ORIGINAL ARTICLE

Inferring the temporal dissemination patterns of Aedes indices and weather variables in Penang: a five-year study

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Abstract:

The aim of this study was to assess the temporal characteristics of *Aedes* indices (AI) using weather variables over a period of five years, specifically from 2011 to 2016. This study utilized an integrated epidemiological approach to investigate the temporal distribution of AI with the pattern of weather variables. A retrospective cross-sectional study was conducted to analyze information obtained from the meteorological department and the Ministry of Health, Malaysia. A Pearson correlation analysis was conducted by using five lag-terms of temperature, relative humidity and cumulative rainfall as an attempt to evaluate the relationship between AI and climatic variables as well as its exposure-response effects. In general, the trends of the AI in the study area vary from year to year and demonstrate an increase in all spot areas. Open and construction areas recorded the highest AI values. Results indicate that the overall distribution of AI was analogous to the distribution patterns of monthly temperature. In addition, the highest AI was observed at temperature exceeding 27°C. This study revealed no correlation between AI with weather variables. Nevertheless, the characteristics and pattern of both parameters have potential to be used as a baseline data for dengue vector control programme and can be used to evaluate its efficacy.

Keywords: Aedes surveillance, climate, Malaysia

1. INTRODUCTION

Dengue is a major public health problem in tropical countries worldwide [1, 2, 3]. The main culprits of this disease are the *Aedes. aegypti* and *Aedes albopictus*. The increasing population growth in Malaysia has also invariably increased the number of vector-borne diseases [4, 5]. The increasing numbers of breeding sites for mosquitoes are the main cause of the dengue outbreak in this country [6]. Dengue control and prevention programme are very important to curb outbreaks during or before the event. While the development of dengue vaccine is in various phase of development, vector control to date reamins most effective means to prevent dengue transmission [7, 8].

The best approach to mitigate the spread of outbreaks is to have an effective surveillance system and to foster collaboration amongst various agencies including the public to ensure efficacious elimination of possible breeding sites. The geographical expansion of vector-borne diseases has been partially associated with the current changes in global warming and climate change [9]. The variance of temperatures that can occur during climate change will affect the biology of the dengue vector's development time [10, 11]. A study conducted by Mohammed & Chadee, [12] documented that warmer water temperature (30°C to 33°C) had the fastest development time for *Ae. aegypti* to immature. Dengue control in Malaysia is primarily based on case surveillance through the notification of suspected dengue cases by medical personnel and vector control by space spraying of insecticides. Vector surveillance is conducted by regular larval surveys of *Aedes* mosquitoes and computing of the *Aedes* Index (AI) and Breateau Index (BI) according to specific localities. According to the WHO 2012, the probability of transmission is directly proportional to the density of mosquitoes for local transmission to take place through man-mosquitoes contact.

Most research on vector mosquitoes conclude that the factors influencing dengue vector densities and viral transmission are ecological, biological and social (eco-bio-social) [10, 13, 14]. However, multivariate analyses comprising combinations of these factors; to our knowledge, have not been conducted on a large scale, especially in Malaysia. Prior studies have highlighted the importance of epidemiological investigation to examine the endemisation of dengue. Surveillance is an important component of any prevention and control programme [15, 16]. Unfortunately, most dengue-endemic countries have neither an effective surveillance system nor an effective mosquito control program to date. There are several limitations of the dengue control programs that should be considered in dengue surveillance in order to ensure their effectiveness. Traditional entomological surveillance techniques such as premise/house index (HI); Container Index (CI); and Breteau index (BI) are normally used to measure the exposure of non-immune individuals to the vector based on the presence or absence of *Aedes* larvae and/or pupae at home. Many studies have revealed only a weak correlation between *Aedes* density and dengue incidence at the household level [3]. The primary reason for this is due to spatial and temporal mismatch between the entomological and epidemiological survey. Therefore, an integrated data source is very valuable as all the information on the parameters to be measured will be analyzed holistically to obtain desired results [17]. Data used will include ones generated from climatic factor, urbanization as well as demographic data. In summary, each component of data is interconnected and therefore, needs to be vividly scrutinized from all angles.

2. MATERIALS AND METHODS

2.1 Study site and study population

In this study, the state of Penang was selected as the main research site to study the temporal distribution of *Aedes* indices and weather variables. Penang is a state with a population of 1,902,116 and has the highest population density in Malaysia (1,490 people/square kilometer) [18]. It is the most populated island in Malaysia and has the highest population density in the country. Penang is geographically divided into two sections, (i) the Penang Island and the (ii) Province Wellesley. Penang has five main administrative districts; three of which are in mainland [South Seberang Perai (SPP), Central Seberang Perai (CSP) and North Seberang Perai (NSP)], while the other two districts are on an island [Northeast Penang Island (NPI) and Southwest Penang Island (SPI)].

The selection of this area was justified by several factors. First Penang was a high population density and significant public health implications in relation to the control and prevention of dengue fever (DF). In general, Penang experiences an equatorial type of climate with a warm and humid weather throughout the year. Days are warm and sunny with the temperature of around 30°C; and nights are cool with the temperature of around 22°C. Penang is quite dry in the months of January and February. Rainfall is heavy and is experienced especially from August to November.

2.2 Study design

This study applied an integrated epidemiological design to investigate the temporal distribution of *Aedes* indices (AI) with the pattern of weather variables. A retrospective cross-sectional study was conducted between 2011 to 2016. Information obtained from the meteorological department and the Ministry of Health was analyzed. The data that were used for this research are (i) dengue surveillance data and (ii) weather data (temperature, relative humidity, rainfall) with variation in terms of location and time. Dengue surveillance data in five administrative districts in Penang was used. The data were obtained from the passive surveillance system from the years 2011 to 2016, which consists of 52 weeks of each year. The Malaysian Meteorological Department provides meteorological and seismological services of high quality to fulfill the socio-economic and security needs. In this research, ambient temperature, relative humidity and rainfall data are collected from weather forecast services.

The collection of several types of data sets may provide a baseline that is useful to develop a prediction model of the future dengue outbreak. The acquired outputs were analyzed using causal relationship by implementing the epidemiological trends of *Aedes* indices with the weather pattern. This information was collected and reviewed weekly, and over time, to allow public health epidemiologists and laboratories to understand the spread of dengue outbreak in their catchments area, providing them with the real-time information they need to detect small changes that may be important. The overall research methodology is summarized in Figure 1.

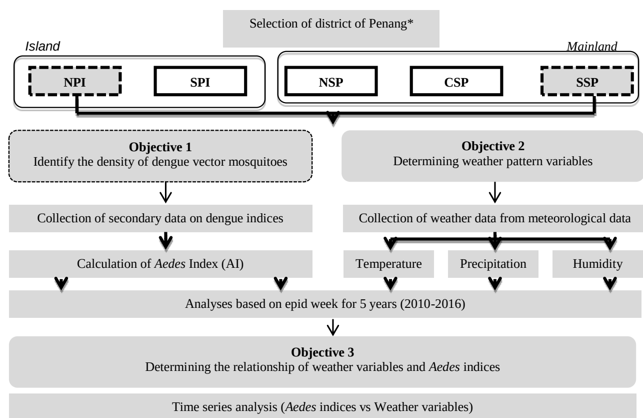

Figure 1. The research design used in this study: The five localities, basic methodology and the management of the data collected are highlighted.

2.3 Data collection and management

Ethical approval was not required for this study. This is an ecological or population-based study that used published data from public domains that did not require information or assessment on human subject. The data were obtained from surveillance data, Ministry of Health Malaysia. This study collected purely dengue surveillance data and did not gather any information about patients' identities. The study was approved by the Ministry of Health (ETR/E/MC/RP/350/2012)

This research relied on two main data sources; (i) The dengue surveillance data (DSD) that were collected from Vector control division, Penang State Health Department while (ii) the weather data (WD) were obtained from Meteorological Department. The original DSD was a daily-based dataset between 2011 to 2016 with five attributes (year, month, types of premise, mean AI, mean BI). The WD is also daily-based dataset with four attributes (month, mean temperature, total precipitation, and mean humidity). Details of the dataset are presented in Table 1.

Table 1. Datasets and their attributes

Dataset	Attributes	Value	Being preprocessed
Dengue surveillance data (DSD)	Data period	2011/January – 2016/December	
	Size		
	Week	1-53	Weekly based is converted
	District	-	5 District (SPI,NPI, NSP, CSP,SSP)
	Types of premise	Residential area, construction area, Religious area, School area, Industrial area, Cemetery area, Open dumping area, Open area, Recreational area	9 Types of premise
Climate (WD)	Data period	2011/January – 2016/December	
	Size		Fitted to the converted DSD
	Mean temperature	-	Weekly based is converted
	Total precipitation	-	Weekly based is converted
	Mean humidity	-	Weekly based is converted

Note: SPI (Southwest Penang Island); NPI (Northeast Penang Island); NSP (North Seberang Perai); CSP (Central Seberang Perai); SSP (South Seberang Perai); DSD (Dengue surveillance data)

Data processing involved two tasks; to convert weekly-based DSD into monthly-based data and to granulate continuous data into discretized ones for the mining mechanism to perform the classification task. The task used to conduct data discretization is unsupervised equal width interval [20]. Penang district is being divided into several districts based on their administrative boundaries. In this study, the changes and secular trends of AI had been monitored temporally. Therefore, annual average AI for each zone was performed using Time-Series analysis to understand the epidemiological trends by monthly basis [21]. In order to examine the temporal trends, AI was plotted over the (12 months) for each district (5 districts). Information from the electronic records was extracted and coded for health outcomes. Monthly AI was calculated and is used as the response variable. All the calculation was done in Microsoft Excel 2010 spreadsheet. The details regarding the types of premise was done in order to obtain the demographic distribution of AI.

2.4 Data analysis

There were six tasks in data discretization and data combination namely; (1) discretization based on district, (2) conversion of weekly-based to monthly-based, (3)discretization of DSD (classification based on types of premise), (4) combination of DSD and WD, (5) discretization of mean temperature. Although it is necessary to discretize continuous data prior to application of the mining algorithm, discretized data may contain inconsistent data leading to different conclusions [19]. Theoretically, same conditions in a dataset should result in the same conclusion (or decision rules). However, deleting all inconsistent data may lead to loss of important information. Therefore, this study adopted the rule. If the decision rule derived from a dataset with a number of cases more than or equal to half the size of an inconsistent sub-dataset, all cases of the rule should be kept and the remaining inconsistent cases eliminated. Otherwise, the whole inconsistent sub-dataset should be eliminated. In order to analyze the relationship between AI and climate variables, a Pearson correlation was conducted using data from 2011 to 2016. Five lag terms of mean temperature, relative humidity and cumulative rainfall were computed to study the exposure-response effects on various lag periods. Each lag term equates to an average mean temperature or cumulative rainfall for one month. Therefore, lag term 1 to 5 represent period up to four months.

3. RESULTS AND DISCUSSION

3.1 Temporal distribution characteristics of *Aedes* indices

The present study focused on five-district areas Penang over a period of six years. Each district was classified into two main zones; (i) Penang Island and (ii) Mainland of Penang. In an effort to understand about the distribution of *Aedes* indices, this study has come out with a graph for a continuous six years in order to study the trend of *Aedes* indices in Penang. Figure 2 shows the graph of temporal distribution of the *Aedes* indices for a continuous period from 2011 to 2016. The graph analysis has been divided into six fractions namely A, B, C, D, E and F in which representing 2011, 2012, 2013, 2014, 2015 and 2016 respectively for a better view of the results.

From the temporal distribution of AI in Penang, several dissemination patterns of AI may be explained. In general, this study found an increase in AI over the years in Penang. The plot of monthly AI for the study period showed increasing trends in both zones. By comparing the zones, Penang Island recorded higher AI as compared to the Mainland. A clear difference and a gradient among the average of AI were observed. The highest AI was recorded in May 2011 in Penang Island with AI more than 9 on average. However, there is a tremendous increment in AI pattern for mainland zones over the past six year’s observations. By referring to the fraction distribution trends for each fraction (A, B, C, D, E and F), the distribution trends in AI for each year is relatively similar in both zones, but didn’t reveal a consistently distinctive seasonal pattern of AI throughout the years of 2011 to 2016.

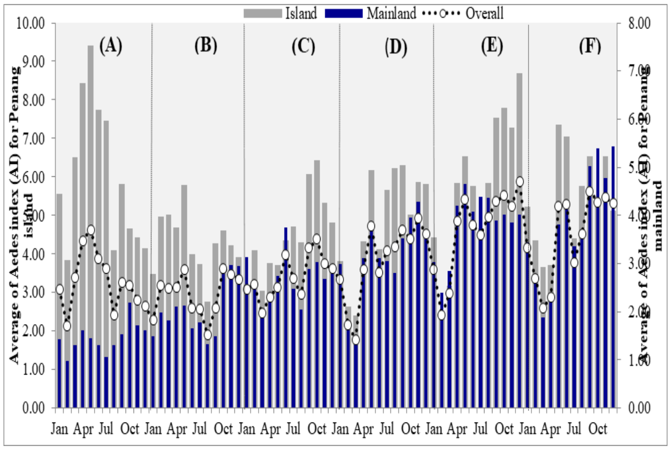

Figure 2. Temporal distribution of *Aedes* index (AI) (shown in black dotted lines) in Penang; Mainland (shown in blue histogram) and Island (shown in grey histogram) in the year 2011 to 2016. The graph has been divided into six fractions namely A, B, C, D, E and F in which representing 2011, 2012, 2013, 2014, 2015 and 2016 respectively.

Penang has five main administrative districts that three districts in mainland [South Seberang Perai (SPP), Central Seberang Perai (CSP) and North Seberang Perai (NSP)]. The other two districts are in the island, which is Northeast Penang Island (NPI), and Southwest Penang Island (SPI). Therefore, in order to identify and analyze different temporal patterns, the values of AI and DF cases were calculated for each month and its descriptive statistics across the study area. To identify the difference in this distribution, the comparison on the profile of AI with DF density was performed which subsequently classified based on districts.

3.2 The effect of ambient temperature on the distribution of *Aedes* indices

In an effort to understand the contribution of temperature towards AI, these studies have come out with a scatter plot graph for overall six years. The distribution of AI and temperature has been represented monthly to study the trends of AI with temperature. Figure 5 shows the scatter plot of monthly AI versus average temperature for mainland of Penang and Penang Island. The scatter plot has been divided into two main fractions namely January to June and July to December which representing by different colour coding; yellow and grey glow colours respectively for a better view of the results.

Analysis of the results shows that the AI is high at temperature above 27°C. The graph shows that the temperature distribution is in the range of 27°C to 29°C contributed to the distribution pattern of AI in the Mainland of Penang (Figure 3A). This study found that higher AI was in September which recorded temperature 28°C and the lowest AI was in February (temperature; 27.53°C). The similar trends in AI and temperature were also noticed for the Island of Penang (Figure 3B). The temperature distribution trends indicate that the temperature level most likely in a range 27°C to 29°C in a relative distribution. Obviously, there is a difference between AI with the temperature for the mainland and island of Penang. It can be observed that the temperature from 27°C to 29°C show the different number of AI at mainland (AI; 1 to 9) and island (AI; 3 to 9).

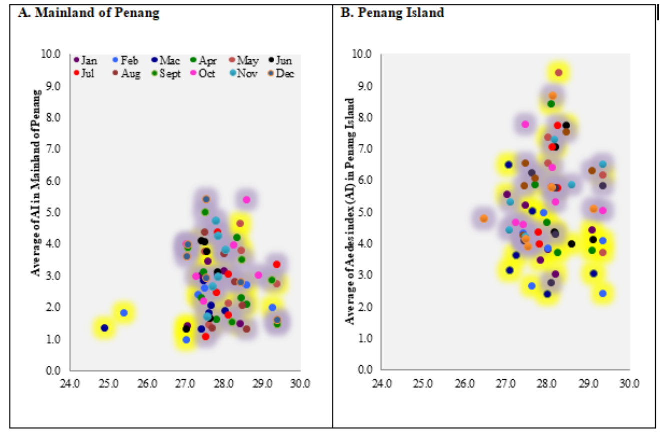

Figure 3. Scatter plot of monthly AI and an average of temperature for 2011 to 2016; (A) Mainland of Penang and (B) Penang Island. Note: Yellow glow indicate first half year (Jan to Jun) and greyish glow indicate the end of the year (Jul to Dec).

In order to assess the size and direction of the relationship between AI and weather variables,the *Pearson's* correlation is calculated to find the relationship between AI and weather variables in Penang during 2011 to 2016. The correlations between AI and weather variables are displayed in Table 2. The study demonstrates that the value has shown a low correlation for all time lag and insignificant value between AI and all weather variables ($p<0.05$). Even though the result doesn't show any relationship between AI and weather variables, but the characteristics and the pattern of both parameters have potential to be used as a baseline data for dengue vector control programme.

Table 2. Correlation between AI and Weather variables* by month for 2011 to 2016; (A) Mainland of Penang and (B) Penang Island.

Forward lagged log AI	MAINLAND			ISLAND		
	Average Temperature	Total Rainfall	Average Relative Humidity	Average Temperature	Total Rainfall	Average Relative Humidity
0 m log	0.054 (0.053)	-0.025 (0.832)	0.091 (0.449)	0.08 (0.945)	0.152 (0.201)	-0.032 (0.791)
1 m log	0.124 (0.300)	0.128 (0.285)	-0.026 (0.828)	0.010 (0.932)	0.217 (0.067)	0.073 (0.543)
2 m log	0.026 (0.829)	0.122 (0.309)	-0.065 (0.585)	0.031 (0.795)	0.144 (0.228)	0.056 (0.642)
3 m log	-0.014 (0.907)	-0.040 (0.739)	-0.042 (0.723)	0.106 (0.376)	-0.134 (0.263)	-0.177 (0.137)
4 m log	0.054 (0.653)	-0.160 (0.179)	-0.116 (0.333)	0.066 (0.579)	-0.331** (0.005)	-0.260* (0.027)

Surveillance is an important component of any prevention and control programme [6]. The findings from this evaluation have an important implication for surveillance and control of DF outbreaks in Malaysia. Based on the epidemiological analysis, AI pattern in Penang either in mainland or island showed a consistent increased for every year. This is due to the increase in breeding sites, which contributed to the recent increase in ecological and environmental modification due to urbanization [22].

The present study also revealed a high density of AI was recorded based on the six year's observations of dengue surveillance data. Open area and construction area were identified as contributing to the highest AI. The high abundance of the *Aedes* mosquitoes in these setting is suspected due to the neglecting of the surrounding environment and may contribute to the favourable condition of the mosquitoes breeding site [23]. With regard to dengue vector proliferation, human ecology is responsible for the creation of a mosquitogenic environment. Furthermore, man is directly or indirectly creating such a situation [6, 24]. From this study, it was found that the trends of the AI in the study area are differing from year to year and this condition may be the influence of the environmental and demographic changes that occur. A greater understanding on the temporal pattern and behaviour is important especially for planning for the prevention and control measures of the dengue fever disease as an early prediction can be done on the trend of the upcoming dengue occurrence.

Climatic condition plays a major role in influencing the trend of dengue outbreak distribution and transmission. The result showed that the overall distribution of AI was similar to the distribution pattern of monthly temperature. The frequency of monthly cumulative temperature was inversely related to the distribution of *Aedes* index. The finding of this study was supported from certain research findings. Previous research on the effect of temperature on the *Aedes aegypti* mosquito has identified various thresholds at which the mosquito and the virus can be sustained. In this study, prolonged exposure at extremely high or low temperature can have a detrimental effect on development at different stages of *Aedes* mosquitoes. Research conducted by Rahman [25] found that high volume of rainfall increases the survival of *Aedes* mosquitoes by providing more breeding sites. Dom *et al*. [26] in his study also found that rainfall is a very important factor that contributes to the trend changes of a dengue outbreak. Incidence cases are high (more than 100 cases) when there is the presence of rainfall and temperature in the relative range above 28.58^{o}C.

Urbanization is also one of the main factors that may influence the trend of dengue cases distribution and transmission. According to Palaniyandi *et al.* (2014) most of the dengue epidemic cases occurred in the metropolitan cities across the country where the population are high and massive infrastructure development creating many manmade opportunities for *Aedes* mosquito breeding sites [27]. Land use play an important role in determining the distribution of dengue cases. Nazri *et al*. [10] found that most of DF cases occurred in urban areas, followed by mixed horticulture areas and some in construction areas. Although several researchers found that vegetation density is one of the crucial factors that contribute to dengue incidence, this study in Subang Jaya found that the vegetation density of an area is not a major factor in influencing the number of dengue incidence.

The findings from this evaluation have an important implication for surveillance and control of DF outbreaks in Malaysia. Based on the epidemiological analysis, AI pattern in Penang both in mainland or island showed a consistent increase each year. This is due to the increase in breeding site, which contributed to the recent increase in ecological and environmental modification due to urbanization with less influenced by the weather variables. The present study also revealed a high density of AI identified at open and construction sites due to the neglect of the surrounding environment and may contribute to the favourable condition of the mosquito breeding sites.

4 CONCLUSION

The integrated data source is very useful in this study because all the information can be holistically measured and analysed in a broader sense. Data used varies from weather factor to urbanization as well as demographic data. The complex process of selecting specific data generation is a vital part of this study. The need for previous statements and findings provides baseline data for the current situation. Findings from previous studies and analysis of the current situation gives rise towards a more accurate understanding on the association and correlation of the parameters studied. Furthermore, up to date information must be taken in consideration to interpret, validate and corroborate the research findings obtained. To summarise, each component of data is principally interconnected and needs to be appraised.

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