The correlation of climate factors on dengue transmission in urban area: Bangkok and Singapore cases.

Sittisede Polwiang

Department of Mathematics, Faculty of Science
Silpakorn University, Thailand

INTRODUCTION

Dengue fever and dengue haemorrhagic fever are an infectious disease in humans, caused by a virus of the Flavivirus genus, Flaviviridae family from mosquito. Approximately a third of world population are living in countries with dengue endemic areas, the major disease burden being in tropical and subtropical regions. The symptoms of dengue fever individuals range from asymptomatic to high fevers, headache, muscle and joint pain. Severe cases of dengue are plasma leakage, and could be death. The dengue virus is transmitted to humans if bitten by infected female mosquitoes. The primary vector is Aedes aegypti and the secondary is Aedes albopictus. Aedes mosquitoes are normally habit in tropical and subtropical areas and have adapted to cohabit with humans in both urban and rural environments (WHO 2016).

Bangkok is the capital city of Thailand with a population greater than 5.7 million and the area is 1,568 km² (Bangkok 2016). Singapore is small country with the area of 719 km², 5.5 million population. 100% of population in both cities live in urban area (Singapore stat 2016). The population density is very high. The cities locate in tropical area which is favorable condition for dengue endemic. Bangkok and Singapore share the same situation that dengue fever is very serious public health problem with more than 5,000 cases reported every year. Several dengue control have been performed in both cities. However, the number of clinical dengue case still increasing in the past few years. The concern of dengue endemic become more serious due to climate change is rising.

Aedes mosquito larvae require clear water to complete their life cycle and premature mosquito stay in the water 7-10 days (CDC 2016). Rainfall will provides the water for Aedes aegypti to lay the eggs and pre-mature stage to develop to adult stage. The most suitable temperature for dengue transmission is 28.7C. In Thailand, dengue fever is normally become wide spread during wet season from June to September. However, in the dense urban populous area like Bangkok, the trend of dengue fever is different. Dengue fever is wide spread in Bangkok during the last quarter of the year. Singapore is located near equator line. The amount of cumulative rainfall is normally high for most of the year and only one month that is a dry month (rainfall less than 60mm) and temperature is almost constant throughout the year. The demographic of Singapore is suitable for dengue transmission.

It has been proposed that the weather variables and seasonality can increase the predictive power of dengue models. Several dengue transmission is temperature dependent under laboratory condition (Liu-Helmersson 2014). Several studies have shown that temperature has a huge impact on dengue transmission. Too high or too low temperature would increase the mortality rate of
mosquito (Yang 2009). A large diurnal temperature range (DTR) reduce the survival rate of mosquito (Carrington 2013). The relationship between weather variables and dengue has been assessed in multiple settings using different statistical methods. However, the connection between dengue and the weather variables in urban areas still remains questionable because of the potential influence of other factors that may have a significant effect on dengue transmission. For example, several man-made such as vases, jars and improper closed water storage are favorite breeding sites for mosquito all year around.

The objective of this study was to evaluate the weather variable to dengue incidence rate in dense populous cities, Bangkok and Singapore. The correlation are calculated and the Poisson model with weather factors are created in this study. To improve dengue prevention, surveillance and early warning system, the pattern of dengue transmission is essential.

Figure 1: the time series of monthly dengue incidence rate, maximum, mean minimum temperature, DTR, monthly rainfall and rain day during 2009-2015 in Bangkok (A) and Singapore (B).

METHODS
Surveillance data
In this study, monthly dengue incidence rate is measured in cases per 100,000. The data of dengue fever in Bangkok was collected from department of disease control of Thailand (2016) and the

**Statistical analysis**

Spearman’s correlation analysis was performed to evaluate the relationship between number of monthly dengue incidence rate and weather variables with time-lag from zero to four months in Bangkok and Singapore during the period 2009-2015. The weather variables used in this study are rainfall is the total monthly rain measure in millimeters (mm), rain day is number of day with rain, diurnal temperature range (DTR), maximum temperature of the month (Tmax), minimum temperature of the month (Tmin) and mean temperature of the month (Tmean).

The lagged-time linear and Poisson regression analysis was calculated to find the formulae to predict the dengue incidence rate.

A basic multivariable Linear regression model can be written as,

\[ D_t = a_0 + \sum_{n=1}^{k} a_n W_{n,\tau}. \]

A basic multivariable Poisson regression model can be written as,

\[ \ln(D_t) = a_0 + \sum_{n=1}^{k} a_n W_{n,\tau}. \]

where \( a_0 \) is intercept, \( t \) is time in month, \( a_n \) is coefficient for weather variables, \( W_{n,\tau} \) is weather variable with time-lag \( \tau \) month. A month variable and previous month dengue incidence rate are also included in the Poisson regression model. All statistical analyses are performed using Minitab 14 for Windows.

**RESULTS**

**The dengue incidence rate and weather data**

In Bangkok and Singapore, dengue is endemic with year-round transmission. In spite of the great effort in mosquito control implemented in both cities during the last decades, outbreaks had occurred with more often and intensity with large outbreaks reported in 2013-2014 in Singapore and 2015 in Bangkok.

Figure 1 displays the monthly dengue incidence rate per 100,000 population, the maximum minimum mean, DTR, rainfall and rain day in Bangkok and Singapore during 2009-2015. In Bangkok, dengue case number is normally below 50 cases per 100,000 population. However, during the last two months of 2015, the numbers were over 100 cases per 100,000 population. These numbers are unusual event. In 2015, the total number of dengue cases in Bangkok was 26,291 or 461.87 per 10000, which is more than double of average 7 years. In Singapore, the numbers of dengue incidence rate are normally below 10 during 2009-2012. However, the numbers surge to 20-60 during 2012-2015. The highest is
During 2009-2015, the monthly maximum temperature in Bangkok is 30-32 °C and minimum is 23-27 °C. The average yearly rainfall is 1863 mm. In Singapore during the same period, the monthly maximum temperature is 32-36 °C and minimum is 24-26°C. The average yearly rainfall is 2033 mm. Thus Bangkok is warmer than Singapore and has lower rainfall. Additionally, Bangkok has 3-6 month of dry month, in one year, around November to April (rainfall below 60 mm) while Singapore has 0-2 months and not consecutive month. Therefore, the dry season in Bangkok is longer than Singapore.

### Statistical analysis results

The spearman’s correlation are calculated to find the relation between dengue incidence rate and weather variables in Bangkok and Singapore during 2009-2015. The correlation between dengue incidence rate and weather variables are displayed in Table 1. In Bangkok, monthly rainfall \( r = 0.451, p < 0.001 \), the number of rainy days \( r = 0.411, p < 0.001 \) are positive correlation with 2 month lag time. DTR \( r = -0.335, p < 0.001 \) is negative correlation with 2 month lag time. Maximum \( r = 0.256, p < 0.05 \), mean \( r = 0.304, p < 0.001 \) and minimum \( r = 0.323, p < 0.001 \) temperature are positive correlation with 4 month lag time. In Singapore, only minimum temperature with 1 month lag time is negative correlation and DTR with zero month lag time is positively correlation. The rest has no statically significance \( ( p > 0.05 ) \).

It is believed that the dengue incidence in the previous month triggers the outbreak in the current month. The dengue incidence rate in the current month is related to the incidence rate occurring in the previous month (Wongkoon 2013). In this study, the correlation between previous and current month for dengue incidence rate are \( r = 0.578 (p<0.001) \) for Bangkok and \( r = 0.872 (p<0.001) \) for Singapore.

<table>
<thead>
<tr>
<th>Time-lag (months)</th>
<th>Rainfall (mm)</th>
<th>Rainy day (Days)</th>
<th>DTR (°C)</th>
<th>Tmean (°C)</th>
<th>Tmax (°C)</th>
<th>Tmin (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangkok</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.049</td>
<td>0.05</td>
<td>-0.175**</td>
<td>-0.153</td>
<td>-0.209</td>
<td>-0.093</td>
</tr>
<tr>
<td>1</td>
<td>0.187</td>
<td>0.228</td>
<td>-0.315**</td>
<td>0.030</td>
<td>-0.062</td>
<td>0.108</td>
</tr>
<tr>
<td>2</td>
<td><strong>0.451</strong>*</td>
<td><strong>0.411</strong>*</td>
<td><strong>-0.335</strong></td>
<td>0.021</td>
<td>-0.078</td>
<td>0.105</td>
</tr>
<tr>
<td>3</td>
<td>0.329**</td>
<td>0.304**</td>
<td>-0.206</td>
<td>0.183</td>
<td>0.128</td>
<td>0.218</td>
</tr>
<tr>
<td>4</td>
<td>0.075</td>
<td>0.114</td>
<td>-0.190</td>
<td><strong>0.304</strong></td>
<td>0.256*</td>
<td><strong>0.323</strong>*</td>
</tr>
<tr>
<td>Singapore</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>-0.045</td>
<td>-0.023</td>
<td><strong>-0.288</strong></td>
<td>0.131</td>
<td>-0.020</td>
<td>0.268*</td>
</tr>
<tr>
<td>1</td>
<td>-0.015</td>
<td>0.072</td>
<td>-0.251*</td>
<td>0.184</td>
<td>0.041</td>
<td><strong>0.299</strong>*</td>
</tr>
<tr>
<td>2</td>
<td>0.004</td>
<td>0.115</td>
<td>-0.142</td>
<td>0.202</td>
<td>0.105</td>
<td>0.261*</td>
</tr>
<tr>
<td>3</td>
<td>-0.022</td>
<td>-0.005</td>
<td>-0.067</td>
<td>0.173</td>
<td>0.113</td>
<td>0.197</td>
</tr>
<tr>
<td>4</td>
<td>0.017</td>
<td>-0.075</td>
<td>-0.069</td>
<td>0.031</td>
<td>-0.005</td>
<td>0.065</td>
</tr>
</tbody>
</table>

* p<0.05, **p<0.01, ***p<0.001 , the bold word denote the variable included in regression
By fitting the weather variables which show statistical significance and dengue incidence rate data. The constant values of the regressions are obtained.

The linear regression for Bangkok is

\[ D_t = -37 + 0.0588 \text{Rainfall}_{t-2} - 0.365 \text{Rainday}_{t-2} - 1.2 \text{DTR}_{t-2} \\
+ 0.74 \text{Tmin}_{t-4} + 1.08 \text{Tmean}_{t-4} + 0.4961 \text{D}_t \]

and for Singapore is

\[ D_t = -19.3 - 0.52 \text{DTR}_t + 1.00 \text{Tmin}_{t-1} + 0.854 \text{D}_t \]

R-square for the linear fitting is 46.5% and 76.5 % for Bangkok and Singapore respectively.

The Poisson regression for Bangkok is

\[ \ln(D_t) = -1.44 + 0.0027 \text{Rainfall}_{t-2} - 0.0066 \text{Rainday}_{t-2} - 0.044 \text{DTR}_{t-2} \\
+ 0.086 \text{Tmin}_{t-4} + 0.051 \text{Tmean}_{t-4} + 0.0141 \text{D}_t \]

and for Singapore is

\[ \ln(D_t) = 1.07 - 0.099 \text{DTR}_t + 0.0552 \text{Tmin}_{t-1} + 0.0444 \text{D}_t \]

Figure 2: The actual dengue incidence rate (continuous line) and the predicted dengue cases (broken line) from January 2009 to December 2015 by the Poisson regression model for Bangkok (A) and Singapore (B).
R-square for the Poisson fitting is 53.4% and 74.5% for Bangkok and Singapore respectively. Figure 2 displays the time series Poisson regression model (broken line), which is created from the equations with the data for the period January 2009-December 2015 and actual dengue incidence rate (continuous line). The prediction model fit well with the actual data in both Bangkok and Singapore.

**DISCUSSION**

*Aedes aegypti* is the mosquito that normally inhabit in urban areas. As rain independent water supply is readily available in the urban area throughout the year. Mosquito need rain for breeding sites, but too much rain may wash out pre-mature mosquito. The possible larval habitats for *Aedes aegypti* in the urban area such as vases, jars or the drainage systems are abundant in the cities. Bangkok and Singapore are a high densely populated area and demographic is suitable for mosquito to inhabit. Dengue virus can spread quickly under this condition. Singapore has only one dry month (rainfall less than 60 mm) in one year compared to Bangkok which is 3-6 months. Thus there is rainfall to provides the breeding for *Aedes aegypti* for all year around in Singapore.

The spearman’s correlation show that weather plays a marginal role in Singapore and moderate role in Bangkok. Time lag is not obvious in Singapore but in Bangkok is 2-4 months. The temperature of Singapore is nearly the same for every months. Thus it is difficult to observe the influence of temperature and high rainfall is almost throughout the year. Therefore, the climate factor is not obviously seen in Singapore.

The results in this study similar to others. Table 2 illustrates the comparison between this study and the others. The time lag varies from zero to 4 months. Chen et al (2010) indicated that temperature play more significant role than rainfall in Taipei and Kaohsiung with time-lag 1-4 months. Gharbi et al (2011) calculated that the dengue incidence in French West indies was correlated with temperature and humidity with time lag 5-11 weeks. Banu et al. (2014) reported that temperature and humidity are correlated dengue incidence in Dhaka with 2 month time. Added found that climate factors are correlated with dengue incidence in French Guiana with 4-6

<table>
<thead>
<tr>
<th>Author</th>
<th>Place</th>
<th>Rainfall</th>
<th>Rain day</th>
<th>DTR</th>
<th>Lagged time</th>
<th>Tmax</th>
<th>Tmin</th>
<th>Tmean</th>
<th>humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>Bangkok</td>
<td>2 m</td>
<td>2 m</td>
<td>2 m</td>
<td>4 m</td>
<td>4 m</td>
<td>4 m</td>
<td>4 m</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Singapore</td>
<td>-</td>
<td>-</td>
<td>0 m</td>
<td>-</td>
<td>1 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chen (2010)</td>
<td>Taipei</td>
<td>1 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1 m</td>
<td>1-2 m</td>
<td>4 m</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Kaohsiung</td>
<td>3 m</td>
<td>-</td>
<td>-</td>
<td>3 m</td>
<td>3 m</td>
<td>3 m</td>
<td>3 m</td>
<td>-</td>
</tr>
<tr>
<td>Gharbi (2011)</td>
<td>French West</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5 w</td>
<td>11 w</td>
<td>-</td>
<td>-</td>
<td>7 w</td>
</tr>
<tr>
<td>Banu (2014)</td>
<td>French Indies</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2 m</td>
<td>-</td>
<td>-</td>
<td>2 m</td>
<td>-</td>
</tr>
<tr>
<td>Adde (2016)</td>
<td>Dhaka</td>
<td>4-6 w</td>
<td>-</td>
<td>-</td>
<td>4-6 w</td>
<td>4-6 w</td>
<td>4-6 w</td>
<td>4-6 w</td>
<td>-</td>
</tr>
<tr>
<td>Wongkoon (2013)</td>
<td>Guiana</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1 m</td>
</tr>
</tbody>
</table>

m= month and w = week
weeks time lag. Wongkoon et al. reported that dengue incidence in Sisaket, Thailand is correlated with rainfall without time-lag.

The regression model indicates that the number of dengue cases in a current month can be estimated by observing the number of dengue cases occurring in the previous month. This may provide a warning indicator to the local communities and health authorities. The dengue incidence corresponds with the number of Aedes larvae in the study site; the number of Ae. aegypti and Ae. albopictus larvae was highest during the rainy season when a dengue incidence outbreak was observed in the area. For Bangkok, Poisson regression is fit better than linear regression (R-square 53.4% and 46.5%). For Singapore, linear regression is fit better than Poisson regression (R-square 76.5% and 74.5%). However, Hii et al. (2009) showed that the weekly mean temperature and cumulative precipitation were statistically significant related to the increases of dengue incidence in Singapore.

Dengue in Singapore showed a minor seasonal correlation due to water-filled containers being present year round, short dry season month and nearly constant temperature throughout the year. Rainfall in Bangkok plays more role in dengue incident rate than temperature because the temperature punctuation is small, the dry season in Bangkok is much longer than Singapore.

The regression model indicates that the number of dengue cases in a current month can be estimated by observing the number of dengue cases occurring in the previous month. This may provide a warning indicator to the local communities and health authorities.

In conclusion, there is no statistical significance between rainfall and dengue incidence rate and temperature play a marginal role in Singapore. Climate factors play moderate role in dengue incidence in Bangkok. This is the result of little different seasonality in both cities.

Reference


Chen S.C., Liao C.M., Chio C.P., et al. 2010 Lagged temperature effect with mosquito transmission potential explains dengue variability in southern Taiwan: insights from a statistical analysis. Sci Total Environ. 408(19):4069-75

Gharbi M., Quenel P., Gustave J., et al. 2011 Time series analysis of dengue incidence in Guadeloupe, French West Indies: Forecasting models using climate variables as predictors, BMC Infectious Diseases201111:166

Hii YL, Rocklöv J, Ng N, et al. 2009 Climate variability and increase in intensity and magnitude of dengue incidence in Singapore. Glob Health Action. 11;2


