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Spatiotemporal responses of dengue fever transmission to the road network in an urban area

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ABSTRACT

Urbanization is one of the important factors leading to the spread of dengue fever. Recently, some studies found that the road network as an urbanization factor affects the distribution and spread of dengue epidemic, but the study of relationship between the distribution of dengue epidemic and road network is limited, especially in highly urbanized areas. This study explores the temporal and spatial spread characteristics of dengue fever in the distribution of road network by observing a dengue epidemic in the southern Chinese cities. Geographic information technology is used to extract the spatial location of cases and explore the temporal and spatial changes of dengue epidemic and its spatial relationship with road network. The results showed that there was a significant "severe" period in the temporal change of dengue epidemic situation, and the cases were mainly concentrated in the vicinity of narrow roads, the spread of the epidemic mainly along the high-density road network area. These results show that high-density road network is an important factor to the direction and scale of dengue epidemic. This information may be helpful to the development of related epidemic prevention and control strategies.

1. Introduction

Dengue fever is an insect-borne disease endemic in tropical and subtropical regions. It is characterized by rapid transmission speed and wide distribution. Each year, approximately 4 billion people are at risk of contracting the dengue virus and there are nearly 100 million confirmed cases (Bhatt et al., 2013; Gubler, 2011). There is no effective vaccine or specific remedy for the dengue virus so mosquito control and habitat management are critical for prevention of dengue fever outbreaks (Guzman et al., 2010; Wilder-Smith, 2014).

Significant changes have occurred in populations, transportation, and residential environments due to urbanization. These changes have altered the transmission and characteristics of dengue fever outbreaks (Hales et al., 2002; Teurlai et al., 2015; Troyo et al., 2009); especially in regions with high population density, the large numbers of dengue fever patients available to mosquitoes may accelerate dengue fever transmission (Wen et al., 2012; Wu et al., 2009). However, the flight range of mosquitoes is limited (Gu et al., 2006; Higa, 2011), so widespread transmission tends to be related to human activity and travel (Gardner and Sarkar, 2013; Huber et al., 2004; Nakata and Rost, 2015). Commuting activity also tends to increase the spread and transmission of outbreaks that are in their later stages (Sanna and Hsieh, 2017; Wen et al., 2012). Therefore, the study of dengue fever outbreaks related to transportation networks and human activity can help in understanding influential factors and changes in disease spread. This knowledge could aid in the prevention and control of outbreaks.

Several studies have shown that road networks correlated to the spatial distribution of dengue fever. Qi et al. (2015) and Li et al. (2017) demonstrated that high risk areas of dengue fever outbreaks are concentrated in areas with a higher density of roads. However, these studies did not explain the interactions between road networks and socioeconomic factors on the spatial distribution of dengue fever. Mahabir et al. (2012) studied the effect of road networks on the distribution of dengue fever cases and found that the distribution of dengue fever cases differed significantly near different road types. This research provided an intuitive understanding of the effect of road networks on the distribution of dengue fever outbreaks, but the temporal changes in dengue fever outbreaks in relation to road networks is limited. The objective of this article is to study the responses of dengue fever to a road network using existing data on road networks and spatiotemporal features of a dengue fever outbreak in a southern Chinese city. The results may provide more effective approaches for disease

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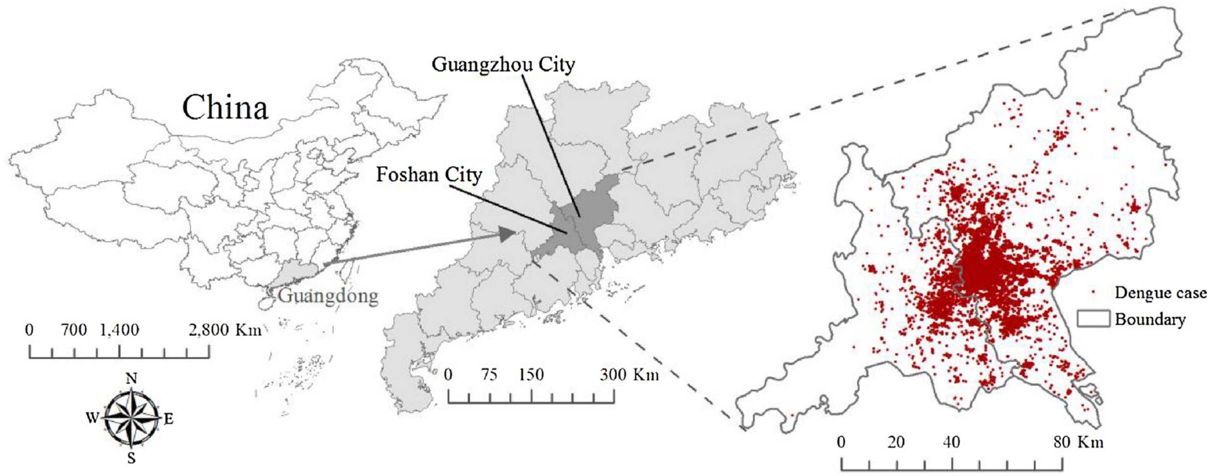

Fig. 1. Study area and dengue cases during the 2014 outbreak in GuangFo region.

prevention and control.

2. Material and methods

2.1. Study area

Guangzhou (113°15′E, 23°6′N) and Foshan (113°5′E, 23°2′N) are major cities of Guangdong Province located in the Pearl River Delta (Fig. 1). The total area of the two cities is 11181 km^2, and there are approximately 20,431,100 permanent residents. Guangzhou and Foshan are adjacent and frequently interact. Under the developmental background of "Guangzhou and Foshan to become one" these two cities have become the economic center of the Pearl River Delta, and Guangdong Province. We refer to this area as the GuangFo region. The GuangFo region has a subtropical monsoon climate, with rain and higher temperatures occurring during the same summer period. The suitable natural and social environment has made this a high risk area for dengue fever outbreaks (Fan et al., 2014; Li et al., 2012; Qi et al., 2015). In 2014, a large scale dengue fever outbreak occurred in the GuangFo region, in which 40379 cases of dengue fever were reported. These represented more than 90% of all dengue cases in Guangdong Province and in China.

2.2. Data collection

2.2.1. Dengue epidemic data

Dengue is a notifiable disease in China which means that, once diagnosed, cases must be reported to the web-based National Notifiable Infectious Disease Reporting Information System (NIDRIS) within 24 h (Cheng et al., 2016). The information of dengue cases include age, sex, address, and time of onset. The address information of the confirmed cases was used in conjunction with geocoding (http://www.gpsspg.com/xGeocoding/) to produce case data for the spatial point layer. More than 99% of DF cases were geocoded accurately, and the remaining cases can not be geocoded due to insufficient information in the DF case records (e.g. missing addresses or much generalized locations such as city or county level). These data were then displayed and processed using ArcGIS (ESRI, Redlands, CA) software. The duration of this study was 48 weeks (January 26 to December 21) (Fig. 2). In 2014, the dengue fever cases in the GuangFo region reached a peak at week 37. Weeks 28–43 (July 27 to November 14) had concentrated outbreaks. Analysis of case data during this period can help us understand the spatiotemporal distribution, spread characteristics, and related elements of the outbreaks.

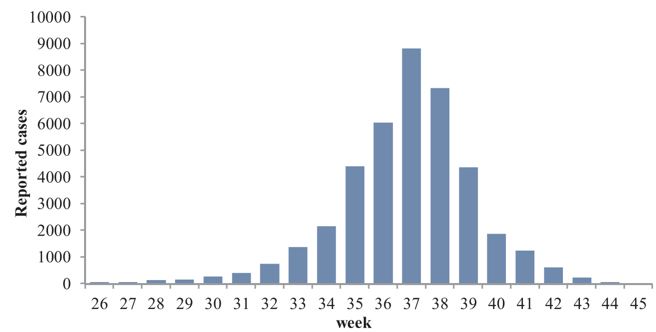

Fig. 2. Weekly distribution of dengue cases during the 2014 outbreak in GuangFo region.

2.2.2. Road network

In China, roads are devided into 5 technical levels (Technical Standards of Highway Engineering, JTGB01-2014), higher level means smaller traffic (e.g. the annal average daily traffic (AADT) of the 1st level highway is above 15000 cars, while AADT of the 5th level highway is below 2000 cars). The GuangFo region has a comprehensive road network. The road networks of the GuangFo region are characterized by overall distribution in the form of density in the center and dispersion in the surrounding areas. The freeways are mainly centered on Guangzhou and Foshan with a combined radial and ringed distribution. Branch roads and paths are distributed along both sides of the main freeways. The road data used in this study came from Resources and Environmental Science Data Center (RESDC, http://www.resdc.cn), and all roads in the data were expressed as the central lines on the roads. All road network data was simplified into 3 groups based on the roads' characteristics in the Guangfo area (Fig. 3). The classification was presented in detail in Table 1.

2.3. Method

2.3.1. Zonal statistics

We used the three ring highways of Guangzhou Inner Ring Road (Ring 1), Provincial Highway S81 (Ring 2), and National Highway G1501 (Ring 3) to divide the study area into four regions (Fig. 4). By observing the distribution features of dengue fever transmission in different periods within the four regions, we studied the distribution of dengue fever and its development characteristics. These three ringed freeways radiate outward from the center of the research area, connecting the main urban areas. There were also differences in population distributions and land usage in the four regions demarcated by these ring roads (Table 2). Therefore, the use of the three ring roads to