

Space-temporal analysis of Chagas disease and its environmental and demographic risk factors in the municipality of Barcarena, Pará, Brazil

Análise espaço-temporal da doença de Chagas e seus fatores de risco ambientais e demográficos no município de Barcarena, Pará, Brasil

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ABSTRACT: Introduction: Chagas disease is a parasitosis considered a serious problem of public health. In the municipality of Barcarena, Pará, from 2007 to 2014, occurred the highest prevalence of this disease in Brazil. **Objective:** To analyze the disease distribution related to epidemiological, environmental and demographic variables, in the area and period of the study. **Methods:** Epidemiological and demographic data of Barcarena Health Department and satellite images from the National Institute For Space Research (INPE) were used. The deforestation data were obtained through satellite image classification, using artificial neural network. The statistical significance was done with the χ^2 test, and the spatial dependence tests among the variables were done using Kernel and Moran techniques. **Results:** The epidemiological curve indicated a disease seasonal pattern. The major percentage of the cases were in male, brown skin color, adult, illiterate, urban areas and with probable oral contamination. It was confirmed the spatial dependence of the disease cases with the different types of deforestation identified in the municipality, as well as agglomerations of cases in urban and rural areas. **Discussion:** The disease distribution did not occur homogeneously, possibly due to the municipality demographic dynamics, with intense migratory flows that generates the deforestation. **Conclusion:** Different relationships among the variables studied and the occurrence of the disease in the municipality were observed. The technologies used were satisfactory to construct the disease epidemiological scenarios.

Keywords: Epidemiology. Spatial analysis. Chagas Disease.

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RESUMO: Introdução: A doença de Chagas é uma parasitose considerada um grave problema de saúde pública. No município de Barcarena, Pará, de 2007 a 2014, ocorreu a maior prevalência dessa doença no Brasil. **Objetivo:** Analisar a distribuição dessa doença relacionada às variáveis epidemiológicas, ambientais e demográficas, na área e no período do estudo. **Métodos:** Foram utilizados dados epidemiológicos e demográficos da Secretaria Municipal de Saúde de Barcarena e imagens de satélites do Instituto Nacional de Pesquisas Espaciais. Os dados de desmatamento foram obtidos por classificação de imagens de satélites, utilizando rede neural artificial. As análises de significância estatística foram realizadas com o teste do χ^2 , e as de dependência espacial entre as variáveis, com as técnicas de Kernel e Moran. **Resultados:** A curva epidemiológica indicou um padrão sazonal da doença. O maior percentual dos casos foi em indivíduos do sexo masculino, pardos, adultos, analfabetos, da zona urbana e com provável contaminação oral. Foi confirmada dependência espacial dos casos da doença com os diferentes tipos de desmatamento identificados no município, bem como aglomerados de casos em áreas urbanas e rurais. **Discussão:** A distribuição da doença não ocorreu de forma homogênea, possivelmente pela dinâmica demográfica do município, com intensos fluxos migratórios que causam os desmatamentos. **Conclusão:** Foram observadas diferentes relações entre as variáveis estudadas e a ocorrência da doença no município. As tecnologias utilizadas foram satisfatórias para a construção dos cenários epidemiológicos da doença.

Palavras-chave: Epidemiologia. Análise espacial. Doença de Chagas.

INTRODUCTION

Chagas disease (CD) is an infectious disease, caused by the protozoan *Trypanosoma cruzi* (*T. cruzi*), which has vector the triatomine insects known as barbers, among other names¹. Severe cases of CD are characterized by cardiac and digestive impairment². This disease can be transmitted to man in different ways - vector, oral, transfusion, among others³⁻¹⁰.

The World Health Organization (WHO) estimates that 5.7 million people are infected with *T. cruzi* worldwide, with Brazil having one of the highest frequencies of this disease in the last decades - about 1.1 million individuals infected¹¹. This fact is related, among others, to the development of anthropic activities of deforestation and occupation of environmentally fragile areas¹²⁻¹⁵. This reduces the natural sources of food and shelter of triatomines, which feed on domestic animals and, eventually, of the man himself, conditioning the processes of peridomestication and domicialization of the disease^{12,13,16}.

In Brazil, most of the diagnosed cases of CD are chronic, although in recent years, acute CD (ACD) has occurred expressively, usually related to the consumption of food contaminated by the pathogen, such as cane juice, açai, babaçu palm, jaci (coquinho), bacaba and buriti^{13,15,17-20}. The Amazon region is considered historically endemic for ACD, and outbreaks in the form of family micro epidemics are common in urban and rural areas^{17,22-25}.

In the state of Pará, CD presents an epidemiological profile with evidence of oral transmission outbreaks in some municipalities, such as Belém (48 cases) between 1968 and 2010; Abaetetuba (19 cases), from 1998 to 2010; Ananindeua (9 cases), from 2003 to 2010;

Barcarena (8 cases), from 2002 to 2010; among others^{23,25}. This possible form of transmission demonstrates the complexity of the epidemiological chain of this disease. In the period from 2007 to 2014, 884 acute and chronic cases of CD were diagnosed in 39 municipalities of this state, and in the Belém microregion, about 130 new and autochthonous cases are reported annually^{11,26}.

Among these municipalities, Barcarena presented the fourth highest number of confirmed cases of CD and the highest prevalence of this disease in Brazil, with a rate of 89.38 cases per 100 thousand inhabitants²⁶. This indicator assumes epidemiological importance due to the migratory flow because of its intense industrialization process that occurred in the last decades, which is related to sociodemographic risk factors of this disease in the municipality, such as unhealthy labor activities, low educational level and population density^{13,16}.

Considering the relationship of the epidemiology of CD with environmental and sociodemographic variables occurring differently in times and places, geotechnologies have assisted in the production of ecoepidemiological analyzes^{27,28}. Thus, several analyzes of the spatial distribution of this disease have used Geoprocessing techniques (GEO)^{29,30}.

Artificial neural networks (ANNs) are artificial intelligence (AI) techniques based on the cognitive learning process, used in epidemiology to automatically classify environmental and demographic information, among others. This technique of AI is used in the health area due to its potential to raise information contained in satellite images related to the characteristics of environments where nosological phenomena occur³¹.

Considering the possibility of a spatial relationship between the epidemiological, environmental and demographic variables, this study aimed to analyze, in the period between 2007 and 2014, the distribution of ACD and the different intraregional characteristics of the city of Barcarena due to the high prevalence of disease, in relation to the state of Pará.

METHODS

This descriptive and cross-sectional study started with a review of the literature on the epidemiology of CD and its relationship with environmental and demographic variables. The study included 83 confirmed cases of ACD, which were compulsorily reported by the Health Department of the Municipality of Barcarena (SESMUB), all of whom were residents of the city in the period from 2007 to 2014.

Due to data from secondary sources, approval by the Research Ethics Committee was not necessary.

Epidemiological data - gender, age, ethnicity, schooling and probable type of contamination - were obtained from the Notifiable Diseases Information System (SINAN); demographic data - zones, districts and localities - in the 2010 Census database, using cartographic bases, in the SIRGAS 2000 projection of the Brazilian Institute of Geography and Statistics (IBGE).

The environmental data - deforestation, land cover and land use - were obtained by automatically classifying an image of the LandSat TM-5 satellite, in the 1:250,000 scale, acquired at the National Institute for Space Research (INPE). For this, an ANN was used, with Back Propagation algorithm. The classification considered the color primitive, with the learning rate of 0.9 and number of interactions equal to 100. Subsequently, the total area of each environmental class was calculated using the calculate geometry technique, in the sense of a quantitative evaluation of its occurrence in the municipality.

In order to filter the variables data by removing incompleteness, redundancy and inconsistencies, a debugging process was performed using the TabWin 3.6 program.

Three expeditions were then made to the study site. In the first, meetings were held with communities and municipal health and environmental managers in order to present the project and establish partnerships for its development. In the second, the studied variables were georeferenced, such as the addresses of the patients with confirmed cases of ACD and the type of coverage and use of the soil. And in the third one, the georeferencing of the highway and waterway network of the municipality was carried out, in the sense of digitally reconstituting its streets, rivers and vicinities, aiming to update the cartographic databases due to the need to visually express the correct location of the studied variables.

The georeferencing of the addresses of the residences of all 83 patients with ACD was performed with the use of a Global Positioning System (GPS) receiver. This technique was necessary for the indexation of these addresses in the cartographic databases of the districts of the municipality in the sense of the interrelationship of the environmental and demographic variables, aiming at the implementation of the Geographic Database (BDGEO), with ArcGis 10.2 software.

The indicators generated by the descriptive and inferential analyzes of the epidemiological and demographic variables were presented through a table and a graph using the Epi Info 7 and Bioestat 5.0 programs. For the hypothesis tests, the χ^2 adherence test was used, as it allowed the evaluation of the statistical significance of the cited variables, with a significant result for a p-value < 0.05 .

In this study, the territories of the five administrative regions of Barcarena - Headquarters, Morucupi, Vila do Conde, Islands and Roads - were used as spatial analysis units due to their capacity to represent the intraregional characteristics of the municipality, in accordance with the Master Plan of Urban Development of the Municipality of Barcarena³².

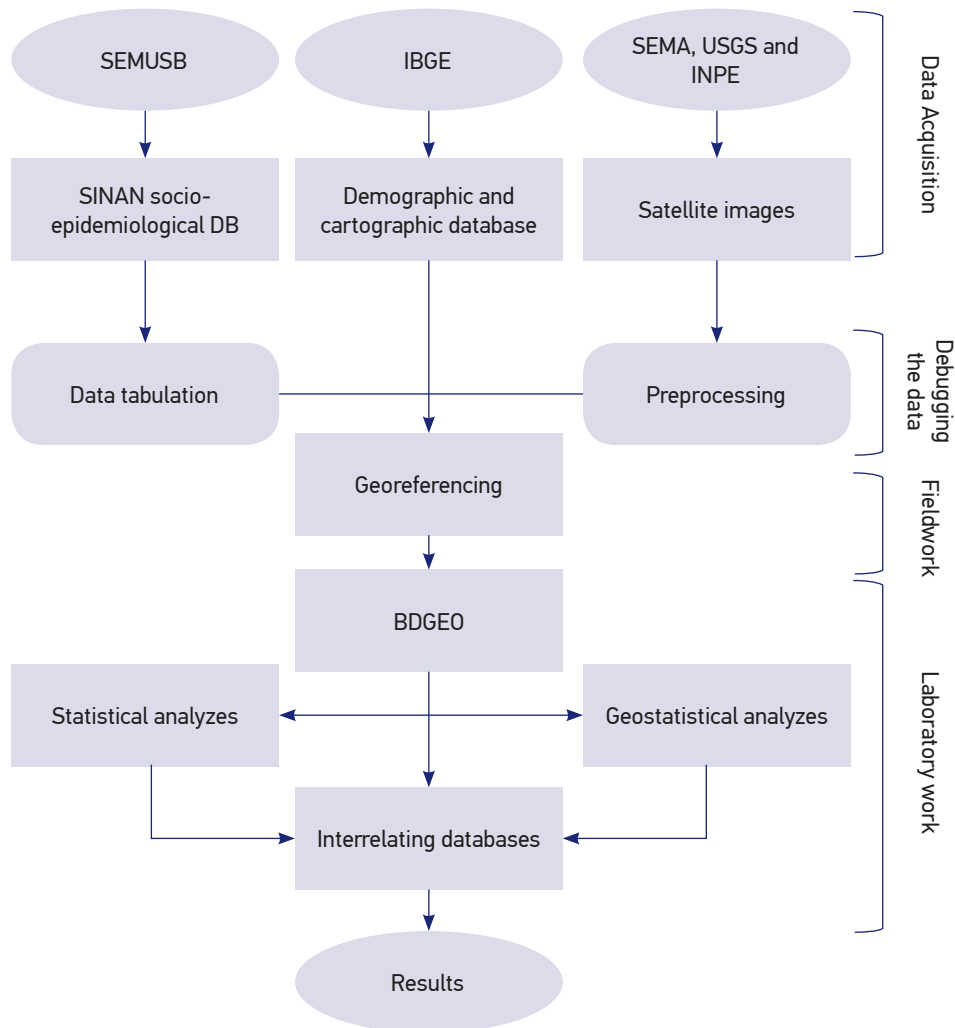
Moran index (I) was used to evaluate spatial autocorrelation between areas with deforestation and DCA cases, which, when being spatialized variables, allowed “negative” or “inverse” autocorrelation hypotheses ($I < 0$), “randomness” ($I = 0$) and “positive” or “direct” ($I > 0$) - all with spatial statistical significance for $p < 0.05$ ³³.

To evaluate the pattern of case distribution, we used the statistical method of estimation of density curves called Kernel, with a distance of up to 300 meters between the cases^{30,34}. These analyzes were generated through the software ArcGis 10.2 and TerraView 4.3.3.1. The graphical systematization of the adopted methodology can be observed in Figure 1.

RESULTS

The 83 confirmed cases of ACD in the municipality of Barcarena occurred differently in the 5 administrative regions, and the highest number of cases was observed in the Headquarters region (29), followed by Morucupi (24), Islands (16), Roads (8) and Vila do Conde (6).

The analysis of the cases occurred in the period of study showed a high prevalence of this disease in Barcarena in relation to the state of Pará, with a rate of 89.38 cases per



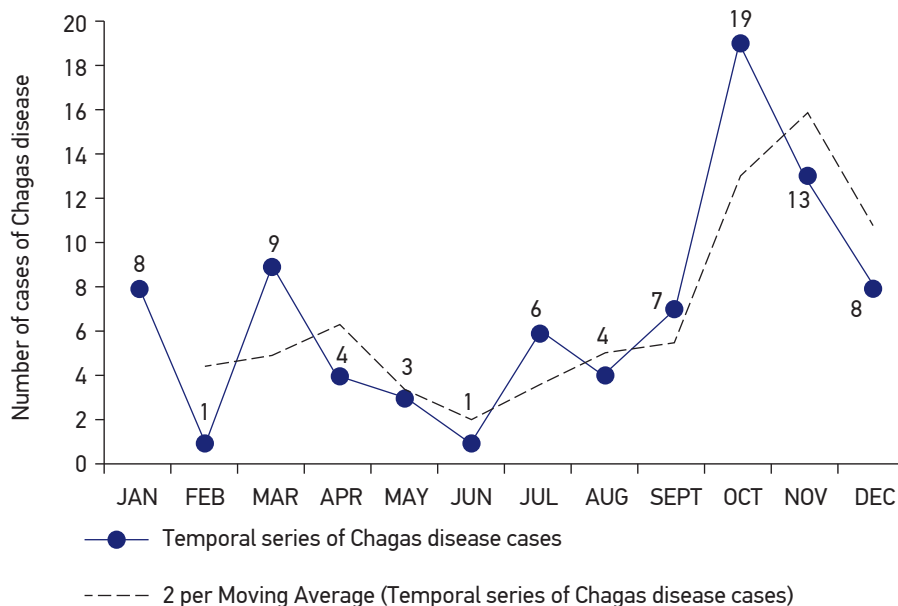
SESMUB: Health Department of the Municipality of Barcarena; IBGE: Brazilian Institute of Geography and Statistics; SEMA: State Department of Environment; USGS: United States Geological Survey; INPE: National Institute of Space Research; DB: Database; BDGEO: Geographic Database; SINAN: Notifiable Diseases Information System.

Figure 1. Systematization of the work methodology.

100 thousand inhabitants and a lethality of 6.02% (5 in 83 cases). The epidemiological reporting curve per month in the study period showed a pattern of seasonal distribution, with fewer cases and a decreasing trend in the first semesters of the series. However, there were significant peaks or increases in the number of cases in the second semesters, especially in the months of October, as shown in Figure 2.

The analysis of the epidemiological profile showed that the gender variable was not statistically significant. The highest percentage of cases of infection occurred in the brown population (74.70% - 62/83); in the adult age group - 18 to 59 years old (56.63% - 47/83); among the illiterate (66.27% - 55/83); among residents of the urban area (53.01% - 44/83); and the possible source of oral transmission (69.88% - 58/83). It was observed that all the epidemiological and demographic variables were significant, with p-value < 0.05, except gender, which presented a p-value of 0.3799 (Table 1).

The classification of digital images of satellites using ANN identified areas in the municipality where anthropic relations based on deforestation occurred with various forms of land use - exposed soil, pasture, mining and urban mesh. The use of the bivariate Moran's I showed a significant spatial relationship between the location of ACD cases and the recent deforestation in the studied period, with p-value = 0.0001 for all areas. This technique also showed a direct relationship between these two variables, with positive indexes ($I > 0$) in the five regions of the municipality, namely: Roads, with $I = 0.81$; Islands Region, with $I = 0.73$; Vila do Conde, with $I = 0.46$; Morucupi, with $I = 0.31$; and Headquarters, with $I = 0.19$. These data can be checked in Figure 3.



*p = 0,0001.

Figure 2. Monthly seasonal analysis of Chagas disease cases, 2007 to 2014, Barcarena, Pará.

Table 1. Quantification and frequency of cases of Chagas disease in relation to the main epidemiological and demographic variables, 2007 to 2014, Barcarena, Pará.

Variable	n	%	p-value
Gender			
Male	46	55,42	0,3799
Female	37	44,58	
Ethnicity			
White	8	9,64	< 0,0001
Black	1	1,20	
Yellow	1	1,20	
Brown	62	74,70	
Indigenous	0	0,00	
Ignored	11	13,26	
Age group (years)			
Child (1 to 12)	18	21,69	< 0,0001
Adolescent (13 to 17)	11	13,25	
Adult (18 to 59)	47	56,63	
Elderly (60 or over)	7	8,43	
Schooling			
Illiterate	55	66,27	< 0,0001
Middle School	18	21,68	
High School	6	7,23	
Superior	4	4,82	
Zone			
Urban	53	63,86	0,0157
Rural	30	36,14	
Probable source of transmission			
Oral	58	69,88	0,0001
Vector	17	20,48	
Ignored	8	9,64	
Total	83	100,00	

The Kernel technique showed a pattern of spatial distribution of confirmed cases of ACD, with agglomerates in urban areas such as the Headquarters and Morucupi regions. Thus, the ACD in Barcarena is not homogeneously distributed, which was observed from the characterization of areas with different densities of cases (Figure 4).

DISCUSSION

In the study period, the municipality of Barcarena presented the highest prevalence of CD in Brazil²⁶. This fact may be associated to the particularities of the demographic dynamics

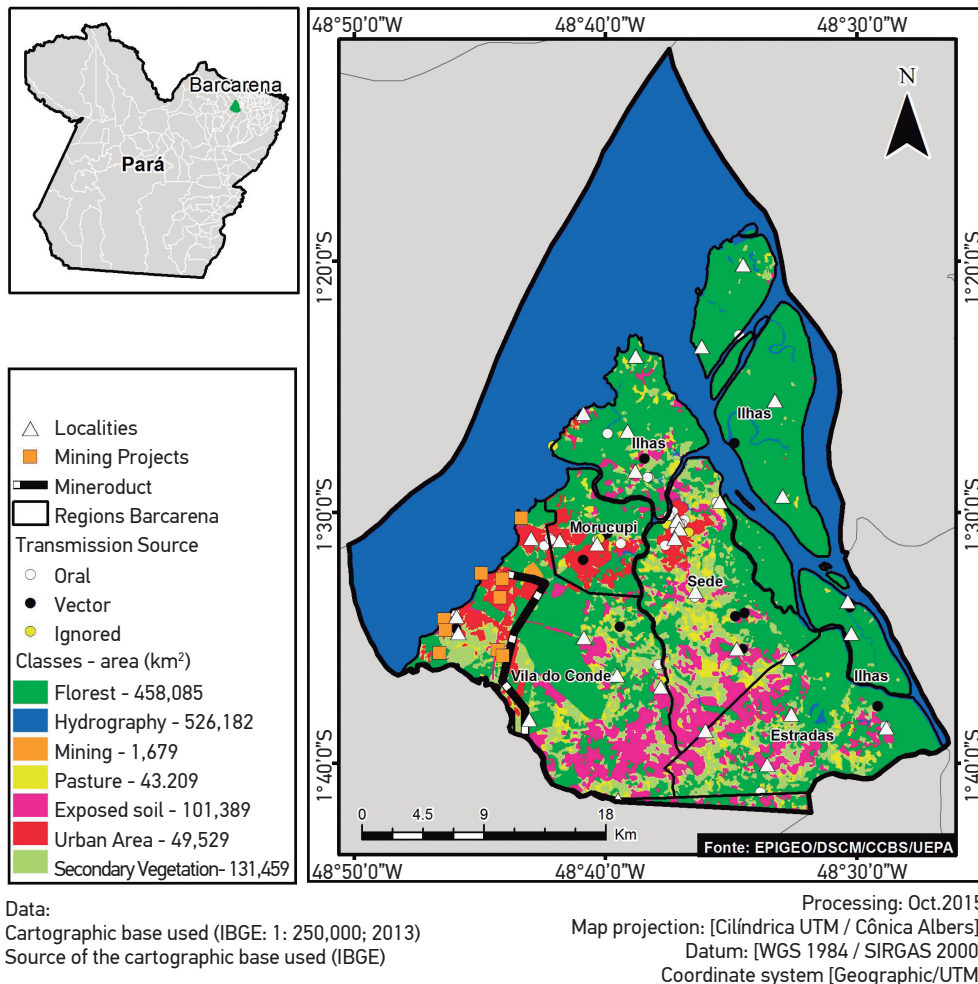


Figure 3. Environmental classification and spatial distribution of Chagas disease cases, 2007 to 2014, Barcarena, Pará.

- migratory flow and precarious housing conditions of the populations -, to the environmental factors - occupation of floodplain areas, mainly in the Islands Region, where palm trees are found (ecotypes preferences of triatomines) - and to economic activities - ostensible cattle raising, mining, highway openings, and disorderly expansion of the urban network -, which influence the permanence of the disease^{4,12,13,15,16}.

The seasonal distribution of the confirmed cases of ACD occurred more expressively in the second semester of the analyzed years, especially in the months of October - which comprise the driest season of the year - characterized by lower rainfall and higher temperatures. These periods are also marked by the greater occurrence of deforestation by means of burning, increasing the temperature in certain regions of the municipality³⁵.

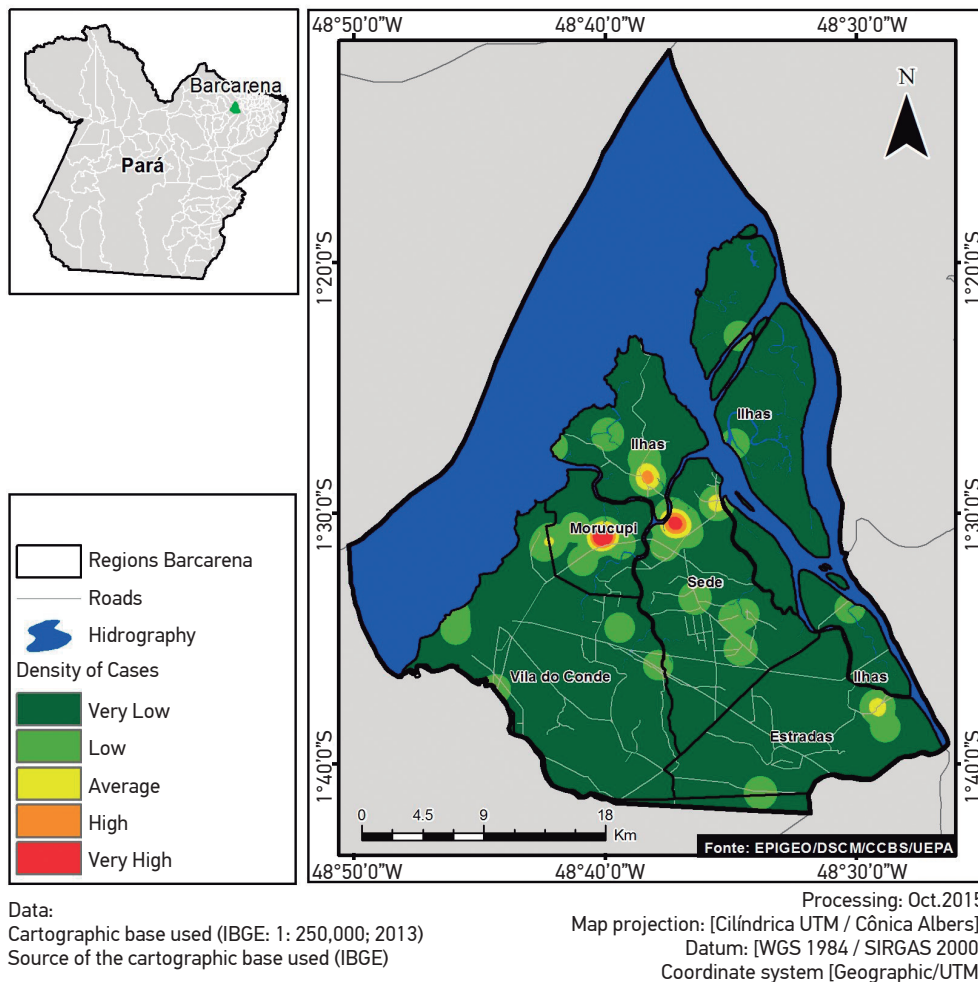


Figure 4. Density of Chagas disease cases, 2007 to 2014, Barcarena, Pará.

Thus, the increase in the number of cases and the temperature in the second semester may be related to the dispersion of the vectors of the disease, which move from their wild environment to the human peridomesticum^{36,37}, increasing the chances of vector transmission. This period is also characterized by the higher açai crops, which, when contaminated by the pathogen and incorrectly handled, may have their consumption related to the evidence of oral transmission of the disease^{17,21,22,24}.

In the present study, it was observed that the number of ACD cases in relation to gender did not present a statistically significant difference, and there was no risk of contamination related to this variable³⁸. Regarding ethnicity, the prevalence of ACD in brown individuals was observed. However, a study carried out in Salvador, Bahia, indicated the black ethnic group as the one most associated with the prevalence of the disease, due to its social fragility³⁹.

Regarding the age group, most of the individuals affected by ACD are of productive age (18 to 59 years)⁴⁰, suggesting the relationship between work activities and the risk factors of disease transmission, that is, the frequent exposure of rural populations (islands and roads) to live with the vectors contaminated with the pathogen, through the extraction of açai and family farming, among other activities^{13,41,42}.

With regard to schooling, the highest number of cases occurred in individuals with low schooling, evidencing the social vulnerability in which they are inserted. The precarious economic situation of this part of the population causes it to live in the periphery, where the lack of sanitary infrastructure and basic education is a risk factor that exposes it to the different types of CD transmission. In this sense, several studies have shown that an expressive number of chagasic patients presented low level of education, including illiteracy^{38,43}.

It was observed that most of the confirmed cases occurred in the urban area of the municipality, corroborating studies carried out in the Amazon that have indicated changes in the epidemiological profile of the disease, in which isolated acute cases or family micro epidemics were registered^{17,21,22,24}. Regarding the probable source of transmission, the highest number of records presented oral form, which may be associated with the ingestion of contaminated regional fruit juices, such as açai and bacaba^{17,21,22,25}.

The results showed a significant relationship between the areas where deforestation occurred and the areas with ACD cases in the municipality of Barcarena. This fact is conditioned by the historical dynamics of occupation of the territory, which, due to the establishment of developmentalist projects, has undergone intense migratory flows in the last decades, generating several types of anthropism - pasture, mining, urban sprawl, among others⁴⁴⁻⁴⁶.

The dynamics of occupation implied the formation of new urban and periurban centers in environmentally fragile areas and the occurrence of the disease in these localities, either by oral or vector transmission. This change in the epidemiological profile of CD, which in the past was restricted to wild environments, evidenced a process of urbanization of the disease²⁰.

Spatial analysis using the Kernel technique showed that the distribution of ACD in the municipality did not occur homogeneously. The Islands Region presented low environmental impact and low case density, except in Trambioca Island, where high density of the disease was observed, with seven confirmations in the same family, characterizing a micro epidemics - these events have been reported in previous studies in the Amazon region^{17,23}.

The Headquarters and Morucupi regions presented high deforestation and high density of cases, possibly related to an ACD urbanization process, with probable source of oral transmission, pointing to the establishment of a different epidemiological cycle of the other areas, which were by vectorial transmission. The Vila do Conde and Roads regions presented high deforestation and low density of cases, a fact that can be explained by the distance between their locations, whose distribution was random.

Moran's I showed direct spatial correlations in all areas with different intensities. The Islands Region was considered strong due to the low anthropism and the highland forests rich in palm trees, preference ecotypes of triatomine and risk factors of CD to the resident population. In the Headquarters and Morucupi regions, the correlation was weak, due to the diverse anthropisms present in these areas, with low density of triatomines^{24,47} and probable source of oral transmission.

Within the scope of the development of this study limitations were observed in the analysis of the epidemiological variables. This may be related to the inadequate process of reporting data in municipal epidemiological surveillance systems.

CONCLUSION

In this study, we observed the existence of different epidemiological, environmental and demographic relationships associated with the notification of CD in the municipality of Barcarena, between 2007 and 2014. These relationships were characterized by a seasonality, with a higher occurrence of cases in the second semesters, when there are high temperatures and low rainfall rates. The socioepidemiological profile of the individuals affected by the disease was: low level of education, being adult, being brown, possible form of oral transmission and being resident of urban area, evidenced visually with the Kernel technique, also showing different densities of cases in the diverse territories.

From the automatic classification of satellite images, deforestation and several types of land occupation were observed in the municipality, occurring in a differentiated way in the areas of the five administrative regions. The analysis of the spatial correlation between the epidemiological and environmental variables using Moran's I showed an inhomogeneous distribution of the disease.

In the Headquarters region, the possible source of transmission was oral, with clusters of cases in the urban area. In the Islands Region, a possible vector transmission was observed, with expressivity of the disease in an area of secondary vegetation and in floodplain forest,

where there are large numbers of palm trees and populations residing in the local, being areas of great risk of contamination associated with deforestation.

Considering the different relations of the studied variables, the computational tools used in the spatial analysis of the data were satisfactory for the construction of ecopidemiological scenarios of ACD. Thus, these tools present great potential to provide health managers with information of continuous and systematic surveillance of the disease studied.

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