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Agent Based Modeling on Dynamic Spreading Dengue Fever Epidemic

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Abstract

Agent based model (ABM) is a computational model for simulation, behavioral representation and interaction of autonomous agents. The main problem definition related to how to make a dynamic model of dengue fever with consideration of their behavioral and interaction agent. This paper aims to develop interactive behavioral agents and related simulation models for such dynamic spreading dengue fever epidemic. This model construction consists of two agents, namely a human agent as a host and mosquito as a vector, where temperature and humidity are the environmental parameters. These environmental parameters deployed data and information from National Meteorology Climatology and Geophysics agency and supported by recent community health data of Bogor region. The verification stage evaluated model performance of two periods between January to June and between July to December 2015 showed the fitness of the model. During simulation stage where 100 humans agent and 10 mosquitoes agent were observed, indicating the decreasing of mosquito by 26.3% and the number of infected human decrease to 16% from the period of January until June to July until December 2015 respectively. These evaluation results showed that the agent based model results succeeded to follow a similar trend of decreasing pattern as actual data.

Keywords*: agent based model, behavior, dengue fever, dynamic spreading, simulation*

1. Introduction

An epidemic is the occurrence cases of disease that spreading widely and quickly by infection and affecting many individuals in an area or population at the same time [1]. The spread of infectious disease in a population is a serious health problem and can be an economic threat. The epidemic model aims to controlling spread infections disease and the model commonly used for policy strategies in preventive medicine such as vaccinations, fogging and counseling. Most of the models for epidemic simulation are based on Ordinary Differential Equation (ODE) or statistical model [2-5]. Unfortunately, ODE and statistical model ignore the effects of individual behavior, interaction and assume a homogeneous environment [2].

In order to catch a real picture of how the interaction between actors and their environment, researchers proposed agent based models for involving behavior, interaction and environment factor. Some studies have been conducted such as developing agent based model an Aedes aegypti population dynamics [6]. The model used LAIS simulator and given information about agent larva, pupa and adults, but without information and data of climatology specified. An agent based model for the spread of dengue fever was previously investigated by [7], the result showed that the growing rate of mosquito higher during a summer season than during the winter season. Multi agent modeling and simulation of an Aedes aegypti mosquito population [8] was developed to study whether or not an artificial trap can be effectively used as an active based population control measure. The model for enhancing dengue fever modeling through a multi-scale analysis framework [9] using MASON simulator was developed using climate parameters, socio-economics and demography.

Agent based model (ABM) is a computational model for simulation, representation behavior and interaction autonomous agent [10]. ABM is one of dynamic approach besides Cellular Automata. ABM has the ability to construct individual system units at the different levels of representation to describe nonlinear relationships between those units. ABM consists of

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agents, relationship and dedicated and relevant environment. An agent is an actor who has attributes and behaviors. The relationship is the topology of connectedness defines how and with whom agents interact. Agents live in and interact with their environment in addition to other agents.

Dengue fever as one of the most rapidly spreading mosquito-borne viral disease in the world, especially in tropical area like Indonesia. The infections caused by the dengue virus and is transmitted by the Aedes aegypti mosquito. In Indonesia, estimated 100.347 dengue infections occur in the year of 2015 [11]. Several studies related to the monitoring dengue fever in Indonesia have been conducted, such as the studies to predict dengue fever in Bogor [3] and the model showed that spreading dengue fever outbreak was a side-effect of temperature, humidity and precipitation. The studies to predict dengue fever in Surabaya with influence climate [4] was conducted, the model showed that climate was influence spreading outbreak dengue fever. Studies to visualization dengue was conducted using Cellular Automata [12] with static dataset, the result show that CA pattern similar to the SIR model (a classical and popular approach).

This paper explained how to develop agent based model for spreading dengue fever. This study focused on simulation behavior agent, interaction agent, and interaction agent with the environment. Parameters environment used are temperature and humidity. The datasets climate from Meteorology Climatology and Geophysics Council. The verification and validation used data randomization with three scenarios, and the evaluation was conducted by comparing the result of the proposed model with actual data from Public Health Office Bogor.

2. Research Method

In order to achieve the research objective, some steps were done as follows: agent analysis, environmental analysis, design model used UML.

2.1. Agent Analysis

Agents are either separate computer programs or, more commonly, distinct parts of a program that are used to represent social actors, individual people, organizations such as firms, or bodies such as nation-states. The agent has attribute and behaviors. The proposed model has two agents are mosquito and human. Each agent has behaviors defined in the Table 1 and attributes defined in the Table 2. For the simplicity, we will not explain all of the behaviors in detail, but will instead focus on the most important ones.

Table1. Performance of Behaviors Agent

Agent	Behaviors	Explanation
Mosquito	Bite	Mosquitoes will bite humans if energy reaches half of its maximum energy
	Spreading of the virus	If mosquitoes have been infected with dengue virus, and age > 12 days, then the mosquito capable of spreading the virus to humans
	Fly	Fly that causes the change of coordinates
	Reproduction	Once mosquitoes lay eggs capable of producing 100 eggs (expert interviews), assuming a 10 percent were able to transmit the disease and require human blood as a source of energy
Human	Move	Move That causes the change of coordinates
	Birth	Add count of human
	Die	Reduction count of human

Source: [7-8]

2.2. Environment Analysis

The environment is the virtual world in which the agents act. Commonly, environments represent geographical spaces, climate. The proposed model used two environment parameter are temperature and humidity. Table 3 show performance of temperature to behavior mosquito agent and Table 4 show the performance of humidity to the behavior mosquito agent.

Table 2. Performance of Attributes Agent

Agent	Attributes	Explanation
Mosquito	Id_mosquito	The identification number of each mosquito
	Age	Mosquitoes have a maximum age of 33 days
	Health state	Mosquitoes have a health status of susceptible or infected
	Energy_duration	The duration of the maximum energy of mosquitoes last for 3 days (259 200 seconds)
	Fertility	Mosquitoes are able to reproduce as much as four times during his lifetime (expert interviews)
	Position	Coordinates for stay mosquito
Human	Id_human	The identification number of each human
	Age	Human have a maximum age of 70 years old
	Health state	Human have a health status of susceptible, infected or recovered
	Position	The coordinates for stay human

Source: [8-9] [Expert Interview]

Table 3. The Value ranges of temperature parameters on the behavior of mosquitoes

Range of Temperature (^{0} *Celsius*)	Mosquito Behavior
0 ≤ temperature ≤ 10 and temperature > 39	Inactive
10 < temperature< 20	The flying random
20 ≤ temperature ≤ 39	The flying random, bite
25 ≤ temperature≤ 27	Reproduction
Temperature< 0 and temperature> 41	Die

Source: [9]

Table 4. The value ranges of humidity parameter on the behavior of mosquito

Range of Humidity (%)	Mosquito Behaviors
Humidity > 70	Reproduction, flying random, bite
60 ≤ Humidity ≤ 70	The flying random
Humidity < 60	Die

Source: [7,13]

2.3. Design Model

The proposed design model use Unified Manipulation Language (UML) [14]. The design was developed to answer the requirement analysis. The design consists of use case diagram, sequence diagram and class diagram. Each diagram will define in the subsection as follows.

2.3.1 Use case Diagram

Use case diagram illustrates what activities are carried out by a system from the standpoint of the outside observer. Use case diagram for agent based model spreading dengue fever as shown in Figure 1. Figure 1 shows interaction agent mosquito and human in the environment. Mosquitoes check some parameters of the body, such as fertility and energy duration and check some parameters of the environment, such as temperature and humidity, then took a bite human if the condition of the body and the environment allow and then complete their reproduction if still fertile. Updating health states will perform instantly as soon bite process complete.

2.3.2. Sequence Diagram

Sequence diagram is an interaction diagram that explains how an operation is run, what message is sent and the implementation thereof. Figure 2 shows the sequence diagram in the dengue infection process. Figure 2 show if agent mosquito susceptible bite human was containing a virus, the mosquito will change state health into infected mosquito. If infected mosquito bite susceptible human, the human gets infected and have probabilities to recover.

2.3.3. Class Diagram

A class diagram is an illustration the overall system by showing its classes and describes the relationship between classes. Figure 3 shows the class diagram agent based model on dengue fever.

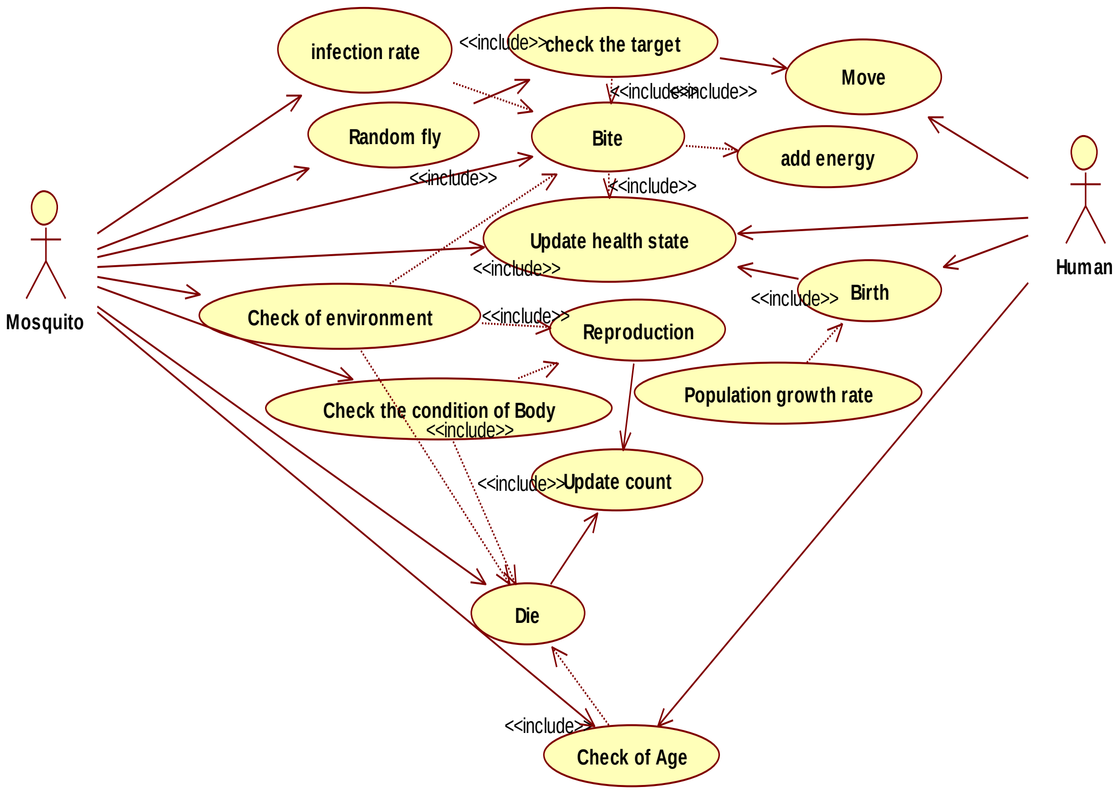


Figure 1. Use case diagram for interaction agent

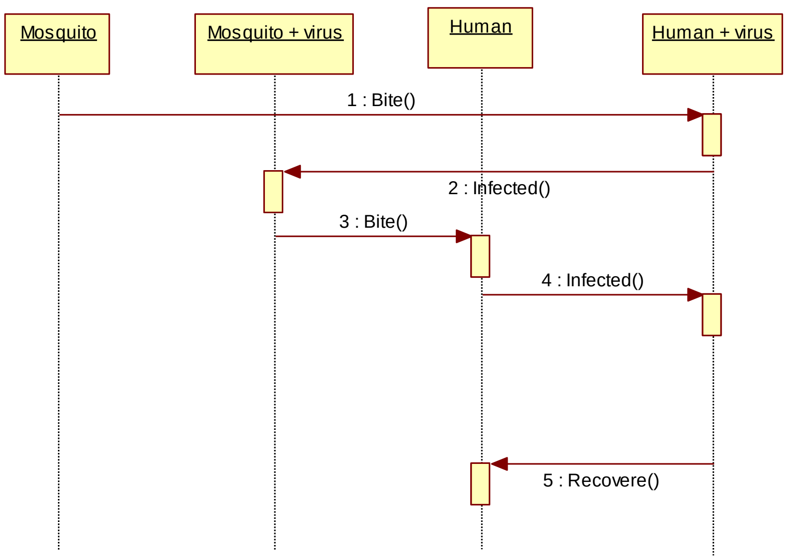


Figure 2. Sequence diagram of infection process of dengue fever

The result of system design by using UML was provided in Figure 3 which shows a class diagram of agent based models for dengue, which consisted of mosquito, human, environment and infection process. Each class consists of attributes and methods reflecting their behavior individually.

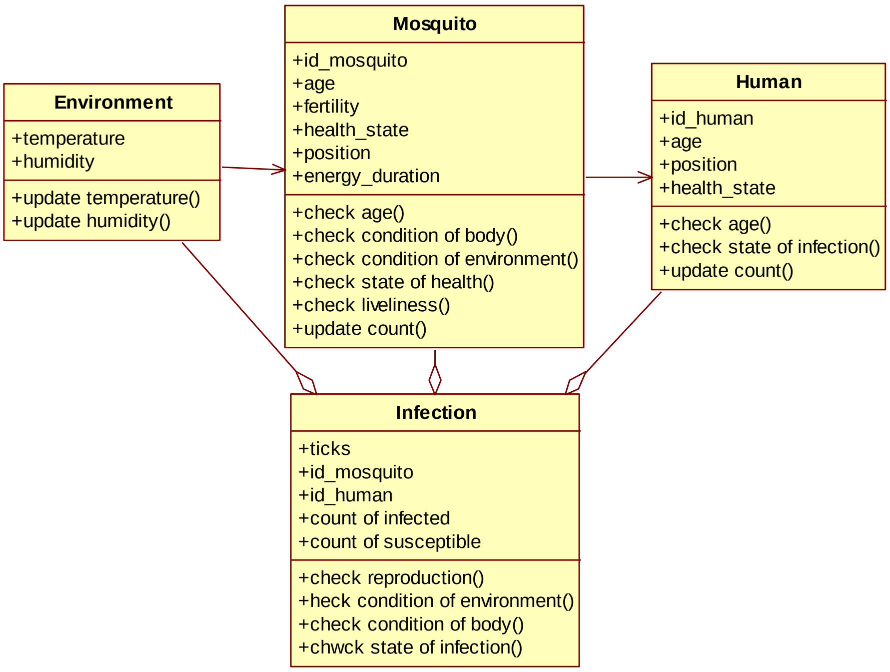


Figure 3. Class diagram of agent based model dengue fever

3. Results and Discussion

3.1. Implementation of the Agent Based Model

This model was implemented using Netlogo [15], a scripting language based on Java Development Kit (JDK). Initially, Netlogo enables its users, in our case, epidemiology, to execute its simulations by adjusting its parameters. It is a set of open source Java based libraries for agent based modeling. Figure 4 shows the implementation result agent based model for dengue used Netlogo.

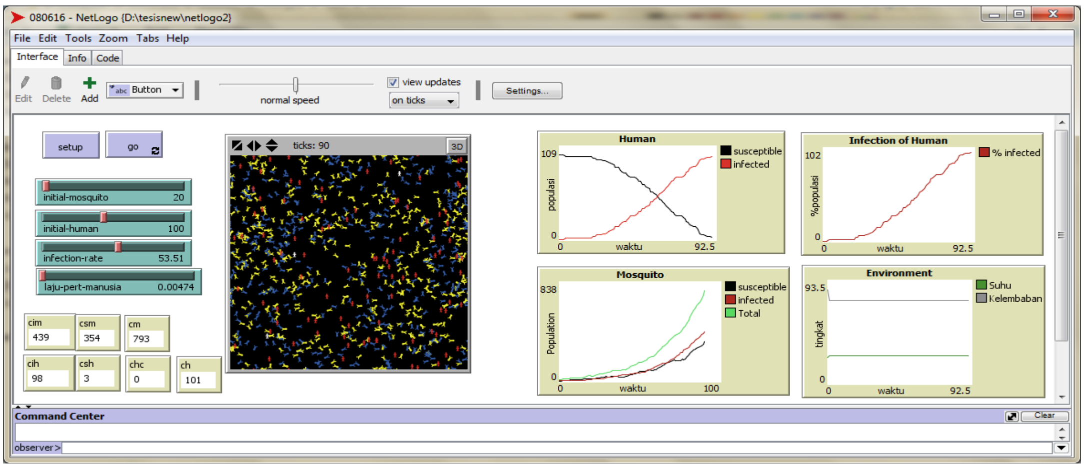


Figure 4. Implementation result of ABM for dengue fever

In addition, Figure 4 shows an implementation result of applying for dengue fever's ABM which consists of a button *setup* and *go*. Button *setup* serves to initialization simulation data and button *go* to run the application. The *slider* shows the number of initialization humans, mosquitoes, infection rate, and the rate of population growth. As seen in Figure 4, the graph shows that humans are susceptible will decrease when the number of people infected increase and the result of the trend proposed model was similar to that of the SIR model (a classic and popular approach) [17]. The infection of human illustrates the total percentage of infected humans. Mosquito graph shows the number of mosquitoes in the model where the numbers affected by temperature and humidity. Environment describes the temperature and humidity in the model. Model runs in unit time of ticks. One tick in simulation shows one day in actual systems.

3.2. Evaluation Model

Evaluation model consisted of two methods of verification and validation. Verification model was conducted by synthesis of randomized data process with three scenarios. The scenarios are by generating data in assumption of current available parameterized normality, the second one by generating data in the assumption of a fully correlated relationship between observed parameters and the later with assumption of anti-correlated between observed environmental parameters on dengue spreading. The validation stage was conducted by comparing the model yielded by the proposed model by using an agent based model on those the actual data.

3.2.1. Verification

Verification model was conducted by a synthesis of random data process with 3 scenarios. The first scenario was applied on current normality distribution of temperature and humidity which lead to an optimal environment for the growth of mosquito. The range of temperature between 25^0 *Celsius* to 27^0 *Celsius* with humidity of > 70 percent. The second scenario investigated the range of low temperature between 10^0 *Celsius* to 19^0 *Celsius* with 65 percent humidity. The third scenario observed when the fluctuating temperatures between optimal temperature and lower temperature. For the third scenario, there were assumed that 20 mosquitoes agents, 100 human agents, with an infection rate of 53.51 %, where the current population growth rate 0.474% annually and the number of ticks 90 counts. The synthesis data read in the form file.*csv*. Figure 5 shows the result from the first scenario with optimal parameters, Figure 6 shows the result from the second scenario with low parameters, as Figure 7 shows the result from the third scenario with fluctuating parameters.

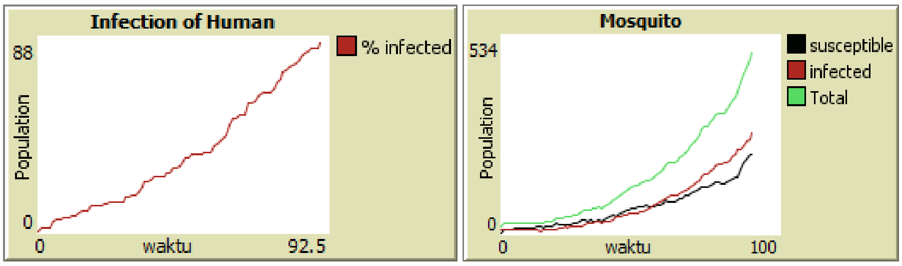


Figure 5. The result of experiment with optimal parameter value

Figure 5 shows the result of an experiment with optimal parameters. The model showed that percentage infected human and count of mosquito refer to increase.

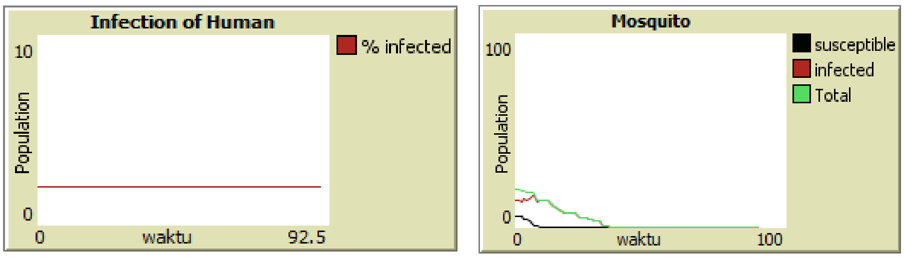


Figure 6. The result of experiment with lower parameter values

Figure 6 shows the result of experiment with low parameters, the model showed that percentage of infected stable or not happen and count of mosquito consist of decrease.

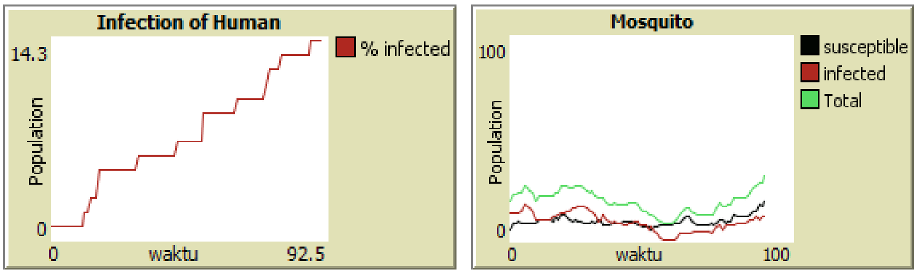


Figure 7. The result of experiment with fluctuative parameter values

Figure 7 shows the result of experiments with time and population level parameters, the model showed that percentage of infected human and count mosquito are fluctuative both in case of infection of human and mosquito.

3.3. Validation Model

The validation model was conducted by comparing the result of model with actual data. The dataset temperature and humidity were collected from Meteorology Climatology and Geophysics office in Dramaga region, Bogor in 2015. The dataset was divided into two periods, the first period was observed from January until June, the second part was observed from July until December. The data initialization for the evaluation model used 10 count mosquitos, 100 count humans, the infection rate is 0.11 [5], population growth rate is 0,00474 [18]. The validation results showed that the mosquito growth in the first period is higher than the second period (Figure 8) and number of infections human was decreased from first period to second period (Figure 9).

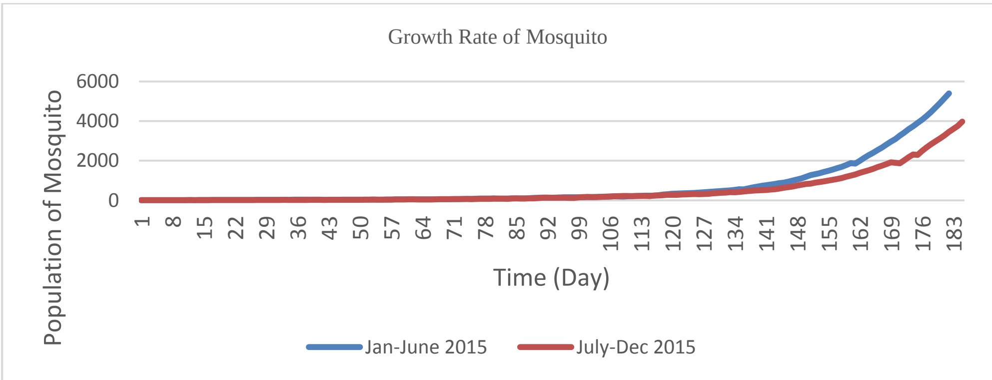
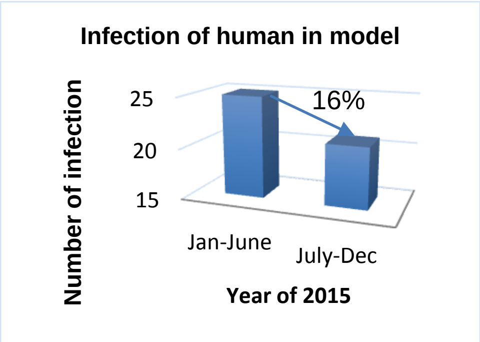


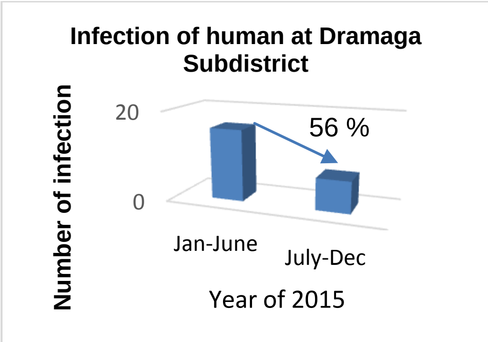
Figure 8. The result of mosquito growth rate

Figure 8 shows a comparison result of mosquito growth rate during these periods from the model. The growing of mosquito on period January until June more than higher period July until December. The model shows a descending trend by 26.3 % from first period to second period. The dataset of the first period of January to June preserved nearer optimal result in comparison to a second period of July to December.

In the case of how the trend of infected human in percentage, Figure 9 provides information about infection with human agents has decreased from the first period (January to June) to second period (July to December). Figure 9 (i) shows the percentage of infected humans from the model. It was the greatness of decreasing by 16 %. Figure 9 (ii) shows the percentage of infected humans from the Dramaga Sub district. In dataset Sub district Dramaga on 2015 has decreased infection great 56%. The result of simulation and actual data have pattern similar trend is decreasing. The percentage number is different because the simulation does not use the real data and spatial distribution. The simulation constraint related to space limitations and the time required for the simulation of agents that took a longer time to complete the whole stages. It required a higher performance of computing power. However, agent based model was capable to manage the sensitivity of temperature and humidity on the behavior of each agent, and particular provision of showing interaction between agents and their environment. During the later evaluation, the model was succeeded to provide a more flexible switching.



(i)



(ii)

Figure 9. The percentage of infected humans

4. Conclusion

Above discussion indicated that the agent based model on spreading dengue fever was successfully developed by observing related parameters and interaction, supported all relevant agents, behavior agent, attribute agent, interaction agent, and environmental factors. The proposed model was capable to show the trend of dengue fever by deploying information and data of agents and their environment. Moreover, the evaluation result showed this model was capable show nearer pattern similar trend of dengue fever with current actual data.

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