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THE SIMULATION OF EGG HATCHING TREND OF *AEDES AEGYPTI* ASSOCIATED WITH RAINFALL DISTRIBUTION

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ABSTRACT

Aedes aegypti is primary vector of Zika virus, dengue, and chikungunya which go through four different stages of life cycle: Egg, Larva, Pupa, and Adult. The mosquito might be able to lay 100 eggs at a time. The eggs can hatch when there is water and submerged in the water, but it can survive without water almost to 8 months by sticking to the walls of a container. In this research, the trend of egg hatching was simulated by using a stage-structured Lefkovitch matrix model. The matrix model consists of a function of egg hatching which associated and depends on rainfall distribution. The purpose of the function is to identify the relationship between egg hatching and rainfall which provide water to egg. Using the same mathematical model, the population of adult *Aedes aegypti* has also simulated which the population related to egg simulation and rainfall. The graphical results were shown to illustrate the relationship between the rainfall, egg number and adult *Aedes aegypti*. We found that there was a significant relationship between the rainfall and these two stages of mosquito life cycle which are egg hatching number and adult *Aedes aegypti*. However, it is recommended to look for more possible factors such as the size of an opening container and humidity which possible to contribute to the development of mosquito to acquire more accurate results.

Contribution/Originality: The study contributes in the existing literature which stated that both factor rainfall and temperature involved in the development of mosquito life cycle. We found that, the rainfall distribution factor is the most significant to identify the trend of development of mosquitos' population and meanwhile the factor of temperature influences more on the increase of dengue virus transmission.

1. INTRODUCTION

Dengue fever is a contagious tropical or a mosquito-borne viral disease which transmitted by female *Aedes aegypti* mosquito. The dengue can be spread into two forms which are Dengue Fever (DF) and Dengue Hemorrhagic Fever (DHF). Patients with DF might go to develop DHF which can evolve to severe form or death known as Dengue Shock Syndrome (DSS) [1]. DHF and DSS can occur in both children and adults.

The *Aedes aegypti* originates from Africa and now exist globally in tropical and subtropical region. The distribution of this mosquito might through global trade and shipping activities. These mosquitoes usually breed around the human habitat and bite during the day. They are easily recognizable by their peculiar white spotted body and legs. The infected female *Aedes aegypti* can spread dengue virus mainly through the bites [2]. The transmission occurs when the mosquito bites a person who already gets infected by dengue fever and the virus will

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enter the mosquito. The mosquito bites a susceptible person, and then dengue virus will spread in that person [3]. Besides, the infected female mosquitos also can spread the virus to their eggs [4]. To produce their eggs, the female mosquitoes require a protein which can be obtained from human blood. However, adult male mosquitoes feed on nectar, and they do not involve both transmitting virus and reproducing.

There are four main stages of the life cycle which are eggs, larvae, pupae and adult. Many articles have stated that the factors of temperature and rainfall contribute to the increase of number of mosquito which the main vector of spreading dengue virus [5]. However, in Malaysia the temperature was recorded as almost unchanged compared than rainfall distribution. Therefore, the purpose of this study is to simulate the first stage of mosquito which is egg stage associated with rainfall distribution using Lefkovitch matrix model. Using the same mathematical model, the population of adult *Aedes aegypti* was also simulated because the adult is the main life stage of mosquito which involved in both transmitting virus and reproducing egg. A model proposed in previous research [6]; [7]; [8] will be considered and discussed in order to achieve the objectives of this research. We focused on Shah Alam city since the reported cases of dengue are always high and only first three months in 2016 was considered because these months have high dengue cases compared to others period.

2. METHOD

The projection matrix of *Aedes aegypti* life cycle was considered to forecast the population of mosquito based on distribution of rainfall. In this section, all the methods used to achieve the objectives of this research will be clearly explained. Generally, the population model is described in matrix algebra with consist of transaction rate of *Aedes aegypti* life cycle.

2.1. Population Projection Matrix

In this research, a Lefkovitch matrix model was used to simulate each stage in the life cycle of *Aedes aegypti* mosquitoes. The mosquitoes have gone through four life cycle stages: egg, larva, pupa, and adult. However, in this research, the adult stages are divided into two stages namely Adult 1 and Adult 2. The Adult 1 was described as a mosquito that can produce and lay the first eggs to convert into Adult 2. The stage of Adult 2 is an adult has been laying egg more than one time and gone through several egg laying processes. The Lefkovitch matrix model was used to simulate the population number of *Aedes aegypti* because it is one of the best stage-structured matrix models [9]. Only female mosquitoes are considered because they directly involved in egg laying process.

2.2. Lefkovitch Matrix Model

The population sizes with respect to age are difficult to determine precisely rather than considering the stages of population life cycle. Therefore, the stage-structured matrix model was constructed by considering the growth of mosquito life cycle stages and breeding maturity [10]. The population of *Aedes aegypti* mosquito is easier to identify based on their life cycle than its age because each life stage can be differently classified based on the growth of physical size. In this section, the simulation number of mosquito population at any time t will be assigned as $N(t)$ and the transition matrix A is the transformation based on mosquito life cycle. The simulation of population at time $t+1$ can calculate by multiply matrix A and $N(t)$.

$$N(t+1) = \begin{bmatrix} P_1 & 0 & 0 & F_4 & F_5 \\ E_1(t) & P_2 & 0 & 0 & 0 \\ 0 & G_2 & P_3 & 0 & 0 \\ 0 & 0 & G_3 & P_4 & 0 \\ 0 & 0 & 0 & G_4 & P_5 \end{bmatrix} \times N(t) \tag{1}$$

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The transition matrix A consist of five elements which completely depending on stage of mosquito life cycle, i from egg, larva, pupa, Adult 1 and Adult 2. The element P_i is referred as the proposition of *Aedes aegypti* survive and stay in the same stage i. The G_i is the proposition of surviving and growing of the mosquito from stage i into the next stage $(i+1)$. The parameter F_i is described as the fertility of mosquito in stage i. The fertility rates are set only for adult stages which the mating process and producing eggs occurred during this stage.

2.3. Transition Rate of Aedes Aegypti Life Cycle

We let that the survival rate and the duration rate for stage i respectively denoted as s_i and d_i. The transition rate, P_i can be computed using the formula as follows.

$$P_i = \frac{s_i(1-s_i^{d_i-1})}{1-s_i^{d_i}} \tag{2}$$

Since the plus of proportion, G_i and P_i is equal to the total population of stage i survive, then transition rate, G_i can be obtained by using the formula as follows.

$$G_i = \frac{s_i^{d_i}(1-s_i)}{1-s_i^{d_i}} \tag{3}$$

The fecundity rate of F_2 and F_3 are equal to 0 since only adult 1 and adult 2 could produce eggs. Therefore, only the transaction rate F_4 and F_5 are considered for the transaction matrix A. Since, the time duration required by each stage to survive and grow might be different then the time estimation must be assumed based on environmental and biological factors.

2.4. Transition Rate of Egg Hatching

Water is the main source in the process of egg hatching. Therefore, we assumed that only uncovered and opening containers can be filled with amount of water caused by rainfall. The amount of water stagnated in the container will be a breeding site for the mosquito. In this situation, we considered that the heavy rainfall distribution possibly influences the egg hatching process by overflowing the water in containers. The Egg hatching process was directly associated with rainfall distribution can be described as a function of water depth with respect to time t (days).

$$E_1(t) = s_1 c_1 \left(\frac{wd(t-1)}{wd_{max}} \right)^{c_2} \tag{4}$$

The parameter s_1 is the proportion of the *Aedes aegypti* in egg stage will survive and move to the larva stage, $wd(t-1)$ was taken as the amount of rainfall or stagnant water in a container at time t disregarding the shape of the container. The wd_{max} is the average depth of the container. Meanwhile, c_1 is probability of egg hatching and c_2 is the pattern of egg hatching [6];[7];[8].

2.5. Simulation of Egg Hatching and Adult Stage Associated with Rainfall

The proportion of G_i, P_i and $E_1(t)$ can be calculated by using the information in Table 1 obtained from our previous studies(referred [7];[8]).

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Table-1. The Survival Rate and Duration of Each Stage in Mosquito Life Cycle

i	Stage	Survival rate, s_i	Age (days), d_i
1	Egg	0.9890	< 4
2	Larvae	0.9898	4 – 8
3	Pupae	0.9898	9 – 10
4	Adult 1	0.9100	11 – 14
5	Adult 2	0.9100	15 - 24

The daily *rainfall* of January, February and March in year 2016 were considered because the monthly cases of Dengue fever are reported higher than other months in the city of Shah Alam. The data of rainfall obtained from Meteorology Department, Malaysia. The measurement of rainfall is in millimeter (mm).

2.6. Implementation

In this section, the simulation is obtained where the matrix A is multiplied by the initial population of mosquito, $N(t)$. We set the initial number of eggs in the container is 1000 eggs. The information in Table 1 will be used to obtain each rate in matrix A using the formula G_i, P_i and $E_1(t)$. The values of $E_1(t)$ will change depend on Rainfall distribution. The value of c_1 and c_2 are 0.27901 and 5 respectively.

$$N(1) = \begin{bmatrix} 0.74622 & 0 & 0 & 8 & 16 \\ E_1(1) & 0.79588 & 0 & 0 & 0 \\ 0 & 0.19392 & 0.49744 & 0 & 0 \\ 0 & 0 & 0.49240 & 0.71360 & 0 \\ 0 & 0 & 0 & 0.19640 & 0.85260 \end{bmatrix} \times \begin{bmatrix} 1000 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

The simulation of mosquito population for the following days, $N(t+1)$ were obtained by using Maple where the population of each stage in the mosquito life cycle change exactly depend on daily rainfall distribution.

3. RESULT AND DISCUSSION

The simulation of the mosquito population obtained from model, $N(t)$ are illustrated graphically into Figure 1, Figure 2 and Figure 3 to observe the trend between simulation of egg number associated with rainfall and the influences on the number of adult population. In the previous section, we mentioned that month January, February and March in 2016 were considering since the dengue cases were reported high in these months. The observation on the trend of egg number is important because it influences the adult population. The further explanations will discuss in this section. In Figure 1, we found that the trend of egg number during the month was very significant starting in the week 10. The rainfall received consecutively between week 11 to 18 allowing adult mosquitoes to produce eggs because the rainfall might provide the breeding sites [8]. Although, the frequency of receiving rain in the next week is low but the number of eggs continue to increase. This could be occurred due to receiving rain between the week 11 to week 18 provided enough breeding site for adult mosquito to lay their eggs. This situation, it also affects the number of adult mosquitoes that increase gradually based on the number of eggs.

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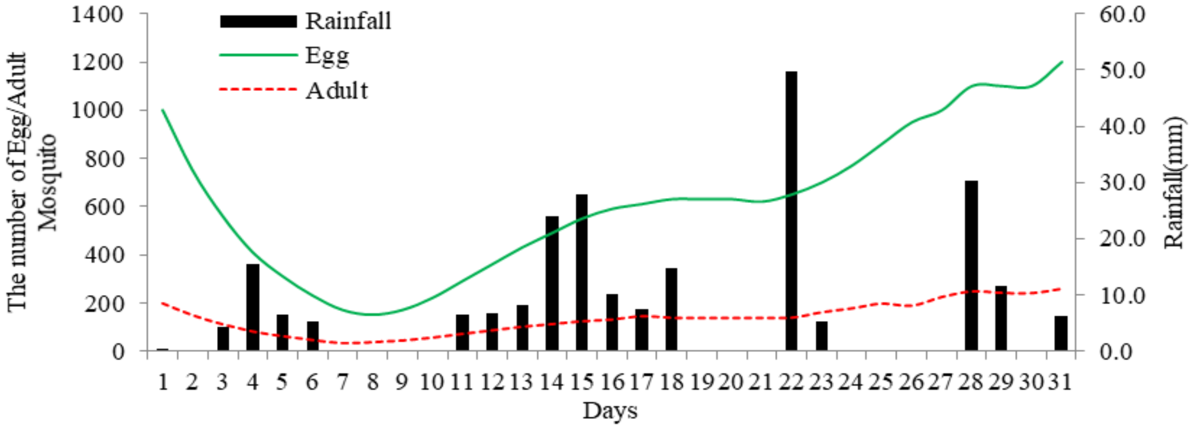

Figure-1. The Relationship of Egg Number, Adult and Rainfall Distribution on January 2016

At the beginning of February (refer Figure 2), the number of eggs was high but the number goes down suddenly starting from week 8 to 25. We noticed that the frequency of receiving rainfall in this month is less than January. We could say that the rainfall distribution received in this month might affect the existence of mosquitoes breeding site where there might be none and lack of stagnant water in opening containers. However, this number increased drastically starting from the week 25 onwards. Hence, the adult mosquitoes also have the same trends as eggs.

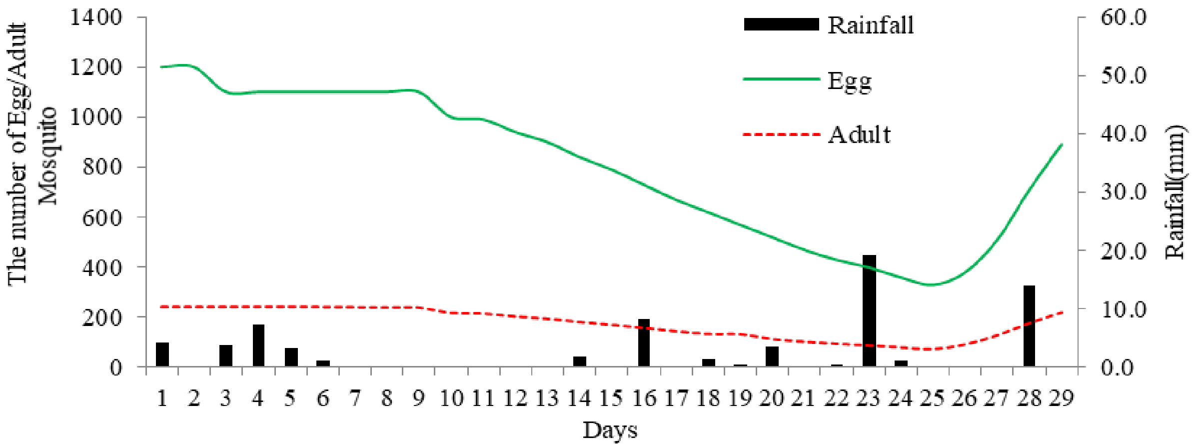

Figure-2. The Relationship of Egg Number, Adult and Rainfall Distribution on February 2016

Referring to Figure 3, the number of eggs keeps increasing from the last month. This situation persists until week 10 in March and suddenly, the trend of eggs number goes down in the following weeks. We can observe there are five consecutive weeks received high rainfall starting from week 10 until week 14. The high rainfall might cause the stagnant water in the containers overflow and if there are eggs in the container, the abundant water will wash out the eggs from the container. The egg number will decrease, and the process of egg hatching almost does not occur. This situation also influences the development of adult mosquitoes and production of egg as well [11]. The fluctuation of egg number trend continued to decline until the end of the month which throughout the weeks the receiving rains were very low, and the weather become dry. However, the adult mosquitos that have arisen from the weeks before are very active because this period is most appropriate for mosquitoes to spread the virus to humans. It is advisable to keep people cautious if this trend of rain happen. Eliminate mosquito breeding site is one of the best methods that can help reduce the development of mosquitoes.

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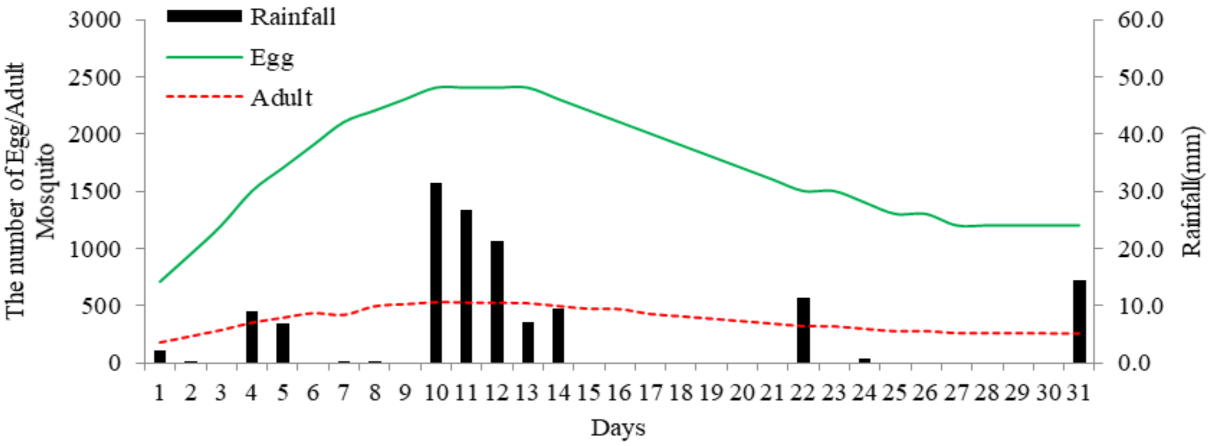

Figure-3. The Relationship of Egg Number and Rainfall Distribution on March 2016

4. CONCLUSION

Using the stage-structured matrix model for mosquito simulations gives some insight into the development of the life cycle of mosquitoes. This simulation is an alternative method to reduce dengue disease by studying the life cycle of mosquitoes. In this study, the factor of rainfall is the main role because it is seen that rain can provide breeding sites for the mosquitoes. Based on the results we get from this study, we found that the number of eggs will increase if there is a moderate rainfall distribution that provides enough water in the container. However, high rainfall can affect the amount of eggs which the heavy rains cause water in containers to overflow and carry eggs out from the water and containers. This situation causes the hatching process to almost do not occur and then affects the number of adult mosquitoes. The spread of dengue virus also decreases but the dry or moderate weather will make the adult mosquito active in the spread of the dengue virus. However, future studies are recommended to consider other factors such as humidity and mosquito habitat areas.

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REFERENCES

[1] J. G. Rigau, G. G. Clark, D. J. Gubler, P. Reiter, E. J. Sanders, and A. V. Vorndam, "Dengue and dengue haemorrhagic fever," *Lancet*, vol. 352, pp. 971–977, 1998. *View at Google Scholar*

[2] World Health Organization (WHO), "Vector-Borne viral infections. Initiative for vaccine research." Retrieved http://www.who.int/vaccine_research/diseases/vector/en. [Accessed Retrieved April 5, 2013], n.d.

[3] B. F. Eldridge, *Biology and control of mosquitoes*. California: University California Davis, 2008.

[4] J. V. Murray, C. C. Jansen, and P. D. Baro, "Risk associated with the release of wolbachia-infected aedes aegypti mosquitoes into the environment in an effort to control dengue," *Frontiers in Public Health*, vol. 4, pp. 43, 2016. *View at Google Scholar* | *View at Publisher*

[5] L. C. Chien and H. L. Yu, "Impact of meteorological factors on the spatiotemporal patterns of dengue fever incidence," *Environment International*, vol. 73, pp. 46-56, 2014. *View at Google Scholar* | *View at Publisher*

[6] N. Yusoff, H. Budin, and S. Ismail, "Simulation of population dynamics of aedes aegypti using climate dependent model," *World Academy of Science, Engineering and Technology*, vol. 6, pp. 136-144, 2012.

[7] N. Tokachil and N. Yusoff, "Effect of rainfall on population dynamic," *Mathematics and Statistics Journal*, vol. 1, pp. 17-23, 2015.

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[8] N. Tokachil, N. Yusoff, A. Saaid, N. Appandi, and F. Harun, "Effect of water availability in opening containers of breeding site on Aedes aegypti life cycle," *AIP Publishing*, vol. 5, pp. 1-6, 2015.

[9] J. Boardman, D. Hrozencik, M. Kwon, U. Irfan, and Z. Aklilu, "Using population models in the teaching of eigenvalues. Rutgers University, Center for Discrete Mathematics & Theoretical Computer Science." Retrieved from http://dimacs.rutgers.edu/. [Accessed September 3, 2016], 2007.

[10] T. Takenori and N. Hisao, "An analysis of life history evolution in terms of the density-dependent lefkovitch matrix model," *Mathematical Biosciences*, vol. 112, pp. 155-176, 1992. *View at Google Scholar* | *View at Publisher*

[11] N. Tokachil and N. Yusoff, "The simulation of egg number of aedes aegypti using stage-structured matrix model," *Journal of Technology Management and Business*, vol. 5, pp. 8-14, 2018.

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