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MODELLING THE PREDICTION OF DENGUE OUTBREAK USING SYSTEM DYNAMICS APPROACH

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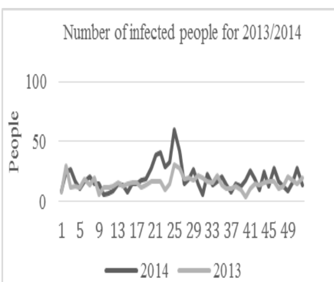
Graphical abstract



Abstract

Dengue virus had become the dominant mosquito-borne disease in Malaysia. With no positive progress on the development of vaccine, other ways in dealing with the virus is to predict the next outbreak which is also the aim of this paper. This dengue model based on system dynamics approach gives valuable information to decision makers in determining the strategies for vector control. The array of factors involved such as temperature, rainfall and population density that significantly influence virus transmission, give opportunity for a system approach in providing answer to the complicated relationship which exist in dengue system. System dynamics dengue model is able to simulate reasonable and promising results, which can be used as basis for future researcher to model more accurate and detail dengue transmission control system.

Keywords: Predicting dengue outbreak, system dynamics, early warning system

1.0 INTRODUCTION

Dengue is the leading mosquito-bourne disease among countries in the tropics and sub-tropics regions. The link between dengue and health related issue such as mortality and morbidity is well discussed in literatures [1,2]. World Health Organization (WHO) estimates the possibility of 500,000 people to be infected with severe cases of dengue each year. The severe cases such as dengue fever (DF) and dengue hemorrhagic fever (DHF) can cause fatal illness that require hospitalization.

In Malaysia, the early reported cases of DF and DHF were reported in 1902 and 1962 respectively [3,4]. Since then, several notable outbreaks occurred throughout Malaysia with the first major outbreak in 1970. The trend continues to worsen due to the increase in the number of cases each year. The cases reported in 1995 had growth from 6543 to 108,698 cases in 2014 with cumulative death rate of 1608 people is recorded throughout the country during this period [5].

In Malaysia, Kuala Lumpur and Selangor among the two states which reported the highest dengue cases in 2013 and 2014. As a result, a number of research have been found studied on dengue issues located in Selangor and Kuala Lumpur [6,7]. However, limited study was found on various dengue issues particularly in Kedah. Despite of an increasing number of dengue cases has been reported lately, it is important to conduct a research focus on prediction of dengue outbreak in Kedah.

2.0 OVERVIEW OF DENGUE

2.1 What is Dengue?

Dengue is a virus that transported through contact of various species of mosquito to human. There are five type of dengue virus namely DEN-1, DEN-2, DEN-3, DEN-4 and DEN-5 [8]. In Malaysia, two main species of mosquito that responsible in transmitting these virus are *Aedes aegypti* and *Aedes albopictus* [9]. These two species are constant problems for Malaysia as it can be found abundant at indoor and outdoor of homes either in rural or urban areas [10].

2.2 Dengue Trend in Kedah

Kedah which have twelve districts covers over 9,000 km² of land in northwestern part of peninsula Malaysia. Known as the "rice bowl" of Malaysia, Kedah economies are mainly driven by agriculture, industrial and tourism [11]. Similarly to Selangor and Kuala Lumpur, the trend of dengue in Kedah has increase for the past few years. Figure 1 below illustrate weekly number of dengue cases for the years of 2013 and 2014 in Malaysia. The early period of both years illustrate a steady increase from the first week to third week. However, the number of cases dropped for the following week. The cases in 2014 continue to rise dramatically than cases in 2013 between the periods 19^{th} to 27^{th}. The trend for both years reached its peak at 25^{th} week with 31 cases for 2013 and 60 reported cases for 2014. However, the cases decrease to 19 cases in 2013 and 15 cases in 2014 for 27^{th} week.

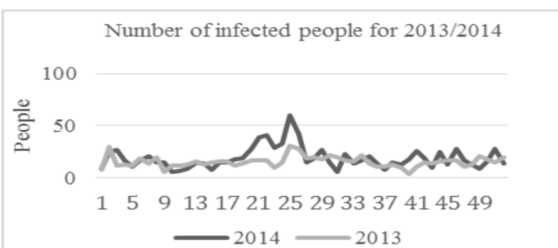


Figure 1 Number of people infected with dengue recorded for 52 weeks

According to Bain [12], the growing trends for each year can be reversed through the development of effective dengue vaccine. However, in this current situation, an effective vaccine is yet to be found. Thus, a new perspective on the solution towards combating dengue should be taken into consideration. From the perspective of modelling, the impact of the dengue on the mortality and morbidity can be reduced by developing an early prediction model [2]. By knowing the trend beforehand, the government can obtain valuable information to improve conventional dengue surveillance. The conventional system that lacked with predictive features can be improve to implement an effective policies that focus on time period with higher outbreak possibilities [13]. Since dengue is a complex problem [14], an appropriate modelling approach that are able to consider all the variables into a single model is needed

To fill this gap system dynamics (SD) is adopted in this study to predict early dengue outbreaks looking at the influence of temperature, rainfall and population density. Several studies has been done in developing early prediction model that associate to climate factor [15, 16]. Yet, the studies to consider population density with climate factors into a single model is still lacking in the literature. Numerous studies on the role of population density that contribute to the likelihood of contact between human and mosquito has been reported in the literature [17, 18]. By definition, SD is an analytical approach that is capable of representing these phenomena by feedback process, hence, contributing to better understanding of the complexity of behavior representation over time [19]. The principal objective of this paper is to highlight the contribution of SD to model the complex interactions in the dengue transmission system, which includes the temperature, rainfall and population density component in the dengue system.

This paper is structured as follows. Section 3 presents the literatures on the impact of rainfall, temperature and population density on the dengue outbreak. Also, SD studies on various dengue issues have been discussed in this section. Then section 4 presents data collection and analysis involving the development of the dengue model. After that, the outcomes are given and elaborated. The discussion and recommendations are in the last sections

3.0 LITERATURE REVIEW

3.1 Studies on the Impact of Temperature, Rainfall and Population Density on Dengue Outbreak

Temperature, rainfall and population density have been the subject of discussion by many researcher. In these studies, temperature and rainfall are the main reasons for the rapid mosquito development and the abundance of mosquito breeding site [20,21]. In ideal temperature (25°C to 30°C), mosquito in early stages develop rapidly to transform into adult mosquito, thus increasing the rate of contact between people and mosquito [22]. Although, rainfall is known to have positive relationship with breeding site [20], it also have negative relationship with mosquito contact rate. Mosquito faced difficulties in finding human due to the heavy rain and winds [13].

Apart from that, Cheong *et al.* [13] also suggested population density as a worth factor consider in the study. By definition, population density is the number of inhabitants living in particular area (inhabitants/km²) [17]. High population density in affected area may increase the likelihood of dengue spreading due to mosquito are easy to access the available victims [23].

3.2 Predicting the Outbreak of Dengue

There are many accomplished literature shows that modelling is one of useful approach in predicting the dengue outbreak. Among the preferred approach are statistical [15, 23] and mathematical modelling

[24, 25]. These studies contributed significantly to the understanding of dengue trends prediction trend. However, these approaches have limitation in explaining the relationship between factors through feedback processes. Therefore, to fill the needs, a best suited approach to tackle this complex dengue problem is using SD simulation. According to Sterman [26], other than feedback process, SD is able to solve the complex problem that involved non-linear trends and multiple interactions. Since it was first introduced in 1950, various researchers had taken the opportunity to apply SD in their research since that. Among other is in public health problems, for instance, heart disease [27,28], obesity [29,30], HIV/AIDS [31,32] and patient flow [33,34].

In regards to dengue, number of SD research has been found studied on various dengue issues. For instance, Supriatna and Anggriani [35] highlights the decisive factors by developing a model of mosquito dengue transmission. Through this model, they identify wolbachia infection to be an effective intervention for controlling the dengue population. The perspective of developing interventions or policies from SD model is also similar to Ritchie-Dunham and Méndez Galván [36]. In their research, they tested eight interventions that include the degree of fumigation, larvicide and education campaign to reduce the number of infected dengue cases. Other than that, Brailsford *et al*., [37] and Ibrahim *et al*., [38] used SD approach to capture and predict the fast-changing growth of mosquito life. However, this paper aims to develop a holistic model of early warning system for dengue outbreak in Kedah, Malaysia. In this paper, the cause-and-effect relation between temperature, rainfall, population density and dengue transmission are highlighted.

4.0 METHODOLOGY

4.1 Data Collection

Data are obtained from the website of Ministry of Health Malaysia, Malaysian Meteorological Department and Ministry of Rural and Regional Development. Data involve in this study are dengue cases, temperature (°C), rainfall (mm) and population density (people/area) for state of Kedah. The data was collected in 2014 and classified into 52 weeks.

4.2 Modelling Process

In this study, SD approach is adopted to conceptualize, to model, and to analyse the dengue situation in Malaysia. SD works by connecting all the relevant factors in cause-and-effect relationship as well as analyzing the effect of modifying some factors for system improvement.

In general, there are five iterative steps of SD modelling process. During the problem identification stage, various information and data on the dengue issue are collected. Then, a mapping tool of causal loop diagram is highlighted in the model conceptualization stage. It is followed by model formulation, where the earlier causal and loop diagram is converted into various sectors of stock and flow diagrams that consist of four elements - namely stock, flow, converter, and connector. Stock is used to accumulate elements within the system. Inflow and outflow are the channels for elements to move in and out of the stock. The factors that influenced the flow are known as converters, while connector portray the cause and effect relationship between the variables

Next, the developed model is tested by comparing the result from the simulated and the actual behaviour system. In the early stage, the developed model is tested for dimensional consistency to identify the flaws in the model. The adjustment for the developed model is made after each flow is closely examined and identified. After the developed model passed the entire required test, it is used for policy design and evaluation process. For the purpose of this study, the model required input from historical data to develop the future trends. With this information, the previous and current policies can be reviewed and improved to accommodate future trends of dengue situations.

4.3 Model Boundary

In SD, model boundary represents the variable that are important for generating and performing the behaviour of the model [39]. In this research, the model boundary is divided into three sectors namely mosquito control, transmission control and human control. For the purpose of this paper, the focus is on mosquito control (see Figure 2) which mosquito population, population density, temperature, rainfall, and dengue cases are the main variables are considered in the model.

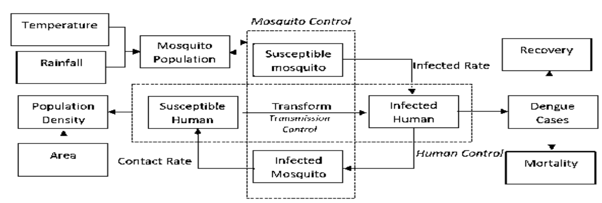


Figure 2 The holistic view of dengue system framework

4.4 Model Formulation

The causal loop diagram for the mosquito control section is presented in Figure 3 below. The positive polarity (+ve) indicates a positive relationship between the factors and vice versa. In general, mosquito experience four stages of life cycle namely egg, larvae, pupae and adult. The studies by Carrington *et al*., [40] and Brady *et al*., [41] discussed all the stages related to dengue transmission. However, in this study the focus is only on the adult mosquito in mature stage due to it's the only phase that mosquito interact with human during the oviposit process.

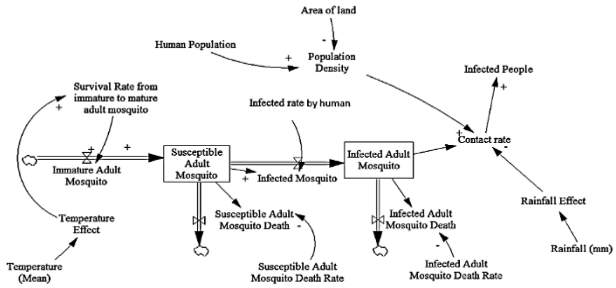


Figure 3 Stock and flow diagram of dengue transmission process

Referring to the diagram, the adult mosquito is divided into two parts namely susceptible and infected. Susceptible mosquito is mosquito that is not yet infected by the virus. In order for susceptible mosquito to be infected, it first needs to be in contact with infected human. The successful contact between infected human and susceptible mosquito will lead to infected mosquito. An infected mosquito is then able to spread the disease by repeating the process to susceptible human. Infected human then reported as dengue cases. The model is simulated from week 1 to week 52 (baseline trend), and is extended until week 100, which is considered as prediction trend.

4.5 Model Parameter

The parameters used in this study are obtained from various sources such as literatures and reports from government agencies. The purpose of this parameter is to generate the behaviour trends for the variables and to run the model. Based on SD, future trend of the dengue is not simply based on historical data; it is also obtained from the structure of created policies. Some of the important parameters involved in the model are shown in Table 1. These parameters have been chosen since they are influential to the dengue system. Most of the values for baseline in Table 1 represent the historical data and was used to generate the behaviour of the past and future trends.

In this research, the generated trend starts from the period of 1st week to 52th week in 2014. The period of 52th week considers the latest period with complete record (one year data) when this study is conducted. After the model generated the historical trends, the model then used to generate future trends from week 53th to 65th. During this process, the baseline value for temperature, rainfall and the human population is set to random

Table 1 List of important parameters in the model

Variable/Parameter	Baseline		Unit
	Minimum	Maximum	
Rainfall	0.01	23.1	mm
Temperature	26.5	29.56	Celsius
Infected rate	0.375	0.375	Vector/week

4.6 Model Validation

In general, validation process involve seeking multiple points of contact between the model and reality for identifying the gap between the points [42]. For this paper we applied the testing of mean square error (MSE). In this test, the aim is to measure the error between the predicted and actual values. The less error obtain from the analysis cause to the better result [43].

The formula for MSE is shown in equation 1 below:

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(\hat{Y}_i - Y_i)^2. \qquad (1)$$

Referring to equation 1, the number of ý, y and n are defined as: n = number of week; y = historical data of dengue cases recorded in Kedah; ý =simulated data from prediction model of dengue cases recorded in Kedah.

5.0 RESULT AND DISCUSSION

5.1 Baseline Findings

From the trend obtain for actual data as presented in Figure 4, the most active outbreaks is between week 21st to 25th. This is due to the warmer temperature (28 to 29^{0}C) and less rainfall (below 10mm per day) during that period. Warmer temperature influence the speedy development and increase the survival rate of mosquito population [40]. On the other hand, limited amount of rainfall will reduced the mosquito population by reducing the breading area [44]. Less cases is recorded in 10th week with 6 reported dengue cases throughout Kedah.

The highest value can be observed during the period of 25th week. However, the number of infected people is slightly different to the actual value. For instance, the highest number of cases recorded is 60 cases; however the predicted value is 54 cases. This is also the same with the lowest recorded cases, the actual value is 6, yet the predicted value is approximately 7 cases.

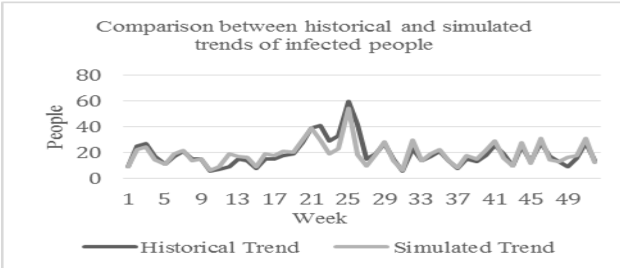


Figure 4 The comparison between historical and simulated trends of dengue infected people in Kedah

5.2 Result of Prediction

From the baseline findings (historical trend), the model has been extended from week to week. For instance, the prediction trend of the infected people with dengue from week 53 to week 65 is presented in Figure 5. The result shows a slowly increase in number of cases, but dramatically increases in week 63 and can be considered as a critical period. The critical period is when the transmission of the virus becomes rapid and wider. However, the following week shows a dramatic decrease until week 65. This may due to less frequent of rainfall during this week. With the time expansion from week 66 to week 100, the behaviour trend is shown in Figure 6. Generally, SD with Vensim software is able to run a variety of model's outputs, with the time setting option according to the preferable period chosen by modelers.

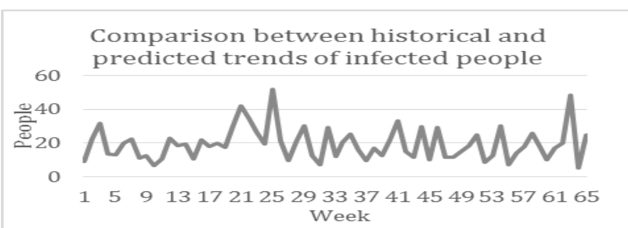


Figure 5 The predicted number of dengue infected people in Kedah, between week 1st two week's 65th

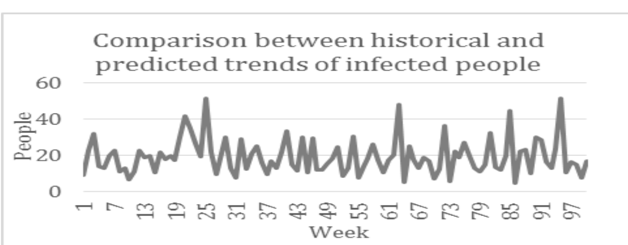


Figure 6 The predicted number of dengue infected people in Kedah, between week 1st two week 100th

For the purpose of forecasting, statistical approach such as Box-Jenkins technique is normally one of the preferable approach instead of SD. This is due to its capability to potray the seasonality-periodic fluctuations for studies that involve monthly data such as dengue cases [45]. Other studies include the techniques of poisson and negative binomial [46], generalized additive [47], seasonal autoregressive integrated moving average (SARIMA) and Box-Jenkins [48]. However, one of the main limitations of these techniques is the lack of feedback process that is needed in modeling the complex system like dengue [14]. Nevertheless, SD modelling is able to highlight the feedback process as well as to predict the future trends. The SD-prediction trend is different from the statistical-prediction trend as it is developed based on policies rather than depended heavily on data. An example of SD-based prediction is reported by James *et al*. [36] which depict the usage of SD in designing policies for combating dengue fever in Mexico.

5.2 Result of Validation

The summary value of MSE analysis is 25.53. Based on the analysis, the MSE value obtained for this model is 25.53. The value is high due to the wide different in historical and simulated trends for the period 21th to 27th.

6.0 CONCLUSION

In conclusion, the developed dengue model is able to simulate reasonable and promising results that might assist decision makers such as Ministry of Health to predict the future dengue outbreaks in Kedah. The early of prediction trend obtain from the model are able to provide the important information to decision makers to help them prepare suitable strategies to overcome the dengue outbreak in specific period. These strategies are identified through critical period that possess higher likelihood for dengue outbreak. Yet, there is more work to be done in developing and validating the model. Nevertheless, this can be the opportunity to improve the model by adding other significant variables such as recovery rate, urbanization and human migration that might result to the better findings.

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