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Mathematical Model of Dengue Disease Transmissior Considering the incubation Period Both Intrinsic and Ext

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Abstract: *Dengue fever is an infectious disease in tropical regions, where its spread is trai Aedesaegypti mosquito. Modeling the spread of dengue disease will facilitate in understanding the the spread of disease in a population. There have been several mathematical models of the spread o. this paper will be modified a model that considering the incubation period. At its transmission in h and mosquitoes, viruses undergo an incubation period before the virus can move from mosquitoes and vice versa humans to mosquitoes. In this paper will discuss the transmission of dengue m involving the incubation of virus in humans it called Intrinsic Incubation Period and model inv incubation period in humans and in mosquitoes. The virus incubation period in mosquitos it call Incubation Period. The fixed points were determined on this paper on both models, there were two namely free disease fixed point and endemic fixed point. Stability analysis performed on both . numerical approach also performed. It was found that model with intrinsic incubation oscillates stable value, and model with the effect of intrinsic and extrinsic incubation oscillates cyclically.*
Keywords: *dengue fever, incubation, mathematical model, SIR model, stability*

I. Introduction

Dengue fever has been existing in Australia, Europe, Asia, South America and Africa sir century. Dengue virus is transmitted by the bite of Aedesaegypti mosquito as the main factor. M transmission of dengue disease will facilitate in understanding the dynamics of the transmission of population. There have been several models that have been made by several researchers [1], [2], [3].

In this study, will be assessed a model that refers to the study of Pongsumpun [1], a mod related to the intrinsic incubation period, as well as a combination of intrinsic and extrinsic incub were considering in this paper.

Extrinsic incubation period is the period in which the start time of the entry of gameto mosquito's body to the stage where virus entered into the salivary glands, or in other words the peri virus could be transmitted by mosquitoes.

Intrinsic incubation period is the time in which the virus is present in the human body unti to transmit to mosquito.

II. Mathematical Model

The human population is divided into three classes, namely susceptible human (S_H), infe (I_H), and recovered human (R_H). Susceptible humans are human that not immune and have not be Infected humans are human that already infected and can transmit the virus to mosquito thro Recovered humans were considered obtained immunity, thus no recovered human could get infected

Mosquitos populations divided into two classes, namely susceptible mosquitoes (S_V), a mosquitoes (I_V). Susceptible mosquitoes are susceptible to dengue fever. Infected mosquito is m could infect virus in to other individuals. It was assumed that human and mosquito population size that the birth rate equals the death rate. average individual mosquito bites on humans per day is c mosquitoes were never recovered after becoming infected.

The following are the parameters that exist in the model: $N_T$is total human population mosquito population, $\alpha$is human birth rate, b is average of mosquito bites on humans, $\zeta_H$is probabili virus transmitted from mosquitoes to humans, $\zeta_H$is probability of dengue virus transmitted from mosquitoes, $\delta_H$is a natural human death rate, r is rate of recovered of infected humans, D is rate of of mosquitoes, $\delta_V$is natural mortality rate of mosquitoes.

In this work, the model developed by Pongsumpun [1] was used as the standard model as (1). Further, this model was modified also by Pongsumpun [1] by taking into account the effect of t extrinsic incubation period as expressed in (2).

$$\frac{d}{dt}S^H = \alpha N_T - \frac{b\zeta_h}{N_T}S^H I^V - \delta_H S^H$$

$$\frac{d}{dt}R^H = rI^H - \delta_h R^H \qquad (1)$$

$$\frac{d}{dt}S^V = D - \frac{b\zeta_V}{N_T}S^V I^h - \delta_V S^V$$

$$\frac{d}{dt}I^V = \frac{b\zeta_V}{N_T}S^V I^H - \delta_V I^V$$

and

$$\frac{d}{dt}S^H = \alpha N_T - \frac{b\zeta_H}{N_T}S^H(1-c)I^V - \delta_H S^H$$

$$\frac{d}{dt}I^H = \frac{b\zeta_H}{N_T}S^H(1-c)I^V - (\delta_h + r)I^H$$

$$\frac{d}{dt}R^H = rI^H - \delta_H R^H \qquad (2)$$

$$\frac{d}{dt}S^V = D - \frac{b\zeta_V}{N_T}S^V I^H - \delta_V S^V$$

$$\frac{d}{dt}I^V = \frac{b\zeta_V}{N_T}S^V I^H - \delta_V I^V$$

2.1. Mathematical Model Considering Intrinsic Incubation

This model is a modification the model (1), considering the intrinsic incubation pe percentage of infected humans but incapable of transmitting the disease. This is known incubation. Thus, *(1-z)* is the proportion of infected human that can transmit virus to mosquitc equation (1) would result the following equation

$$\frac{d}{dt}S^H = \alpha N_T - \frac{b\zeta_h}{N_T}S^H I^V - \delta_H S^H$$

$$\frac{d}{dt}I^H = \frac{b\zeta_h}{N_T}S^H I^V - (\delta_H + r)I^H$$

$$\frac{d}{dt}R^H = rI^H - \delta_H R^H \qquad (3)$$

$$\frac{d}{dt}S^V = D - \frac{b\zeta_V}{N_T}S^V(1-z)I^H - \delta_v S^V$$

$$\frac{d}{dt}I^V = \frac{b\zeta_V}{N_T}S^V(1-z)I^H - \delta_V I^V$$

given:

$N_T = S^H + I^H + R^H$ and $N_V = S^V + I^V$

To simplify the equation (3), it is assumed

$S_H = \frac{S^H}{N_T},\ I_H = \frac{I^H}{N_T},\ R = \frac{R^H}{N_T},\ S_V = \frac{S^V}{N_V},\ I_V = \frac{I^V}{N_V}$, and $N_V = \frac{D}{\delta_V}$(4)

and obtains

$$\frac{dS_H}{dt} = \alpha - \gamma_h S_H I_V - \delta_H S_H$$

$$\frac{dI_H}{dt} = \gamma_H S_H I_V - (\delta_H + r)I_H \qquad (5)$$

$$\frac{dI_V}{dt} = \gamma_V'(1 - I_V)I_H - \delta_V I_V$$

where $\gamma_V' = b\zeta_V'$ with $\zeta_V' = \zeta_V(1-z)$, and $\gamma_H = b\zeta_H n$ with $n = \frac{D/\delta_V}{N_T}$.

2.2. Mathematical Model Considering Intrinsic And Extrinsic Incubation

In this model both intrinsic and extrinsic incubation effect were considered. The syst equations obtained are:

$$\frac{d}{dt}S^H = \alpha N_T - \frac{b\zeta_H}{N_T}(1-c)S^H I^V - \delta_H S^H$$

$$\frac{d}{dt}I^H = \frac{b\zeta_H}{N_T}(1-c)S^H I^V - (\delta_H + r)I^H$$

$$\frac{d}{dt}R^H = rI^H - \delta_H R^H \qquad (6)$$

$$\frac{d}{dt}I^V = \frac{b\zeta_V}{N_T}S^V(1-z)I^H - \delta_V I^V$$

The system equations in (6) were simplified by using equations (4), and results equation's:

$$\frac{dS_H}{dt} = \alpha - \gamma_H S_H I_H - \delta_H S_H$$

$$\frac{dI_H}{dt} = \gamma_H' S_H I_V - (\delta_H + r)I_H \qquad (7)$$

$$\frac{dI_V}{dt} = \gamma_V(1 - I_V)I_H - \delta_V I_V$$

where $\gamma_V' = b\zeta_V'$ with $\zeta_V' = \zeta_V(1-z)$, and $\gamma_H' = b\zeta_H n$ with $n = \frac{D/\delta_V}{N_T}$.

III. Results

3.1. Analytical Results

The fixed point of the system of differential equations (5) and (7) were obtained by setti $\frac{dI_H}{dt} = 0$ and $\frac{dI_V}{dt} = 0$, and produced two types of fixed point, Disease-free equilibrium (DFE) and t fixed point.

3.1.1. The intrinsic Incubation Effect

The fixed points i.e, for the model with intrinsic incubation were denoted as $P^0(S_H, I_H, I_V)$: and the endemic fixed point $P^*(S_H^*, I_H^*, I_V^*)$ with

$$S_H^* = \frac{\delta_H b\zeta_V' + \delta_V(\delta_H + r)}{b^2\zeta_H\zeta_V' n + \delta_H b\zeta_V'}$$

$$I_H^* = \frac{\delta_h b^2\zeta_h\zeta_v' n - \delta_h\delta_v(\delta_h + r)}{b^2\zeta_h\zeta_v' n(\delta_h + r) + \delta_h b\zeta_v'(\delta_h + r)} \qquad (8)$$

$$I_V^* = \frac{\delta_H b^2\zeta_H\zeta_V' n - \delta_H\delta_V(\delta_H + r)}{\delta_H b^2\zeta_H\zeta_V' n + \delta_V b\zeta_H n(\delta_H + r)}$$

to simplify it suppose $\zeta = \frac{b\zeta_V'}{\delta_V}$, $L = \frac{\delta_H + r}{\delta_H}$, $A^0 = \frac{b^2\zeta_H\zeta_V' n}{\delta_V(\delta_H + r)}$, thus

$$S_H^* = \frac{L+\zeta}{\zeta + LA^0} I_H^* = \frac{A^0 - 1}{\zeta + LA^0} I_V^* = \frac{\zeta(A^0 - 1)}{A^0(\zeta + L)} \qquad (9)$$

The fixed point $P^0(1,0,0)$ we obtain Jacobi matrix J_{P^0} which was determined using $\det(J_{P^0} - \lambda$ obtain

$$\lambda_1 = -\delta_H,\ \lambda_{2,3} = -q \pm \sqrt{q^2 - 4zk}$$

with

$q = r + \delta_H + \delta_V$, $z = \delta_V(r + \delta_H)$, $k = 1 - A^0$, $\gamma_H = b\zeta_H n$, $\gamma_V' = b\zeta_V'$.

The eigenvalues λ_2 and λ_3 characterize the behavior of the system around the point P^0. All eigenva negative if $A^0 < 1$, it means that the $P^0(1,0,0)$ will stable if $A^0 < 1$.

The fixed point $P^*(S_H^*, I_H^*, I_V^*)$ we obtain Jacobi matrix J_{P^*} which was determined usin ***λI=0.*** The characteristic equation for ***JP**** is

$$P(\lambda) = \lambda^3 + v_0\lambda^2 + v_1\lambda + v_2$$

with

$$v_0 = \delta_H\left(\frac{\zeta + LA^0}{\zeta + L}\right) + \delta_H L + \delta_V A^0\left(\frac{\zeta + L}{\zeta + LA^0}\right)$$

$$v_1 = \delta_H^2 L\left(\frac{\zeta + LA^0}{\zeta + L}\right) + \delta_V\delta_H A^0 + (A^0 - 1)\left(\frac{\delta_V\delta_H\zeta L}{\zeta + LA^0}\right)$$

$$v_2 = \delta_V\delta_H^2 L(A^0 - 1)$$

The eigenvalues of equation (11) is not easy to determine, therefore, the stability around the $P^*(S_H^*, I_H^*, I_V^*)$ will be investigated using the *Routh-Hurwitz criteria*.

Based on the *Routh-Hurwitz* criteria, the fixed point $P^*(S_H^*, I_H^*, I_V^*)$ will be stable if and only if th requirements are met:

$v_0 > 0$, and $v_1 > 0$, and $v_0 v_1 > v_2$

Based on the condition above, if $A^0 > 1$ we obtain $v_0 > 0$, and $v_1 > 0$, and $v_0 v_1 > v_2$. *Hurwitz* criteria are met. The fixed point $P^*(S_H^*, I_H^*, I_V^*)$ stable if $A^0 > 1$, in which further $\sqrt{A^0} = R_0$

[5].

3.1.2. The Intrinsic And Extrinsic Incubation Effects

The fixed points i.e. for the model with intrinsic and extrinsic incubation were $P^0(S_H, I_H, I_V) = P^0(1,0,0)$ and the endemic fixed point $P^*(S_H^*, I_H^*, I_V^*)$ with

$$S_H^* = \frac{\delta_H b\zeta_V + \delta_V(\delta_H + r)}{b^2\zeta_H\zeta_V n + \delta_H b\zeta_V}$$

$$I_H^* = \frac{\delta_H b^2\zeta_H\zeta_V n - \delta_H\delta_V(\delta_H + r)}{b^2\zeta_H\zeta_V n(\delta_H + r) + \delta_H b\zeta_V(\delta_H + r)} \quad (12)$$

$$I_V^* = \frac{\delta_H b^2\zeta_H\zeta_V n - \delta_H\delta_V(\delta_H + r)}{\delta_H b^2\zeta_H\zeta_V n + \delta_V b\zeta_H n(\delta_H + r)}$$

to simplify it suppose $\zeta = \frac{b\zeta_V}{\delta_V}$, $L = \frac{\delta_H + r}{\delta_H}$, $A^1 = \frac{b^2\zeta_H\zeta_V n}{\delta_V(\delta_H + r)}$, thus

$S_H^* = \frac{L+\zeta}{\zeta + LA^1}\, I_H^* = \frac{A^1 - 1}{\zeta + LA^1}\, I_V^* = \frac{\zeta(A^1 - 1)}{A^1(\zeta + L)}$ (13)

The fixed point $P^0(1,0,0)$ we obtain Jacobi matrix J_{P^0} which was determined using (0, and obtain

$$\lambda_1 = -\delta_h,\ \lambda_{2,3} = -q \pm \sqrt{q^2 - 4zk}$$

with

$q = r + \delta_H + \delta_V$, $z = \delta_V(r + \delta_H)$, $k = 1 - A^1$, γ_H =b$\zeta_H n$, $\gamma_V = b\zeta_V$.

The eigenvalues λ_2 and λ_3 characterize the behavior of the system around the point P^0. will be negative if $A^1 < 1$, it means that the $P^0(1,0,0)$ will stable if $A^1 < 1$.

The fixed point $P^*(S_H^*, I_H^*, I_V^*)$ we obtain Jacobi matrix J_{P^*} which was determined **λI=0.** The characteristic equation for ***JP****** is

$$P(\lambda) = \lambda^3 + v_0\lambda^2 + v_1\lambda$$

with

$$v_0 = \delta_H\left(\frac{\zeta + LA^1}{\zeta + L}\right) + \delta_H L + \delta_V A^1\left(\frac{\zeta + L}{\zeta + LA^1}\right)$$

$$v_1 = \delta_H^2 L\left(\frac{\zeta + LA^1}{\zeta + L}\right) + \delta_V\delta_H A^1 + (A^1 - 1)\left(\frac{\delta_V\delta_H\zeta L}{\zeta + LA^1}\right)$$

$$v_2 = \delta_V\delta_H^2 L(A^1 - 1)$$

The eigenvalues of equation (15) is not easy to determine, therefore, the stability aroun $P^*(S_H^*, I_H^*, I_V^*)$ will be investigated using the *Routh-Hurwitz criteria.*

Based on the *Routh-Hurwitz* criteria, the fixed point $P^*(S_H^*, I_H^*, I_V^*)$ will be stable if and only requirements are met:

$v_0 > 0$, and$v_1 > 0$, and$v_0 v_1 > v_2$

Based on the condition above, if $A^1 > 1$ we obtain $v_0 > 0$, and $v_1 > 0$, and $v_0 v_1 > e$ *Hurwitz* criteria are met. The fixed point $P^*(S_H^*, I_H^*, I_V^*)$ stable if $A^1 > 1$, in which further $\sqrt{A^1}$ = as *the basic reproduction number* indicating the expectation number of infected human during tl [5].

3.2. Numerical Results

Simulations performed because the system difficult to observe directly, from simulatio learned things that could happen in population dynamics based on models. Simulation refers to s above. The value of the parameters:

$\alpha_H = 0.0000391, \alpha_V = 0.071, \delta_H = 0.0000391,\ \delta_V = 0.071,\ \zeta_H = 0.5,\ \zeta_{VI} = 0.7$, b = 0.6, r z = 0.3 .

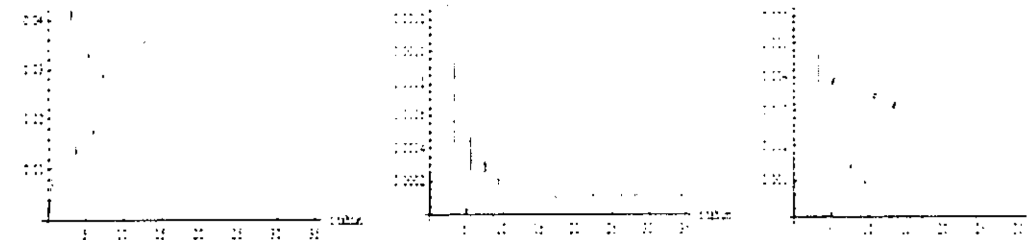

Figure 1 The proportion of susceptible humans (S_H), infected humans (I_H), and infected mosquitoes with intrinsic incubation.

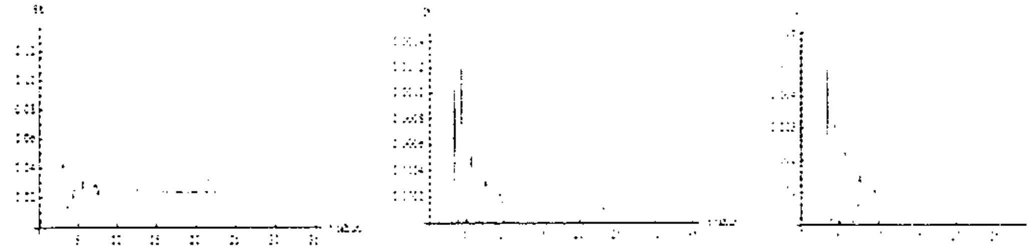

Figure 2 The proportion of susceptible humans (S_H), infected humans (I_H), and infected mosquitoes with intrinsic incubation, with a different value of z and other parameters remain.

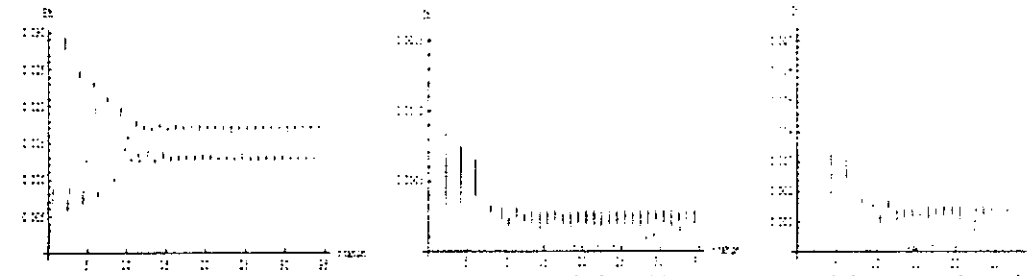

Figure 3 The proportion of susceptible humans (S_H), infected humans (I_H), and the proportion of mosquitoes (I_V) model with intrinsic and extrinsic incubation.

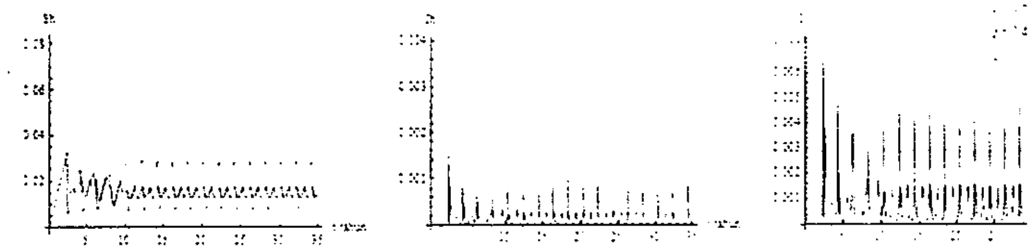

Figure 4 The proportion of susceptible humans (S_H), infected humans (I_H), and infected mosquitoes with intrinsic and extrinsic incubation with a different value of z and ε with values of other paramet

IV. Conclusion

In general, the resulting model can indicate the presence in an endemic area for certai values. We obtained two fixed points, namely the free disease fixed point and endemic fixed pc model.

Analytical results show that the number of each subpopulation human and mosquito reacl condition around the free disease fixed point with condition $R_0 < 1$ and stable around endemic fixe condition$R_0 > 1$.

Fig 1 and fig 3 shows that a model with intrinsic incubation oscillates towards a stable model with the effect of extrinsic and intrinsic incubation period oscillates cyclically.

(z) caused an increase in the proportion of susceptible humans (S_H), decrease in proportion of i (I_H) and infected mosquitoes (I_V), and time towards stable more slower.

Fig 4 shows that changes value of z and ε gives a different oscillation behavior in tl susceptible humans (S_H), infected humans (I_H), and infected mosquitoes (I_V).

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