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Correlation of dengue incidence and rainfall occurrence using wavelet transform for João Pessoa city

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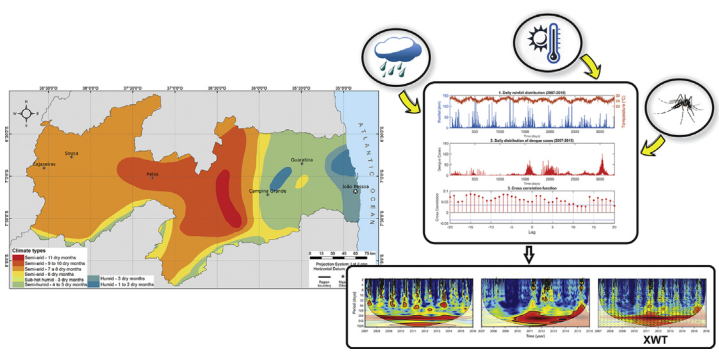
HIGHLIGHTS

- Dengue incidence is strongly leaded by specific rainfall frequencies.
- Greater time-lag association in the third month after the onset of rainfall
- Rainfall and dengue incidence time series has a weak correlation at lag-0.
- Identification of rainfall lags might be useful predictors of dengue incidence.
- Cross-wavelet analysis identified the periods when the time series were in-phase.

GRAPHICAL ABSTRACT



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ABSTRACT

Dengue, a reemerging disease, is one of the most important viral diseases transmitted by mosquitoes. In this study, 55,680 cases of dengue between 2007 and 2015 were reported in Paraíba State, among which, 30% were reported in João Pessoa city, with peaks in 2015, 2011 and 2013. Weather is considered to be a key factor in the temporal and spatial distribution of vector-transmitted diseases. Thus, the relationship between rainfall occurrence and dengue incidences reported from 2007 to 2015 in João Pessoa city, Paraíba State, Brazil, was analyzed by means of wavelet transform, when a frequency analysis of both rainfall and dengue incidence signals was performed. To determine the relationship between rainfall and the incidence of dengue cases, a sample cross correlation function was performed to identify lags in the rainfall and temperature variables that might be useful predictors of dengue incidence. The total rainfall within 90 days presented the most significant association with the number of dengue cases, whereas temperature was not found to be a useful predictor. The correlation between rainfall and the occurrence of dengue cases showed that the number of cases increased in the first few months after the rainy season. Wavelet analysis showed that in addition to the annual frequency presented in both time series, the dengue time series also presented the 3-year frequency from 2010. Cross wavelet analysis revealed that such an annual frequency of both time series was in phase; however, after 2010, it was also possible to observe 45° up phase arrows,

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which indicated that rainfall in the present year led to an increased dengue incidence the following year. Thus, this approach to analyze surveillance data might be useful for developing public health policies for dengue prevention and control.

1. Introduction

Dengue virus (DENV) infection leads to different clinical symptoms, ranging from mild self-limiting illness dengue fever (DF) to severe life-threatening diseases including dengue hemorrhagic fever (DHF) and dengue shock syndrome (DSS) (Her et al., 2017). Globally, DENV is one of the most important arboviruses that causes human diseases, infecting 50–100 million people annually (Simmons et al., 2012; McBride and Bielefeldt-Ohmann, 2000).

The annual incidence and methods utilized to estimate the incidence vary, with an estimated 58 million dengue cases and over 9000 deaths occurring in 2013 (Shepard et al., 2016), and since the 1980s, there has been an increase of 4.5 times in the number of reported cases in the Americas (San Martín et al., 2010). Americas accounted for 14% (9–18 million infections) of suspected infections worldwide, of which more than half occurred in Brazil and Mexico (Kakkar, 2012; Chakravarti et al., 2012). Brazil consists of five regions (north, northeast, central-west, southeast and south), which are divided into 26 states and a federal district, Brasília. There were approximately 210 million inhabitants in 2010, the majority living in urban areas in the southeastern and northeastern regions. Brazil is a tropical country with high temperatures, abundant rainfalls and significant humidity with variations between dry and wet weather, which are favorable to the proliferation of dengue vectors (Ribeiro et al., 2006; Goncalves and Rebelo, 2004; Forattini and Brito, 2003).

Rainfall patterns may provide favorable conditions for the growth of *Aedes aegypti* mosquitoes (Hii et al., 2012). Studies have shown the influence of weather variables on the magnitude of dengue distribution (Hii et al., 2009; Johansson et al., 2009; Wu et al., 2007) involving alterations in infectivity and survival rates of vectors in the incubation period of dengue virus and in the mosquito life cycle development (Yang et al., 2009; Fouque et al., 2006).

Similar to other vector-borne diseases, seasonal patterns in cases and vector abundance suggest that dengue transmission is sensitive to exogenous climatic factors (Negev et al., 2015). More specifically, vector density is correlated to the number of cases (Araújo et al., 2018) and climate variables, producing seasonal patterns that have been widely described, as discussed, for example, by Hii et al. (2009), Johansson et al. (2009) and Wu et al. (2007). However, the interannual cycles of dengue need to be examined. While many studies of climate–disease couplings have emphasized the potential application of these associations to early warning systems, the forecasting ability of the resulting models has not been systematically evaluated. This critical step must be carried out with an "out of fit" data if such models are to become useful tools to guide public health policy (Hii et al., 2012). In addition, analyses of climate–disease correlations must take into account a common property of disease data that can mask the patterns such as temporal series of cases that are typically nonstationary, with changes in the mean and/or the variance overtime.

Therefore, in the present paper, the number of dengue incidences and their correlation to rainfall data were described, according to the wavelet transform analysis between these two time series to support and guide health policies of the decision makers. The wavelet transform was used in the present study because it maintains the time and frequency localization in a signal analysis since it transforms a one-dimensional time series into a diffuse two-dimensional time-frequency image simultaneously, using a basic equation described in the literature as a mother-wavelet (Santos et al., 2003, 2009, 2013; Santos and Morais, 2013). Then, it was possible to get information on both amplitudes of any periodic signals within the series, and how this amplitude varies over time. These types of mathematical transformations can be applied to signals to obtain further information that is not readily available in the raw signal.

2. Materials and methods

2.1. Study area

Paraíba State is located between latitudes 6°S–8°S and longitudes 35°W–39°W (Fig. 1) and is part of northeastern Brazil, which consists of nine states: Alagoas, Pernambuco, Bahia, Rio Grande do Norte, Ceará, Piauí, Maranhão, Sergipe and Paraíba. Paraíba State covers an area of 56,372 km^2 and has a population of 3.94 million inhabitants, 76% of which are in urban areas (IBGE, 2017). The distribution of rainfall over Paraíba State is characterized by high spatial and temporal variability and the climate is one of the most important elements for economic and social conditioning in all stages of development in the region.

Most of the region has low rainfall rates, high average temperatures, acute water deficits, generally thin and often salty soils, and hyperxerophytic caatinga vegetation. Increased environmental degradation, observed in all regions of the state, has contributed to the development of desertification processes and, consequently, to the reduction of natural habitats.

The central part of Paraíba State, a very dry region, is part of the so-called polygon of droughts; however, in the coastal area, in which João Pessoa city is located, the annual average rainfall depth is >1000 mm. According to the Köppen classification, the following climatic types exist in Paraíba State: semiarid, sub-hot humid, semi-humid and humid (Fig. 2). In a general analysis of the temperatures in Paraíba State, there is a spatial variation that depends directly on the relief and the air masses. The higher areas have milder temperatures, while the low-lying areas are essentially hot (Fig. 3).

2.2. Data collection

Dengue suspected cases included people who lived or traveled to dengue endemic areas followed by the appearance of clinical symptoms (over a 14-day period), such as fever, with two or more of these manifestations: nausea, vomiting, skin erythema, generalized body ache, myalgia, arthralgia, petechiae, thrombocytopenia and a positive tourniquet test. Medical professionals were responsible for the clinical classification of the disease, along with laboratory confirmation through serology, NS1 test or polymerase chain reaction (PCR) tests. Reporting files for the Information System for Notifiable Diseases [*Sistema Nacional de Agravos de Notificação* (SINAN)] are mandatorily filled by the medical staff, due to the ordinance #104 of the Brazilian Ministry of Health, which classifies dengue as a compulsory notification disease. Therefore, monthly notifications of dengue cases are available by the Health Department of Paraíba State [*Secretaria Estadual de Saúde*] from 2007 to 2015. Data were processed using software of geographical information system ArcMap 10.1® in order to obtain the spatial distribution and perform the spatial analysis of dengue cases in Paraíba State from 2007 to 2015 (Fig. 4).

Daily data on rainfall were estimated with the product 3B42 V7 derived from the Tropical Rainfall Measuring Mission (TRMM) satellite and retrieved from the TRMM online visualization and analysis system,