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Spatial mapping of temporal risk to improve prevention measures: A case study of dengue epidemic in Lahore

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A B S T R A C T

Background: Dengue is identified as serious vector born infectious disease by WHO, threatening around 2.5 billion people around the globe. Pakistan is facing dengue epidemic since 1994 but 2010 and 2011 dengue outbreaks were worst. During 2011 dengue outbreak 22,562 cases were reported and 363 died due to this fatal infection in Pakistan. In this study, Lahore District was chosen as it was severely affected in 2011 dengue outbreak with 14,000 reported cases and 300 deaths. There is no vaccine developed yet for the disease control, so only effective early warning, prevention and control measures can reduce the potential disease risk.
Methods: This study proposes a method for detecting spatial autocorrelation of temporal dynamics of disease using Local Index of Spatial Autocorrelation (LISA) using three temporal indices: (a) how often the dengue cases occur, frequency index; (b) how long the epidemic wave prevails, duration index; (c) how significant dengue cases occur in successive periods, severity index. Overlay analysis of LISA value for each temporal index resulted in eight risk types.
Results: The mapping of spatio-temporal risk indices and their overlay analysis identified that 10.6% area of Lahore (184.3 km^2 and population density 119,110 persons/km^2) had high values for frequency, duration, and severity index ($p < 0.05$) and 16% area (having 25% population) is at potential risk of dengue.
Conclusion: Spatial risk identification by using local spatial-autocorrelation helps in identifying other possible causes of disease risk and further strategic planning for prevention and control measures.

1. Introduction

Dengue is a vector born infectious disease transmitted by bite of an infected *Aedes aegypti* or *Aedes albopictus* mosquito. Dengue virus (DENV) has four stereotypes of the genus *Flavivirus*, family Flaviridae, namely DENV-1, DENV-2, DENV-3 and DENV-4. Disease symptoms appear after 3–14 days from first infected bite (World Health Organization, 2009). The number of disease cases has increased dramatically throughout the globe in last decade, around 2.5 billion people are at risk of dengue (World Health Organization, 2009, 2014; Ahmad et al., 2014). WHO estimates that around 50–100 million dengue cases are reported every year in over 100 endemic countries (World Health Organization, 2009).

In last 20 years at least seven epidemics have been reported in Pakistan (Ahmad et al., 2014). First laboratory confirmed dengue case was reported in 1994 from Karachi, but a sudden rise in cases and annual epidemic trend first

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occurred in Karachi in November 2005 (Ahmad et al., 2014; Mukhtar et al., 2012). Since then geographic expansion of dengue infections with increased frequency and severity has been reported in 105 out of 146 districts of Pakistan (Mukhtar et al., 2012). Increased population density, poor monsoon rainwater and solid waste management and national and international travel can be the possible cases of increased epidemic. As Dr. Paul Reiter (CDC Dengue Laboratories, Entomology Section) at the 1999 Dengue Symposium in Cairns explained, "people are vectors of the dengue virus, travelling the world, infecting Mosquitoes" (Shakoor et al., 2012). In the years 2010 and 2011, Pakistan faced the worst dengue outbreak in history with DENV-2 and DENV-3 as the predominant serotypes (Ahmad et al., 2014; Khan and Hasan, 2011; Ali et al., 2013). In 2010s outbreak 21,204 dengue infections were reported with 170 deaths (Mukhtar et al., 2012; Khan and Hasan, 2011). Similarly, outbreak in 2011 resulted in 22,562 dengue cases and 363 deaths out of which 14,000 cases and 300 deaths were reported from Lahore alone (Mukhtar et al., 2012; Fatima et al., 2016). Dengue epidemic typically occurs in monsoon season (July to September) and 2010 and 2011 were flood years due to excessive monsoon rains. During 2012 dengue remained under control as strict action plan launched by government of Punjab, but in 2013 district Swat (in Khyber Pakhtunkhwa province) experienced outbreak with more than 7000 suspected cases and 26 deaths (Khan and Hasan, 2011; Khan and Khan, 2015). In this outbreak, DENV-2 and DENV-3 were the most prevalent serotypes (Ali et al., 2013). One of the major unusual features of 2013s trend was that cases were reported from areas that do not fall in the traditional endemic belt of the country. According to Ali et al., for 2013s Swat outbreak, history of travel to dengue endemic areas was significantly associated with number of cases ($p = 0.023$) (Ali et al., 2013).

Disease is becoming catastrophic in nature due to its severity in the country. As rapid urban sprawl, increasing temperature, uneven rainfall, rural–urban migration and pockets of illegal settlements are providing fertile ground for *Aedes* breeding and rise of dengue transmission (Fatima et al., 2016; Wu et al., 2009; Nazri et al., 2011). Studies have shown that many factors contribute to the increasing number of patients such as varying climatic conditions, environmental risk factors (i.e. unavailability of piped water supply, lack of adequate waste management, dense housing patterns and mismanaged water storage containers), and socio-economic factors (Cheong et al., 2013; Khormi and Kumar, 2011; Yu et al., 2011). It has been observed that most dengue cases occur in potential hazardous areas that were neglected in prevention and control measures (Yu et al., 2011). Since no vaccine is available for any one of the four stereotypes, only effective prevention and control strategies can reduce the risk of disease. Thus, effective tools to visualize spatial and temporal spread of disease are vital as they help in identifying areas where timely control measures are required. Geographic information system (GIS) provides effective tools for mapping spatial spread of disease but only spatial mapping does not identify the statistical significant disease clusters (Dom et al., 2010; Nazri et al., 2013). Spatial statistics is now widely used to analyze the spatial autocorrelation of risk rates and to identify the origin of epidemic outbreak (Nazri et al., 2013).

Different methods have been used for disease mapping to pinpoint target areas with potential environmental risk factors (Dom et al., 2010; Nazri et al., 2013). Point pattern analysis is often used to visualize disease clustering but accurate position of cases involves privacy concerns and only visual clustering of cases location does not identify the actual disease burden (Wen et al., 2006). Geostatistics analyzes the spatial autocorrelation of disease covariates and specifies areas under environmental hazard (Rotela et al., 2007). Kernel density estimation, kriging, spline, and Inverse Distance Interpolation (IDW) are geostatistical methods used for continuous disease risk-surface estimation. Map of spatial clusters, considering total number of disease cases, is static snapshot, it totally ignores the temporal dynamics of disease occurrence. Thus, it becomes harder to analyze whether disease is in outbreak condition or kept under control by health department. Time series statistical techniques such as Knox test, Auto Regressive Integrated Moving Averages (ARIMA) or time series wavelet model are widely used for forecasting the outbreak but it totally ignores the spatial dynamics of disease thus cannot suggest adequate control strategies for different localities (Dom et al., 2013).

This paper proposed a spatio-temporal model for mapping risk clusters. Overlay analysis technique was used for identifying areas at high risk and origin of epidemic outbreak across geographic space. The model analyzed dengue outbreak at Union Council (UC) level, "UC" is the smallest local governing unit in Pakistan, using surveillance data of 2011 instead of relying on annual disease cases showing overall epidemic burden. There are 151 UCs and most are in urban Lahore with average covering area of 3 km^2 and average UC population around 73,000. Study used 52 weeks of the year as temporal scale.

2. Materials and methods

2.1. Study area and data

Lahore District, located in northern Punjab (31°32′59″ N 74°20′37″E) with an area of 1735 km^2, is second largest metropolitan city of Pakistan (Fig. 1). Lahore has an extreme climate with both warm and cold effects and in monsoon region of South Asia. The rainfall and humidity are ideal to nurture the habitat of dengue and malaria. Lahore is selected as study area as it is under dengue epidemic from 2006, but dengue outbreak in 2011 was worst with high death toll (Naqvi et al., 2015). Dengue outbreak in 2011 was considered as the worst outbreak since 1994 (Table 1). Fig. 2 shows the temporal progression of dengue in year 2011, the cases are concentrated between weeks 34 and 41. Dengue is environmental risk disease but monitoring of all environmental factors is not possible at micro spatio-temporal scale as large equipment and human resource are required, so only dengue confirmed cases (78% of the total) with complete home addresses, severity of disease, gender and age were used for year 2011 as correct patient record for only 2011 was available with exact