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Modeling of the Spread of Malaria in the Bangka Belitung Islands Province Using the SEIR Method

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ABSTRACT

Malaria is an infectious disease caused by plasmodium through the bite of the *Anopheles sp*. female mosquito. (Roach, 2012). Malaria disease which hit the Bangka Belitung Islands Province in 2005 experienced a spike, reaching 36,901 people out of 981,573 residents and claimed the lives of 12 local residents. In 2011, the Bangka Belitung Islands Province was declared an endemic area for malaria. This research aims to model and interpret the spread of malaria using the SEIR model and predict the spread of malaria using parameter estimates. The steps in analyzing the SEIR model on the spread of malaria are making assumptions, forming a SEIR model, determining the equilibrium point and analyzing the stability of the equilibrium point, determining the basic reproduction number, and carrying out a simulation of the SEIR model that has been obtained. The SEIR model is classified into 4 classes, namely Susceptible (susceptible individuals), Exposed (individuals who have symptoms), Infected (infected individuals), and Recovered (recovered individuals). The data used in this research is data on the number of Susceptible, Exposed, Infected, and Recovered malaria cases in 2022 obtained from the Bangka Belitung Islands Provincial Health Service. The SEIR mathematical model is used to calculate the equilibrium point and basic reproduction number. Based on the SEIR model simulation results, it was found that the susceptible population decreased from the 0th month to the 48th month. As for the exposed population, there were 9,623 people in month 0, but in this condition the population decreased drastically per month. Furthermore, for the infected population there were 129 people in month 0, but in this condition the number of infected decreased drastically per month along with the decrease in the exposed population. For individuals who recovered, there was a increase from the 0th month to the 48th month.

Keywords: Malaria, SEIR, Model

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1. Introduction

The government always strives to improve optimal health service efforts for the community related to health development priorities, one of which is through improving health services (Alim et al., 2020). However, until now there are still many diseases that are health problems. Malaria is a disease that is still a world health problem today.

Malaria is an infectious disease caused by plasmodium through the bite of the Anopheles sp mosquito. female (Roach, 2012). There are several cases of malaria that have been recorded, one of which is the World Malaria Report in 2021

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which estimates that there were 241 million cases of malaria and 627,000 deaths due to malaria worldwide in 2020. This represents around 14 million more cases in 2020 compared to 2019, and 69,000 more deaths.

Malaria is generally found in remote or difficult-to-reach places, especially in countries with low and developing economies. Indonesia is one of the developing regions with a tropical and subtropical climate that is favored by Anopheles sp mosquitoes. as their habitat (Roach, 2012). Until now, Indonesia is still one of the countries at risk of malaria because 80% of districts or cities in Indonesia are endemic to malaria.

The Bangka Belitung Islands are one of the regions in Indonesia where malaria is endemic (Eby, 2011). Considering that there are so many malaria diseases that attack humans and the nature of transmission is so fast, it causes quite large losses to health. The malaria disease that hit the Bangka Belitung Islands Province in 2005 experienced a spike, reaching 36,901 people out of a population of 981,573 and claimed the lives of 12 residents (RH, 2006). In 2011, the Bangka Belitung Islands Province was declared an endemic area for malaria. According to the government, the number of malaria sufferers has continued to decrease in the last 4 years. The government has prepared various programs to prevent the spread of malaria. However, there has been no real action against the former tin mining area which is a breeding ground for malaria mosquitoes. Apart from that, the topographic factor of the area in the Bangka Bellitung Islands, which is mostly swamps, forests, beaches, and mangrove forests with sloping sandy beaches, low land, and hills with dense forests, thus supports the breeding of Anopheles sp mosquitoes (Asmiani et al., 2021).

Therefore, we need a way to control the spread of malaria so that it does not become more widespread. This control can be carried out through mathematical modeling (Hidayati et al., 2017). The mathematical model that will be used to see the level of spread of malaria is the SEIR model (Sulistioningtias & Lestari, 2018). From this mathematical model, a system of differential equations will be formed from which the equilibrium point of the system can be identified and the stability around the equilibrium point can be analyzed (Sulistioningtias & Lestari, 2018). Through this model, disease-free equilibrium points, basic reproduction numbers, and stability around the equilibrium point will be analyzed (Ashari et al., 2021).

The problems above prompted researchers to research to find out how big the spread of malaria is in cities and districts in the Bangka Belitung Islands Province with the title "Mathematical Modeling of the Spread of Malaria in the Bangka Belitung Islands Province Using the SEIR Method".

2. Methodology

2.1. Research Procedures

The method that will be used in this type of quantitative research is a literature review. The research flow diagram can be seen in Figure 1 below.

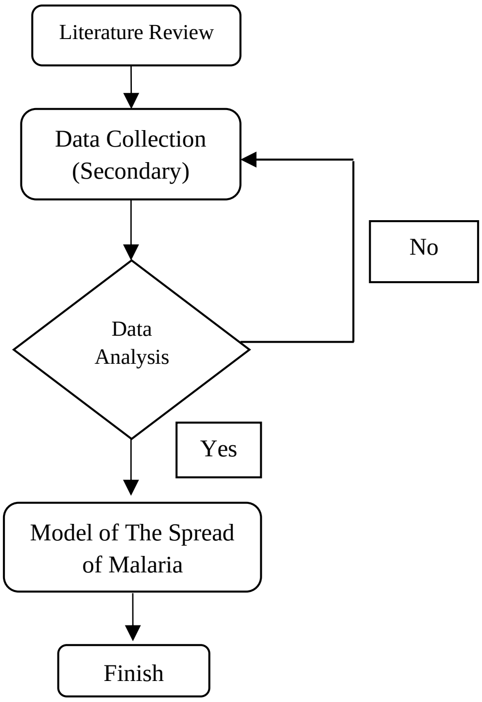

Figure 1. Research Flow Diagram

2.2. Method of Collecting Data

Data collection was carried out by taking the dataset from the dataset provider's website (Cahyaningsih et al., 2020). This research uses secondary data from the number of malaria cases in districts/cities in the Bangka Belitung Islands Province based on data from the Bangka Belitung Islands Provincial Health Service in 2022. This research utilizes technology, namely using mathematical software.

2.3. Analysis Method

SEIR Model

The SEIR model divides the human population N into four variables, namely humans who have the potential to be infected with the virus (susceptible), humans who show symptoms of being infected with the virus (exposed), humans who have been infected with the virus (infected), and humans who have recovered (recovered) (Ihsan, Side and Pagga, 2021).

$$S(t) + E(t) + I(t) + R(t) = N \tag{1}$$

The susceptible population is converted to the exposed population at a rate of β. The exposed population becomes the infected population at a rate δ, then the infected population becomes a recovered population at a rate σ.

Differential Equations

A differential equation is a form of the equation that contains the derivative of one or more dependent variables concerning one or more independent variables (Ihsan et al., 2021). Based on the number of independent variables, differential equations are classified into two, namely ordinary differential equations and partial differential equations (Ihsan et al., 2021).

Ordinary differential equations are a form of the equation that involves the derivative of one or more dependent variables concerning one independent variable (Ihsan et al., 2021). An example of an ordinary differential equation is presented in equation (2).

$$x\frac{dy}{dx} + 5y = 6 \tag{2}$$

Equilibrium Point and Stability

The equilibrium point is a fixed point that does not change with time. Suppose we are given a system of differential equations of the form

$$\begin{aligned}\frac{dx}{dt} &= f(x,y)\\ \frac{dy}{dt} &= g(x,y)\end{aligned} \tag{3}$$

A point (x_0, y_0) can be said to be an equilibrium point of system (3) if it fulfills the conditions $f(x_0, y_0) = 0$ and $g(x_0, y_0) = 0$. The equilibrium point (x_0, y_0) is a solution from system (2) which has a constant value because $\frac{dx}{dt} = 0$ and $\frac{dy}{dt} = 0$ at the point (x_0, y_0). The situation that causes $\frac{dx}{dt} = 0$ and $\frac{dy}{dt} = 0$ is called an equilibrium state and the point that meets this is called the equilibrium point (Ihsan et al., 2021).

Analysis of the stability of the equilibrium point is carried out using the Jacobi matrix. Determining the stability of the equilibrium point is obtained by looking at the eigenvalues, namely λi with $i = 1,2,3,...,n$ which is obtained from $\det(\lambda I - A) = 0$ where I is the identity matrix. In general, it can be concluded that the stability of the equilibrium point has two behaviors, namely:

1. Stable if
    a. Every eigenvalue has negative real part. Re ($\lambda i < 0$) for all i.
    b. The real component of each complex eigenvalue is negative ($Re(\lambda_i) < 0$) for all i.
2. Unstable if
    a. Every eigenvalue has positive real part Re($\lambda i > 0$) for all i.
    b. The real component of each complex eigenvalue is positive ($Re(\lambda_i) > 0$) for all i.

Basic Reproduction Number

The basic reproduction number (R_0) is a number that indicates susceptible individuals who can suffer from a disease caused by one infected individual. This number is needed as a reference to determine the level of spread of a disease. The basic reproduction number is obtained by determining the eigenvalues of the Jacobian matrix of a system of equations (model) calculated around the disease-free equilibrium point. (Side et al., 2016). Three conditions will arise, namely:

1. If $R_0 < 1$, then the disease will disappear.
2. If $R_0 = 1$, then the disease will persist.
3. If $R_0 > 1$, then the disease will escalate into an epidemic.

3. Result and Discussion

3.1. Formation of The SEIR Model

In forming the SEIR model, several assumptions were used, namely:

a. The population is open, where in the population there is a change in population size caused by birth and death.
b. There is the transmission of susceptible individuals (S) and infected individuals (I)
c. Every individual born is in the Susceptible (S) group
d. There are births and deaths in the population
e. If the Susceptible (S) group shows symptoms, they will be classified into the Exposed (E) group.
f. If the Exposed (E) group is infected it will enter the Infected (I) group
g. Infected Group (I) can infect other individuals
h. Infected individuals (I) who recover are included in the Recovered (R) group
i. Death can occur in groups S, E, I, and R
j. In the exposed (E) and infected (I) groups, there were deaths due to disease
k. Individuals who have recovered will not develop the disease

The SEIR model diagram for the spread of malaria can be seen in Figure 2.

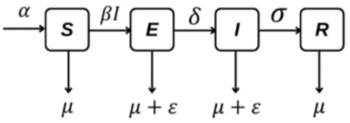

Figure 2. The SEIR model diagram

The SEIR model diagram can be transformed into a mathematical model of differential equations shown in equation (4).

$$\begin{aligned}\frac{dS}{dt} &= \alpha - (\beta I + \mu)S,\\ \frac{dE}{dt} &= \beta SI - (\delta + \mu + \varepsilon)E,\\ \frac{dI}{dt} &= \delta E - (\sigma + \mu + \varepsilon)I,\\ \frac{dR}{dt} &= \sigma I - \mu R.\end{aligned} \tag{4}$$

The variables and parameters used in the SEIR model are presented in Table 1.

Table 1. Variable and Parameter in The SEIR Model.

Variabel	**Keterangan**
S	Number of vulnerable individuals
E	Number of symptomatic individuals
I	Number of infected individuals
R	Number of individuals recovered
α	Birth rate
β	Rate of susceptible individuals (S) to latent (E)
δ	The rate at which individuals become infected
σ	The individuals's rate of recovery
μ	Natural death rate
ε	Rate of death due to disease

3.2. SEIR Model Analysis

Equilibrium Point

The equilibrium point in the SEIR model will occur at time

$$\left(\frac{dS}{dt},\frac{dE}{dt},\frac{dI}{dt},\frac{dR}{dt}\right) = (0{,}0{,}0{,}0)$$

There are 2 types of equilibrium points, namely

1. Disease-free equilibrium point
2. Endemic equilibrium point

The disease-free equilibrium point is obtained by assuming I = 0, the disease-free equilibrium point is obtained E_0 = (S,E,I,R) = $(\frac{\alpha}{\mu}, 0,0,0)$.

For the endemic equilibrium point E_1 = (S, E, I, R) where

$$S = \frac{(\delta+\mu+\varepsilon)}{\beta S}$$

$$E = \frac{\beta\alpha\delta - \mu(\delta+\mu+\varepsilon)(\delta+\mu+\varepsilon)}{\beta\delta(\delta+\mu+\varepsilon)}$$

$$I = \frac{\beta\alpha\delta - \mu(\delta+\mu+\varepsilon)(\sigma+\mu+\varepsilon)}{\beta(\delta+\mu+\varepsilon)(\sigma+\mu+\varepsilon)}$$

$$R = \frac{\sigma\beta\alpha\delta - \sigma\mu(\delta+\mu+\varepsilon)(\sigma+\mu+\varepsilon)}{\beta\mu(\delta+\mu+\varepsilon)(\sigma+\mu+\varepsilon)}$$

Equilibrium Point Stability Analysis

The stability of the equilibrium point is obtained by linearizing equation 4.

So we get the Jacobian matrix for disease-free equilibrium (E_0).

To determine the stability of E_0 by finding the eigenvalues of the JE_0 matrix using the formula, $|JE_0 - \lambda I| = 0$,

By using the Sarrus method, eigenvalues are obtained $\lambda_1 = -\mu$, $\lambda_2 = -(\delta+\mu+\varepsilon)$, $\lambda_3 = -(\sigma+\mu+\varepsilon)$, $\lambda_4 = -\mu$ where all eigenvalues are negative so that the disease-free equilibrium point is stable.

Basic Reproduction Number

The basic reproduction number determines the stability of the spread of disease or a limit for disease occurrence. To find the R_0 value, use the new generation matrix method which is based on variables E and I and calculated at the disease-free equilibrium point. then it is obtained R_0

$$R_0 = \frac{\alpha\beta\delta}{\mu(\delta+\mu+\varepsilon)(\sigma+\mu+\varepsilon)} \tag{5}$$

3.3. Model Simulation

The initial values obtained are in Table 2.

Table 2 – The initial values

Variable	**Value**
S	15.900
E	6.022
I	9.623
R	129

The simulation uses the parameter values in Table 3.

Table 3 – The parameter values in The SEIR Model

Variable	**Values**
α	0,015
β	0,909
δ	0,021
σ	0,976
μ	0,0004
ε	0,023

The parameter values that have been obtained are then substituted into equation (5), and the value $R_0 = 0.031764 < 1$ is obtained, which means that one individual infected with malaria does not cause other individuals to become infected with malaria.

SEIR model simulations for parameters are presented in Figure 3, Figure 4, Figure 5, and Figure 6.

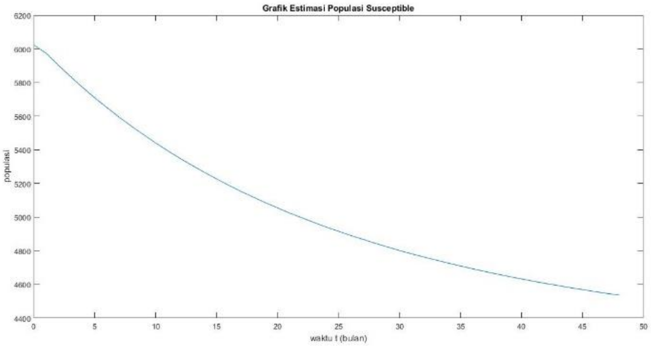

Figure 3. Graphic Estimate of The Spread of Malaria in Susceptible Populations

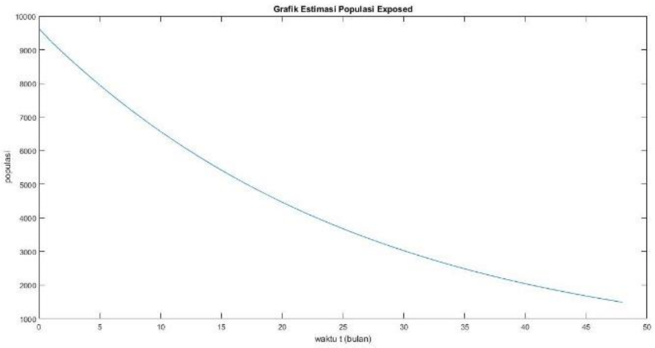

Figure 4. Graphic Estimate of The Spread of Malaria in Exposed Populations

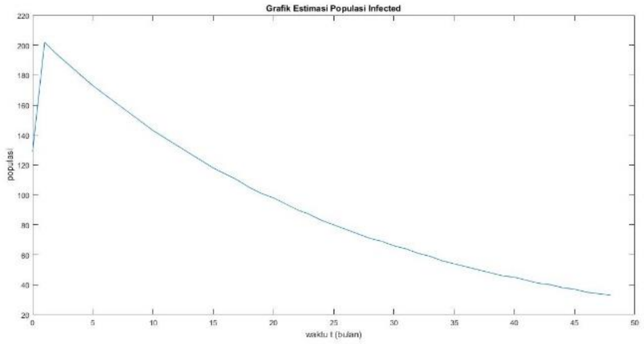

Figure 5. Graphic Estimate of The Spread of Malaria in Infected Populations

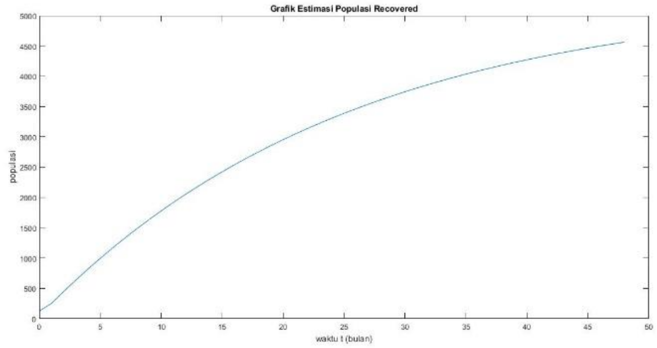

Figure 6. Graphic Estimate of The Spread of Malaria in Recovered Populations

The model simulation in Figure 3 shows that the susceptible population decreased from month 0 to month 48. As in Figure 4, the exposed population was 9,623 people in month 0, but in this condition, the population decreased drastically per month. Furthermore, in Figure 5, for the infected population, there were 129 people in the 0th month, but in this condition, the number of infected people increased to 202 people in the 1st month and then decreased drastically per month along with a decrease in the exposed population. For individuals who recovered, it can be seen in Figure 6, it increased from month 0 to month 48.

4. Conclusions and Recommendations

4.1. Conclusions

Based on the research results, the conclusions obtained are as follows.

1. Establishment of a SEIR model for the spread malaria based on the assumptions made and the SEIR model diagram.

$$\frac{dS}{dt} = \alpha - (\beta I + \mu)S$$
$$\frac{dE}{dt} = \beta SI - (\delta + \mu + \varepsilon)E$$
$$\frac{dI}{dt} = \delta E - (\sigma + \mu + \varepsilon)I$$
$$\frac{dR}{dt} = \sigma I - \mu R$$

2. Analysis of the basic reproduction number in the spread of malaria shows that $R_0 = 0.031764$, which means that one individual infected with malaria does not cause other individuals to become infected with malaria.
3. The results of the SEIR model simulation on the spread of malaria showed that the susceptible population decreased from the 0th month to the 48th month. As for the exposed population, there were 9,623 people in the 0th month, but in this condition, the population decreased drastically per month. Furthermore, for the infected population there were 129 people in month 0, but in this condition the number of infected people increased to 202 people in the 1st month and then decreased drastically per month along with the decrease in the exposed population. For individuals who recovered, there was an increase from the 1st month. 0 until the 48th month.

4.2. Recommendations

Based on the research results, the suggestions obtained are as follows.

1. Can be a source of information and references regarding the application of mathematics, namely analytical methods and other sciences used for other research.
2. It is hoped that it can help provide input for the government to take action to prevent and reduce the spread of malaria infection.

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