Environment International 73 (2014) 46–56

Contents lists available at ScienceDirect

Environment International

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

Impact of meteorological factors on the spatiotemporal patterns of dengue fever incidence

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ARTICLE INFO

Article history:
Received 10 December 2013
Accepted 22 June 2014
Available online xxxx

Keywords:
Dengue fever
Temporal delayed effect
Spatiotemporal modeling
Distributed lag nonlinear effects
Climatic effect

ABSTRACT

Dengue fever is one of the most widespread vector-borne diseases and has caused more than 50 million infections annually over the world. For the purposes of disease prevention and climate change health impact assessment, it is crucial to understand the weather-disease associations for dengue fever. This study investigated the nonlinear delayed impact of meteorological conditions on the spatiotemporal variations of dengue fever in southern Taiwan during 1998–2011. We present a novel integration of a distributed lag nonlinear model and Markov random fields to assess the nonlinear lagged effects of weather variables on temporal dynamics of dengue fever and to account for the geographical heterogeneity. This study identified the most significant meteorological measures to dengue fever variations, i.e., weekly minimum temperature, and the weekly maximum 24-hour rainfall, by obtaining the relative risk (RR) with respect to disease counts and a continuous 20-week lagged time. Results show that RR increased as minimum temperature increased, especially for the lagged period 5–18 weeks, and also suggest that the time to high disease risks can be decreased. Once the occurrence of maximum 24-hour rainfall is >50 mm, an associated increased RR lasted for up to 15 weeks. A temporary one-month decrease in the RR of dengue fever is noted following the extreme rain. In addition, the elevated incidence risk is identified in highly populated areas. Our results highlight the high nonlinearity of temporal lagged effects and magnitudes of temperature and rainfall on dengue fever epidemics. The results can be a practical reference for the early warning of dengue fever.

1. Introduction

Dengue fever is one of the most significant and widespread vector-borne diseases that causes more than 50 million infections annually. Approximately 2.5 billion people in over 100 countries are at risk for developing this disease. It is especially prevalent in the tropical and subtropical regions of Southeast Asia and the Western Pacific (WHO, 2009). Dengue fever is transmitted by the mosquito vectors, e.g., *Aedes aegypti* and *Aedes albopictus*. However, unlike yellow fever or other mosquito-borne diseases, there is no vaccine available for dengue fever. Therefore, understanding the space–time characteristics of dengue fever epidemics and revealing the risk factors are essential to preventing the disease. Among them, meteorological factors have been evident in their importance to the space–time dynamics of dengue fever transmissions (Kuhn et al., 2005). To develop a disease early warning system (EWS), it is essential to understand the empirical relationships between meteorological factors and dengue fever (Descloux et al., 2012; Hii et al., 2009, 2012; Kuhn et al., 2005; Lowe et al., 2011a, 2013; Rubio-Palis et al., 2011; Yu et al., 2011). Especially, the selection of significant delayed temporal lags with respect to weather variables is important for the EWS development of dengue fever epidemics (Hii et al., 2012; Hurtado-Diaz et al., 2007; Luz et al., 2008; Wu et al., 2007). However, previous studies showed that the identified most significant temporal lags could vary significantly among locations (Arcari et al., 2007; Hurtado-Diaz et al., 2007). Some studies selected multiple temporal lags to demonstrate the delayed effects of meteorological variables on dengue fever (Wu et al., 2007; Yu et al., 2011). In addition, the longest lag time associated with either rainfall or temperature is generally identified as two months, as seen in studies of Taiwan and Indonesia (Arcari et al., 2007; Wu et al., 2007).

Identifying the temporal associations between meteorological variables and dengue fever incidences can encounter several challenges: 1) the collinear nature of weather variables and 2) the disease can interplay with various confounding factors. These characteristics add elements of uncertainty and increase the difficulty in understanding the underlying temporal effects of meteorological variables on dengue virus transmission and spread, especially in the cases that conventional regression approaches have been most widely used method for the

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http://dx.doi.org/10.1016/j.envint.2014.06.018
0160-4120/

analyses of empirical associations (Arcari et al., 2007; Hurtado-Diaz et al., 2007; Wu et al., 2007). In addition, the influences of meteorological factors on dengue fever transmission can depend upon not only the temporal lags but also their magnitudes. Alternatively, the distributed lag model (DLM) was developed to provide a systematic framework to analyze multiple time series and to quantify outcomes of interest resulting from contributing factors over a certain period of time (Braga et al., 2001). The DLM has been applied to assess the lag distribution of the disease outcomes under a variety of environmental exposures including air pollution (Fraga et al., 2011; Welty and Zeger, 2005), and weather factors (Braga et al., 2001, 2002; Ha et al., 2011; Teklehaimanot et al., 2004). An advanced DLM combining spatial functions was also applied in Asian dust storm research (Yu et al., 2012) and dengue fever studies (Lowe et al., 2011b, 2013), providing a broader scope to detect comprehensive spatiotemporal impacts of climate conditions on human health. Nonetheless, these DLM models dealt with risk factors along with each lag separately and did not consider the interaction between risk factors and lags. Recently the development of the distributed lag non-linear model (DLNM) relaxes the shape assumptions of the DLM and allows the consideration of the nonlinearity of both predictors and their associated delayed effects (Gasparrini et al., 2010). The DLNM has been applied to several time-series studies to assess the concurrent and deferred impacts of weather variables (temperature and rainfall) on mortality (Guo et al., 2012; Yang et al., 2012), malaria (Kim et al., 2012), and heart disease (Guo et al., 2013). To our knowledge, the DLNM has not been used in analyzing space–time data. Specifically, no spatial function was considered in its original development.

In this study, we propose a spatiotemporal quasi-Poisson model of dengue fever that is based on the DLNM approach. The proposed model is used to investigate the delayed effects of the selected averaged and extreme measures of weekly meteorological conditions and the incidence of dengue fever by relying on weekly-recorded cases of dengue fever from 1998 to 2011 in southern Taiwan. In addition, the

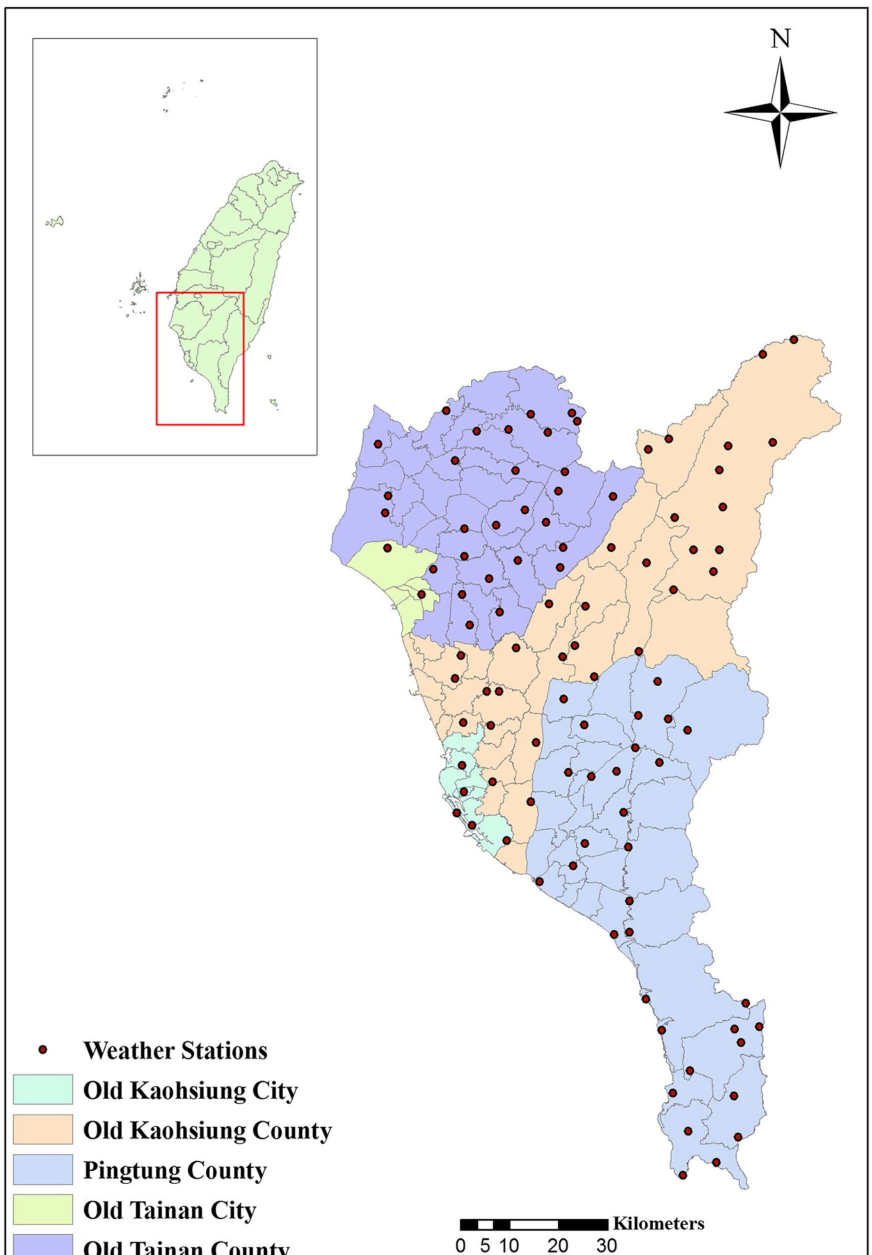

Fig. 1. Map of the study area, which includes 107 districts in southern Taiwan, and the location of automatic observation stations and weather stations.