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Assessing the vulnerability of Brazilian municipalities to the vectorial transmission of *Trypanosoma cruzi* using multi-criteria decision analysis

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ABSTRACT

Despite the dramatic reduction in *Trypanosoma cruzi* vectorial transmission in Brazil, acute cases of Chagas disease (CD) continue to be recorded. The identification of areas with greater vulnerability to the occurrence of vector-borne CD is essential to prevention, control, and surveillance activities. In the current study, data on the occurrence of domiciliated triatomines in Brazil (non-Amazonian regions) between 2007 and 2011 were analyzed. Municipalities' vulnerability was assessed based on socioeconomic, demographic, entomological, and environmental indicators using multi-criteria decision analysis (MCDA). Overall, 2275 municipalities were positive for at least one of the six triatomine species analyzed (*Panstrongylus megistus*, *Triatoma infestans*, *Triatoma brasiliensis*, *Triatoma pseudomaculata*, *Triatoma rubrovaria*, and *Triatoma sordida*). The municipalities that were most vulnerable to vector-borne CD were mainly in the northeast region and exhibited a higher occurrence of domiciliated triatomines, lower socioeconomic levels, and more extensive anthropized areas. Most of the 39 new vector-borne CD cases confirmed between 2001 and 2012 in non-Amazonian regions occurred within the more vulnerable municipalities. Thus, MCDA can help to identify the states and municipalities that are most vulnerable to the transmission of *T. cruzi* by domiciliated triatomines, which is critical for directing adequate surveillance, prevention, and control activities. The methodological approach and results presented here can be used to enhance CD surveillance in Brazil.

1. Introduction

Chagas disease (CD) is a chronic and potentially fatal infection resulting from the interaction between humans and the protozoan *Trypanosoma cruzi* (Chagas, 1909). The main mode of transmission of this parasite is by hematophagous insects of the Triatominae subfamily (Lent and Wygodzinsky, 1979), and synanthropic triatomine control is the main strategy used to prevent human infection (Coura and Dias, 2009; Abad-Franch et al., 2010).

The overall prevalence of CD in Latin America was estimated to be approximately 7–8 million infected people in recent years (Rassi et al., 2010; WHO, 2014). In Brazil, about 4.6 million of people are estimated to be infected with *T. cruzi* (Martins-Melo et al., 2014), with approximately 6000 deaths annually (Martins-Melo et al., 2012). The latest national survey of the seroprevalence of CD in Brazil showed a dramatic reduction in *T. cruzi* vectorial transmission among children (Ostermayer et al., 2011). However, acute CD cases continue to be recorded in the country; between 2000 and 2011, 1252 acute cases were recorded in Brazil, mainly in the Amazon region (MS/SVS, 2013).

Currently, more than 60 triatomine species are known in Brazil, but few exhibit synanthropic behaviors (Gurgel-Gonçalves et al.,

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2012). The five species most frequently captured during a CD control and monitoring program in Brazil were *Triatoma infestans*, *Panstrongylus megistus*, *Triatoma brasiliensis*, *Triatoma pseudomaculata*, and *Triatoma sordida* (Vinhaes and Dias, 2000; Costa et al., 2003; Silveira and Dias, 2011). Additionally, in the Amazon region, the main species related to vector-borne and oral transmission are *Rhodnius pictipes* and *Rhodnius robustus* (Abad-Franch and Monteiro, 2007). *T. infestans* has been the main target of vector control campaigns, and in 2006, the Intergovernmental Commission of the Southern Cone Initiative, PAHO/WHO, formally certified Brazil as free of vector-borne transmission of *T. cruzi* by *T. infestans*, although residual foci of this species still occur in the country (Silveira and Dias, 2011; Abad-Franch et al., 2013).

After the control of *T. infestans*, studies found that other triatomine species continued to infest households in different Brazilian states (Oliveira and Silva, 2007; Almeida et al., 2008; Bedin et al., 2009; Villela et al., 2009; Gurgel-Gonçalves et al., 2010; Silva et al., 2011, 2012; Maeda et al., 2012; Belisário et al., 2013). These studies indicate the need to strengthen triatomine surveillance programs in Brazil, with actions based on effective tools for monitoring and evaluating the vulnerability of states and municipalities to *T. cruzi* transmission by domiciliated triatomines.

The great extent of the endemic area of CD, the different transmission patterns observed throughout the country, the existence of various species of synanthropic triatomines, and a progressive reduction in and/or limitation of the equipment and human and financial resources needed to sustain the continuity of the control actions justify applying methods to effectively prioritize triatomine surveillance and control activities (Silveira, 2004; Martins-Melo et al., 2014). Thus, the present study aimed to assess the vulnerability of municipalities in the non-Amazonian regions of Brazil to *T. cruzi* transmission by domiciliated triatomines based on socioeconomic, demographic, entomological, and environmental indicators.

2. Materials and methods

2.1. Epidemiological data

Vector-borne cases of CD from the seroprevalence survey of 2001–2008 (Ostermayer et al., 2011) and newly confirmed vector-borne acute cases of CD registered in the *Sistema Nacional de Agravos de Notificação* (SINAN) of the Ministry of Heath of Brazil between 2006 and 2012 were analyzed.

The data were examined for possible duplication and inconsistencies. Tabulations were performed using Tabwin 3.2 and Microsoft Office Excel 2007 software. Only notifications that indicated cases of vector-borne transmission in the non-Amazonian regions of Brazil were selected; acute CD cases resulting from other mechanisms of transmission (oral, tranfusional, congenital, accidental, or unknown) were not considered. All municipality records were georeferenced based on information provided by the Instituto Brasileiro de Geografia e Estatística (IBGE) (http://www.ibge.gov.br).

2.2. Entomological data

Information on the occurrence of six selected triatomine species (*P. megistus*, *T. infestans*, *T. brasiliensis*, *T. pseudomaculata*, *Triatoma rubrovaria*, and *T. sordida*) was provided by the Grupo Técnico de Doença de Chagas of the Secretaria de Vigilância em Saúde of the Ministry of Health of Brazil. This information corresponded to household captures between 2007 and 2011 in non-Amazonian regions (Appendix A). Thus, we excluded the municipalities of the northern region (with the exception of the state of Tocantins) where vectorial transmission by domiciliated triatomines is not frequent.

We developed an entomological indicator based on the species' colonization behaviors and levels of natural infection by *T. cruzi* using data from the literature (Costa et al., 2003; Silveira, 2011; Silveira and Dias, 2011; Gurgel-Gonçalves et al., 2012). According to these data it was possible to establish a hierarchy of vectorial importance for *T. cruzi* transmission: *T. infestans* > *P. megistus* or *T. brasiliensis* > *T. sordida* or *T. pseudomaculata* or *T. rubrovaria*. For this purpose, we weighted the vectorial importance of these triatomine species: 5 for *T. infestans*; 3 for *P. megistus* and *T. brasiliensis*; and 2 for *T. sordida*, *T. pseudomaculata*, and *T. rubrovaria*. Thus, the importance assigned to *T. infestans* was 1.66 times greater than *P. megistus* or *T. brasiliensis* and 2.5 times greater than *T. sordida* or *T. pseudomaculata* or *T. rubrovaria*. When this classification was complete, the sum of the weights of the species occurring in each municipality was calculated. Therefore, a municipality with a record of all of these species would have a weighted value equal to 10, whereas a municipality without the occurrence of these species would have a null value. If a municipality presented only *T. sordida*, for example, the municipality would receive a value of 2.

2.3. Socioeconomic, demographic, and environmental data

The socioeconomic and demographic indicators used were obtained from the 2010 census conducted by the IBGE (http://www.ibge.gov.br) and from the *Atlas Brasileiro de Vulnerabilidades Socioambientais*, organized by the Brazilian Center for Analysis and Planning (CEBRAP) and by the Department of Environmental Health Surveillance and Occupational Health of the Secretariat of Health Surveillance, Ministry of Health (http://189.28.128.179/atlasvulnerabilidade/index.php).

For the analyses, the following indicators were used: the percentage of properties in rural areas with individuals living in extreme poverty, the population density, and the percentage of the total anthropized area in the municipality. These indicators were selected based on previous studies that highlighted the association of socioeconomic, demographic, and environmental variables with vector-borne CD (Bustamante et al., 2007; Sarkar et al., 2010; Ostermayer et al., 2011; Mischler et al., 2012; Moreno et al., 2012).

Information on deforestation (2009) of the Caatinga, Pampa, Cerrado, Atlantic Forest, and Pantanal biomes has been generated by the Ministry of Environment and distributed by the Center for Remote Sensing of the Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) through the Monitoring Project of Brazilian Biomes Deforestation by Satellite (http://siscom.ibama.gov.br/monitorabiomas/). To generalize this variable across areas not covered by the IBAMA data, analyses using ESRI ArcGIS software were performed for the visual detection and manual scanning of the deforestation features in these areas. Clearings were classified as anthropized areas without typologies and were included in the percentage of deforested area in the municipality.

2.4. Multi-criteria decision analysis

The identification of municipalities vulnerable to *T. cruzi* transmission by domiciliated triatomines is a multi-criteria decision problem. Over the last few decades, the decision theory community has devised a wide variety of methods for multi-criteria decision making (Moffett and Sarkar, 2006). Recently, this approach was used to analyze CD risk in Texas in the USA (Sarkar et al., 2010).

Four indicators were used in the multi-criteria decision analysis (MCDA). After selecting the indicators, a free application called PRADIN (Program to Support Decision Making Based on Indicators) Version 3.0 (http://www.anipes.org.br) was used for MCDA. This application implements the algorithm PROMETHEE II (Preference Ranking Organization Method for Enrichment of Evaluations;