Urban Climate 26 (2018) 198–211

Contents lists available at ScienceDirect

Urban Climate

journal homepage: www.elsevier.com/locate/uclim

Bayesian estimates for the mapping of dengue hotspots and estimation of the risk of disease epidemic in Northeast Brazil

M.L.A. Souza[a,*], L.M.B. Andrade[b], M.H.C. Spyrides[b], J.R. Justino[c]

[a] *Federal Institute of Education, Science and Technology of Rio Grande do Norte - IFRN, Brazil*
[b] *Postgraduation Program in Climatic Sciences, Federal University of Rio Grande do Norte – UFRN, Brazil*
[c] *Federal University of Rondônia – UNIR, Brazil*

1. Introduction

Dengue is one of several human health problems in the tropical world and relates to environmental, socioeconomic and infrastructure factors (Ely, 2013; Morin et al., 2015; Santos et al., 2013; Teurlai et al., 2015). Historically, the disease has been predominantly reported between urban and peripheral areas, where population concentration and vector adaptation to domestic or peridomestic environment facilitate transmission (Mosquera Ruiz, 2015; WHO, World Health Organization, 2009).

The disease is an arbovirus with four virus serotypes (DENV-1, DENV-2, DENV-3 and DENV-4) and is considered one of the most worrisome human diseases caused by mosquitoes in tropical and subtropical areas (Christophers, 1960; Consoli & Oliveira, 1998). Dengue has spread rapidly throughout the planet in recent decades, mainly affecting inter-tropical regions (Barcellos & Lowe, 2014). It is estimated that 390 million dengue infections per year occur in the world, with apparent and non-apparent cases (Bhatt et al., 2013; Zellweger et al., 2017). > 100 countries have recorded the presence of dengue in their territories, threatening the lives of > 2.5 billion people (Jeefoo et al., 2011). Due to its endemic and epidemic character of great magnitude, the disease has an important social and economic impact, which may withdraw people from their daily work (Honorato et al., 2014). The estimated direct costs associated with dengue in Brazil are substantial and amount to several hundred million dollars a year (Martelli et al., 2015).

The Brazilian territory is one of the main areas of disease occurrence in the Americas and the world (Bhatt et al., 2013; Fullerton et al., 2014; San Martín et al., 2010). Brazil officially notified > 1.6 million cases in 2015, approximately 12% of cases registered in the American continent. Between 2001 and 2015, 3077 deaths were officially recorded in the country. The SEB[1] and NEB regions, two of the most populous regions of the country (71% of the population), are the regions with the highest number of cases and deaths related to the disease (Organização Pan-Americana Da Saúde (Opas), 2009; Brasil Ministério da Saúde, 2016). Dengue numbers in Brazil, particularly in NEB, reveal the seriousness of the problem by imposing on decision-makers a constant need to monitor, at spatial and temporal levels, the dynamics of the disease. This monitoring may contribute in the attempt of identifying possible hotspots[2] and threats of spread of the disease in space.

It is important to highlight that the identification of potential hotspots of the disease in space can help the public health service to

Abbreviations: EB, Empirical Bayesian Method; DATASUS, Department of Informatics of the SUS; *e-SIC*, Electronic System of the Citizens Information Service; HI, House Index; IBGE, Brazilian Institute of Geography and Statistics; IR, Incidence Rate; LIRAa, *Aedes aegypti* Infestation Index Rapid Survey; Moran's I, Moran's Index; MSE, Mean Square Error; NC, Northern Coast; NEB, Northeast Brazil; NS, Northern Semiarid; NW, Northwest; WHO, World Health Organization; $RR_{A/S}$, Relative Risk – Alert/ Satisfactory; $RR_{R/S}$, Relative Risk – Risk/Satisfactory; SEB, Southeast of Brazil; SC, Southern Coast; SUS, Health Unic System; SS, Southern Semiarid

* Corresponding author.
E-mail address: marcelo.amorim@ifrn.edu.br (M.L.A. Souza).

[1] See abbreviations list.

[2] The definition of hotspot taken into consideration was the one provided by Jeefoo et al. (Jeefoo et al., 2011) which establishes some sort of spatial grouping related to dengue, in such way that areas with epidemic incidence rates (IR > 300) are considered hotspots. The definition of hotspot applied to dengue was also described in the studies by Naish, Tong (2014) and Zellweger et al. (Zellweger et al., 2017).

https://doi.org/10.1016/j.uclim.2018.09.003
Received 13 December 2017; Received in revised form 29 May 2018; Accepted 10 September 2018
2212-0955/

visualize and understand the geographic distribution and trends of disease patterns, contributing to campaigns to combat the disease (Pessanha et al., 2012).

However, evidence-based, from the 1980s to the present day, disease prevention and mosquito control have not improved as expected, although Brazil has more effective vector and thus dengue control methods and products (Degallier et al., 2012). Concern increases due to the dengue vector, *Aedes aegypti*, also transmitting the Chikungunya and Zika viruses. The transmission of dengue and the above mentioned diseases does not only depend on the presence of *Aedes aegypti*, but also on mosquito habits and densities as risk factors, so the use of indexes, such as the House Index (HI), constitutes an important step in the process of entomological surveillance as a perspective of disease control and orientation of the necessary interventions in the inhibition of transmission cycles by the vector mosquito (Gomes, 1998). The HI is one of the indices that, despite the criticism related to its efficiency as a dengue transmission risk measurer and mosquito control method, remains one of the main surveillance tools of many larvae infestation control programs around the world (Bowman et al., 2014; Focks, 2003).

The following are among the factors contributing to the spread of dengue: increase in the production of disposable materials, population growth associated with lack of urban planning and lack of adequate public health infrastructures, climate conditions, inadequate water storage and migration (Costa, 2013).

As it is a climate-dependent disease, it is verified that the environmental and climatic conditions directly interfere in the life cycle of the transmitting mosquito, *Aedes aegypti*, and consequently in their vectorial capacity (Favier et al., 2005; Lucio et al., 2013; Sahay, 2017; WHO, World Health Organization, 2009). Dengue assumes seasonal and interannual patters of occurrence, thus, occasional outbreaks of the disease may be related to variations in temperature and rainfall caused by climate phenomena such as the El Niño – Southern Oscilation (ENSO) (Cazelles et al., 2005; Gagnon et al., 2001; Vincenti-Gonzalez et al., 2018).

The possible climate changes in progress can affect the entomological and epidemiological dynamics. In other words, climate change may influence the spatial distribution of *Aedes aegypti* and the disease ((Campbell et al., 2015; Naish et al., 2014; Sahay, 2017)). There is evidence that the earth will undergo an average temperature increase of 2 °C in the coming years, reaching 6 °C in the most pessimistic scenario, with catastrophic consequences for ecosystems and mankind (Marengo et al., 2009). High temperatures affect mosquito reproduction rates, accelerate viral replication and decrease the duration of the reproductive cycle of the dengue vector, resulting in a larger amount of infected mosquitoes in a shorter period of time with the risk of huge interannual dengue outbreaks (Vincenti-Gonzalez et al., 2018).

The main area of the Earth that will suffer maximum heat loads will be the intertropical region, with significant impacts on health and well-being of populations living in this area (Omonijo, 2016). NEB is located exactly in the intertropical strip of the planet and presents predominance of semiarid climate, mainly in the region called "drought polygon". The NEB semiarid is subject to long periods of droughts that immensely contribute with the lowest socioeconomic indicators of the region (Ab'Sáber, 1999). The marks of regional underdevelopment are based on the historical, political and economic backgrounds imposed over time to the region (Soares, 2008). Due to its low socioeconomic indicators, being a large area of semiarid climate with persistence of endemic diseases, NEB is the Brazilian region of greatest socioeconomic, climatic and epidemiological vulnerability in relation to possible climatic impacts (Confalonieri et al., 2009).

This study aimed to estimate dengue incidence rates for NEB municipalities using the Empirical Bayesian method for the 2001–2015 period and to identify dengue hotspots considering the homogeneous precipitation NEB regions. On the other hand, it was intended to estimate the relative risk of dengue incidence epidemic rates according to the classification of the House Index in the municipalities of the region.

2. Material and methods

This is an exploratory-descriptive study with an ecological design of aggregated data and quantitative approach.

2.1. Study Area

The study area constitutes the NEB region (Fig. 1). The geographical position of this region is approximately between latitudes of 1°N and 18.5°S and longitudes of 34.5°W and 48.5°W. The region is composed of nine states of the Federation - Maranhão (MA), Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Sergipe (SE), Alagoas AL) and Bahia (BA) - comprising 1794 municipalities in a territorial extension of 1,554,291 km^2.

The NEB presents a climate diversity that can be explained by a conjunction of factor associated to the physiography of the Northeast Brazil and the acting of meteorological systems. Topography, the proximity to the vast Amazonian forest and the variability and interaction of meteorological systems in different time scales are the main responsible for the climate diversity of the region (Mendonça & Danni-Oliveira, 2007; Santos E Silva et al., 2012; Vianello & Alves, 2012). The region also presents significant variations in rainfall, with a strong seasonal and spatial variability, which is subject to the global changes in course with the occurrence of both heavy rainfalls and drought climate extremes (Marengo et al., 2011; Vianello & Alves, 2012).