Detecting dengue outbreaks in Malaysia using geospatial techniques

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Abstract

Dengue is a complex disease with an increasing number of infections worldwide. This study aimed to analyse spatiotemporal dengue outbreaks using geospatial techniques and examine the effects of the weather on dengue outbreaks in the Klang Valley area, Kuala Lumpur, Malaysia. Daily weather variables including rainfall, temperature (maximum and minimum) and wind speed were acquired together with the daily reported dengue cases data from 2001 to 2011 and converted into geospatial format to identify whether there was a specific pattern of the dengue outbreaks. The association between these variables and dengue outbreaks was assessed using Spearman's correlation. The result showed that dengue outbreaks consistently occurred in the study area during a 11-year study period. And that the strongest outbreaks frequently occurred in two high-rise apartment buildings located in Kuala Lumpur City centre. The results also show significant negative correlations between maximum temperature and minimum temperature on dengue outbreaks around the study area as well as in the area of the high-rise apartment buildings in Kuala Lumpur City centre.

Introduction

Dengue fever (DF) is a vector-borne disease caused by the dengue virus (DENV) transmitted by the mosquito species, *Aedes aegypti* and *Ae. albopictus* (Christie, 1881; Senthil *et al.*, 2014; Shaikh *et al.*, 2014). *Ae. aegypti* is the primary vector of DF in tropical and subtropical regions. Both mosquito species breed in rural and suburban areas (Hawley *et al.*, 1987; Rodhain *et al.*, 1997). After it has been transmitted to a person from the bite of a female mosquito, DENV produces a viraemic state causing the infected person to develop mild to severe DF. Mild infection resembles an influenza-like illness, whereas a severe DF can advance to dengue haemorrhagic fever (DHF) and dengue shock syndrome (DSS) (Gibbons, 2010; Guzman and Istúriz, 2010; Gubler, 2011).

DF incidence has increased globally, particularly affecting those living in tropical and subtropical regions in Southeast Asia, the Americas, and Asia Pacific (Halstead, 2007; Simmons *et al.*, 2012; Yasuno and Tonn, 1970). Approximately 2.5 billion people in 120 countries are at risk of dengue infection (Ng, 2011; Otu *et al.*, 2019) and more than 50 million dengue infections are reported each year, with more than 500,000 individuals hospitalised due to the DF (Guzman *et al.*, 2010). The number of reported DF cases increases each year, causing high mortality globally (Beatty *et al.*, 2011).

Since the 20th century, DF has become the most critical public health issue in urban areas due to the increase in urbanisation, globalisation, lack of mosquito control strategies and climate change. The urban areas provide an ideal breeding environment for the *Aedes* mosquitoes. Several species breed in artificial human-made environments, such as illegal dumpsites and building sites (Chang *et al.*, 2011). Moreover, stagnant water trapped in non-biodegradable containers, such as vehicle tyres, plant pots and the like during the rainy season becomes the breeding ground for these mosquitoes (Lowe *et al.*, 2011; Wan-Norafikah *et al.*, 2012). Collectively, the factors mentioned above contribute to DENV transmission.

In Malaysia, the DF endemic is a never-ending war since Penang's first dengue case in 1902 (Skae, 1902). Ever since then, dengue has become a significant public health problem in the country (Smith, 1957; Rudnick *et al.*, 1965). Although many initiatives based on legislation, community participation, pesticides (either active against the adult mosquitoes or the larvae) and integrated control strategies have been taken, the number of reported dengue cases continues to rise (Lee *et al.*, 2008; Malaysia, 2009; Nazni *et al.*, 2009). In Malaysia, the cumulative dengue case was 157% higher in 2019 compared to 2018 (World Health Organisation, 2019). By the end of July 2019, Malaysia reported 79,151 dengue cases nationwide, with the Selangor state contributing 40,849 (Crisis Preparedness and Response Centre,

2020). The increasing number of dengue cases is alarming for a developing country like Malaysia because it has highly populated city centres (*e.g.* Petaling Jaya and Kuala Lumpur) suitable for dengue transmission. Some studies done in Malaysia argue that the presence of *Aedes* mosquitoes and increasing dengue cases may be associated with the dense urban population (Nazri *et al.*, 2009, World Health Organization, 2009).

Geographic information systems (GIS), a robust approach to geospatial analysis, have been applied in epidemiological and public health studies for many years assessing dengue location and identifying potential risk factors involved in disease transmission (Mohammed *et al.*, 2019; Moha *et al.*, 2020; Murugesan *et al.*, 2020). To date, GIS dengue applications in Malaysia have only used the individual dengue case data and focused on small local areas of Klang Valley near the nation's capital, Kuala Lumpur (*e.g.* Subang Jaya and Hulu Langat districts in Selangor) (Nazri *et al.*, 2009; Dom *et al.*, 2010; Er *et al.*, 2010). However, there is still a lack of evidence with regard to outbreak identification and the area of vulnerability in the Klang Valley area. This research's primary aim was to identify the dengue outbreak location together with analysing the spatiotemporal trend of dengue outbreaks using geospatial techniques in Malaysia's most urbanised area.

Materials and methods

Study area

Kuala Lumpur and Petaling Jaya are in the heart of Klang Valley, one of Malaysia's fastest growing urban areas (Figure 1). The Klang Valley is the centre of Malaysia's industry and commerce. The latest census report indicates that this area's population has expanded to 6.3 million (SPAD, 2016). Spatial data regarding the administrative boundaries (state, district, sub-district, boundary map, road map, Klang Valley city centre and local authority boundary map) were collected from the Klang Valley local authorities and the Department of Survey and Mapping Malaysia (JUPEM).

The Petaling District, which includes Petaling Jaya, Shah Alam, and Subang Jaya have recorded the highest number of dengue cases in Selangor (JKN Selangor, 2016). From the University Malaya Medical Centre (UMMC), we obtained the confirmed dengue case data for its catchment area (101°39'11.50"E, 3°6'48.59"N) (Figure 1). This hospital was chosen for this study because it is situated in the Petaling District and Kuala Lumpur, with a consistently high number of dengue cases. Furthermore, UMMC maintains an annual record of dengue cases required in

Figure 1. Study area location.

understanding the characteristics of dengue transmission in Malaysia.

Data acquisition

Dengue cases

These data were obtained from the UMMC. Only dengue cases confirmed through laboratory testing using serological tests for immunoglobulin M (IgM) antibody against any of the four different dengue serotypes (IgM capture enzyme-linked immunosorbent assay; ELISA) were included in this study. The reason for using laboratory-confirmed data rather than the reported dengue cases was to avoid inaccurate information and to know which cases were new. Cases could have been misdiagnosed since signs and symptoms of other diseases, such as typhoid and malaria are similar to those of dengue. In addition, the reported cases may not include all those infected since it does not include asymptomatic patients. We also acquired age, gender and geographical address of the confirmed dengue cases as well as information and photographs of known dengue outbreak locations from the Department of Health and Environment of Kuala Lumpur City Hall (DBKL).

Meteorological data

Daily meteorological data for the period of January 2001 until December 2011 were obtained from Meteorological Department, Malaysia. The variables used to examine the effects of the weather on the dengue outbreak pattern included rainfall, maximum and minimum temperature, wind speed, and humidity. Spearman's correlation coefficient (r) was used to determine the relationship between various variables. This method provides accurate information about the variables' relationships, which is crucial. The results vary between +1 and –1, where the positive correlation ($r=$ +1) refers to a 45° upward line slope, while the negative ($r=$ –1) refers a 45° downward line slope. A positive r value (near +1) indicates that the increase of weather variables would also increase the dengue outbreak, while a negative r value (near –1) indicates that the increase of weather variables will reduce the dengue outbreak. Values of r around 0 mean a random relationship. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) software.

Geospatial and statistical analysis

First, point level geo-coding technique was applied by converting the patients' addresses into an absolute location (latitude and longitude) using Google Earth. The absolute location data first was standardised using Microsoft Excel. Next, the standardised data were imported to ArcGIS software version 10.5. There were 9348 dengue cases throughout the study area in the 2001-2011 period.

To pinpoint the location of the dengue outbreak, we applied quadrant analysis, which involved superimposing previous dengue cases data onto a regular square grid. In line with the Malaysian Ministry of Health's official definition of a dengue outbreak (*i.e.* the occurrence of two or more dengue cases ≤200 m of each other and less than 14 days apart as described by the Malaysian Remote Sensing Agency (2014)), we distinguished between 1 (=two or more dengue cases) and 0 (=one no dengue case) on a systematic 200-meter grid of projected coordinates Kertau RSO Malaya (m) system for the study area. The Kertau RSO Malaya meter was the common map projection that has been in topographic mapping and engineering surveys for Malaysia. The triangulated irregular network (TIN) method (Academic Press, 2020) was applied to the final data in ArcGIS to create a three-dimensional (3D) mapping overlaying of the 11-year results.

Results

A total of 1274 outbreaks were identified from 2001 until 2011 (Table 1). The highest number of reported outbreaks was 226 occurred in 2008 followed by 195 in 2004 and 174 in 2007. We found that the dengue outbreaks had 2-cycle patterns, with the first starting in 2001when the number of outbreaks continued to increase until it peaked in 2004 and then dropped drastically in 2005. The second cycle started in 2006 demonstrating the same outline as the first one. Here the number of outbreaks continued to increase until peaking in 2008 and then dropping to its lowest in 2011. This retrospective study indicated that dengue outbreaks had a pattern with cycles that occurred continuously for an average of two consecutive years

The dengue outbreak map generated from the quadrant analysis is shown in Figure 2 where the outbreaks are colour-coded, with the lowest number of outbreaks in dark green and the highest in red. Most outbreaks were centred at the Kuala Lumpur area, in particular around the west side of Kuala Lumpur city, which is close to the Petaling Jaya border and known as Zone 1. In addition, outbreak locations were also detected around the western area of Petaling Jaya. As further seen in Figure 2, there are several areas in Kuala Lumpur and Petaling Jaya that consistently score the highest number of dengue outbreaks. For example, Zone 1 in Kuala Lumpur not only recorded the highest number of outbreaks in 2004 (76) but also the highest dengue outbreak number for five more years: 2002 (29), 2003 (27), 2006 (31), 2007 (25) and 2009 (17). A change of outbreak distribution was noted in 2006, when the higher concentration of dengue outbreaks switched from western Kuala Lumpur to the western part of Petaling Jaya.

The highest dengue outbreaks persistently occurred in residential areas (Figure 3). The analysis showed that there are two high-rise apartment buildings located in Zone 1 of Kuala Lumpur city centre in the area where the highest dengue outbreak number was consistently recorded. Apartment Building 1 is situated in Zone 1,

Table 1. The annual number of dengue outbreaks between 2001 and 2011.

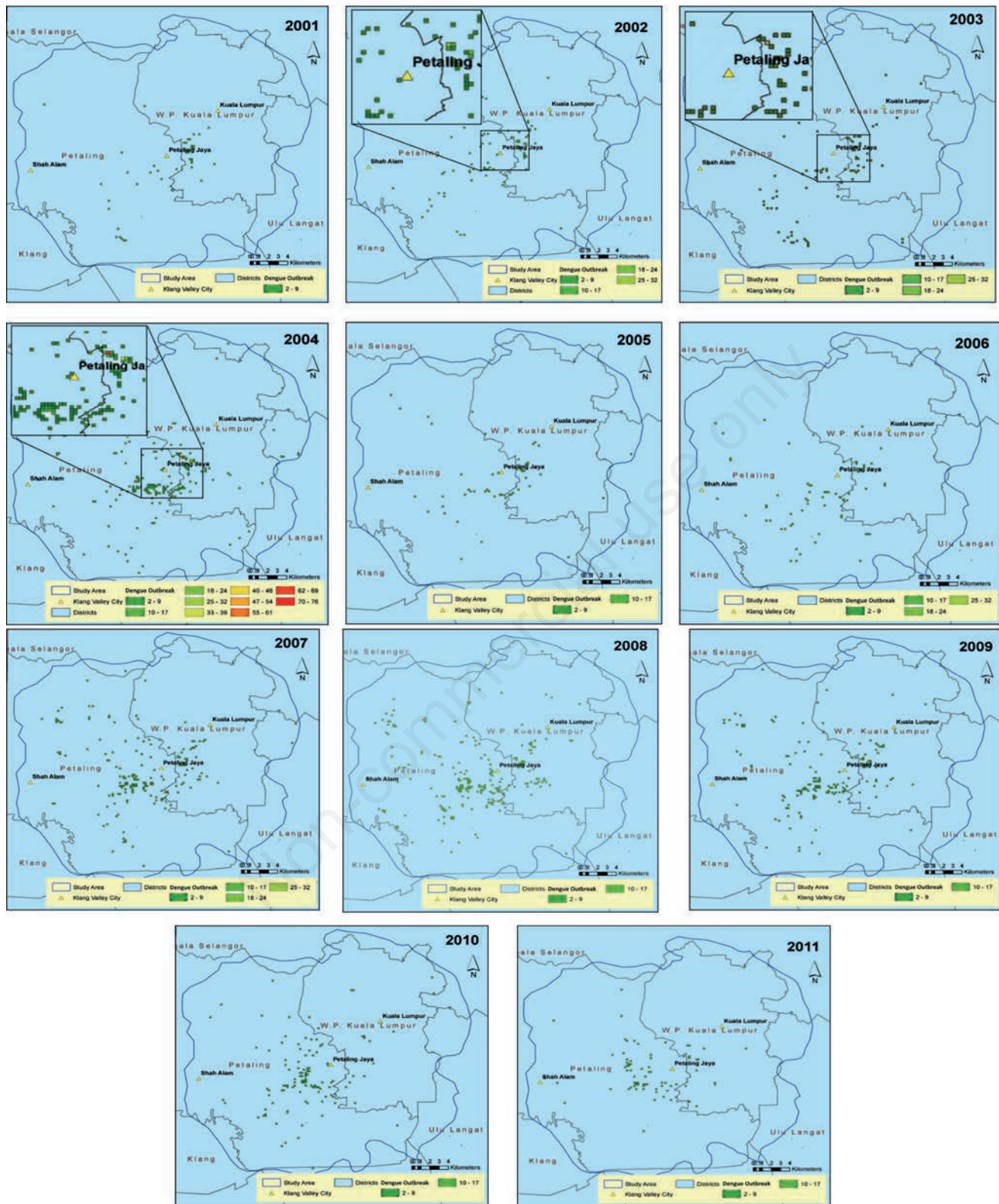| Time (year)	Outbreak (no.)
2001	43
2002	85
2003	87
2004	195
2005	52
2006	65
2007	174
2008	226
2009	156
2010	117
2011	74
Total	1274

Figure 2. Distribution and number of annual dengue outbreak locations from 2001 to 2011. The highest number of outbreaks occurred in 2003 (27), 2002 (29) and 2004 (76).

where the consistently high number of outbreaks had been recorded. A similar result was also observed in Petaling Jaya, which saw the highest dengue outbreak number in 2008 (13) followed by 2010 (13) and 2011 (17).

Figure 4 shows the photographs of the two high-rise, residential apartment buildings, both with over ten floors. These two buildings reported the highest dengue outbreaks in Kuala Lumpur during the study period. Figure 5 shows stagnant water in the drain system of Apartment Building 1 and 2 (photograph provided by the DBKL).

The results of Spearman's correlation analysis of the environmental variables with respect to dengue outbreaks are displayed in Tables 2 and 3, the former dealing within the whole study area and the latter with Zone 1 in Kuala Lumpur. In both areas, the maximum temperature was found to negatively correlate with the dengue outbreaks at a statistically significant level, as did the minimum temperature but less strongly so.

We also found that some of the variables showed weak negative correlations, *i.e.* rainfall and temperature in the whole study area, as well as rainfall, temperature and humidity in Zone 1, while some others did not. However, the wind variables had a weak positive correlation in both areas.

Discussion

The primary aim of this study was to analyse the spatiotemporal trend of dengue outbreaks using geospatial techniques in Malaysia's most urbanised area. Our analysis revealed that the highest number of dengue outbreaks consistently occurred in residential areas, which was particularly pronounced at the vicinity of

two high-rise apartment buildings. Like other urban cities in other developing countries, most of the population live in densely populated neighbourhoods (*e.g.* in apartment buildings). This situation results from rapid urban development and urban processes that affect the influx of people from rural areas to the city, resulting in local explosive population growth (Honório *et al.*, 2009; Braga *et al.*, 2010; Paz-Soldan *et al.*, 2011). High living costs force people to find comparatively low-cost residential areas and their choice has often been apartment in buildings with ten floors or higher, *e.g.* Pantai Dalam in Kuala Lumpur and Old Klang road area in Petaling Jaya.

High-density populations in endemic areas increase dengue transmission that can lead to dengue outbreaks (Wen *et al.*, 2010), a risk which is exacerbated by waste management failure. Other than that, residents' low awareness and attitudes, such as disposing of rubbish (*e.g.* non-biodegradable plastics, car tyres and tin cans) everywhere, work as trigger events (Hayes *et al.*, 2003, Ma *et al.*, 2008). Such conditions eventually become suitable habitats for mosquitoes, thereby increasing vector opportunities for *Ae. aegypti* and other carriers of the infection (Lawson *et al.*, 2001) resulting in increased biting rates and infections (Er *et al.*, 2010). Similar findings have also been reported in previous studies done in several Asia Pacific countries (Wen *et al.*, 2006; Er *et al.*, 2010; Wen *et al.*, 2010).

The structure of residential buildings is another factor that may cause dengue outbreaks (Aris, 2019). Most dengue outbreaks found in this study occurred in people living in flats in high-rise apartment buildings. Iyagba (2005) and Cheong (2014) explained that building factors, especially related to high-rise buildings, can contribute to dengue outbreaks in urban areas (Iyagba, 2005; Cheong *et al.*, 2014). Thus, building structures and conditions can become trigger factors, *e.g.* for the dengue outbreaks. This possi-

Table 2. Correlation between environmental variables and dengue outbreaks in the study area.

Variable	Rainfall	Temp	Haze	Max. temp.	Min. temp.	Wind	Humidity	Dengue
Rainfall	**1.00**	−0.10	−0.26	−0.04	-0.05	−0.02	0.12	−0.04
Temp.	−0.10	**1.00**	0.17	0.32	0.23	−0.01	0.09	−0.03
Haze	−0.26	0.17	**1.00**	0.17	0.05	0.03	−0.12	0.00
Max. temp.	−0.04	0.32	0.17	**1.00**	0.47	0.06	−0.08	−0.21*
Min. temp.	−0.05	0.23	0.05	0.47	**1.00**	0.10	0.05	−0.14*
Wind	−0.02	−0.01	0.03	0.06	0.10	**1.00**	−0.10	0.01
Humidity	0.12	0.09	−0.12	−0.08	0.05	−0.10	**1.00**	0.01
Dengue	−0.04	−0.03	0.00	−0.21*	−0.14*	0.01	0.01	**1.00**

*Significant correlation between dengue with environmental variables.

Table 3. Correlation between environmental variables and dengue outbreaks in Kuala Lumpur's Zone 1.

Variable	Rainfall	Temp	Haze	Max. temp.	Min. temp.	Wind	Humidity	Dengue
Rainfall	**1.00**	−0.10	−0.26	−0.04	−0.05	−0.02	0.12	−0.05
Temp.	−0.10	**1.00**	0.17	0.32	0.23	−0.01	0.09	−0.08
Haze	−0.26	0.17	**1.00**	0.17	0.05	0.03	−0.12	0.03
Max. temp.	−0.04	0.32	0.17	**1.00**	0.47	0.06	−0.08	−0.27*
Min. temp.	−0.05	0.23	0.05	0.47	**1.00**	0.10	0.05	−0.21*
Wind	−0.02	−0.01	0.03	0.06	0.10	**1.00**	−0.10	0.05
Humidity	0.12	0.09	−0.12	−0.08	0.05	−0.10	**1.00**	−0.05
Dengue	−0.05	−0.08	0.03	−0.27*	-0.21*	0.05	−0.05	**1.00**

*Significant correlation between dengue with environmental variables.

bility is plausible when examining the building gutters on the roof designed to remove rainwater. Notably, the gutters were not covered to prevent the accumulation of rubbish, leaves, debris, and dust. The accumulation of these objects clogged the gutter and caused the rainwater to stagnate, thus providing an ideal habitat for the mosquitoes to breed.

Other building elements, such as improper floor surfaces, also contribute to dengue upsurge by providing ideal conditions for *Aedes* mosquitoes to breed. Previous studies suggest that the building's structure and material can increase the *Aedes* populations, for example when debris accumulate on the floor causing water to be blocked and stagnated (Montgomery and Ritchie, 2002; Sairi *et al.*, 2016). Other types of building structures (*e.g.* corridors and walkways) could also become breeding grounds for *Aedes* mosquitoes. Several studies in Asian countries show similar findings as our

study (Thammapalo *et al.*, 2005; Lau *et al.*, 2013; Lee *et al.*, 2013), which support the idea that high-rise apartment buildings provide a complete ecosystem for the *Aedes* mosquitoes. However, further research is warranted to investigate the influence of different building's structural design (*e.g.* terraces, balconies, gutters, roof structures and floor finishes) on *Aedes* reproduction. This study's findings could be a starting point for future dengue epidemiological study in Klang Valley. Health officials and policymakers could use these results to plan sustainable urban development policies.

This study's secondary aim was to investigate the effects of the weather on dengue outbreak frequency. Although the association between climate and dengue are complex and challenging to study, we found a negative association in relation to maximum and minimum temperatures in the locations studied. These findings are similar to those reported by Yu (2011) and Jemal and Al-Thukair
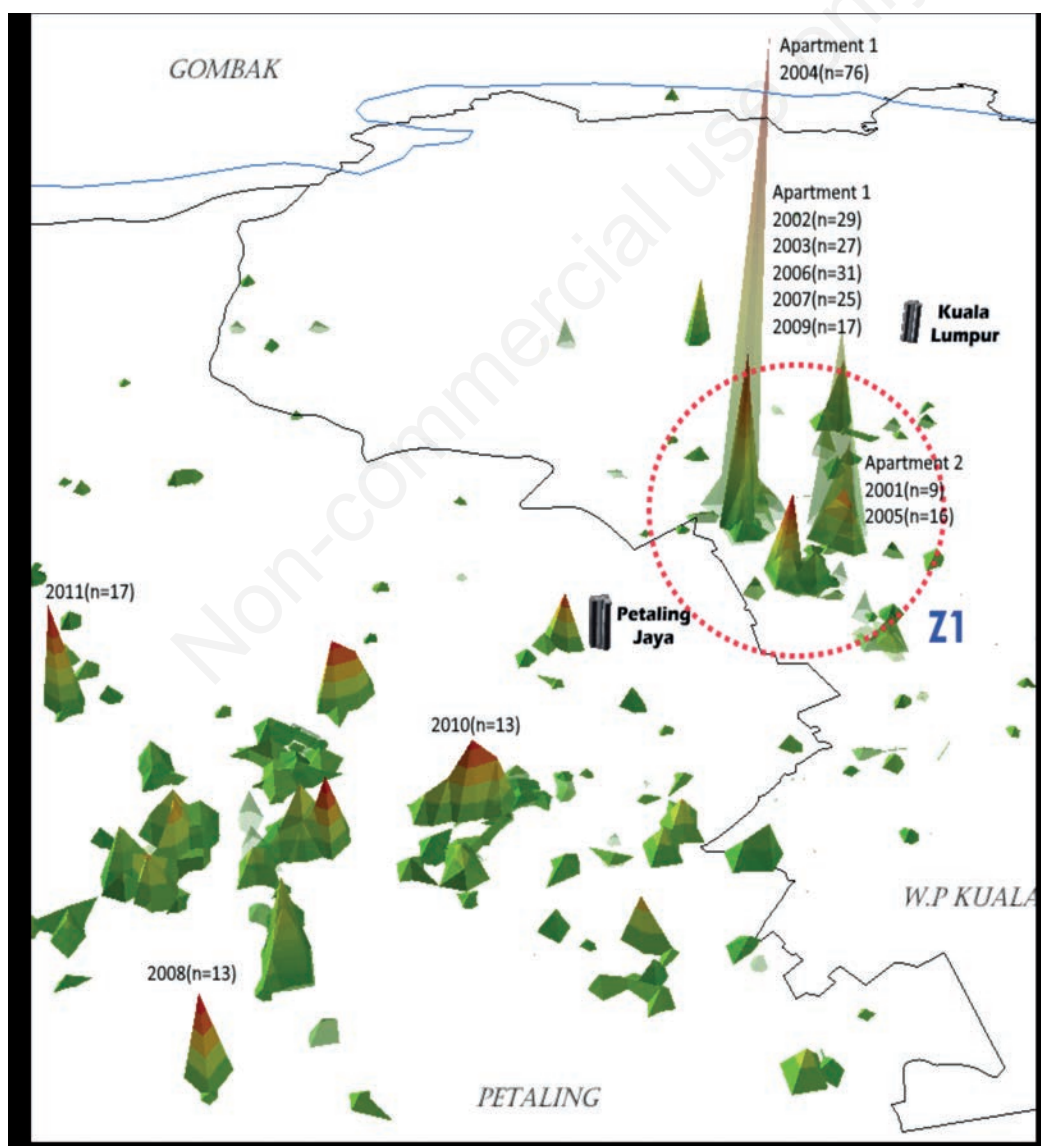

Figure 3. Location and number of the strongest dengue outbreaks in Petaling and Kuala Lumpur.

(2018) (Yu *et al*., 2011; Jemal and Al-Thukair, 2018). According to their studies in Taiwan, temperatures higher than 30°C can decrease vector growth. However, these findings contrasted with those reported by Marinho (2016) and Liu *et al*. (2017), who showed that the temperature positively affected the dengue incidence, even when it is above 30°C. (Marinho *et al*., 2016; Liu *et al*., 2017). The increasing temperature accelerates biochemical reactions in the vector increasing viral development as well as vector reproduction, thus increasing dengue transmission risk (Scott and Morrison, 2010; Chan and Johansson, 2012). However, increased temperatures do not only speed up replication and incubation rates but can also negatively impact vector fitness and its capacity to transmit the virus (Lafferty, 2009). Previous observations found a negative correlation between temperature and dengue outbreak during summer, when the increased temperature may hin-

der the viral growth (Liu *et al*., 2020). Other than that, the long school holiday in summer could also contribute to the low dengue incidence rate as most children stay at home. Thus, there is less physical interaction with peers than when at school. Although the exact mechanisms of weather effects on dengue transmission largely remain unclear, we show that that temperature significantly influences the infection rate. Nonetheless, further studies are warranted to better understand the complex relationship between weather variables and dengue transmission.

Dengue has a complex epidemiology as it includes many dynamic transmission interactions between virus, vector and the human host. These factors influence the transmission directly and indirectly, and our study cannot account for all possible variables. Additional data are needed, such as knowledge of virus serotype and genotype, host immune status, vector density, urban water sup-

Figure 4. Two high-rise residential apartment buildings in the study areas that had high numbers of dengue outbreaks. Top: Apartment Building 1; Bottom: Apartment Building 2 (for location see Figure 3).

ply and waste management data. Knowledge and application of this multitude of data should contribute significantly to combating dengue transmission in the future.

One possible limitation lies in the sole use of retrospective data. This is due to the process of construction of GIS data that takes long time as well as technical problems involving the quality of the original dengue data. However, this study has shown a feasible way to utilize better disease surveillance records and environmental information for the study of spatio-temporal disease patterns and environmental risk assessment. The surveillance records of previous years can be studied retrospectively to look for a trend or pattern that can provide advice for future decision-making in disease prevention and control.

Conclusions

We conclude that dengue remains a major threat to socio-economic activities and certain geographical conditions promote mosquito reproduction and disease transmission. The geospatial application through quadrant analysis described here identified residential areas with high population densities as the places with the highest number of dengue outbreaks, and that the temperature variable plays a major role for dengue transmission. Since neither drugs nor vaccines are currently available, vector control is the only way to break the transmission cycle. Findings from this study should contribute to the planning of more effective vector control interventions as geospatial applications can support public health departments and agencies in planning control and surveillance.

Figure 5. Stagnant water in the high-rise apartment buildings, which provides ideal habitats for Aedes mosquito breeding. Top: Apartment Building 1; Bottom: Apartment Building 2 (for location see Figure 3).

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