

Triatomine dispersion rates and their association with socioeconomic and environmental conditions in Northeastern Brazil, from 2009 to 2013

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ABSTRACT

Triatomines are vectors of *Trypanosoma cruzi*, the etiological agent of Chagas disease, which affects between 6 and 12 million people in Latin America, with an incidence rate of 12 thousand cases per year. In the Ceara State, the predominance of the caatinga biome, coupled with a large rural area with precarious human habitations, provides several shelters for these insects. In this study, we determined the spatiotemporal distribution of triatomine dispersion rates in the Cariri region, Southern Ceara and ascertained the possible association between these rates with socioeconomic and environmental factors. Dispersion rates (number of positive localities/number of searched localities × 100) were analyzed regarding 13 municipalities from the Ceara State, from 2009 to 2013. Socioeconomic and environmental variables collected from national research institutes were associated with the dispersion rates and their local empirical Bayesian estimates. All the municipalities recorded dispersion rates over 10% in all years, and 11 municipalities had average rates over 40% for the period of study. Significant differences were observed among the municipality means. The highest rates were observed in Antonina do Norte and Potengi. According to the correlation analysis, the proportion between the occupied population and the total population showed a significant negative correlation, as well as the percentage of the population who lives under adequate sanitary conditions. Both, the percentage of revenues from external sources and the percentage of urban households in reforested blocks had a significant positive correlation. Our results show that socioeconomic and environmental variables can be factors that contribute to both, the maintenance and the reduction of the elevated dispersion rates observed in the study area. Similar researches that encompass more municipalities from that region may reinforce Chagas disease surveillance and control in the Northeast of Brazil.

KEYWORDS: Triatominae. Socioeconomic factors. Public health. Spatial analysis. Bayesian analysis

INTRODUCTION

Chagas disease, also known as American Trypanosomiasis, is caused by *Trypanosoma cruzi*, a protozoan first described by Carlos Chagas in the Brazilian state of Minas Gerais, in 1909. This disease is a zoonosis and is endemic in 21 countries in the Americas, where it affects approximately 6 million people. There are 70 million individuals exposed to the risk of infection in the Americas, and the incidence of Chagas disease is around 30 thousand cases per year. Although mortality has significantly declined, the disease can cause irreversible and chronic

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consequences on the heart, digestive system and nervous system¹.

The insects that transmit the *Trypanosoma cruzi* protozoan belong to the subfamily Triatominae (Hemiptera, Reduviidae), composed by exclusively hematophagous members, in all nymph stages as well as in adulthood².

In the Ceara State, Northeastern Brazil, the first human cases of Chagas disease were diagnosed by xenodiagnosis, in 1942³. In the 1980s, the estimated prevalence of human Chagas disease in Ceara was 0.84%, and there were seropositive people in 93 out of 141 municipalities⁴. From 1990 to 1997, 35 individuals died of the disease in the state⁵. The last national survey on the seroprevalence of Chagas disease that occurred from 2001 to 2008, found six children infected with *T. cruzi* in Ceara. In two of these cases, the conditions indicated a probable vector transmission⁶. Estimates of the World Health Organization (WHO) based on data from 2010 indicated a total of 46 cases of Chagas disease resulting from vector transmission in Brazil, each year⁷, although it is estimated that only 10-20% of Chagas disease cases are actually notified, corroborating the Brazilian history of underreporting of Chagas and other diseases of compulsory notification⁸.

There are 152 species allocated to the subfamily Triatominae, grouped into 18 genera containing five tribes⁹. The Ceara State presents land predominantly covered by the biome caatinga, with a large rural area and precarious human habitations. This ecosystem provides shelters to some triatomines of public health importance, such as *Triatoma brasiliensis* Neiva 1911, *Triatoma pseudomaculata* Corrêa & Espínola 1964, *Panstrongylus lutzi* (Neiva & Pinto 1923), *Panstrongylus megistus* Burmeister 1835 and *Rhodnius nasutus* Stål 1859¹⁰.

The aim of this study was to analyze the triatomine dispersal rates from the capture records of the control program in the municipalities of the Cariri region, Ceara State, from 2009 to 2013, and to verify whether these data are associated with socioeconomic and environmental conditions of the municipalities. The development of studies in the Northeast region is justified by the high indexes of triatomine infestation^{5,11,12}. In addition, secondary species for transmission of Chagas disease such as *P. lutzi* and *R. nasutus* seem to have started a peridomicile and intradomicile cycle^{5,13} so that the entomological surveillance is fundamental to manage actions for Chagas disease control.

MATERIALS AND METHODS

Study area

The Cariri region is situated in the Southern Ceara

State, Northeast of Brazil, between latitudes 6°41'40"N and 7°39'00"S, and longitudes 39°37'20"E and 40°30'00"W, in the semi-arid region of the state. This region comprises 13 municipalities, belonging to the 20th Regional Health Coordination [*Coordenadoria Regional de Saúde* (CRES)] in Ceara. They cover an area of 8,885,668km², with a population of 328,410 people, according to the Brazilian Institute of Geography and Statistics [*Instituto Brasileiro de Geografia e Estatística* (IBGE)]¹⁴. The climate is characterized by scarce and irregular rainfall, little cloud cover, strong solar radiation, high evaporation rates and mean temperature around 27 °C. The vegetation is predominantly the caatinga. The municipalities are: Altaneira, Antonina do Norte, Araripe, Assare, Campos Sales, Crato (main city), Farias Brito, Nova Olinda, Potengi, Salitre, Santana do Cariri, Tarrafas and Varzea Alegre.

Entomological surveillance performed from 1998 to 2008 in the Cariri region showed high indices of triatomine infestation in rural localities. In that period, *T. brasiliensis* and *T. pseudomaculata* were captured in the domestic and peridomestic environments of all the municipalities and at all stages of development¹¹, thus the area stands out from the other areas of the state.

Data source

Vector control-surveillance staff from the municipalities collected triatomines in the peridomestic and domestic environments, and sent the specimens to the Regional Health Coordination (CRES). The CRES, in turn, elaborated a database concerning the dispersion rate ($I_d = \text{number of positive localities/number of researched localities} \times 100$) for the five years of study (2009-2013) and for each municipality.

The socioeconomic and environmental variables were retrieved from national researches, at the municipal level, made by national research institutes [(Brazilian Institute of Geography and Statistics (IBGE), the National Institute for Educational Studies and Research (INEP), the National Treasury (STN) and the United Nations Development Programme (PNUD)]. The following variables were selected: average monthly salary of formal workers¹⁵, percentage of occupied population¹⁵, percentage of population with nominal monthly income of at least half the minimum salary¹⁴, 6-14 schooling years rate in regular schools¹⁴, IDEB score in the early years of the elementary school¹⁶, IDEB score in the final years of the elementary school¹⁶, PIB per capita¹⁷, percentage of revenues from external sources¹⁸, Municipal Human Development Index¹⁹, percentage of population with adequate sanitary sewage at home¹⁴, percentage of urban households located

in reforested blocks¹⁴, percentage of urban households located in blocks with paving, curb and sidewalk¹⁴. These were secondary data, and approval from the research ethics committee for studies involving human participants was not required, according to the National Health Council, Resolution 510/2016²⁰.

Statistical analysis

First, an exploratory data analysis was performed. Then, we prepared choropleth maps related to the altitude and the triatomine dispersion rates (I_d) recorded in the municipalities.

For each year, the municipalities were divided into three groups: low, midrange or high dispersion rate. The group definition took into consideration all the values presented by the 13 municipalities throughout the period 2009-2013, which were divided into two quantiles. These quantiles were used to form the groups, as they analyzed the triatomine dispersion rates in that region, at the study moment.

As the geographical analysis units (in this case, the municipalities) present varied sizes, the estimation of crude rates is not appropriate, since the small number of observations in some units leads to unrepresentative estimates with high variability. Bayesian smoothing may be the solution for this problem, including the geographical localization of the municipality as an additional information, promoting better estimates. These spatial statistical methodologies are called bayesian empirical, considering that auxiliary data are obtained from the sample itself²¹.

Due to the high variability of the dispersion rates among municipalities, we calculated the dispersion rates based on global and local Bayes estimators²². The Shapiro-Wilk normality test was used to verify the normality of dispersion rates and their respective empirical Bayesian estimates, as well as the other variables. To compare the dispersion rate with its respective empirical Bayesian estimates, the Pearson correlation test was applied. The Analysis of Variance test (ANOVA) was applied to verify whether there was variation of the dispersion throughout the years and among the municipalities studied^{23,24}.

Afterwards we tested the association between socioeconomic and environmental variables and the dispersion rates adjusted by the Bayes estimator.

Choropleth maps of socioeconomic and environmental variables that showed significant Pearson's linear correlation were plotted. For all statistical tests, the significance level was set at 5% (α).

The freely available R statistical package version 3.3.2²⁵ was used to run the statistical analysis. The Quantum GIS

version 2.18 (Las Palmas)²⁶ was used to elaborate the maps and the GeoDa software version 1.12²⁷ was used to calculate the Bayesian estimates and run the spatial statistical analysis.

RESULTS

Among the 13 municipalities studied, Potengi was the only one to present dispersion rates over 50% in all the years of the research. The municipalities of Assare and Varzea Alegre showed rates above half in four of the five years studied. Salitre presented rates of at least 50% for three years. Santana do Cariri and Tarrafas showed rates above half in two years. Municipalities that have not shown dispersion rates over 50% in any of the studied years were Crato and Nova Olinda. The municipality with the highest mean dispersion rate for the five years was Antonina do Norte ($I_d = 92.31$), followed by Potengi ($I_d = 78.38$), while Nova Olinda ($I_d = 20.62$) showed the lowest mean, followed by Crato ($I_d = 28.39$) (Figure 1).

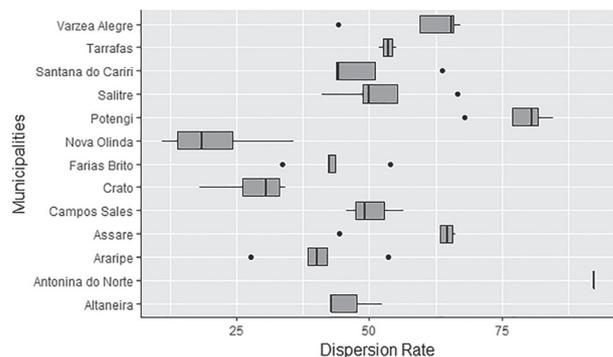


Figure 1 - Triatomine dispersion rates for the 13 municipalities that form the 20th Regional Health Coordination (CRES) of the Ceara State, from 2009 to 2013. The boxes represent the variability of dispersion rates for each municipality, and the points represent outlier rates.

There was a slight variation of the mean dispersion rate throughout the studied years (Figure 2). The municipalities of Antonina do Norte, Campos Sales, Crato and Tarrafas did not send complete collection data to the CRES.

According to the chart presented in Figure 2 and the result of the Analysis of Variance (ANOVA), there is not a significant difference (p -value = 0.92) among the dispersion rates, throughout the study. However, for the same period, there is heterogeneity of the dispersion rates among municipalities (p -value < 0.01). According to the Tukeytest, we observed that the municipalities of Antonina do Norte and Potengi presented the highest dispersion rates for the period, they do not differ from each other, but they differ from almost all the other municipalities. The same occurs to Nova Olinda and Crato, as they showed the lowest rates

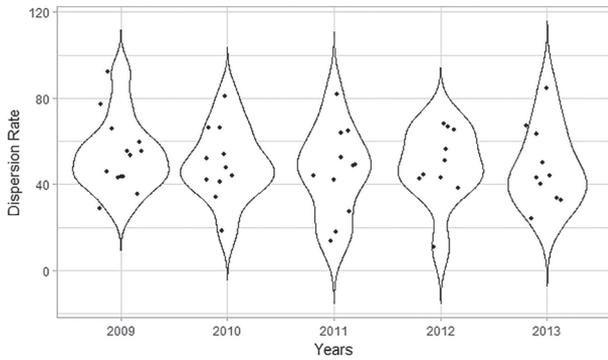


Figure 2 - Violin plots of triatomine dispersion rates for the five studied years in the 13 municipalities that form the 20th Regional Health Coordination (CRES) of the Ceara State.

and do not differ from each other, but they differ from all the other municipalities .

The municipalities of Potengi, Assare, Antonina do Norte and Varzea Alegre showed the highest dispersion rates in the region. The first three are bordered and are in the North middle portion of the study area. Potengi and Assare are located West of the Araripe Plateau and belong to the Chapada do Araripe micro-region. Both municipalities are situated at over 450 m altitude (Figure 3). The municipalities of Antonina do Norte and Varzea Alegre belong to the Varzea Alegre micro-region and are at over 300 m altitude. Varzea Alegre is the second most populous municipality of the research area, with 38.434 inhabitants.

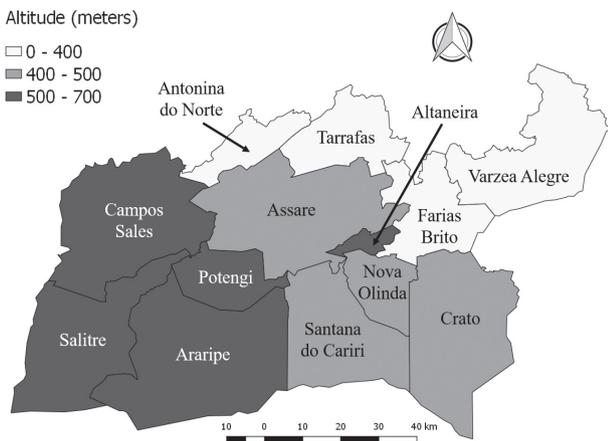


Figure 3 - Map of the mean altitude of the 13 municipalities that form the 20th Regional Health Coordination (CRES) of the Ceara State.

Araripe, Campos Sales and Salitre represent the highest municipalities from the study area, once they are between 570 and 680 m in altitude and showed midrange dispersion rates for the region. The municipalities of Crato and Nova Olinda showed the lowest rates, always under 40%. Both municipalities belong to the Cariri Metropolitan Region (CMR) and are in the most economically active portion of

the study area, being Crato the most populous among the 13 municipalities studied, with 121,428 inhabitants.

The municipality of Potengi was the only one included in the high dispersion rate group, every year. Assare and Varzea Alegre showed high rates in four of the five years. The municipalities of Crato and Nova Olinda presented low dispersion rates in all the studied years. In 2009, six municipalities formed the high dispersion rate group, against only three in the last year of the study (Figure 4).

As a high variability was found for the dispersion rates, we performed global and local empirical Bayesian estimates for all the studied years (Figure 5). These estimates were compared to each other and also to the crude values, to check whether there were correlations. There was a positive significant ($\alpha = 5\%$) correlation between the global Bayesian estimates and the crude rates ($\rho \text{ rho} = 0.95$), between the local Bayesian estimates and the crude rates ($\rho \text{ rho} = 0.92$), and between global and local estimates ($\rho \text{ rho} = 0.97$).

The Bayesian estimates promoted a subtle change regarding the themed maps. The municipality of Farias Brito changed from midrange to low dispersion rate. In addition, regarding the local empirical Bayes, the municipality of Varzea Alegre changed from high to midrange rate, what probably has occurred due to spatial effects of local Bayes (Figure 6).

The correlation analysis between the socioeconomic and environmental variables and the local Bayesian estimates of the dispersion rates showed a negative significant ($\alpha = 5\%$) correlation for a 6-14 schooling years rate in 2009 and 2013. On the other hand, the percentage of revenues from external sources showed a positive significant correlation for all the studied years, as well as for the mean of the period. Regarding territory and environment, the percentage of population with adequate sanitary sewage at home showed a negative significant correlation in 2010 and 2012, as well as for the mean. On the contrary, the percentage of urban households located in reforestation blocks showed a positive significant correlation in 2010, 2013 and also for the mean of the period (Table 1).

Potengi was the municipality with the lowest 6 to 14 schooling years rate (92.7%). On the contrary, Campos Sales and Farias Brito had the highest rates (98.3% and 99.3%, respectively). Regarding the revenues from external sources, Antonina do Norte leads with the highest percentage (97.7%), while the municipalities of Crato, Araripe and Nova Olinda showed the lowest values in the studied area (82.4%, 84.9% and 85.6%, respectively). The municipality with lowest sewage cover was Tarrafas (2.2%), followed by Potengi (7.8%). However, Potengi had the highest reforestation rate (96.3%), followed by Tarrafas (94.4%) (Figure 7).

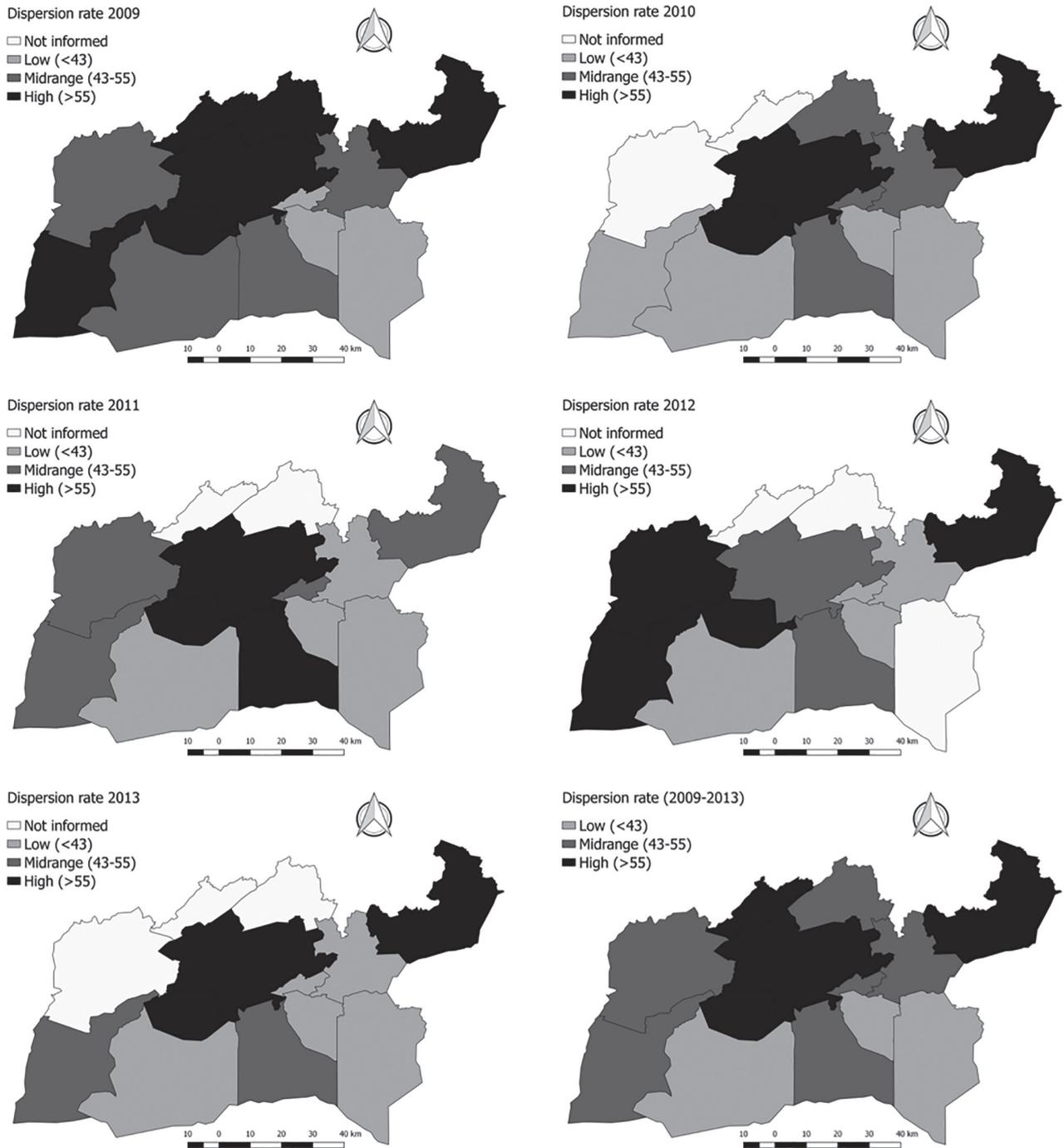


Figure 4 - Maps of triatomine dispersion rates from 2009 to 2013 and the mean for the period, in the 13 municipalities that form the 20th Regional Health Coordination (CRES) of the Ceara State.

DISCUSSION

In a study conducted between 1998 and 2008, regarding the same municipalities of the present research, Gonçalves *et al.*¹¹ have also found the highest dispersion rates in Antonina do Norte, Assare, Potengi and Varzea Alegre. These authors believed that these municipalities presented these results due to the presence of specific factors such

as environment conditions, type of vegetation, territorial proximity and the use of tree trunks to build shelters for domestic animals. All of these factors may influence the dispersion of triatomine bugs to areas that are not covered by the surveillance system, contributing to the maintenance of triatomines in the region¹³.

The municipalities of Araripe, Campos Sales and Salitre are among the four with the highest altitudes in the study

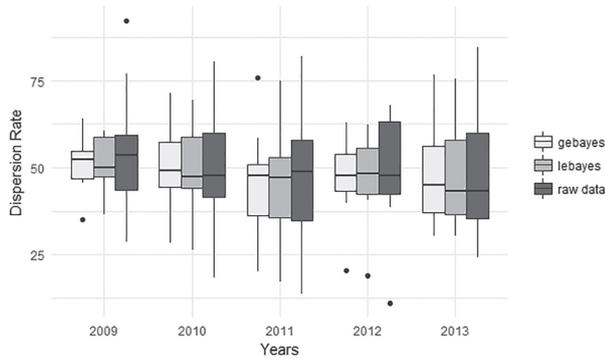


Figure 5 - Triatomine dispersion rates and global and local Bayesian estimates for the 13 municipalities that form the 20th Regional Health Coordination (CRES) of the Ceara State, from 2009 to 2013; “gebayes” represents the global Bayesian estimates, “lebayes” represents the local Bayesian estimates, and “raw data” represents the original dispersion rates.

area, and they presented dispersion rates between 40% and 52% for the average period of 2009-2013. Most of the geographical area of these municipalities is on the Araripe Plateau, situated within the caatinga biome, among the states of Ceara, Pernambuco and Piaui. This plateau offers a wide variety of phytophysionomies and an environmental dynamic that is distinct from the other lowland areas within the caatinga. The area is under heavy anthropogenic pressure due to agricultural expansion, disorderly occupation and hunting²⁸. Lima *et al.*²⁹, when investigating dwellings and outbuildings in rural areas in the Sergipe State, calculated the triatomine dispersion rate in 66.7%, with triatomines found in both, domestic and peridomestic environments. In the latter, the authors frequently found corrals, waste deposits and chicken coops, and many of which consisted of makeshift structures. This dispersion rate matches the rates presented by most of the municipalities in our study.

The municipality of Farias Brito, whose dispersion rate was around 40% in the period 2009-2013, presents a

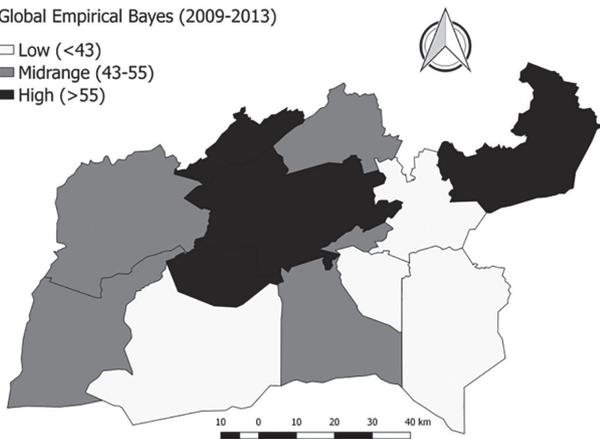
deforestation level over 80%, according to IBGE¹⁴. Freitas *et al.*¹⁰ reported, during the research in the municipality, that the species *R. nasutus* was found associated with bird nests in palm trees, as macauba (*Acrocomia aculeata*), a quite common palm tree in the region, have become the species natural habitat. Still according to these authors, the municipality of Farias Brito is predominantly covered by hyper xerophilic caatinga, where shrubs like marmeleiro (*Croton* sp.) and jurema-preta (*Mimosa tenuiflora*) predominate. These species of plants are used by the rural population as a domestic energy source since their wood is used to produce fire to cook and to build shelters for animals¹⁰. The increased deforestation and anthropogenic invasion of natural ecotopes of Chagas disease can lead to the urbanization of insects that find shelters in deforested areas of municipalities and rural peridomiciles.

In a study conducted by Dias *et al.*³⁰ in the Chapada do Araripe, 521 specimens of *R. nasutus* were collected in five palm species: babassu (*Attalea speciosa*), buriti (*Mauritia flexuosa*), carnauba (*Copernicia prunifera*), catole (*Syagrus oleracea*) and macauba-barriguda (*Acrocomia intumescens*). From the 50 palms that were cut down and dissected, 86% harbored at least one triatomine specimen or presented with exuvia or eggs. Four hundred and fifteen triatomines (79.7%) were found in babassu and catole specimens.

When analyzing natural ecotopes of *T. brasiliensis* populations in the Jaguaribe Valley, in Ceara, Valença-Barbosa *et al.*³¹ collected 157 triatomines in 21 specimens of xiquexique (*Pilosocereus gounellei*), a shrubby cactus. In total, 44 xiquexique shrubs were investigated corresponding to an infection rate of 47.7%. The authors suggested that *P. gounellei* is an important ecotope of wild *T. brasiliensis* populations in the caatinga, and that bugs from cacti might be involved in house infestation, in lowland areas where no rocky outcrops occur.

Global Empirical Bayes (2009-2013)

□ Low (<43)
 ■ Midrange (43-55)
 ■ High (>55)



Local Empirical Bayes (2009-2013)

□ Low (<44)
 ■ Midrange (44-54)
 ■ High (>54)

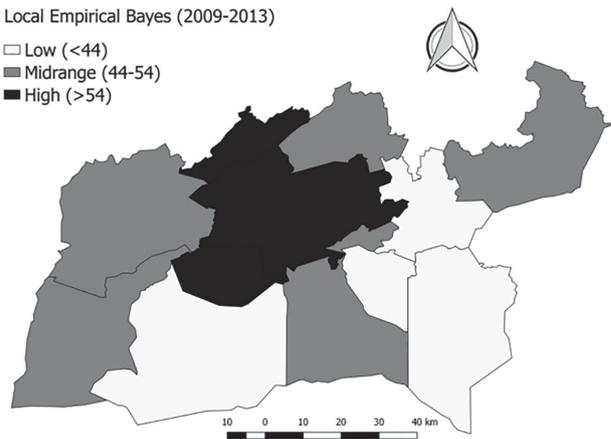


Figure 6 - Maps of global and local Bayesian estimates of the triatomine dispersion rates for the average period 2009-2013, in the 13 municipalities that form the 20th Regional Health Coordination (CRES) of the Ceara State.

Table 1 - Pearson's linear correlation coefficients and the respective 95% confidence intervals (CI) to represent the association between socioeconomic and environmental variables with local Bayesian estimates of triatomine dispersion rates, in the 13 municipalities forming the 20th Regional Health Coordination (CRES) of the Ceara State, from 2009 to 2013.

	Pearson's Correlation [95% CI]					
	2009	2010	2011	2012	2013	Mean
Salary	-0.27 [-0.71; 0.32]	0.19 [-0.46; 0.70]	0.12 [-0.51; 0.67]	-0.05 [-0.66; 0.59]	0.03 [-0.61; 0.64]	-0.09 [-0.61; 0.47]
Occupied population	-0.61* [-0.87; -0.09]	-0.63* [-0.89; -0.06]	-0.60* [-0.88; -0.01]	-0.25 [-0.76; 0.44]	-0.35 [-0.80; 0.35]	-0.59* [-0.86; -0.06]
Income of ½ salary	0.55* [0.05; 0.84]	0.21 [-0.44; 0.72]	0.31 [-0.34; 0.77]	-0.28 [-0.77; 0.42]	0.16 [-0.52; 0.71]	0.30 [-0.29; 0.73]
Schooling	-0.62* [-0.87; -0.12]	-0.48 [-0.84; 0.15]	-0.49 [-0.84; 0.14]	-0.14 [-0.71; 0.53]	-0.69* [-0.92; -0.11]	-0.53 [-0.83; 0.02]
IDEB early years	-0.21 [-0.68; 0.38]	-0.49 [-0.84; 0.14]	-0.41 [-0.81; 0.24]	-0.89* [-0.97; -0.61]	-0.63* [-0.90; -0.01]	-0.48 [-0.81; 0.09]
IDEB final years	-0.16 [-0.65; 0.42]	-0.44 [-0.82; 0.21]	-0.44 [-0.82; 0.20]	-0.62 [-0.90; 0.08]	-0.67* [-0.91; -0.08]	-0.43 [-0.79; 0.14]
PIB	-0.59* [-0.86; -0.06]	-0.25 [-0.74; 0.40]	-0.40 [-0.80; 0.25]	-0.23 [-0.75; 0.46]	-0.38 [-0.81; 0.32]	-0.45 [-0.80; 0.13]
Revenues from external sources	0.57* [0.03; 0.85]	0.77* [0.33; 0.93]	0.79* [0.37; 0.94]	0.67* [0.07; 0.91]	0.68* [0.09; 0.91]	0.80* [0.44; 0.93]
MHDI	-0.81* [-0.94; -0.47]	-0.41 [-0.81; 0.24]	-0.52 [-0.85; 0.10]	-0.24 [-0.75; 0.45]	-0.51 [-0.86; 0.16]	-0.56* [-0.85; -0.02]
Sanitary sewage	-0.49 [-0.82; 0.07]	-0.74* [-0.93; -0.26]	-0.71* [-0.92; -0.20]	-0.64* [-0.90; -0.01]	-0.58 [-0.88; 0.07]	-0.57* [-0.85; -0.03]
Deforestation	0.54 [-0.01; 0.84]	0.67* [0.12; 0.90]	0.46 [-0.18; 0.83]	0.56 [-0.09; 0.88]	0.66* [0.05; 0.91]	0.64* [0.14; 0.88]
Urbanization	-0.03 [-0.57; 0.52]	-0.07 [-0.64; 0.55]	-0.09 [-0.65; 0.53]	-0.17 [-0.72; 0.51]	-0.15 [-0.71; 0.52]	-0.15 [-0.64; 0.43]

*significance level set at 5%; IDEB (Basic Education Development Index); PIB (Gross Domestic Product); MHDI (Municipal Human Development Index)

Jurema-preta stands out among the plant species found in the Cariri region, due to its high density and high geographical coverage. Boles and boughs of *M. tenuiflora* are widely used by rural populations, either for protection and isolation of domestic animals or as energy source. However, triatomines in the young form can be found under the bark of the plant. In addition, its storage in the peridomestic environment attracts synanthropic animals, as possums and rodents, easing the triatomine dispersion from the natural to the peridomestic environment¹³. The common use of endemic palm trees and shrubs as energy sources, in the construction of shelters for animals, or yet as an income source through the commercialization of their byproducts, places the rural populations from the Cariri region in a vulnerable position regarding the vector transmission of Chagas disease. The introduction and storage of the above-mentioned plants in the peridomestic and/or domestic environments potentiates the risk of infection by *T. cruzi* in these communities, also contributing to the domiciliation process of species that are still considered as wild.

In a study conducted in the Pernambuco State, bordering Ceara, Silva *et al.*³² reported the occurrence of 3,323 triatomines in both, the peridomestic and domestic environments of 185 municipalities. Six species were identified, and *T. brasiliensis* and *T. pseudomaculata* represented 73.4% of the specimens collected.

In the municipalities of Nova Olinda and Crato, the mean dispersion rate between 2009-2013 was under 30%, representing the lowest mean for the 13 municipalities during the study period. Both municipalities belong to CMR, where the urbanization level and population growth are far more marked than the other municipalities of the 20th CRES. According to IBGE³³, the participation of agriculture in the CMR economic structure is of only 2.84%. Besides that, the population has grown 14% from 2000 to 2010. The marked urbanization process in that metropolitan region has deviated the population from typically rural habits to the cities, decreasing the risk of vector transmission of Chagas disease.

The sampling technique used in the study is not the most appropriate considering that, according to Valença-

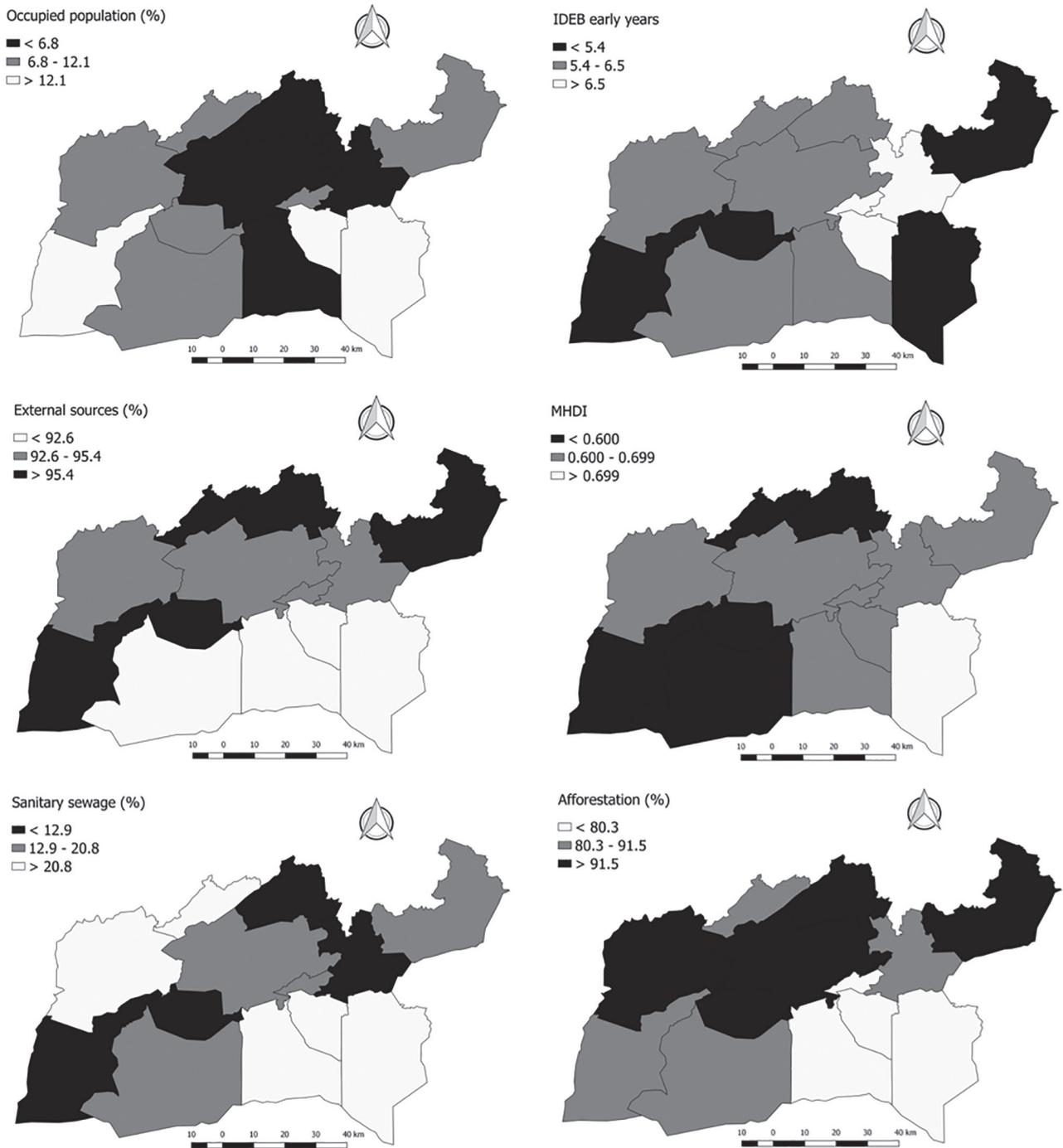


Figure 7 - Maps of occupied population; IDEB score in the early years; revenues from external sources; MHDI; sanitary sewage and afforestation, according to IBGE, for the 13 municipalities that form the 20th Regional Health Coordination (CRES) of the Ceara State.

Barbosa *et al.*¹², the active searches made by trained and motivated agents have commonly detected around 40% to 60% of the infestation foci, while non-detected foci are not eliminated. Abad-Franch *et al.*³⁴ estimated the sensibility of the active research conducted by control agents by about 20% for localities with low intensity of infestation and around 40% for high intensity localities. Although the vector control-surveillance staff of the municipalities are

trained by the Regional Health Coordination, the dispersion rates presented in the study may be underestimated due to the low sensibility of the sampling technique.

From 2007 to 2011, the SVS³⁵ registered the capture of almost 800 thousand triatomines in the peridomestic and domestic environments. It is considered that this record encompasses less than 10% of all triatomines inside or around dwellings. According to the SVS³⁶, the

entomological surveillance for Chagas disease must be implemented all over the country, primarily supported by two pillars: passive surveillance, when the population participates in the triatomine notification process; and active surveillance, made by municipal control teams in partnership with regional health coordination offices, without the need of prior notification.

From this context, the use of spatial statistical analysis techniques to study the occurrence of vectors of Chagas disease has been widely disclosed, both for the recognition of the importance of these methods and for accelerating softwares development^{12,34}.

Thereby, identifying more vulnerable areas for the occurrence of synanthropic triatomines has been a valuable tool to reorient actions related to prevention, control and epidemiological surveillance of Chagas disease³⁷. According to our results, the municipalities of Antonina do Norte, Assare, Potengi and Varzea Alegre showed high dispersion rates associated with high socioeconomic vulnerability. These municipalities must receive special attention from the Regional Health Coordination.

To fight the coexistence of areas with various degrees of risk, vector control and surveillance actions should be adjusted to the established risk. Aside from taking into consideration the operational capacity of the municipalities, the stratification of a traditionally endemic area is based on a set of variables that could potentially influence the infestation (or reinfestation) process and, consequently, the vector transmission of Chagas disease in the domestic environment³⁵.

Prevention and control interventions targeted at elevated risk areas represent effective strategies to limit possible outbreaks, not just for reducing the operational costs but also for supporting the control of neglected tropical diseases³⁸.

CONCLUSION

The results of this study suggest that socioeconomic and environmental variables may partially explain the high triatomine dispersion rates observed in some municipalities from the Cariri region. Children schooling rate, as well as the municipality dependency on external resources, proved important factors related to the maintenance of high triatomine dispersion rates. The deforestation level of the municipalities also seemed to play an important role in triatomine dispersion, since many triatomine species are commonly found associated with palm trees and some shrub species.

The municipalities belonging to the Cariri Metropolitan Mesoregion showed the lowest dispersion rates, suggesting that the urbanization process has apparently reduced the risk of the vector transmission of Chagas disease to that

population, despite the social problems generated by this type of process. Meanwhile, the use of some plant species in the rural areas of Ceara State as domestic energy sources, for protection and isolation of domestic animals, and for commercialization of their byproducts, allows the maintenance of triatomines in the peridomestic and domestic environments.

Finally, we emphasize that studies addressing the relationship between triatomine dispersion, socioeconomic conditions and urbanization processes are the key for an efficient control of the transmission of Chagas disease in the Brazilian Northeast.

AUTHORS' CONTRIBUTION

WST and TBP designed the study and wrote the protocol; DMS and ALCF collected data; TBP and WST conducted the analysis; TBP drafted the manuscript; WST and DMS contributed to the manuscript; SPCF and JRSM were responsible for reviewing the manuscript.

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