

Ecohealth System Dynamic Model as a Planning Tool for the Reduction of Breeding Sites

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Abstract. Dengue is still one of major health problem in Indonesia. Dengue transmission is influenced by dengue prevention and eradication program, community participation, housing environment and climate. The complexity of the disease coupled with limited resources necessitates different approach for prevention methods that include factors contribute to the transmission. One way to prevent the dengue transmission is by reducing the mosquito's breeding sites. Four factors suspected to influence breeding sites are dengue prevention and eradication program, community participation, housing environment, and weather condition. In order to have an effective program in reducing the breeding site it is needed to have a model which can predict existence of the breeding sites while the four factors under study are controlled. The objective of this study is to develop an Ecohealth model using system dynamic as a planning tool for the reduction of breeding sites to prevent dengue transmission with regard to dengue prevention and eradication program, community participation, housing environment, and weather condition. The methodology is a mixed method study using sequential exploratory design. The study comprised of 3 stages: first a qualitative study to 14 respondents using in-depth interview and 6 respondents for focus group discussion. The results from the first stage was used to develop entomology and household survey questionnaires for second stage conducted in 2036 households across 12 sub districts in Bandung City. Ecohealth system dynamic model was developed using data from first and second stages. Analyses used are thematic analysis for qualitative data; spatial, generalized estimating equation (GEE) and structural equation modeling for quantitative data; also average mean error (AME) and average variance error (AVE) for dynamic system model validation. System dynamic model showed that the most effective approach to eliminate breeding places was by ensuring the availability of basic sanitation for all houses. Weather factors such as precipitation can be compensated with the eradication of breeding sites activities which is conducted as scheduled and at the same time for the whole areas. Conclusion of this study is that dengue prevention and eradication program, community participation, and housing environment contributed to breeding places elimination influenced the existence of the breeding sites. The availability of



basic sanitation and breeding places eradication program done timely and collectively are the most effective approach to eradicate breeding sites. Ecohealth dynamic system model can be used as a tool for the planning of breeding sites eradication program to prevent disease transmissions at city level.

1. Introduction

World Health Organization (WHO) has declared dengue as the most important disease caused by vector with the number of cases worldwide expected to increase with global climate change.¹ In the past 50 years, dengue cases increased 30 times. Indonesia has become dengue endemic area since 1968 with increasing incidence and has spread in 33 provinces and 440 districts/cities. West Java is one of the provinces that have the most number of dengue cases in Indonesia. Bandung is the city with the highest number of dengue cases in West Java.² There are as many as 3.822, 5.057, 5.127 and 3.132 cases in 2011, 2012, 2013, and 2014, respectively.³

Top-down approach has been widely applied to the prevention and eradication, but has not been able to eliminate or reduce this disease in a sustainable manner. Constant change in society and the environment caused challenges in the greater efforts to tackle dengue.^{4,5}

Studies have proven that dengue is a disease with multifactorial influences. Changes in weather is one factor that greatly affect highly sensitive mosquito vectors.⁶ The weather changes affect the host, the pathogen as well as vectors affecting reproduction rate. Warm temperatures will affect mosquitoes gonothropic cycle that makes them reproduce quickly and efficiently.⁷⁻¹⁰

Mosquitoes vector develop well provided there were ideal breeding places. The more densely populated urban areas causing reduced environmental carrying capacity due to unplanned development. The inadequate availability of clean water forcing people to collect water in containers that become ideal breeding places. No feasible basic sanitation, nonexistence waste management, and changes in the land-use increase the presence of breeding sites.¹¹⁻¹³

The prevention and eradication of dengue mainly aimed at vector control, especially in removing mosquito breeding places. Community participation become the most important part of the program. Community-based programs are difficult to succeed if it does not involve creativity and novelty in its application.¹⁴ Interventions in combating and prevention of dengue fever should be based on the appropriate time, place and method.¹⁵⁻¹⁸

Dengue fever with multifactor influence requires an approach that could explain the dynamics and complexity of the problem. The systems approach is the most appropriate approach to be able to explain the relationship and the role of each variable in a complex situation. *Ecohealth* is the study of changes in the biological, physical, social and economic environment, as well as its relationship to health. *Ecohealth* approach provides a thorough overview of the dynamics of dengue problem that can be used to determine the most appropriate intervention.¹⁹

The dynamic factors affecting dengue fever require tool that can describe the problem as a whole. Modeling to describe dengue fever can be done by simulating the system dynamics. System dynamics is an approach to understanding a complex system over time. The system dynamics emphasizes understanding the structure of a system is as important as understanding each component of the system.²⁰⁻²³

System dynamics model can integrate a wide range of variables that affect dengue fever and calculate the behavior of each variable in the tested model. Simulations using the model will be very useful to provide a description of the intervention that should be done based on the most appropriate place, time, and selection of method before it is applied on the field.²⁴ The objective of this study is to develop a model using *Ecohealth* approach to be used as a tool to reduce the breeding places of mosquitoes as an effort to prevent dengue transmission.

2. Method

The modeling of system dynamics using Ecohealth approach is developed using software Powersim Studio ver.7. Variables that used are variables that considered represent the system's main purpose

which is to measure system performance indicators in the form of number of house free from pupae (ABJ). Data, either as a primary or secondary, become an input for the model in the form of stock, level, flow rate, and constants.

Data gathered using *mixed method with sequential exploratory design* approach.²⁵ The data collection method consisted of 2 phases: 1) the initial stage is a qualitative data collection through in-depth interviews with 14 respondents and focus group discussions with 6 respondents. The analysis of the qualitative stage is used as a basis for making the instruments for quantitative data.

The second stage of survey is held in 2,035 household in 16 subdistricts out of 151 subdistricts in Bandung City. Subdistricts were selected using stratified random sampling method. Household sample for entomology examination was calculated based on the criteria for the productivity of breeding places research. Information from stage one and two such as number of larvae per house and the existence of breeding places will be used as the base to run models. The analysis of the data was presented in other article.¹⁴

System dynamics has three roles in developing the model. The most important is the system structure that will characterize its behavior. The second is the nature of the structure where mental model play important role in the dynamic of the system. The third is that change can be used to alter the structure based on scenarios.

The assumed model consists of a set of parameters. Parameter estimation is used to utilize data or observation from a system to develop mathematical models. Parameters value in this study was drawn from the above mentioned data collection.

This framework to develop the model was based on Sterman²⁴ system dynamic model development focusing in system thinking. Additional step is added to construct and test the simulation model. The main characteristic is the existence of a complex system, the change of system behavior and the existence of close loop feedback. The feedback used to describe new information about system condition that will yield decision.

3. Results

Step in model development

- Problem articulation to find real problem in dengue prevention especially on breeding sites existences, identify key variables and concepts, determine time horizon and characterize the problem dynamically for understanding and designing policy
- We develop causal loop diagram into flow diagram with variables for each subsystem defined.
- We translate system description into level, rate and auxiliary equation with estimated parameters as mentioned above
- Testing the model to compare the simulated behavior of the model to the actual behavior of the system.

Base model development showed there are three endogenous system and subsystem that interact and related to each other, which are house and environment subsystem, the mosquito's breeding places subsystem, and dengue program and community participation subsystem.

House and environment subsystem

The growth of population can generate more houses means that there was more houses to consider regarding breeding places. The subsystem looked into houses with available basic sanitation and trash management system which influence by weather especially precipitation.

$$\text{Number of Population} = (258.613 \times (2 + (0,1 \times ('year' - 2.010)))) + 2.000.000$$

Equation based on Bandung population census with 258.613 is estimation in population growth in 10 years and 2,000.000 was Bandung population baseline from 1990. Healthy houses estimated using the smallest number from total houses with basic sanitation, trash management, and clean water availability. Healthy houses increased influence by total number of houses and policy on basic sanitation, clean water and dengue program.

Dengue program and community participation subsystem. Community participation influence dengue program in form of larvacides and breeding sites eradication activities. This subsystem

comprised of larvacide effort and breeding sites eradication which influenced by weather conditions especially temperatures.

Mosquito breeding places subsystem is the factors leads to the occurrences of mosquito breeding places. This subsystem comprised of houses with and without breeding places influence by pupa eradication effort. Breeding places increased based on assumption that breeding sites increased with increased precipitation. On the highest level of dengue program, number of eggs estimated to be almost the same with the level of highest egg hatching. Figure 1 showed the main Ecohealth model for dengue.

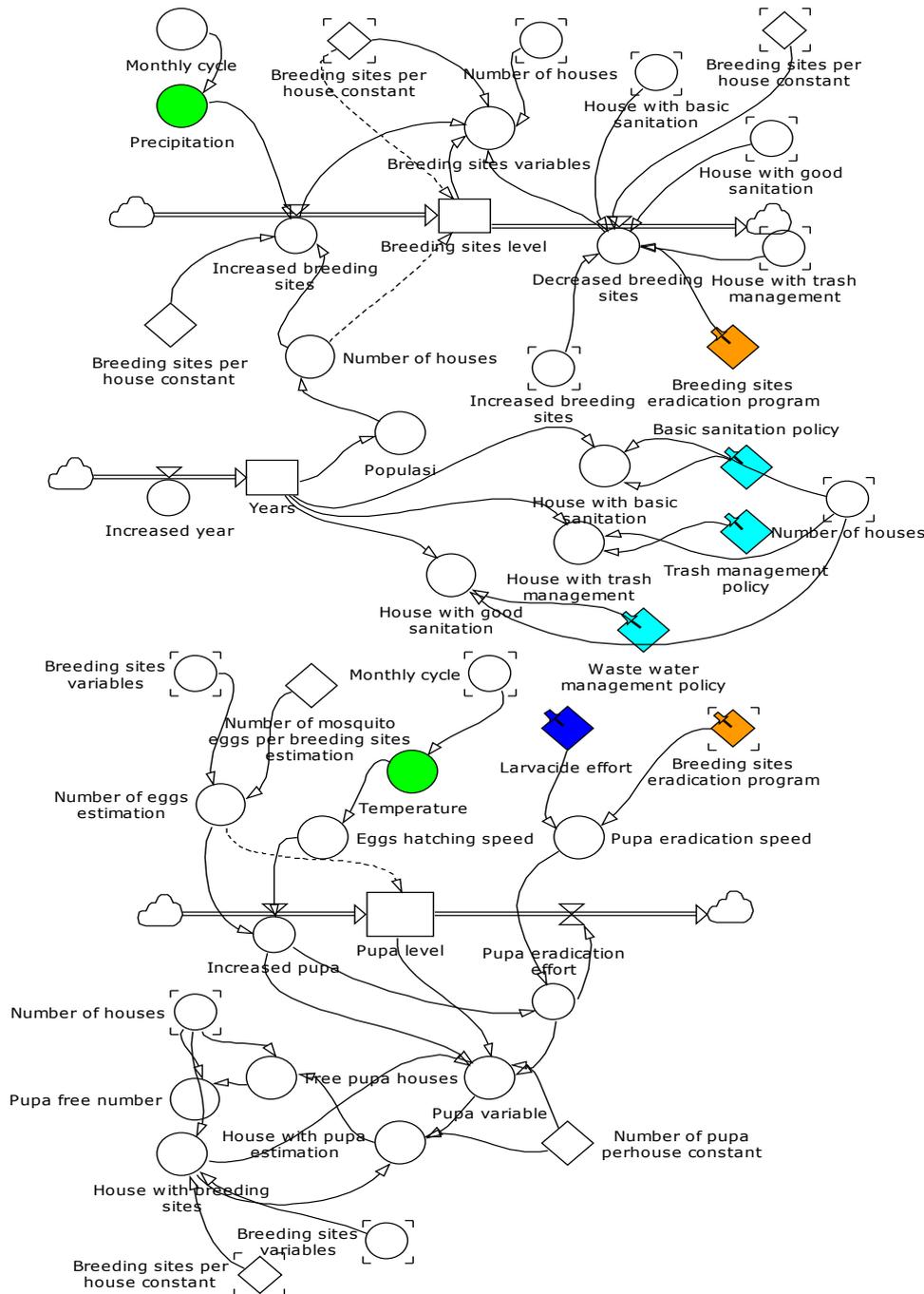


Figure 1. Main *Ecohealth* System Dynamic Model for dengue

Validation of the model performance is done by comparing the amount and nature of the error using 1) absolute mean error (AME) which is a deviation (difference) between the average value (mean) of a simulation results to the actual value; and 2) absolute variation error (AVE) which is a deviation of simulation variance value to the actual value.

Tabel 1. Validation Model Performance Table

	AVE	AME	p Value	t Value
ABJ				
Sanitation	0,000023	0,00089	0,48	0,7049
Breeding sites eradication	0,000056	0,00695	< 0,0001*	4,152
Larvacide	0,000023	0,00089	0,48	0,7049
Healthy House				
Sanitation	0,022	0,0006	0,40	0,845
Breeding sites eradication	0,009	0,00002	0,46	0,730
Larvacide	0,0228	0,0006	0,40	0,848
Larvae-free House				
Sanitation	0,0265	< 0,0001	0,54	0,605
Breeding sites eradication	0,24	< 0,0001	0,0003*	4,3
Larvacide	0,26	0,27	0,54	0,6

As stated in the previous section, the main target of dengue program is to achieve the main indicator of dengue transmission, which is 95% ABJ value. Based on the dynamics system model, achieving these targets are closely related to the presence of healthy houses that are affected by the availability of basic sanitation, the activity of breeding sites eradication program, and larvacides program. Below is the used formulation of the performance indicators.

- The number of larvae.

The existence of larvae becomes a key factor in achieving performance. Value for estimation is obtained from the results of previous studies as follows: each mosquitoes lay their eggs on average 100 eggs with hatching rate are different depending on the temperature (36%, 70%, and 65% at 24°C, 27°C, and 30°C respectively).

- The existence of the breeding place shortly become a decisive part for larvae presence. Based on the survey, the number of breeding places per house is 2.9 units on average.
- The number of healthy house

Healthy house is defined as a house that has good basic sanitation and free of disease vectors including mosquito vectors. Increasing healthy house is a response to the availability of basic sanitation with the existing growth rate of 1% per year.

To prepare the scenario, model parameters that can be modified and applied to the real system are required. Those parameters act as a policy representation that can be used and applied to the real system. The policy parameters can be identified by observing intensively the feedback relationship among the variables that exist in the overview system and also simulate the development of policies that may be done.

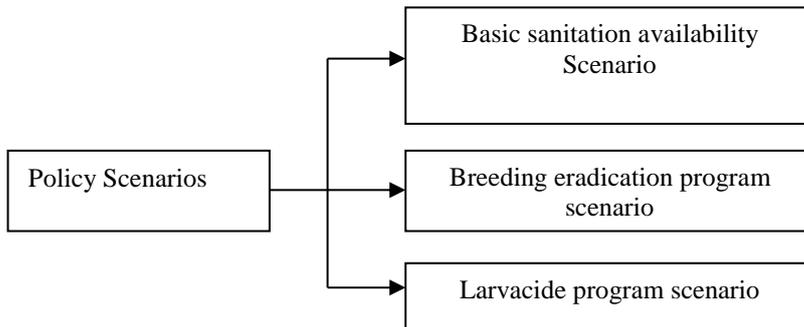


Figure 2. Policy Scenarios

Based on Figure 2, the number of healthy houses with the availability of basic sanitation scenario will be obtained on the entire house in 2024 (for the medium scenario) and in 2019 (for the ideal scenario). For the low scenario, the number of healthy houses will reach the number of entire house in 2045.

4. Model Run Results from Availability of Basic Sanitation Policy

Based on Figure 3, the number of healthy houses with the availability of basic sanitation scenario will be obtained on the entire houses in 2024 (for the medium scenario) and in 2019 (for the ideal scenario). For the low scenario, a healthy number of new houses will reach the number of entire houses in the year 2045.

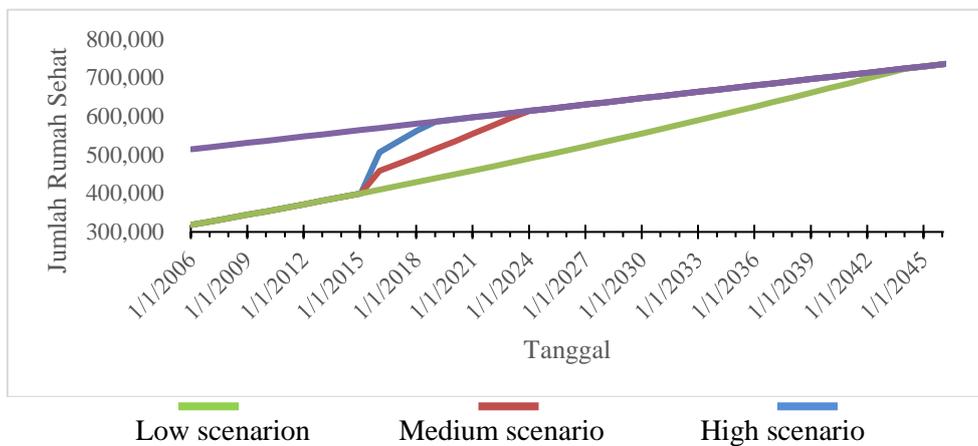


Figure 3. Simulation of Healthy Houses Growth based on the Availability of Basic Sanitation Facility Scenario

Figure 4 shows the houses growth with the breeding place in the medium and long term. Figure 4.a on the left shows the houses growth with breeding sites will be affected by rainfall that fluctuates depending on the season. Figure 4.b on the right shows the length of time required to achieve maximum results.

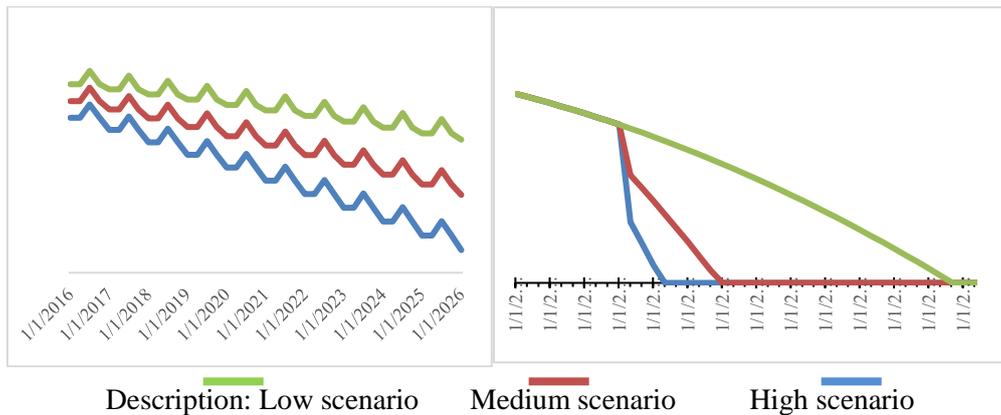


Figure 4 a

Figure 4 b

Figure 4 Simulation of Houses Growth with Breeding Sites based on Basic Sanitation Scenario

Based on simulation results, it appears that with the improvement of basic sanitation facilities, the number of breeding places experiencing a fluctuate declining trend in two (2) years cycles in the initial year (2016), but then increased in the second year (2017). This is due to the growth of the home which is faster than the speed of provision of basic sanitation facilities at the beginning of the simulation.

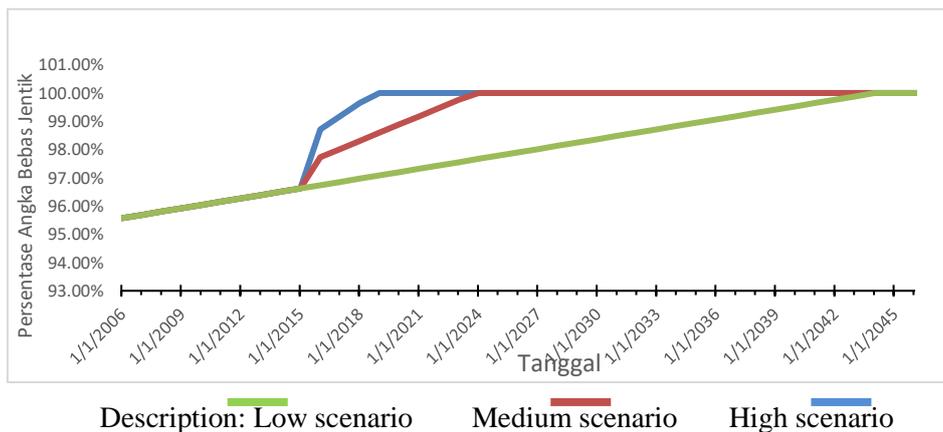


Figure 5. Simulation of House with Breeding Sites Developments and ABJ based on the Availability of Basic Sanitation Scenario

Figure 5 shows the consistency of the number of houses with the breeding place and the number of house with pupae. This is because the larvae condition can only be found if there are breeding places. Based on the entomology survey results, 13% of the breeding places in the city of Bandung contains mosquito larvae. ABJ value will reach the maximum value with the availability of basic sanitation in 2020, whereas if the growth of basic sanitation is in accordance with ABJ existing state, the maximum value will be achieved in 2045. The simulation results of healthy house with good ABJ growth performance shows growth number of healthy house based low scenario (1% per year), medium (2.5% per year), and ideal (4% per year).

5. Discussion of Policy Scenario Results

Based on the analysis of trends in the scenarios that are built to meet the desired output, the policy directives can be done which can be formulated in a thorough sustainable management to prevent transmission to reduce mosquito breeding places in Bandung.

Policy scenario applied in 2016 will deliver real results in 2019 if the policy to increase the provision of basic sanitation facilities applied in high level (4%), in 2026 if in medium level (2.5%)

and in 2046 if the policy is implemented in accordance with existing conditions with increment of 1 (one) percent per year.

In accordance with system behavior, it is known that the provision of basic sanitation policy scenario is the policy that provides best results and the fastest to reduce transmission. To achieve universal access, the addition of basic sanitation policies, including the availability of clean water, must be made with at least a 4% rise so that the target can be achieved in 2019. The provision of infrastructure is very closely related to the allocation of the funds needed.

6. Conclusion

The behavior of the system dynamics model shows the availability of basic sanitation is a very important factor in reducing mosquito breeding places which will improve the performance of the system in the form of increase in ABJ. Breeding places eradication efforts along with larvacide are very important to the performance of the system, especially in anticipation of the weather pattern in the form of rainfall. The above scenario cannot be done partially for the ideal target to be achieved. Both of these activities should be carried out together because both have a dynamic relationship that cannot be separated from one another. System dynamics model that was developed based on the *Ecohealth* approach uses breeding place as a system performance measurement which dengue prevention and eradication program, community participation, and housing environment are a variable system that can be controlled while the weather is a variable that cannot be controlled.

Research Ethics

This research has gained *ethical approval* No. 464/UN6.c2.1.2/ KEPK/PN/2014 on August 14th 2014 from Health Research Ethics Committee of the Faculty of Medicine, Padjadjaran University and the National Unity and Community Protection Area (Badan Kesatuan Bangsa dan Perlindungan Masyarakat Daerah/BKBPM) West Java Provincial Government No. 070/3799/BKBPM on October 30th 2014.

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