 2014).

The Brazilian state of Pernambuco ranks third with respect to prevalence of schistosomiasis. The cases occur in 102 municipalities, 12.7% of which belong to the metropolitan region of Recife, constituting a serious public health problem because of high prevalence and severity of clinical outcomes. From 1999 to 2013, there were 2,578 deaths due to schistosomiasis and 473 hospitalizations in Pernambuco. From 1999 to 2014, there were 1,943 new schistosomal cases of people born, resident in Pernambuco and with medical assistance at the Hospital das Clínicas of the state, which is a reference for the treatment of the disease in the state (Barbosa *et al*., 2016). Since the 1990s, researches have shown spread of the disease to the metropolitan region of Recife affecting residents and tourists in the coastal localities of Itamaracá and Porto de Galinhas (Gonçalves *et al*., 1991; Barbosa *et al*., 2011;

Barbosa *et al*., 2013), which denotes the failure to control this disease in Pernambuco (Maricato, 2003).

Unplanned urbanization results in socio-spatial inequality, which has been demonstrated in the expanding urban peripheries where it results in spatial and environmental segregation due to creation of regions characterized by poverty (Oliveira *et al*., 2018). According to the Trata Brasil Institute (Instituto Trat Brasil, ITB), poor water quality, dysfunctional waste disposal and deposition of human excrements pollute the environment due to crowding by workers inhabiting the growing city peripheries with inadequate sanitation which, consequently, leads to proliferation of diseases, such as schistosomiasis (ITB, 2019). Thus, urbanization unassisted by infrastructure investment produces poor areas where sewage and waste are thrown into the peri-domicile (the area around the household) and ending up in canals rather being taken care of in a rational way. This promotes environmental contamination and infection of the snails that live in these canals (Flauzino *et al.*, 2009), which during rains frequently overflow and flush the snails into streets where people easily can become infected (Barbosa *et al*., 2011).

According to the ITB, Recife is in 77th position among the 100 largest municipalities in the country with respect to basic sanitation (ITB, 2018). The presence of poor people living in inadequate housing structures not far from the intermediate host snails allows the establishment of urban transmission of schistosomiasis (Oliveira *et al.*, 2018). In 2013, autochthonous cases were confirmed in Recife, and although the positive individuals had never left the city, it was not possible to identify the mode of transmission (Barbosa *et al*., 2013). However, one of the reasons for the occurrence of these cases is due to the combination of the following factors: people with active schistosomiasis, lack of sanitation and the presence of breeding sites with the *Biomphalaria* intermediate snail host, which together constitute a predictive epidemiological scenario for the introduction and local maintenance of this disease (Barbosa *et al*., 2013).

Geoprocessing has been efficiently applied in the analysis of environmental data in the search for associations with the occurrence of communicable diseases (Flauzino *et al*., 2009), while spatial health analysis comprises the study of dynamic disease distribution. The use of Geographical Information System (GIS) has proved to be an important tool for disease control and monitoring. It assists prophylaxis measures and enables a constant assessment of the control measures employed, while providing updated information on the actual epidemiological situation in the geographic space (Barbosa *et al*., 2017).

Kernel Density Estimation (KDE) and Map Algebra are useful for the production of risk maps for disease occurrence and are already well known for health data analysis (Carvalho *et al*., 2017; Santos *et al*., 2016; Santos *et al*., 2017). KDE demonstrates risk areas by spatial scanning of points that represent health events aiming at identifying potential clusters. It is a non-parametric technique that estimates the intensity of the occurrence of cases in the study area (Barbosa *et al.*, 2017; Carvalho *et al*., 2017). While kernel mapping by KDE is relatively straightforward, Map Algebra consists of a specialized language with mathematical functions for analyzing geographic data with numerical values, such as those delivered by GIS. It can be used through operative functions applied to one or more quantitative and/or qualitative data layers that can be viewed as individual variables. Established functions are homogeneously applied to points of the map, enabling the identification of risk areas for disease transmission or other occurrences (Tomlin, 1994).

In 2010, a study to map the breeding sites of the city of Recife identified 30 breeding sites of *B. straminea*, a common intermediate host of *S. mansoni* in Brazil, four of which were positive for *S. mansoni* and classified as potential transmission foci. However, no risk analysis for the transmission of schistosomiasis has been performed since then (Barbosa *et al*., 2013). In light of this, the objective of this study was to update and analyze the risk for schistosomiasis transmission in the city of Recife, Pernambuco, using epidemiological data and the analytic tools mentioned above. Our analysis aimed at describing the spatial patterns of morbidity and the factors associated with these patterns by identification of the relationships between the different environmental variables involved. In this way, we expected to enable a strengthened schistosomiasis surveillance, subsidize planning and expand the health care network.

Materials and methods

Study area

The research was conducted in the city of Recife, capital of Pernambuco, located at the core of the Metropolitan Region (RMR). Recife is divided into 94 neighbourhoods (NHs) and eight health districts (Distrito Sanitário, DS) shown in Figure 1, which present the geographic, demographic and socioeconomic differences in the city. According to the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatistica, IBGE), the city has an estimated population for the year 2018 of 1.637.834 inhabitants, with a demographic density of 7.039.64 inhabitants/km² (IBGE, 2018). Recife is located in the tropical area of Brazil at latitude 8º 04' 03" S and longitude 34º 55' 00" W (Prefeitura do Recife, 2020).

Data, sources and units of study

This study was composed by the following databases: i) malacological and abiotic data collected in the breeding sites identified in the city of Recife; ii) sociodemographic data obtained from the 2010 IBGE census; iii) residents of the city of Recife infected with schistosomiasis from 2007 to 2017 according to the Brazilian Notifiable Diseases Information System (Sistema Nacional de Agravos de Notificação, SINAN). The study units were the DSs and NHs of the city. The municipal boundary data (DSs, NHs and census tracts) were obtained from IBGE and Recife City Hall. The infectious agent of the study was *Schistosoma mansoni*, the only schistosome species in Latin America.

Study data were collected in three stages with different foci: i) snail collection and investigation; ii) population and domicile evaluation; and iii) assessment of the number of schistosomiasis cases. This information was grouped by NH and stored in a geographic database (Base de Dados Geográficos, BDG) and then imported into a GIS for analytical procedures.

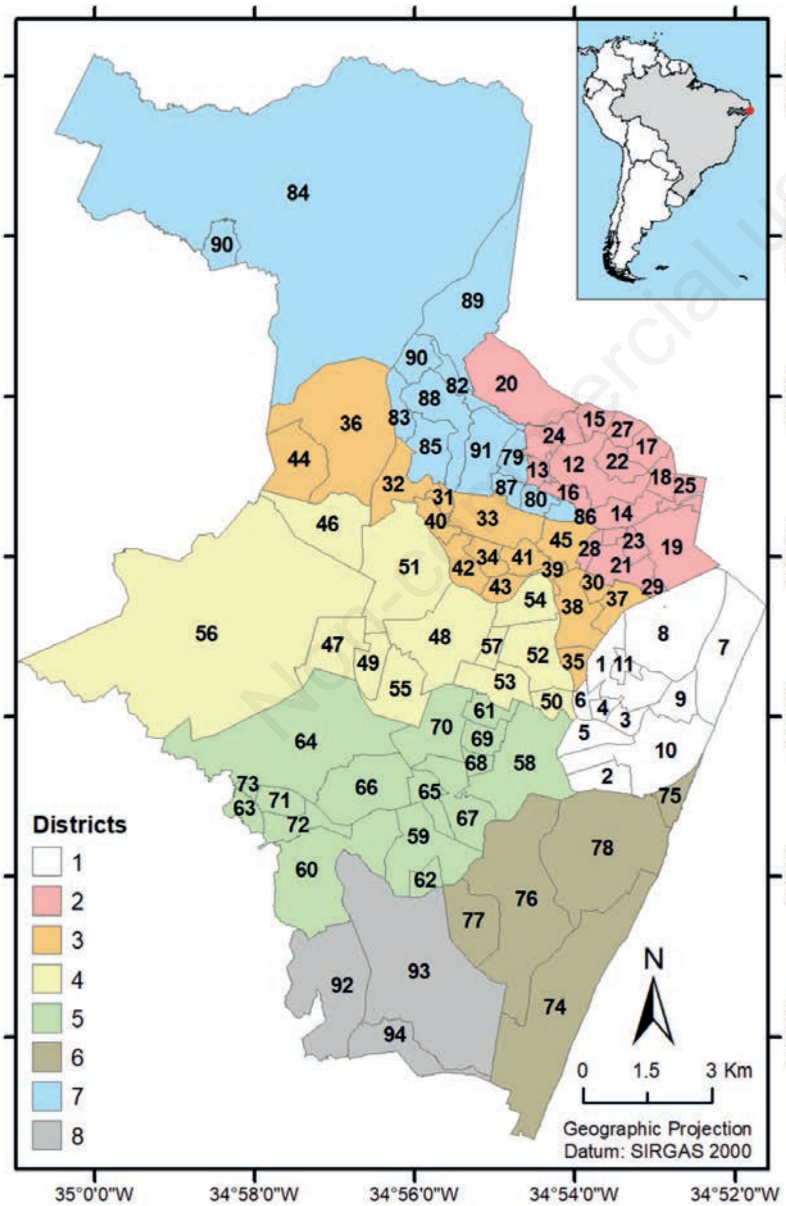
Stage 1

A malacological survey was carried out from March 2016 to September 2017 to identify intermediate *Biomphalaria* snail host of *S. mansoni*, in the water collections of epidemiological importance in Recife. The geographic coordinates of the breeding sites were obtained by a Garmin Montana 650 Global Positioning

System (GPS) receiver and transferred to TrackMaker Pro software (Geo Studio Technology, free version 13.9.596), transformed into shapefiles and used in the spatial data analysis.

Snails were collected by the method of Olivier & Schneiderman (1956) observing the technique of man/minute/shell according to the height of the rainwater harvesting. This method consists of tweezers to collect snails on the surface and substrate and a catch shell for the molluscs submerged in water (shell/area) every 15 minutes per breeding site. Later, the snails were packaged, identified and sent to the Laboratory and Reference Service for Schistosomiasis at the Aggeu Magalhães Institute, Oswaldo Cruz Foundation (LRE/IAM/Fiocruz). In the laboratory, 10% of the specimens from each breeding site were randomly selected identifying the *Biomphalaria* species by genital dissection according to Deslandes (1951). The snails were subjected to light exposure to stimulate cercariae shedding – a method that makes it possible to quantify the intensity of infection (Carvalho *et al*., 2014)) - and finally submitted to molecular testing to identify the parasite DNA using nested polymerase chain reaction (Nested PCR) according to Melo *et al*. (2006).

The harvesting sites were classified as follows: i) breeding sites – all rainwater harvesting that presented *Biomphalaria* snails; ii) transmission foci – all breeding sites in which snails were found releasing *S. mansoni* cercariae; and iii) potential foci – all breeding sites in which *S. mansoni*-infected snails were found using Nested PCR, meaning that parasite DNA was detected in the intermediate snail host even if it was not releasing cercariae. At each identified breeding site an environmental survey was carried out to obtain the



ID	Neighborhoods	ID	Neighborhoods
1	Boa Vista	48	Cordeiro
2	Cabanga	49	Engenho do Meio
3	Coelhos	50	Ilha do Retiro
4	Ilha do Leite	51	Iputinga
5	Ilha Joana Bezerra	52	Madalena
6	Paissandu	53	Prado
7	Recife	54	Torre
8	Santo Amaro	55	Torrões
9	Santo Antônio	56	Várzea
10	Sao José	57	Zumbi
11	Soledade	58	Afogados
12	Água Fria	59	Areias
13	Alto Santa Terezinha	60	Barro
14	Arruda	61	Bongi
15	Beberibe	62	Caçote
16	Bomba do Hemetério	63	Coqueiral
17	Cajueiro	64	Curado
18	Campina do Barreto	65	Estância
19	Campo Grande	66	Jardim São Paulo
20	Dois Unidos	67	Jiquiá
21	Encruzilhada	68	Mangueira
22	Fundão	69	Mustardinha
23	Hipódromo	70	San Martin
24	Linho do Tiro	71	Sancho
25	Peixinhos	72	Tejipió
26	Ponto de Parada	73	Totó
27	Porto da Madeira	74	Boa Viagem
28	Rosarinho	75	Brasilia Teimosa
29	Torreão	76	Imbiribeira
30	Aflitos	77	Ipsep
31	Alto do Mandu	78	Pina
32	Apipucos	79	Alto José Bonifácio
33	Casa Amarela	80	Alto José do Pinho
34	Casa Forte	81	Brejo da Guabiraba
35	Derby	82	Brejo do Beberibe
36	Dois Irmãos	83	Córrego do Jenipapo
37	Espinheiro	84	Guabiraba
38	Graças	85	Macaxeira
39	Jaqueira	86	Mangabeira
40	Monteiro	87	Morro da Conceição
41	Parnamirim	88	Nova Descoberta
42	Poço	89	Passarinho
43	Santana	90	Pau-Ferro
44	Sítio dos Pintos	91	Vasco da Gama
45	Tamarineira	92	Cohab
46	Caxangá	93	Ibura
47	Cidade Universitária	94	Jordão

Source: IBGE (2010), Recife City Hall (2018).

Figure 1. Health Districts and Neighbourhoods of Recife, Pernambuco 2018.

presence (value = 1 - risk area) or absence (value = 0 - no risk) of the following variables: i) human faeces (presence or absence observed in the water body); ii) vegetation cover (presence or absence on the banks of water bodies); iii) flooding (expansion of local water volume in breeding sites due to the volume of rain); iv) number of snails and v) infected snails (presence or absence of snails infected by *S. mansoni*). The variable number of snails received the values 0 (when the number of snails was <10) and 1 (when >10).

Stage 2

For analysis around the residence, the following sociodemographic variables extracted from the 2010 Census (IBGE) were used: i) Home without toilet and with waste water discharge via rudimentary sump, ditch, river/lake/sea or another outflow; ii) Combined household income from none to ½ the minimum wage; iii) Lack of paving (no coverage of public roads with asphalt, cement, cobblestones, stones, *etc.*); lack of manholes or culvert (without opening allowing access to underground boxes, through which rainwater can flow); iv) Presence of open sewage (trench, stream or body of water where domestic sewage is usually released).

The number of permanent private domiciles was counted in each variable category given above and the sum divided by the total number of domiciles in the area. In this way, each variable could be assigned a value ranging between 0 and 1 where 0 means that the home is non-hazardous for schistosomiasis transmission and 1 meaning completely hazardous in this respect.

Stage 3

The data related to schistosomiasis cases of residents of Recife from 2007 to 2017 were obtained from SINAN of the Health Secretariat of Recife. Based on Excel software the following data from the notification form were used for the study: i) confirmed cases of schistosomiasis; ii) municipality; and iii) residential NH.

The aquatic environment is the natural snail habitat. For a transmission cycle to be established and maintained, the presence of an infected individual in this NH is necessary for a period of time to initiate contamination leading to snail infections. The geographic coordinates of the schistosomiasis cases that had been reported in the SINAN were obtained using the site BatchGeo (2020) complemented by the use of the Google Maps/Street View site (Google, 2020) and Brazilian ZIP codes (Código de Endereço Postal, CEP), (CEP, 2020).

Spatial analysis

KDE with quartic function was used to demonstrate the behaviour of the point patterns of human schistosomiasis cases reported in the SINAN, as well as for finding breeding site clusters of potential foci of *Biomphalaria* infected with *S. mansoni* based on the snails collected (calculation of density and adaptive radius). The analysis was performed using TerraView software developed by the National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais, INPE; SP, BR Version 4.2.2), a userfriendly GIS interface allowing view and manipulation of both vector and raster data.

Table 1. Snails collected by neighbourhood in Recife, Pernambuco from March 2016 to September 2017.

Neighbourhood	Breeding sites (no.)	Snails collected (no.)	*S. mansoni* DNA detected
Apipucos	06	238	Yes
Arruda	01	04	No
Barro	02	212	Yes
Bongi	01	05	No
Campo Grande	01	04	No
Casa Forte	01	67	Yes
Cidade Universit.	01	78	Yes
Curado	01	101	Yes
Dois Unidos	01	133	Yes
Engenho do Meio	03	399	Yes
Guabiraba	01	03	No
Hipodrómo	01	04	No
Ibura*	09	954	Yes*
Imbiribeira	01	62	Yes
Iputinga	01	05	Yes
Jardim São Paulo	03	166	No
Jiquiá	01	76	No
Mangueira	01	48	Yes
Prado	03	370	Yes
San Martin	01	237	No
Torrões	01	526	Yes
Várzea	02	38	No
Vasco da Gama	01	70	No
Total	44	3,800	14 positives

*Two breeding sites were found in this NH and both were positive.

Quartic KDE creates a smooth surface of the variation in the density of point events across an area and calculates weights for each point within the kernel's radius, resulting in that points closer to the centre receive a higher weight and therefore contribute more to the cell's total density value (Eck *et al*., 2020). The KDE is a non-parametric, interpolar, statistical technique that allows the estimation of the event intensity by counting all points within a region of influence across the entire area, even in regions where the process has not caused any actual occurrence. Weighting events by distance from each other and the location of interest provides visual recognition of hotspots without changing local characteristics (Barbosa *et al*., 2017).

To perform spatial scanning of the data of breeding sites and schistosomiasis cases, the SaTScan software (version 9.6.1) was applied using the discrete poisson model (positive cases/population) and relative risk. This approach analyzes spatial, temporal or

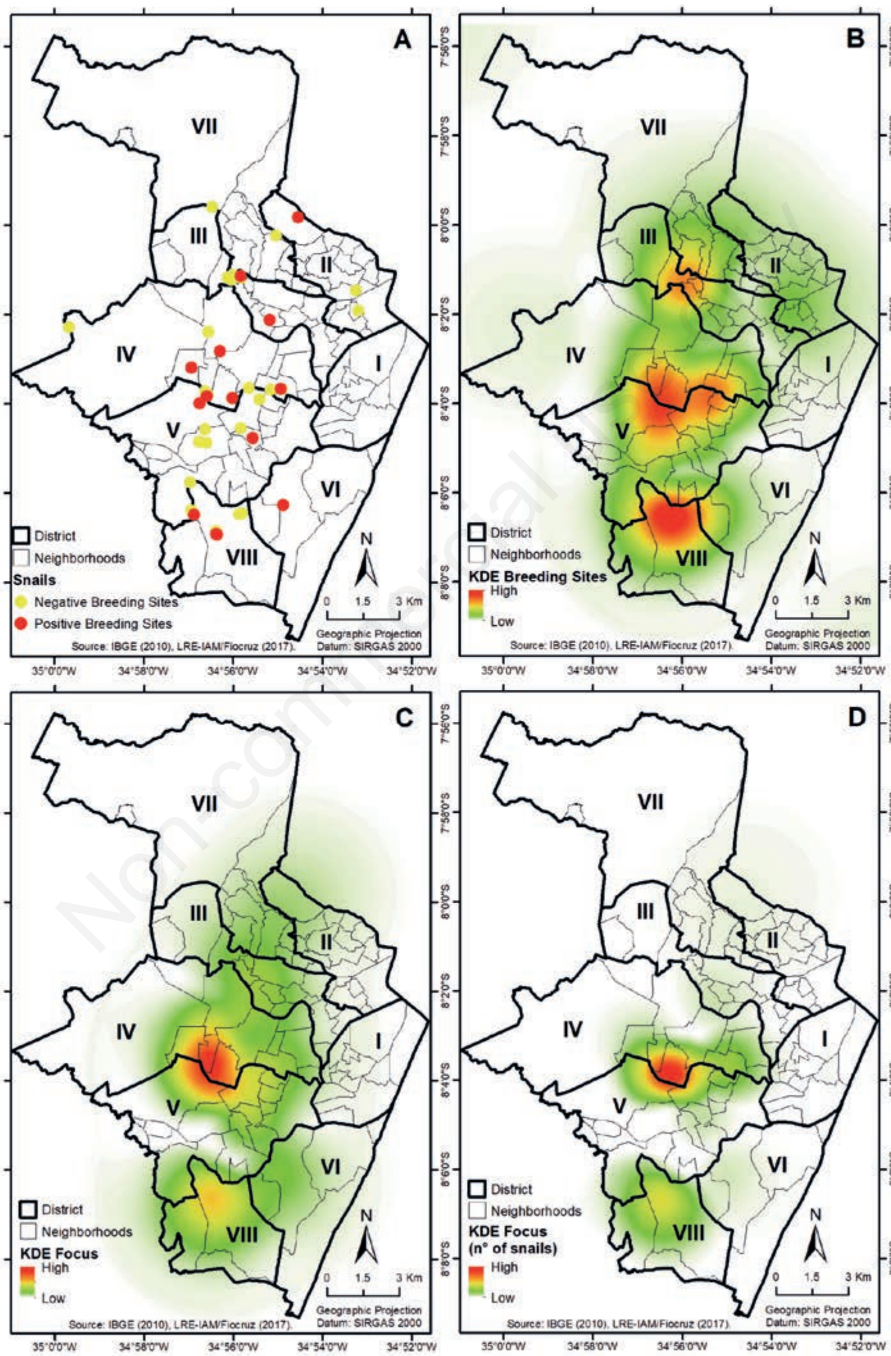


Figure 2. Spatial distribution of snail breeding sites and quantity of snails in the potential foci found in the neighbourhoods of Recife City, Pernambuco in the period 2016-2017. Distribution of breeding sites (A); Kernel (KDE) representation of the breeding sites (B); Kernel (KDE) representation of potential foci (C); and Kernel (KDE) representation of the number of snails per breeding site (D).

spatiotemporal data to detect spatial clusters and verify if they are statistically significant, and the relative risk is used to determine whether a particular location and/or time has a greater or lesser risk of a known event occurring (Kulldorff, 2018).

To identify the risk in each NH, the Map Algebra methodology was used. This tool summarizes the values of ten variables, five variables surveyed in the field and five census sectors of the IBGE for each NH and the combination (sum = Risk, which is represented as R) of the total values of the variables selected for the creation of a choropleth map of risk situations for schistosomiasis transmission. The representations of the values of the classes varied from no risk (0) to very high risk (10) with different levels symbolized by different colours as seen in Figure 4. Map Algebra was performed using ArcGIS 10.3 software (version 10.3).

Results

Forty-four breeding sites were identified in the city of Recife, from which a total of 3.800 snails were collected (Table 1). These sites (waterhole, dam, ditch, canal, stream or natural lake) were located in the peri-domicile of the NHs, 93.3% of which lacked correct sewage for the disposal of human waste, which then results in faecal contamination of the environment.

All snails collected were examined by the classical light exposure technique for potential release of *S. mansoni* cercariae and found to be negative. Breeding sites were investigated in the NHs of Recife (94), identifying them in 24.5% of all (23).

Thus, all samples collected *Biomphalaria* specimens were also examined by Nested PCR to verify the presence of *S. mansoni* DNA at each site. Out of the 44 breeding sites identified in this study, 14 (31.8%) were found to be positive for *S. mansoni* infection by these molecular tests (Table 1). In the NHs of Apipucos, Ibura, Prado, Torrões and Imbiribeira these foci were classified as peri-domiciliary. A greater number of foci were observed in the NHs of DS IV (Cidade Universitária, Engenho do Meio, Iputinga, Prado and Torrões), (Figure 2A). As can be seen in Figure 2B, the application of KDE identified three high-risk transmission clusters for schistosomiasis with the municipalities and number of inhabitants covered shown in Table 2. However, when applied for potential foci (positive breeding sites for *S. mansoni*), KDE only identified one high-risk cluster for schistosomiasis transmission (Figure 2C). This focus was situated between DS IV and V and DS V, while DS VIII only showed intermediate risk (represented by blue text), (Table 3).

By analyzing risk as expressed by snail density in the potential foci (Figure 2D), a high-risk cluster was identified in DS IV and V with intermediate risk in DS VIII (Table 4). This cluster was, however, smaller and more concentrated.

According to the SINAN there were 654 cases of schistosomiasis in Recife between 2007 and 2017. However, georeferencing showed two of the cases to be located in neighbouring municipalities (Olinda and Camaragibe), so only 652 cases were analysed in this research (Figure 3A). When KDE was applied for the cases reported in the SINAN (Figure 3B), several high-risk clusters (red in the Figure 3B) were detected: one between DS I and DS II and one in DS VIII; medium-risk ones (orange in the Figure 3B and blue text in Table 5) in DS II, DS IV and south of DS V, with a small area in DS VI and DS VII. In DS VIII there was also a medium-risk spot on the border between two NHs. Low-risk areas (yellow/green in the Figure 3B) were seen in all districts.

Cases were found in 75 neighbourhoods of Recife, with the most prevalent ones located in DS I, III, IV, V and VIII (Figure 3C). The highest prevalence was found in DS I (in a Santo Antônio/285 residents/ NH with 105 cases/100,000 inhabitants) and the lowest in DS II in Arruda/14,530 residents (0,6

Table 2. Distribution of neighborhoods and number of residents in Sanitary Districts (Distrito Sanitário, DS) III, IV, V and VIII with the presence of snail breeding sites that transmit schistosomiasis in the municipality of Recife.

DS III (municipality/no. of residents)	DS IV and DS V (municipality/no. of residents)		DS VIII(municipality/no. of residents)
Alto do Mandu/4,655	Cidade Universitária/818	Caçote/10,470	Ibura/50,617
Parnamirim/7,636	Cordeiro/41,164	Curado/16.418	
Monteiro/5,917	Engenho do Meio/10,211	Mustardinha/12,429	
	Prado/11,694	San Martin/25,414	
	Torrões/32,015	Jardim São Paulo/ 31,648	

Table 3. Distribution of neighborhoods and number of residents in the Sanitary Districts (Distrito Sanitário, DS) IV, V and VIII with the presence of snail breeding sites that transmit schistosomiasis in the municipality of Recife.

DS IV (municipality/no. of residents)	DS V (municipality/no. of residents)	DS VIII (municipality/no. of residents)
Cidade Universitária/818	Curado/16,418	Cohab/67,283
Engenho do Meio/10,211	San Martin/25,414	Ibura/50,617
Torrões/32,015		

Table 4. Distribution of neighborhood and number of residents in the Sanitary Districts (Distrito Sanitário, DS) IV, V and VIII with the presence of snail breeding sites that transmit schistosomiasis in the municipality of Recife.

DS IV (municipality/no. of residents)	DS V (municipality/no. of residents)	DS VIII (municipality/no. of residents)
Torrões/32,015	Curado/16,418	Cohab/67,283
		Ibura/50,617

cases/100,000 inhabitants). Curado/16,418 residents in DS V also had a low prevalence. No cases were registered in the19 districts covered by DS I, II, III, V and VII.

With respect to the case prevalence presented by by KDE (Figure 3D), two high-risk clusters in DS I (Santo Amaro/27,939 residents, Santo Antônio/285 residents and São José/ 8,688 residents) were identified. In addition, two medium-risk clusters in DS IV (Várzea/70,453 residents and Caxangá/9,634 residents) and DS VIII (Ibura/50,617 residents) were noted. For these DSs (I, IV and VIII), spatial analysis using SaTScan software identified a significant cluster in each.

A purely spatial analysis of the distribution of schistosomiasis cases by SaTScan and the Discrete Poisson model identified 3 clusters (marked with blue circles in Figures 3D and 4C), which had significant P-values, with the following Relative Risk (RR): 2,39 in the largest cluster; 3,18 in the smallest cluster and 5,00 in

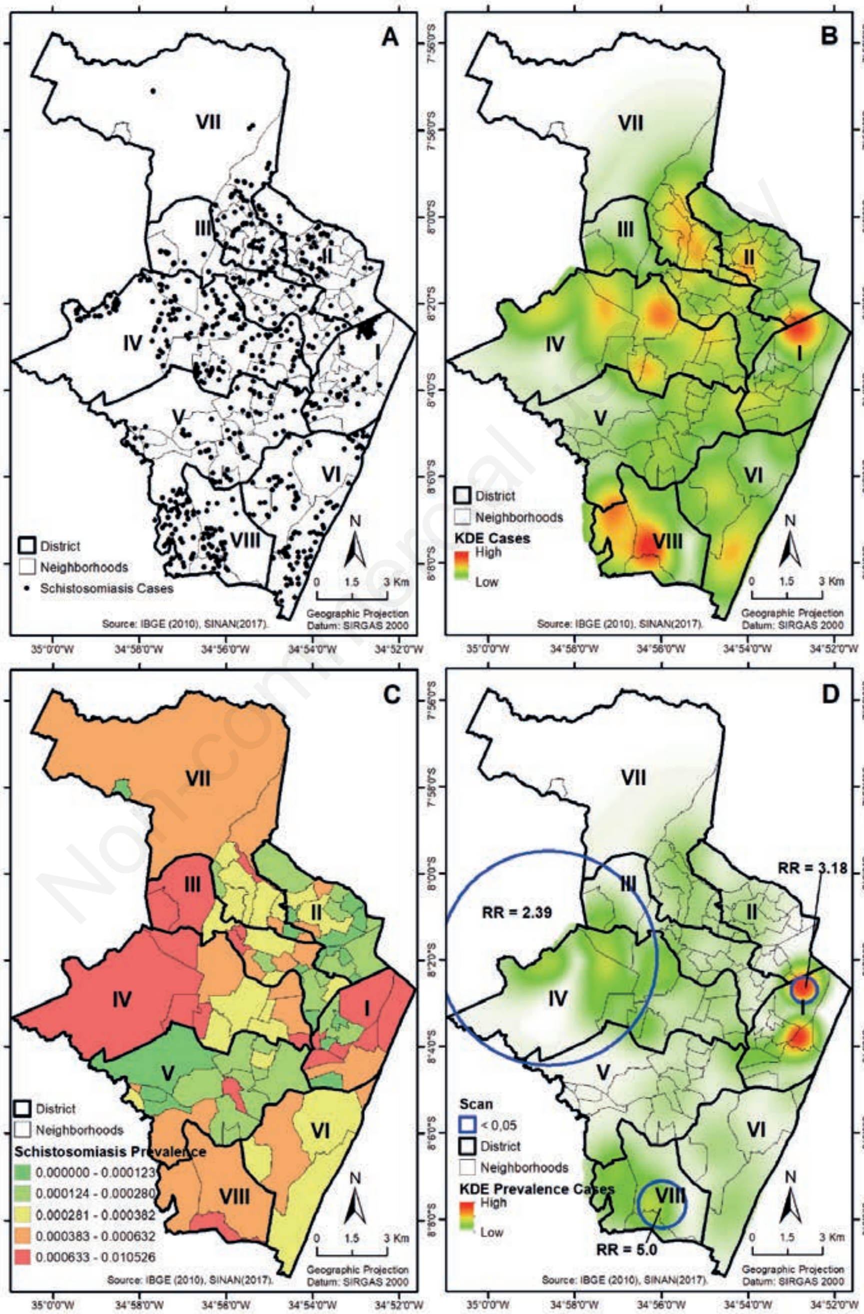


Figure 3. Prevalence of schistosomiasis and identification of statistically significant clusters in the neighbourhoods of Recife, Pernambuco in the period 2007-2017. The spatial distribution of schistosomiasis cases according to SINAN (A); KDE of the schistosomiasis cases (B); choropleth map of schistosomiasis prevalence by NH (C); case prevalence by KDE (D).

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the medium sized cluster. These three significant clusters encompassed 14 NHs in six DSs as shown in Table 6. The results in this analysis indicate that the risk for schistosomiasis was 2,39; 3,18 and 5,0 times higher for those living in the respective areas identified by the clusters (blue circles in the Figures 3D and 4C) compared to residents of other areas in the municipalities.

The application of Map Algebra with the variables of the census sectors of IBGE (waste water discharge and income as well as presence of paving, manholes and open sewage) and the information obtained in the field by the LRE-IAM/Fiocruz (vegetal cover, presence of faeces, flooding, number of snails, number of infected snails) as seen in Figure 4. The outcome of these investigations resulted in maps showing the variables of the census sectors of IBGE (Figure 4A); information obtained in the field by LRE-IAM/Fiocruz (Figure 4B); summation of the data from Figures 4A and 4B (Figure 4C), the latter also highlighting the three statistically significant agglomerations identified by SaTScan.

The map with the IBGE data (Figure 4A) is relatively homogeneous, generally with the low-risk NHs in West (green) and the medium-risk ones in the East (yellow) for most of the eastern NHs in the city of. Only the Recife NH (DS I) showed no transmission risk (white). The risk distribution according to the LRE-IAM/Fiocruz (Figure 4B) showed eight medium risk NHs (yellow); three high risk NHs (orange); and eight very high risk NHs (red), (Table 7). Only one NH (Vasco da Gama/31.025 residents - DS VII showed low risk (green) while all remaining NHs were without risk (white).

By combining the information provided by IBGE and that provided by LRE-IAM/Fiocruz, a new risk map (Figure 4C) was generated, which shows a decrease in the environmental risk for schistosomiasis with very high risk NHs now had moved to only high risk; while Prado - DS IV moved even further - from very high to medium risk.

Discussion

The findings of this study identified the existence of a large number of breeding sites with the presence of *B. straminea* (n=44), many of which included infected snails (n=14) that were therefore considered potential schistosomiasis transmission foci. Indeed, research transmission of schistosomiasis in urban areas is reported to have become more frequent (Santos *et al*., 2016), particularly after the rainy season when flooded streets provide expansion of the breeding sites to also other locations favouring the emergence of new transmission foci (Leal-Neto *et al*., 2013; Gomes *et al*., 2016). These flood situations, which are common in the city of Recife, thus expose the population to a higher risk of schistosomiasis transmission than before (Barbosa *et al*., 2013).

The geoprocessing tools used in this research were fundamental to determine the risk areas for schistosomiasis transmission in the capital of Pernambuco. For example, as seen in Figures 2 and 3, the spatial analysis based on KDE not only showed high-intensity clusters of snail breeding sites in DS VIII but also indicated a high number of schistosomal cases. This corroborates the risk of ongoing disease transmission in Recife, which has been shown in Lauro de Freitas in Bahia by Cardim *et. al.* (2011) and in the locality of Nova Tiúma Municipality of São Lourenço da Mata, Pernambuco by Galvão *et al*. (2010) in a similar way.

In the analysis of the environmental data of the breeding sites obtained by the LRE/IAM-Fiocruz (Figure 4B), it was observed

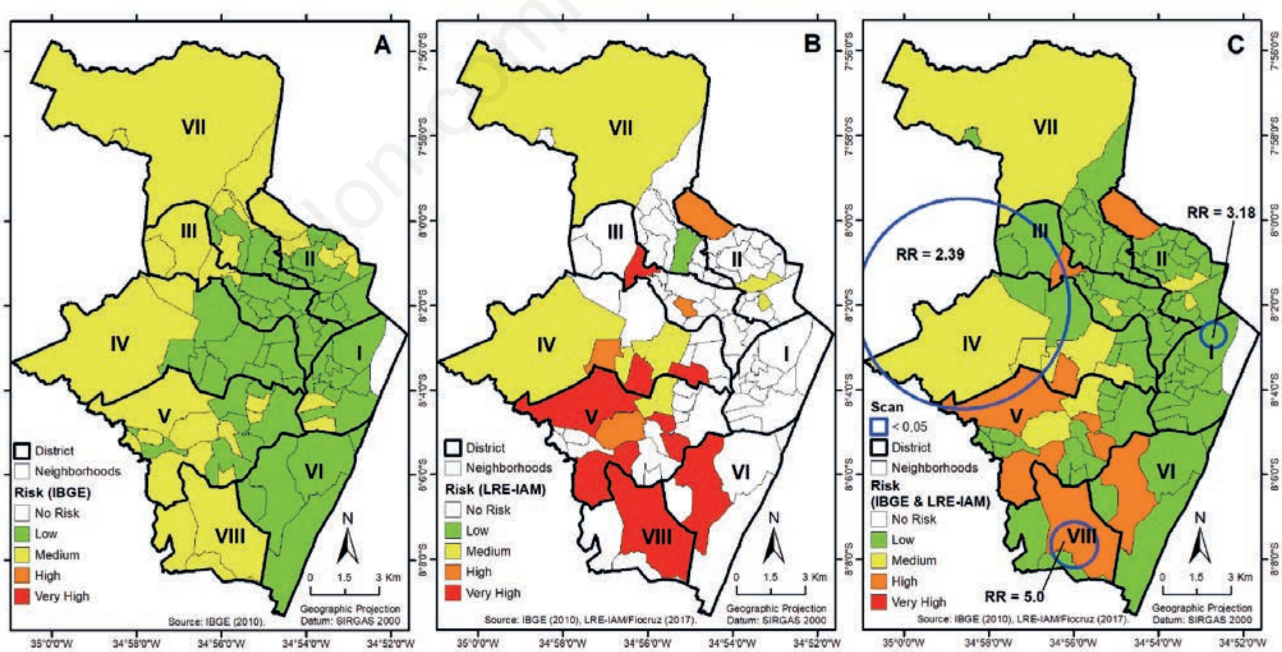

Figure 4. Risk for schistosomiasis transmission using the map algebra analysis technique by neighbourhood of Recife, according to environmental conditions. IBGE data (A); LRE-IAM/Fiocruz data (B); combined IBGE, LRE-IAM/Fiocruz and SaTScan data (C). Variables analyzed in IBGE: home without toilet, income, paving, manhole, open sewage; in LRE/AMI/Fiocruz: presence of faeces, vegetal cover, flooding, number of snails and number of infected snails.

that districts found to be classified as of high risk for schistosomiasis transmission are low-income housing settlement areas partly belonging to the special zones of social interest (Zonas Especiais de Interesse Social, ZEIS), (Prefeitura do Recife, 2019). Schistosomiasis is a disease determined by environmental and behavioural factors related to vulnerable population and as Recife generally has low rates of sanitary conditions, with 65% of the population lacking access to a sewage system (ITB, 2013), the high risk for schistosomiasis is understandable.

In the analysis of the situation with the Map Algebra methodology, it was observed that the risk map of Recife became more heterogeneous compared to the IBGE map with the sociodemographic data (Figure 4A) when the malacological and abiotic data obtained in the field research were added (Figure 4B). We noted the greater risk for schistosomiasis transmission in the NHs of Torrões, Prado, Curado, Jiquiá, Barro, Ibura, Dois Irmãos, Casa Forte, Cidade Universitária and Jardim São Paulo, which demonstrates the importance of collecting environmental data in the snail breeding sites in order to determine the risk more accurately.

When analyzing IBGE and LRE-IAM/Fiocruz data together (Figure 4C) most NHs located in these areas the risk was shown to have decreased with regard to environmental influence in the transmission of the disease from very high (LRE-IAM/Fiocruz) to only high (IBGE variables). The combination of these data visualized a more realistic environmental situation as it analyzed the global sanitation data by NH and the environmental conditions found in the breeding sites. In addition, as we were working with census data by NH (average of data from the IBGE census sectors), it became less pronounced. IBGE data are important for the study, as they are standardized throughout Brazil and makes it possible to reproduce the study in other areas (municipalities, states) without the cost of field work. By overlapping the combined IBGE and LRE-IAM/Fiocruz data with statistically significant cases obtained through cluster analysis by SaTScan (Figure 4C), it was observed that the cluster with the highest RR (5,0) was located in the Ibura NH (DS VIII), a place that presented high environmental, sociodemographic and malacological risk. Based on these findings, the need for greater attention for surveillance and control actions of

Table 5. Distribution of schistosomiasis cases by neighborhood and number of residents in the Sanitary Districts (Distrito Sanitário, DS) I, II, IV, V, VI, VII and VIII in the municipality of Recife.

DS I (municipality/no. of residents)	DS II (municipality/no. of residents)	DS IV (municipality/no. of residents)	DS V (municipality/no. of residents)	DS VI (municipality/no. of residents)	DS VII (municipality/no. of residents)	DS VIII (municipality/no. of residents)
Santo Amaro/ 27,939	Campo Grande/ 32,149	Engenho do Meio/10,211	Barro/ 31,847	Boa Viagem/ 122,922	Brejo do Beberibe/8,292	Ibura/ 50,617
	Torreão/1.083	Iputinga/ 52,200			Macaxeira/ 20,313	Jordão/ 20,777
	Água Fria/43,529	Várzea/ 70,453			Nova Descoberta/34,212	Cohab/67,283
	Bomba do Hemetério/8,472	Torrões/ 32,015			Vasco da Gama/31,025	

Table 6. Distribution of neighborhoods and number of residents in Sanitary Districts (Distrito Sanitário, DS) I, II, IV, V, VII and VIII with the presence of a relative risk for schistosomiasis in the municipality of Recife.

DS I (municipality/no. of residents)	DS II (municipality/no. of residents)	DS IV (municipality/no. of residents)	DS V (municipality/no. of residents)	DS VII (municipality/no. of residents)	DS VIII (municipality/no. of residents)
Santo Amaro/27,939	Dois Irmãos/2,566	Caxangá/9,634	Curado/16,418	Guabiraba/6,330	Ibura/50,617
	Parnamirim/7.636	Cidade Universitária/818			Jordão/20,777
	Sítio dos Pintos/7,276	Cordeiro/ 41,164			
		Engenho do Meio/10,211			
		Iputinga/ 52,200			
		Várzea/70,453			

Table 7. Risk classification for schistosomiasis in the neighborhoods and number of residents by Health Districts (Distrito Sanitário, DS) of the municipality of Recife.

Medium risk NHs (municipality/no. of residents)		High risk NHs (municipality/no. of residents)		Very high risk (municipality/no. of residents)	
Arruda/14,530	DS II	Dois Unidos/32,905	DS II	Parnamirim/ 7,636	DS III
Hipódromo/2,658	DS II	Cidade Universitária/818	DS IV	Prado/11,694	DS IV
Casa Forte/6,750	DS III	Jardim São Paulo/31,648	DS V	Torre/17,903	DS IV
Cordeiro/41,164	DS IV			Barro/31,847	DS V
Engenho do Meio/10,211	DS IV			Curado/16,418	DS V
Várzea/ 70,453	DS IV			Jiquiá/ 10,245	DS V
San Martin/25,414	DS V			Imbiribeira/48,512	DS VI
Guabiraba/6,330	DS VII			Jordão/20,777	DS VIII

schistosomiasis here is clear because people are constantly becoming infected and thus maintaining the disease transmission cycle in this area. The area with the lowest RR (2,39) in the analysis of schistosomiasis cases encompassed NHs of DS III, IV and V with high, medium and low environmental risk, respectively (Figure 4C). This underlines that surveillance and control of schistosomiasis are necessary also in these areas. DS I (Santo Amaro NH) presented a RR of 3,18 when analyzing schistosomiasis cases; however, its risk was low when considering the available environmental, malacological and sociodemographic data (IBGE + LRE/IAM/Fiocruz) requiring only health education regarding the transmission of schistosomiasis. People testing positive in this area were probably infected in other locations as no breeding sites were found in this NH. However, if any breeding sites would occur in the future, this would be a risk area for outbreaks of disease transmission as there are a large number of infected people in these areas. In the whole study area, only the Recife NH (DS I) was devoid of risk for schistosomiasis transmission. According to the Municipal Health Plan (2014 - 2017), the Recife District, also known as Old Recife, is one of the least populous in the city. It is the historical centre with old big houses and therefore a main tourist attraction rather than a fully functioning urban area, which explains the absence of risk in this NH (Gonçalves, 2015).

Although districts show differences with respect to the degree of social vulnerability, the Recife NHs of are characterized by mixed occupation and may integrate subnormal agglomerate areas. The capital has the characteristic of a heterogeneous city, where areas with enormous structural problems are located in direct contact with highly valued areas (Gonçalves, 2015; Santos, 2012). Over time the demographic increase and unplanned urban growth predisposed the emergence of subnormal clusters, mainly in the peripheral regions with several locations lacking basic infrastructure (Castilho, 2011). Such observations express a pertinent interaction between disordered urban sprawl and the formation of places vulnerable to schistosomiasis transmission. Thus, studies integrating social variables through multifactorial analysis, while Map Algebra made it possible to identify the representativeness of environmental vulnerability in the face of an infectious disease as pioneered by Buffon (2018).

Despite advances in knowledge regarding schistosomiasis, the disease persists as a public health problem in Brazil. This requires a substantial allocation of financial resources for prevention measures, such as sanitary drainage and health education, as well as organizing surveys enabling the collection of malacological and parasitological data. Schistosomiasis control can be further improved when combined with geoprocessing for breeding sites and creation of transmission risk maps as recommended by WHO (2002) a utilized in this presentation.

Conclusions

As demonstrated in this paper, both primary and secondary data as well as the use of spatial analysis tools are of fundamental importance to locate high-risk areas for transmission of schistosomiasis when considering the environmental, human and malacological aspects. These tools provide facts that are necessary for the planning of control actions in a timely manner, enabling the expansion of disease surveillance in areas where populations are vulnerable in different regions and environments where

The lack of basic sanitation, faecal contamination of water and the presence of *Biomphalaria* snails are prerequisites for the transmission of *S. mansoni*, increasing the risk factors for its occurrence. The Map Algebra analysis technique turned out to be fundamentally important as it demonstrated places with a high probability of schistosomiasis transmission. Such findings may assist managers in the elaboration of health planning in disease control actions.

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