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Spatial analysis of dengue fever and exploration of its environmental and socio-economic risk factors using ordinary least squares: A case study in five districts of Guangzhou City, China, 2014

Yujuan Yue[a], Jimin Sun[a], Xiaobo Liu[a], Dongsheng Ren[a], Qiyong Liu[a], Xiangming Xiao[b], Liang Lu[a,*]

[a] State Key Laboratory of Infectious Disease Prevention and Control, National Institute for Communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Beijing 102206, People's Republic of China

[b] Department of Microbiology and Plant Biology, University of Oklahoma, OK, USA

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ABSTRACT

Objective: Spatial patterns and environmental and socio-economic risk factors of dengue fever have been studied widely on a coarse scale; however, there are few such quantitative studies on a fine scale. There is a need to investigate these factors on a fine scale for dengue fever.

Methods: In this study, a dataset of dengue fever cases and environmental and socio-economic factors was constructed at 1-km spatial resolution, in particular 'land types' (LT), obtained from the first high resolution remote sensing satellite launched from China (GF-1 satellite), and 'land surface temperature', obtained from moderate resolution imaging spectroradiometer (MODIS) images. Spatial analysis methods, including point density, average nearest neighbor, spatial autocorrelation, and hot spot analysis, were used to analyze spatial patterns of dengue fever. Spearman rank correlation and ordinary least squares (OLS) were used to explore associated environmental and socio-economic risk factors of dengue fever in five districts of Guangzhou City, China in 2014.

Results: A total of 30 553 dengue fever cases were reported in the districts of Baiyun, Haizhu, Yuexiu, Liwan, and Tianhe of Guangzhou, China in 2014. Dengue fever cases showed strong seasonal variation. The cases from August to October accounted for 96.3% of the total cases in 2014. The top three districts for dengue fever morbidity were Baiyun (1.32%), Liwan (0.62%), and Haizhu (0.60%). Strong spatial clusters of dengue fever cases were observed. Areas of high density for dengue fever were located at the district junctions. The dengue fever outbreak was significantly correlated with LT, normalized difference water index (NDWI), land surface temperature of daytime (LSTD), land surface temperature of nighttime (LSTN), population density (PD), and gross domestic product (GDP) (correlation coefficients of 0.483, 0.456, 0.612, 0.699, 0.705, and 0.205, respectively). The OLS equation was built with dengue fever cases as the dependent variable and LT, LSTN, and PD as explanatory variables. The residuals were not spatially autocorrelated. The adjusted R-squared was 0.320.

Conclusions: The findings of spatio-temporal patterns and risk factors of dengue fever can provide scientific information for public health practitioners to formulate targeted, strategic plans and implement effective public health prevention and control measures.

Introduction

Dengue fever is a systemic viral infection transmitted by mosquitoes of the *Aedes* genus (Simmons et al., 2012), and is endemic in more than 100 countries of the Southeast Asia, Americas, Western Pacific, Africa, and Eastern Mediterranean regions (Guzman and Harris, 2015). A study in 2013 estimated that 390 million people had dengue virus infections with 96 million cases annually worldwide, more than three times higher than the World Health Organization 2012 estimates (Bhatt et al., 2013). Dengue fever has evolved from a sporadic disease to a major public health problem with substantial social and economic impacts because of increasing geographical extension, numbers of cases, and disease severity (Guzman and Harris, 2015).

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* Corresponding author.
E-mail address: luliang@icdc.cn (L. Lu).

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Dengue fever is a notifiable disease in China. From 1978 to 2008, a total of 655 324 cases and 610 deaths were reported in Mainland China. From 2009 to 2014, a total of 52 749 cases and six deaths were notified (Chen and Liu, 2015). Dengue fever outbreaks have spread from Guangdong and Hainan in the southern coastal areas to the relatively northern and western areas including Fujian, Zhejiang, and Yunnan, with shorter outbreak intervals as compared to those before the 1990s (Wu et al., 2010). Guangdong has been the area most seriously affected by dengue fever in China (Liu et al., 2014), and the majority of cases have occurred in Guangzhou, the capital city of Guangdong (Wang et al., 2013a). In recent years, Guangdong has had the highest incidence of dengue fever in China (Wang et al., 2013b; Fan et al., 2014; Li et al., 2013). According to the China National Notifiable Disease Surveillance System, an extensive dengue outbreak that posed a substantial socio-economic burden hit China in 2014 (Chen and Liu, 2015), with 47 127 dengue fever cases diagnosed in the country, 45 231 dengue fever cases in Guangdong, and 37 382 dengue fever cases in Guangzhou, among which 30 553 cases were aggregated in the districts of Baiyun, Liwan, Yuexiu, Haizhu, and Tianhe. The latter four districts belong to old districts of Guangzhou.

A better understanding of dengue fever outbreaks, especially spatial patterns, would help in the planning of resource allocation for dengue fever prevention and control (Lai et al., 2015). Most research on the spatio-temporal analysis of dengue fever has been based on a coarse scale (Bhatt et al., 2013; Chen and Liu, 2015; Lai et al., 2015; Hashizume et al., 2012; Corner et al., 2013; Dewan et al., 2017; Lippi et al., 2018; Castro et al., 2018; Shearer et al., 2018), such as the census district (Corner et al., 2013; Dewan et al., 2017), block (Lippi et al., 2018), or municipality (Castro et al., 2018). Most studies on dengue fever in China have been based on an administrative scale, such as the province, city, or district (Liu et al., 2014; Wang et al., 2013a,b; Fan et al., 2014; Li et al., 2013), and only a few studies on the spatio-temporal analysis of dengue fever have been based on the administrative scale of a town with an area in the dozens of square kilometers (Qi et al., 2015). However, dengue fever field monitoring performed by the present authors has shown that adjacent blocks may have significantly different dengue fever outbreaks. In other words, dengue fever outbreaks are similar on a coarse scale, but the spatio-temporal patterns on a fine scale may clearly be different. In order to evaluate the hotspot areas exactly, dengue fever analysis should be explored at as fine a spatial resolution as possible.

Dengue fever outbreaks are known to be strongly influenced by imported cases (Sang et al., 2014, 2015), mosquito density (Sang et al., 2014, 2015; Lai, 2011), meteorological factors (Wang et al., 2013a) (such as air temperature (Sang et al., 2014, 2015; Eastin et al., 2014; Xu et al., 2016; Goto et al., 2013), rainfall (Sang et al., 2014, 2015; Xu et al., 2016; Goto et al., 2013; Castro et al., 2018), relative humidity (Sang et al., 2014), vapor pressure (Sang et al., 2014), air pressure (Sang et al., 2014), and sea surface temperature (Lai, 2011; Laureano-Rosario et al., 2017)), socio-economic factors (Qi et al., 2015; Hagenlocher et al., 2013; Wu et al., 2009), and environmental factors (such as water (Fullerton et al., 2014; Tian et al., 2016), vegetation (Qi et al., 2015), river levels (Hashizume et al., 2012), access to paved roads, and housing conditions (Lippi et al., 2018)). Moreover, in dengue fever field monitoring, the present authors have found that dengue fever is closely related to environmental and socio-economic conditions, such as sanitation status, population density, ventilation conditions, etc.

Meteorological data rather than remote sensing data have been used in most dengue fever research in the past (Fan et al., 2014; Sang et al., 2014, 2015). For an area of 9 600 000 km^2, there are fewer than 800 meteorological stations in China. Furthermore, air temperature rather than land surface temperature has been used in such research (Sang et al., 2014, 2015). Land surface temperature derived from remote sensing images at a moderate spatial resolution has a smaller spatial scale and shows the true environmental condition more directly. Some researchers have studied risk factors of dengue fever using remote sensing data on the coarse scale of a city or neighborhood (Laureano-Rosario et al., 2017; Tian et al., 2016; Khormi and Kumar, 2011), such as sea surface temperature (Laureano-Rosario et al., 2017) and surface water areas (Tian et al., 2016). Others have studied dengue fever on a neighborhood scale but with the existing field investigation data (Delmelle et al., 2016). However, the use of remote sensing images on a fine scale has been scarce in previous studies. Such investigations are lacking, particularly in China. China now has its first high spatial resolution satellite – the GF-1 satellite. This has provided the opportunity to use China's own high resolution satellite data for application in disease prevention and control.

In this study, a dataset of dengue fever cases and environmental and socio-economic factors was constructed at 1-km spatial resolution for five districts of Guangzhou City, China in 2014. Spatial analysis methods including point density, average nearest neighbor, spatial autocorrelation, and hot spot analysis were adopted to analyze spatial patterns of dengue fever, and Spearman rank correlation and ordinary least squares were used to confirm environmental and socio-economic risk factors of dengue fever, in particular land types from GF-1 remote sensing images and land surface temperature from moderate resolution imaging spectroradiometer (MODIS) images.

Materials and methods

Study area

Guangzhou is the capital city of Guangdong Province. It is the largest coastal city in southern China, with an area of 7000 km^2 and about 13.5 million permanent residents. Guangzhou is located in the subtropical coastal area with an oceanic subtropical monsoon climate. In Guangzhou, the summer is long and the winter is short. The average daily temperature in Guangzhou is 16 °C in January and 28.7 °C in July, and the average annual precipitation ranges from 1600 mm to 1900 mm.

A dengue fever outbreak occurred in the five districts of Baiyun, Liwan, Yuexiu, Haizhu, and Tianhe in Guangzhou, China in 2014 (Figure 1).

Dengue fever case data

Data on dengue fever cases from January 1, 2014 to December 31, 2014 were collected from the China Information System for Disease Control and Prevention. Each dengue fever case was confirmed through clinical diagnosis or laboratory diagnosis, and details including the residential address, date of illness onset, etc., were available for each case. With geocoding technology, the address of each dengue fever case was transformed to a particular spatial location with latitude and longitude. A total of 30 553 cases from five districts of Guangzhou in 2014 were used in the analysis. The distribution of these cases is shown in Figure 2, in which the grey grid has a spatial resolution of 1 km. The study area comprised 758 grids. The numbers of dengue fever cases in these grids were obtained using the Data Management Tools and Spatial Statistics Tools of ArcMap 10.1 software. Environmental factor values in these grids were also obtained in this way.

Environmental and socio-economic factors

The environmental factors of land types (LT), normalized difference water index (NDWI), land surface temperature of