Asian Pacific Journal of Tropical Disease

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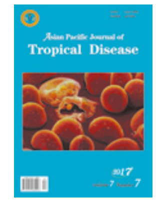

Original article https://doi.org/10.12980/apjtd.7.2017D7-26 

# Modeling of dengue occurrences early warning involving temperature and rainfall factors

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ARTICLE INFO

*Article history:*
Received 9 Feb 2017
Received in revised form 9 May 2017
Accepted 16 Jun 2017
Available online 29 Jun 2017

*Keywords:*
Dengue
Rainfall
Temperature
Host-vector
Basic offspring number
Basic reproductive ratio

ABSTRACT

**Objective:** To understand dengue transmission process and its vector dynamics and to develop early warning model of dengue occurrences based on mosquito population and host-vector threshold values considering temperature and rainfall.
**Methods:** To obtain the early warning model, mosquito population and host-vector models are developed initially. Both are developed using differential equations. Basic offspring number ($R_0^m$) and basic reproductive ratio ($R_0^d$) which are the threshold values are derived from the models under constant parameters assumption. Temperature and rainfall effects on mosquito and dengue are performed in entomological and disease transmission parameters. Some of parameters are set as functions of temperature or rainfall while other parameters are set to be constant. Hereafter, both threshold values are computed using those parameters. Monthly dengue occurrences data are categorized as zero and one values which one means the outbreak does occur in that month. Logistics regression is chosen to bridge the threshold values and categorized data. Threshold values are considered as the input of early warning model. Semarang city is selected as the sample to develop this early waning model.
**Results:** The derived threshold values which are $R_0^m$ and $R_0^d$ show to have relation that mosquito as dengue vector affects transmission of the disease. Result of the early warning model will be a value between zero and one. It is categorized as outbreak does occur when the value is larger than 0.5 while other is categorized as outbreak does not occur. By using single predictor, the model can perform 68% accuracy approximately.
**Conclusions:** The extinction of mosquitoes will be followed by disease disappearance while mosquitoes existence can lead to disease free or endemic states. Model simulations show that mosquito population are more affected by weather factors than human. Involving weather factors implicitly in the threshold value and linking them with disease occurrences can be considered in order to perform an early warning model.

## 1. Introduction

Dengue fever is one of the considered diseases because of the burden. Dengue fever is a disease that causes symptoms like influenza[1] and those will appear within 4–10 days after mosquito bites[2]. This disease causes serious pain, even death such as dengue haemorrhagic fever or dengue shock syndrome. There are four types of dengue viruses that have been known in the world, *i.e.* DEN-1, DEN-2, DEN-3 and DEN-4[1,2]. Dengue fever is found in the tropical and subtropical countries. Around 75% of people who were affected by dengue live in Asia-Pacific region[3-5]. In fact, dengue fever incidences in Southeast Asia countries showed yearly cycle of 3–5 years[3,6]. Increasing in the number of dengue victims in the world could be caused by dengue virus evolution, climate change, globalization and traveling[3].

Dengue fever is a vector-borne disease which is carried by mosquito. The mosquito will carry the dengue virus in their body. The virus is carried by *Aedes aegypti* (*Ae. aegypti*) and *Aedes albopictus* (*Ae. albopictus*) mosquitoes which act as its vector. Both of them are found in tropical and subtropical countries[3].

Many researchers have done researches to handle and prevent dengue by developing mathematical models for mosquito population considering the life cycle and control effort using temephos spraying and thermal fogging[7], dengue disease transmission with two strain viruses[8], controlling dengue disease transmission using repellent for adult and children[9], effect of rainfall to mosquito population and the effect of climate change to dengue disease transmission in unaffected dengue areas[10] and effects of temperature to the mosquito life cycle[11,12]. Dengue vectors were strongly influenced

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Foundation Project: Supported by the ITB Research and Innovation Grant (Grant No. 107j/I1.C01/PL/2017).
The journal implements double-blind peer review practiced by specially invited international editorial board members.

by temperature. Temperature would affect the survival and living habits of the mosquito[3,13-15]. The influence of temperature on mortality of larva, pupae and adult mosquitoes, the ability of mosquito to lay eggs, and the phase transition were modeled into functions of temperature variable[11,12]. In addition, the effect of rainfall to the larva population has been developed[16].

In this paper, we try to develop mosquito population model and host-vector model for dengue fever considering larva growth and the effect of temperature and rainfall to larva and adult mosquito. Under constant parameters assumption, we obtain the equilibrium points for mosquito population model and host-vector model. Basic offspring number for the mosquitoes model and basic reproductive ratio for the host-vector model are also provided by the next generation matrix method to determine threshold condition for the models. We simulate the mosquito model and host-vector model involving daily temperature and rainfall. Both affect the entomological and transmission parameters on the models. Besides that simulation, we found daily basic offspring number and basic reproductive ratio involving the temperature and rainfall. Then, we try to develop the early warning model based on the basic offspring number and basic reproductive ratio using logistics regression where the result is a number between zero and one. We categorize the result into zero or one, where zero is defined by the dengue outbreak which do not occur and one is defined by a dengue outbreak occurs.

## 2. Materials and methods

### 2.1. Data

In this study, we used monthly aggregated dengue cases for Semarang city level from Semarang Health Department. Climate data were obtained from Center for Climate Change and Air Quality Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG). We applied both dengue cases and climate data for the period of January 2003 to September 2013. Daily records of rainfall (mm) and average temperature (°C) of Semarang were used.

### 2.2. Mosquito population model

Mosquito is one of insects which has full metamorphosis processes, *i.e*. egg, larva, pupae, and adult phases. Mosquito life phase can be categorized into two groups based on growing medium, the aquatic and non-aquatic phase. Egg, larva, and pupae phases were included in the aquatic phase and adult phase was included in non-aquatic phase. Mosquito model considering aquatic phase (egg, larva, pupae) and non-aquatic phase (adult) was discussed by involving temperature[11] and then was expanded by considering larva, pupae, and adult phases[12]. The entomological parameters for the mosquito model were estimated based on temperature-controlled experiments[11,12]. We developed the model considering larva and adult phases. We assumed that larva and adult were the important phases in mosquito life cycle. The egg phase was assumed to be included in larva phase and the pupae phase was not considered. This assumption was taken because pupae has ability to survive under less water condition and still be able to transform to adult mosquito[17]. Larva survival is strongly influenced by the environment and some larvae cannot transform into adult mosquito and die. The abundance of mosquito is influenced by the breeding place. Here, we assumed that the existence of breeding place is strongly influenced by the rain which was taken based on the phenomena. Heavy rainfall can erase the existence of mosquito breeding place, while moderate rainfall can increase the mosquito breeding place.

Our subject is started from larva phase. The recruitment rate of female larva was determined by a number of eggs laid by female mosquito then hatched into larva ($\gamma\varphi\rho M$). These new born larva live in mosquito breeding place which is a pond of water in some containers such as flowerpots or cans. When a female mosquito lays eggs, the number of eggs is very ample. It makes sense if we consider logistics factor in the recruitment of new larva because a female mosquito usually lays many eggs. When the eggs hatched, competition between larva could happen and their growing place was very limited [$\gamma\varphi\rho M(1-(L/C)^p)$]. Due to rainfall giving impact on mosquito breeding place, we introduced a factor $p$ that can support or diminish their breeding place. After spending several days, larva could transform into adult mosquito ($\delta_m L$). Some of them still remained as larva and the less died [$\mu_l(1-\theta)L$]. The death process also occurred in adult mosquito phase ($\mu_m M$).

The mathematical model of mosquito population can be written as:

$$\frac{dL}{dM} = \gamma\varphi\rho M\left[1-\left(\frac{L^p}{C}\right)\right] - \delta_m L - \mu_1(1-\theta)L$$

$$\frac{dM}{dt} = \delta_m L - \mu_m M \tag{1}$$

Model (1) provides two equilibrium points under constant entomological parameters assumption, those are trivial equilibrium point, $X_0 = (L_0, M_0) = (0, 0)$, and non-trivial equilibrium point, $X^* = (L^*, M^*)$.

$$L^* = C(1-Q_0)^{\frac{1}{p}}$$

$$M^* = \frac{\delta_m}{\mu_m} L^* \tag{2}$$

with $Q_0 = \mu_m[\delta_m + (1-\theta)\mu_l]/(\gamma\varphi\rho\delta_m)$.

To check the stability of equilibrium points, we look for eigenvalues of Jacobian matrix for each equilibrium point. We obtain stability conditions for $X_0$ is $Q_0 > 1$ and condition of existence and stability to $X^*$ is a value $0 < Q_0 < 1$.

Furthermore, we look for basic offspring number of model (1) using Next Generation Matrix. Thus, we obtain basic offspring number in form:

$$R_0^m = \sqrt{1/Q_0} \tag{3}$$

Based on the basic offspring number and obtained stability condition, we can conclude that equilibrium point $X_0$ will be stable if and only if $R_0^m < 1$ and equilibrium point $X$ will be stable if and only if $R_0^m > 1$.

### 2.3. Dengue model

Dengue fever is a vector-borne disease and the vectors are *Ae. aegypti* and *Ae. albopictus*. Host-vector model is used as the foundation for dengue model. However, we consider previous mosquito population model to be adapted in the host-vector model. The mathematical model is written as:

$$\frac{dS_h}{dt} = \mu_h N_h - \frac{\beta_h b\omega S_h I_h}{N_h} - \mu_h S_h$$

$$\frac{dI_h}{dt} = \frac{\beta_h b\omega S_h I_h}{N_h} - (\mu_h + \tau_H) I_h$$

$$\frac{dR_h}{dt} = \tau_h I_h - \mu_h R_h \quad (4)$$
$$\frac{dL}{dt} = \gamma\varphi\rho\,(S_m + I_m)\left[1 - \left(\frac{L}{C}\right)^p\right] - \delta_m L - \mu_l L\,(1-\theta)\,L$$
$$\frac{dS_m}{dt} = \delta_m L - \frac{\beta_m b S_m I_h}{N_h} - \mu_m S_m$$
$$\frac{dI_m}{dt} = \frac{\beta_m b S_m I_h}{N_h} - \mu_m I_m$$

Under constant parameters assumption, we obtain disease and vector free equilibrium point, $X_{dvf} = (N_h, 0, 0, 0, 0, 0)$, disease free equilibrium point, $X_{df} = (N_h, 0, 0, L^{df}, S_m^{df}, 0)$ with $L^{df} = C\,(1 - Q_0)^{1/p}$ and $S_m^{df} = \delta_m L^{df}/\mu_m$, endemic equilibrium point, $X_e = (S_h^e, I_h^e, R_h^e, Q_1, S_m^e, I_m^e)$ and the last equilibrium point does not exist. However, in this case, we will only consider disease and vector free, disease free, and endemic equilibrium points. With $X = (S_h, I_h, R_h, L, S_m, I_m)$.

$$S_h^e = \frac{(b\beta_m\mu_h + \mu_h\mu_m + \mu_m\tau_h)\,N_h^2\mu_m}{b\beta_m\,(b\omega\beta_h\delta_m Q_1 + N_h\mu_h\mu_m)}$$

$$I_h^e = \frac{N_h\mu_h\,[\delta_m\beta_m\beta_h\omega b^2 Q_1 - \mu_m^2 N_h\,(\mu_h + \tau_h)]}{(\mu_h + \tau_h)\,b\beta_m\,(b\omega\beta_h\delta_m Q_1 + N_h\mu_h\mu_m)}$$

$$R_h^e = \frac{N_h\tau_h\,[\delta_m\beta_m\beta_h\omega b^2 Q_1 - \mu_m^2 N_h\,(\mu_h + \tau_h)]}{b\beta_m\,(b\omega\beta_h\delta_m Q_1 + N_h\mu_h\mu_m)} \quad (5)$$

$$Q_1 = C\,(1 - Q_0)^{1/p}$$

$$S_m^e = \frac{(\mu_h + \tau_h)\,(b\omega\beta_h\delta_m Q_1 + N_h\mu_h\mu_m)}{(b\beta_h\omega\,(b\beta_m\mu_h + \mu_h\mu_m + \mu_m\tau_h)}$$

$$I_m^e = \frac{\mu_h\,[\delta_m\beta_m\beta_h\omega b^2 Q_1 - \mu_m^2 N_h\,(\mu_h + \tau_h)]}{\mu_m b\beta_h\omega\,(b\beta_m\mu_h + \mu_h\mu_m + \mu_m\tau_h)}$$

To check the stability of equilibrium points $X_{dvf}$, $X_{df}$ and $X_e$, we look for eigenvalues of Jacobian matrix for each equilibrium point. We get stability condition for $X_{dvf}$ which is $Q_0 > 1$ or $R_0^m < 1$. The existence condition for $X_{df}$ and $X_e$ is $0 < Q_0 < 1$ or $R_0^m > 1$, and stability condition for both $X_{df}$ and $X_e$ will be described using basic reproductive ratio.

Furthermore, we compute basic reproductive ratio of model (5) using Next Generation Matrix. Thus, we obtain basic reproductive ratio in form:

$$R_0^d = \sqrt{\frac{b^2\beta_m\beta_h\omega\delta_m C\,(1 - Q_0)^{1/p}}{N_h\mu_m^2\,(\mu_h + \tau_h)}} \quad (6)$$

With this basic reproductive ratio, we get the stability condition for $X_{df}$ and $X_e$. We can conclude that the equilibrium point $X_{df}$ will be stable if and only if $R_0^d < 1$ and the equilibrium point $X_e$ will be stable if and only if $R_0^d > 1$.

## 2.4. Parameters

The model will be related to weather factors, the rainfall and temperature. Relation between model and weather factors was associated in used parameters. Parameters $\varphi$, $\rho$, $\delta_m$, $\theta$, $\mu_m$, $\beta_h$, $\beta_m$ and $b$ were assumed to be affected by the temperature. Parameter $p$ was assumed to be influenced by rainfall and parameters $\mu_l$ and $\theta$ was assumed to be influenced by rainfall and temperature.

Function of temperature parameters ($\varphi$, $\delta_m$, $\theta$, $\mu_m$ and $\mu_l$) were obtained from Yang *et al.*[12], but we gave an additional condition for parameters $\mu_l$ and $\theta$. Parameter was assumed to be the same with $\mu_l$ but $\theta$ was dimensionless. Functions of temperature for several parameters($\beta_h$, $\beta_m$ and $b$) were adapted from Liu-Helmersson *et al.*[15]. We tried to construct a function of temperature for parameter based on phenomena that the eggs could hatch when the water surface temperature was appropriate[17]. Water surface temperature was assumed to be represented by the air temperature. We also constructed a function of rainfall for parameter $p$ based on the phenomena that heavy rainfall can erase the existence of mosquito breeding place, while moderate rainfall that lasted for a long time will increase the place. The compartment diagram for dengue model is shown in Figure 1. Definition of used variables and parameters is explained in Table 1.

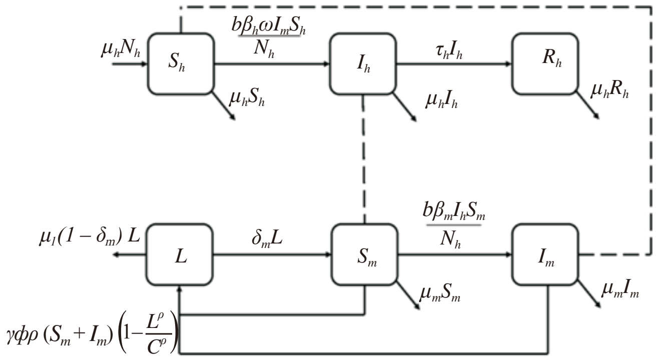


**Figure 1.** Compartment diagram for dengue model.

Six compartments were used in the model. Host and vector have similar cycle where each group can be infected when the infected compartment of each group interacts with susceptible compartment of different group. Bold line explains cycle of compartments in each group and dotted line explains disease transmission process between different groups.

**Table 1**

Description of variables and parameters.

| Variables/ Parameters | Description |
|---|---|
| $L$ | The number of larva population |
| $M$ | The number of mosquito population |
| $S_m$ | The number of susceptible mosquito population |
| $I_m$ | The number of infected mosquito population |
| $S_h$ | The number of susceptible human population |
| $I_h$ | The number of infected human population |
| $R_h$ | The number of recovery human population |
| $\mu_h$ | Human birth and death rate |
| $\mu_l$ | Larval survival rate |
| $\mu_m$ | Mosquito survival rate |
| $\delta_m$ | Transition rate larva to mosquito |
| $\theta$ | Proportion of larva remain in larva phase |
| $\gamma$ | Probability of the egg hatch the female larva |
| $\varphi$ | Female mosquito ovulation rate |
| $\rho$ | Probability of the egg hatch |
| $p$ | The effect of rainfall on the mosquito breeding place |
| $C$ | Larva's carrying capacity in best condition |
| $N_h$ | Total number of human population |
| $\beta_h$ | Virus transmission rate from infected mosquito to susceptible human |
| $\beta_m$ | Virus transmission rate from infected human to susceptible mosquito |
| $b$ | Biting rate |
| $\omega$ | Number of targeted human |
| $\tau_h$ | Human recovery rate |

Heavy rainfall is defined when the rainfall exceeds 50 mm. 50 mm of rainfall becomes the threshold to give impact on the existence of mosquito breeding place and larva survival. We assumed if rain happens in small rate ($0 \leq R \leq 10$), it will give no impact to mosquito breeding place. We defined “no impact” as a normal condition and it equals to 1/2. If rain happens in moderate rate ($10 \leq R \leq 50$), it will give advantage to mosquito breeding place. The advantage is assumed to follow a parabolic path. It gives maximum impact when 25 mm rate of rain. If rain happens very bad ($R \geq 50$), it will give disadvantage to mosquito breeding place by diminishing their site. Parameters related to the availability of mosquito breeding place ($p$) and larva survival ($\mu_l$) when heavy rain occurs are illustrated in Figure 2. Likewise, the effect of temperature on hatching eggs ($\rho$) is also illustrated in Figure 2. Maximum impact of temperature to hatch eggs is assumed to occur in average temperature of Semarang city. Functions of the parameters are decribed in Table 2.

### 2.5. Early warning model

Early warning (EW) model in this paper was developed by linking the value of $R_0^d$ or $R_0^m$ with the number of monthly incidence of dengue. The EW model was developed using logistic regression. Result of the model then was categorized into either an outbreak (extraordinary events) or not an outbreak. Value of $R_0^d$ and $R_0^m$ were obtained daily. Minimum value, maximum value, and average value of $R_0^d$ and $R_0^m$ were used to relate with monthly incidence.

In this paper, the model used two conditions, outbreak (true) or not outbreak (false). To determine the occurrence of an outbreak, we defined $i$-th month as an outbreak when the number of dengue cases reach 226 cases. Value of 226 is an average of dengue cases that occurred in Semarang city on January 2003 until September 2013.

We applied single predictor $X$ in our model. The predictor candidates were selected from daily $R_0^d$ and $R_0^m$ which were calculated based on temperature and rainfall. The daily $R_0^d$ and $R_0^m$ then were computed to be monthly by applying average, minimum and maximum values. Thus, we obtained six predictor candidates which are average of $R_0^d$ ($X_1$), minimum of $R_0^d$ ($X_2$), maximum of $R_0^d$ ($X_3$), average of $R_0^m$ ($X_4$), minimum of $R_0^m$ ($X_5$) and maximum of $R_0^m$ ($X_6$). We have clustered dengue cases data into two categories and to obtain the model, regression equation can be described by:

$$\ln \frac{\psi (X)}{1-\psi (X)} = \beta_0 + \beta X \quad (7)$$

where $\psi (X)$ is probability of dengue outbreak to be occurred.

## 3. Results

### 3.1. Simulation

In this paper, we simulated the dynamics of the mosquito population and dengue model involving rainfall and temperature factors.

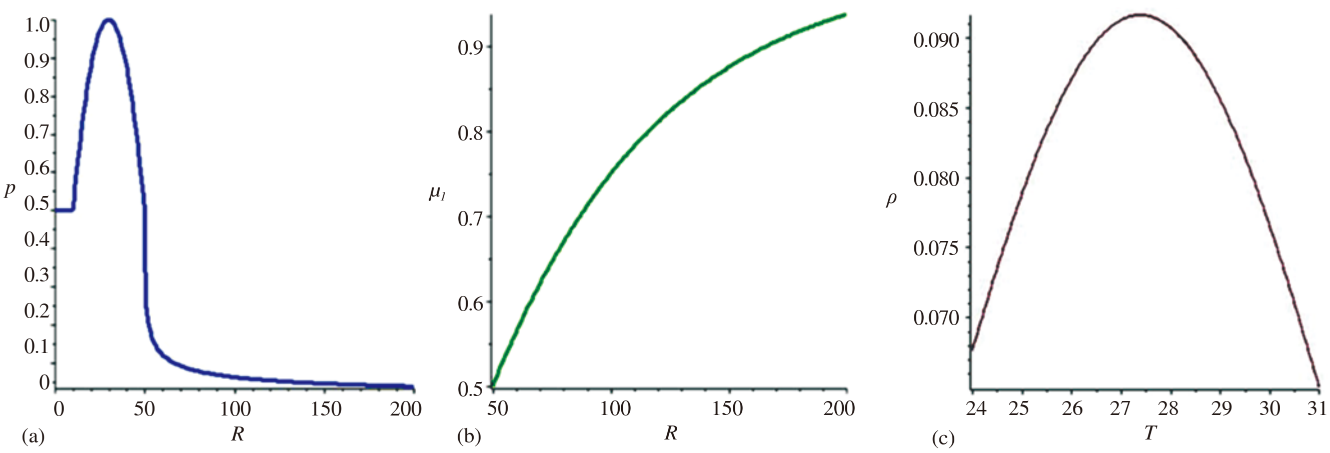


**Figure 2.** Constructed parameters based on mosquito life cycle phenomena affected by temperature and rainfall.
a: Parameter $p$ (effect of rainfall to mosquito breeding place) respect to $R$ (rainfall); b: Parameter $\mu_l$ (larva survival rate) respect to $R$ (rainfall) when $R \geq 50$; c: Parameter $\rho$ (probability of hatching eggs) respect to $T$ (temperature).

**Table 2**
Parameters which computed using temperature and rainfall data.

| Parameter | Reference |
|---|---|
| $\varphi (T) = -5.4 + 18T - 0.2124T^2 + 1.015 \times 10^{-2}T^3 - 1.515 \times 10^{-4}T^4$ | [12] |
| $\rho (T) = 1/(4\sigma\sqrt{2\pi}) \exp [-1/2 (T-\mu)^2/(4\sigma)^2]$ | Constructed |
| $\delta_m (T) = -1.847 + 0.8291T - 0.1457T^2 + 1.305 \times 10^{-2}T^3 - 6.461 \times 10^{-4}T^4 + 1.796 \times 10^{-5}T^5 - 2.61 \times 10^{-7}T^6 + 1.551 \times 10^{-9}T^7$ | [12] |
| $\mu_l (R, T) = \begin{cases} 2.315 - 0.419T + 0.02375T^2 - 7.358 \times 10^{-4}T^3 + 7.503 \times 10^{-6}T^4, R < 50 \\ 1 - \exp (-R \ln 2/50), R \geq 50 \end{cases}$ | [12]<br>Costructed |
| $\mu_m (T) = 0.8692 - 0.1590T + 0.01116T^2 - 3.408 \times 10^{-4}T^3 + 3.809 \times 10^{-6}T^4$ | [15] |
| $p (R) = \begin{cases} 1/2, R < 10 \\ -1/800R^2 + 3/40R - 1/8, 10 \leq R < 50 \\ 1/2 (1 + \sqrt{R-50}), R \geq 50 \end{cases}$ | Constructed |
| $\beta_h (T) = 0.001044T (T - 12.286) (32.461 - T)^{1/2}$ | [15] |
| $\beta_m (T) = \begin{cases} 0.0729T - 0.9037, 12.41 \leq T \leq 26.1 \\ 1, 26.1 \leq T \leq 32.5 \end{cases}$ | [15] |
| $b (T) = (0.03T + 0.66)/7$ | [15] |

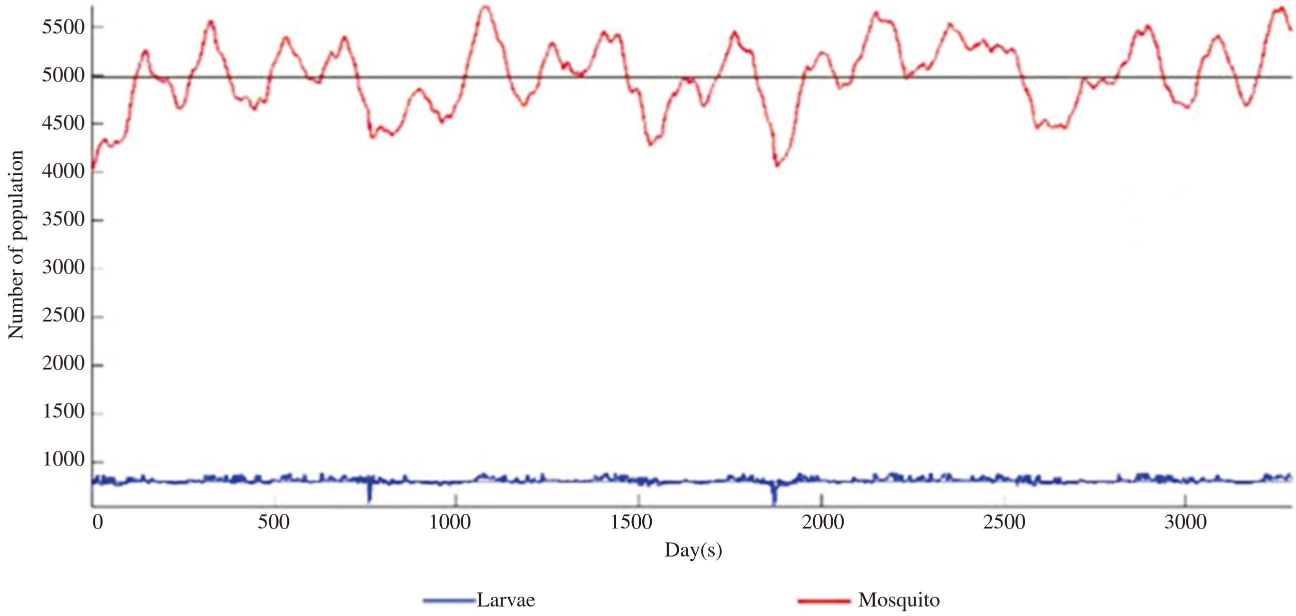


**Figure 3.** Simulation of larva and mosquitoes population in model (1) involving temperature and rainfall.

We simulated the model (1) and (4) using rainfall and average temperature data from January 1st 2003 until September 30th 2013 in Semarang. We computed the data in accordance with mosquito breeding phenomena for this simulation. The rate of mosquito ovulation ($\varphi$), transition rate larva to mosquito ($\delta_m$), and larva survival rate ($\mu_l$) were set using the average of 7 days temperature. We also considered average of 7 days rainfall in larva survival rate. We used average of 2 days temperature for the rate of hatching eggs ($\rho$), average of 3 days temperature for the effect of rainfall on mosquito breeding place ($p$), and average of 15 days temperature for mosquito survival rate ($\mu_m$). Daily temperature was applied to compute transmission rates ($\beta_h$, $\beta_m$) and mosquito biting rate ($b$).

Other parameters for this simulation were selected to be $\gamma$ = 1/2, $C$ = $10^3$, $\mu_h$ = 0.001 214 5/30, $\omega$ = 6, $\tau_h$ = 1/14 and $N_h$ = $10^5$. Besides simulating model (1) and (4) involving rainfall and temperature, we compared the simulation results with the equilibrium points using parameters based on the average of rainfall and average temperature in Semarang city. Semarang city has average 6.4 mm of rainfall per day and average 27.39 °C of temperature. Equilibrium point for each variable is represented by the black line in Figures 3 and 4. We found out that the number of mosquito population will fluctuate around its equilibrium point or close to its equilibrium point. Furthermore, it is obvious that the weather factor is more influential on vector population than human population.

### 3.2. Proposed early warning system

The models were logistic regression with single predictor. Predictor candidates were obtained by selecting the $R_0^d$ and $R_0^m$. By looking at the significance of regression coefficients of each predictor and correctness percentage in Table 3, the chosen predictors were $X_1$ (Monthly average value of $R_0^d$), $X_2$ (Minimum value of $R_0^d$) and $X_5$ (Minimum value of $R_0^m$).

The main models that we offered for EW is model with $X_2$ as a predictor (EW1) provide 68.2% accuracy. Alternative models that we offered is model with $X_5$ as a predictor (EW2) provide 67.4% accuracy.

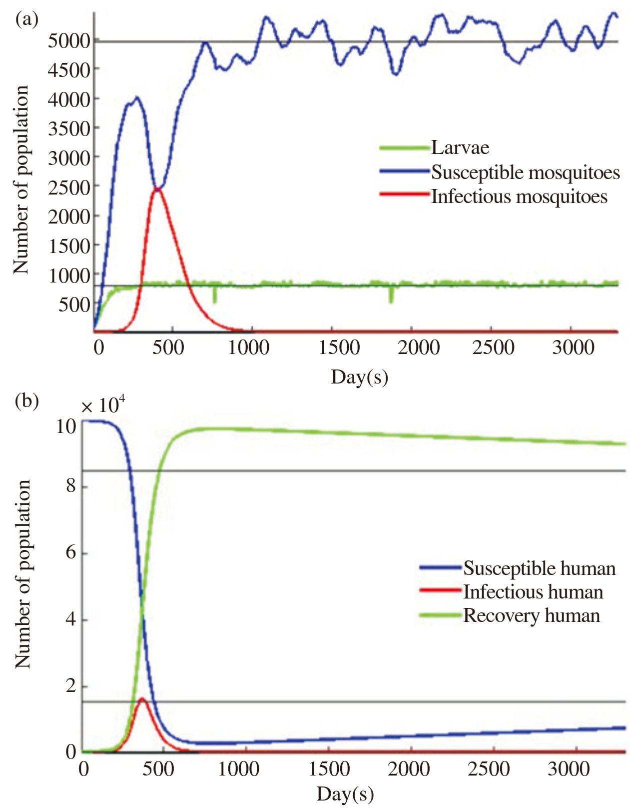


**Figure 4.** Simulation of human and vector population in model (4) involving temperature and rainfall.

a: Number of vectors population; b: Number of human population.

**Table 3**

Predictor, its significance and accuracy percentage of logistics regression.

| Predictor | Siginificance | Correctness |
|---|---|---|
| $X_1$ | 0.030 | 68.2% |
| $X_2$ | 0.010 | 68.2% |
| $X_3$ | 0.079 | 65.1% |
| $X_4$ | 0.028 | 65.9% |
| $X_5$ | 0.043 | 67.4% |
| $X_6$ | 0.084 | 65.1% |

EW 1 model

$$\psi(x_2) = \frac{\exp(2.968 - 1.559x_2)}{1 + \exp(2.968 - 1.559x_2)} \quad (8)$$

EW 2 model

$$\psi(x_5) = \frac{\exp(3.853 - 1.579x_5)}{1 + \exp(3.853 - 1.579x_5)} \quad (9)$$

## 4. Discussion

We have demonstrated mathematical model for mosquito population and dengue and simulating the effect of rainfall and temperature. From model (1), we had basic offspring number (3) and, from model (5), we had basic reproductive ratio (6). Both of them became threshold value to determine the survival of mosquitoes and dengue disease resistance. From model (1) and (4), we also could see relationship between basic offspring number and basic reproductive ratio. We found condition that vectors of dengue disease is the key to dengue disease spread. If vectors of the disease disappear, the disease will also disappear. If vectors of the disease exist, the disease will also be possible to remain in the population. In addition, from the simulation, it can be concluded that rainfall and temperature affected the vector population more than the human population. From the result, control of dengue vectors (in this case the *Ae. aegypti* and *Ae. albopictus*) is important.

Semarang is one of cities in Indonesia which has high number of dengue cases. Threshold values for both of the models are 0.5, $\psi(x_2) = 0.5$ and $\psi(x_5) = 0.5$. From the main model, this threshold condition is obtained when $x_2 \approx 1.904$ and, from the alternative model, the threshold condition is obtained when $x_5 \approx 2.440$. Outbreak condition for the main model is when the value of $R_0^d$ is less than or equal to 1.904 and outbreak condition for alternative model is when the value of $R_0^m$ is less than or equal to 2.440. The smallest value of $R_0^d$ that is used for the main model is 0 and the smallest value of $R_0^m$ that is used for the alternative models is 1.38. However, from the definition of $R_0$, then, from the main model, outbreak condition is occurred when the value of $R_0^d$ between 1 and 1.904 and, from the alternative model, outbreak condition is occurred when the value of $R_0^m$ between 1.38 and 2.440.

Although both models were able to provide accuracy above 60% with a single predictor, the model could be developed more and the accuracy could be increased. Things that need to be investigated to increase the accuracy of the models are humidity, host index, influence of the previous dengue cases, and climate data from other climate stations, considering Semarang city has more than one climate station.

## Conflict of interest statement

We declare that we have no conflict of interest.

## Acknowledgments

This research is supported by the ITB Research and Innovation Grant (Grant No. 107j/I1.C01/PL/2017). Authors would like to thank Dr. Ardhasena Sopaheluwakan from Center for Climate Change and Air Quality Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) Jakarta, Indonesia and Health and Climate Vulnerability Assessment (HCVA) Team for the fruitful discussion.

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