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# Spatio-temporal patterns of dengue fever cases in Kaoshiung City, Taiwan, 2003–2008

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A B S T R A C T

Dengue fever is a serious vector-borne disease with worldwide incidence and is now considered to be a pandemic. A large body of literature has been developed to explore how the virus spreads and the role of its mosquito vector in this process. A data set of individual dengue fever cases collected in Kaoshiung City, Taiwan, has enabled us to examine dengue's spatial and temporal patterns between 2003 and 2008. Using geocoded individually reported cases, we detected and studied the changes in the spatial clusterness over time. We applied geospatial analysis to further study the spatio-temporal patterns of dengue fever cases in our data set, including hot spot/cold spot analysis and geographically weighted regression models. Using this data of individual cases, we confirmed, to some degree, the importance of the roles that population density, transportation arteries, and water bodies play in the spread of dengue fever. While these factors tend not to change drastically over time, the volatile changes in spatio-temporal patterns detected by our analysis suggest that additional environmental or socioeconomic factors need to be explored.



## Introduction

Dengue, also known as breakbone fever, is one of the most prevalent arthropod-borne diseases in the world today. It is an extremely painful disease caused by infection with any of the four serotypes of dengue viruses. Tens of millions of cases of dengue fever and hundreds of thousands of the more dangerous dengue hemorrhagic fever occur each year worldwide. Dengue is considered to be an emerging infectious disease pandemic due to its currently explosive growth rate, with disease incidence increasing 30-fold between 1960 and 2010 (WHO, 2009). It is endemic to most tropical, equatorial areas of the world, including Africa, Asia, the Pacific, Australia, and Latin America, and is also occasionally reported in the southern United States. Approximately 70% of the total 2.5 billion people living in endemic areas are at risk of infection (WHO, 2009). Situated in the subtropical zone, Taiwan experiences regular outbreaks of dengue. Over 1200 cases were reported in Taiwan in 2011, a 15% increase over that reported in 2009 (Taiwan CDC, 2009).

Dengue fever (DF) is the most common disease manifestation and is characterized by fever, headache, severe muscle and joint pain, exhaustion, swollen glands, and rash. While extremely painful, most of those infected recover within 7–10 days. Dengue hemorrhagic fever and dengue shock syndrome, while far less common than dengue fever, are severe, sometimes fatal, forms of infection (Ranjit & Kissoon, 2010; Varatharaj, 2010). The greatest risk factor for developing these forms of disease is infection by several viral serotypes, all of which are expanding and overlapping their ranges.

Dengue fever is spread by the bite of two species of *Aedes* mosquitoes, both of which are increasing their geographical distribution, allowing entry of viruses into new populations of susceptible human hosts. The tropical/subtropical-dwelling *Aedes aegypti* is the primary vector, but transmission by *Aedes albopictus* is increasing. The latter is able to survive colder winters, increasing the disease's geographical range (Lambrechts, Scott, & Gubler, 2010). Both species of mosquitoes are found in Taiwan, but

*Abbreviations:* DF, Dengue Fever; GIS, Geographical Information System; GPS, Global Positioning System; GWR, Geographically Weighted Regression; *I*, Moran's Index.

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*A. aegypti* is the major vector in southern Taiwan, including Kaoshiung City, the focus of this study and a region of the country with consistently high rates of disease (CDC Taiwan, 2011). Transmission in such coastal areas and within cities has high levels of spatial heterogeneity, with transmission traveling from large and dense population areas, such as Kaoshiung City, to those with less population (Chowell & Sanchez, 2006; Siqueira et al., 2004).

Peak periods of dengue infection throughout the world occur from early summer to late fall, when mosquito numbers are high (WHO, 2010). Due to the importance of climatic factors in the survival and egg-laying activity of mosquitoes, weather is often used to predict disease outbreaks (Wu, Guo, Lung, Lin, & Su, 2007). *A. aegypti* inhabit in domestic settings, particularly in large urban areas with high population density (Whitehorn & Farrar, 2010). Dengue may, however, also be present in rural areas (Thammapalo, Chongsuvivatwong, Greater, & Dueravee, 2007), but rarely in mountainous areas above 4000 feet. *A. aegypti* lays their eggs in artificial, uncovered water containers around human habitations. In Kaoshiung City, pots and bottles are often used to grow plants since space in homes is limited. Discarded bottles and tires are also common by the streets and in yards of that city (Lai, 2011). Tires and water storage vessels are associated with increased numbers of mosquitoes and DF cases (Chen, Hwang, & Guo, 1994). Gutters and receptacles in gardens, courtyards, and cemeteries also serve as mosquito breeding sites as do small items of discarded trash, including Styrofoam and cellophane wraps from discarded food containers (Heukelbach, de Oliveira, Kerr-Pontes, & Feldmeier, 2001). Accordingly, risk of disease is higher in the less sanitary environments prevailing in low income communities resulting from inconsistent or nonexistent refuse collection (Kuno, 1997; Weiss & McMichael, 2004).

Due to the current lack of effective treatment options and the absence of a vaccine, prevention is the most important means of protection. Some preventative measures limit human–mosquito contact using door and window screens as well as netting. Other measures use insecticides, larvicides, and predatory organisms to kill mosquitoes, while still other measures utilize educational programs that encourage the populace to eliminate water-filled mosquito breeding sites. In order to effectively implement protective measures, the ability to accurately predict locations of disease incidence over time would aid public health workers in pinpointing areas of high risk and not only protect local residents but also limit secondary disease spread. Other studies have utilized technologies such as the Geographical Information System/Global Positioning Systems (GIS/GPS) for DF surveillance and identification of clustering (Chadee, Williams, & Kitron, 2005; Morrison, Getis, Santiago, Rigau-Perez, & Reiter, 1998; Nakhapakorn & Tripathi, 2005). Due to the rapidity of the temporal and spatial spread of the disease, such surveillance systems have some limitations including the failure of physicians to correctly identify DF cases at the beginning of an outbreak or, conversely, to over-reporting later during the outbreak as lower numbers of the suspected cases may be laboratory-confirmed. Effective use of GIS in many endemic areas may be limited by the lack of zoning maps at an appropriate scale, especially in rural areas. Address-matching, also known as geocoding, is widely used to convert street addresses of patients to mappable locations. However, this process is also problematic due to changing of addresses over time. Alternative strategies, such as individually locating and verifying each case, are extremely labor-intensive (Morrison et al., 1998) and often are not feasible because of budget and time constraints.

The flight range of *A. aegypti* is very limited (50–100 m) (WHO, 1986). Consequently, disease spread may rely heavily upon either infected mosquitoes being transported from one region to another or from movement of infected persons. This would suggest that proximity to transportation arteries such as major roadways or rivers may be an important factor to consider in the development of any predictive models of the geographical spread of dengue. This study analyzes the spatial-temporal patterns and spread of dengue in Kaoshiung City in southern Taiwan between 2003 and early 2008 in order to determine the predictive relevance of parameters suggested to impact disease incidence. This will assist public health officials in determining whether the most effective plan for disease control would be blanket coverage of the entire at-risk area as opposed to focusing attention on suggested or known spatio-temporal distributional trends.

## Materials and methods

### *Data*

We received from the Health Bureau of Kaoshiung City in Taiwan a data set that includes all daily reported DF cases from 2003 to 2008. The reported DF cases were geocoded to latitude/longitude coordinates with time stamps in dates. Given that reported DF cases showed strong cyclic occurrences that normally start in mid or late summer and end in late fall, we designate the 2003 year to represent the cycle that starts in 2003 but ends in 2004. Consequently, we have data for 5 annual cycles of 2003–2004, 2004–2005, 2005–2006, 2006–2007, and 2007–2008. In addition to reported DF cases, we also used data from Census 2000 in Taiwan to establish population counts at the *Li* level, which is equivalent to the census blockgroup level in the US. Based on the population counts, population densities were computed for all *Li*'s.

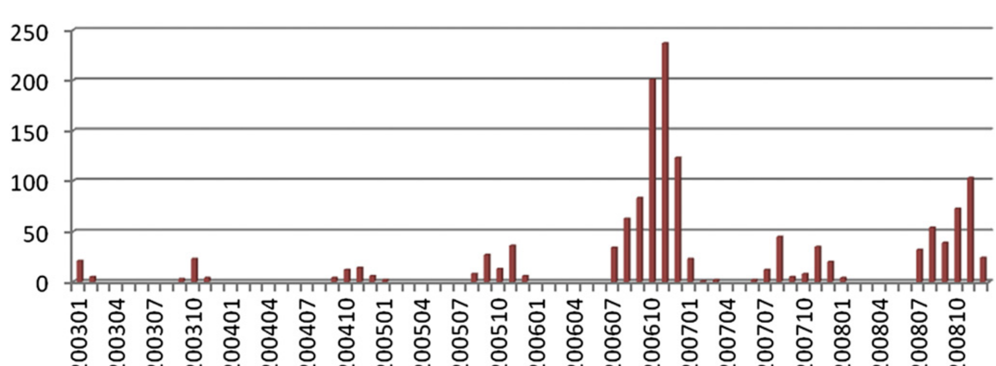


**Fig. 1.** Dengue cases in Kaoshiung City, Taiwan, 2003–2008. Numbers of DF cases reported monthly from January 2003 until December 2010 are graphically depicted.