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The Effect of Social Media for a Zika Virus Transmission with Beddington DeAngelis Incidence Rate: Modeling and Analysis

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Abstract. This paper discuss a modified mathematical model of Zika virus transmission and analyzes the impact of the awareness programs on social media the modification of of Zika Virus model with saturated incidence rate. The Beddington-De Angelis functional responses used to describe the interaction between a suspected human and an infected human. The dynamics of the model were analyzed by identifying the disease-free (DFE) and endemic equilibrium (END). Next Generation Matrix (NGM) was used to determine the Basic Reproduction Number. The stability of DFE and END were analyzed locally by computing the determinant of Jacobian. The DFE was identified as locally stable when the basic reproduction number was less than unity; and was identified as unstable otherwise. Meanwhile, the END was identified as existents when the basic reproduction number was greater than unity. The Routh-Hurwitz Criterion showed that the END was locally stable under a specific condition. A sensitivity analysis was also computed to determine the most influential parameter value of the model. In the end, the stability of DFE and END were also identified numerically depending on certain parameter values.

Keywords: *Zika Virus, dynamics, social media, reproduction number, Next Generation Matrix, Beddington-De Angelis, saturated incidence rate*
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INTRODUCTION

Zika virus is mostly transmited through a bite from an Aides aegypti mosquito during the day or night. Zika is also spread through a sexual contact between an infected human and an uninfected human. In some cases, Zika is also passed on by pregnant women to her fetus which, causes birth defect. No vaccine has been found to prevent Zika virus [1]. Based on [2], preventing Zika can be done by using insecticide-treated bed nets and mosquito repellent using condom and prohibiting pregnant women to travel to area with Zika outbreak [1].

Recently, most people change their mode of communication from face-to-face into online communication. Social media is one of the best forms of technology that responds to people's needs to communicate and share information online. Some common social media are Facebook, Twitter, Youtube, Whatsapp, and Instagram can be accessed easily by using smart phones and cellular applications [3].

In a disease's epidemiology, social media has an important role to inform the disease's outbreak. Social media and TV advertising is one method to prevent transmission. Misra [4] has made a mathematical model to see the impact of TV advertising and social media on the dynamics of infectious diseases. There are vulnerable populations that are vulnerable to infection as well as populations that often access information through social media. The Zika virus transmission can be informed through social media, then people can take preventive measures. Zika virus outbreak is expected to be controlled or does not spread into outer territory. The mathematical model of social media impact for the epidemiological disease has been researched by some authors. In 2014, the effects of media for influenza epidemic was discussed [5]. The SEIR model was constructed by including the media function. The

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function $f(I, p)$ was determined to reduce the transmission. In 2018, a mathematical model of Zika virus transmission has been constructed and developed [6] [7]. In this paper, we study the impact of awareness programs on social media. The new parameter m, which becomes the basis of the exponential will be analyzed. We consider some of the trigger factors and preventive actions which are explained in a saturated model using Beddington DeAngelis incident rate.

RESULT

Mathematical Model

Let $(S_h, I_h, R_h, S_v, I_v)$ is the solution of the system, with positive initial value. N_h and N_v are the total population of human and mosquitoes respectively, whereas $N_h = S_h + I_h + R_h$ and $N_v = S_v + I_v$. We assume all parameter and variables are positives. Then the solution of system are in the following :

$$\left\{\Omega = (S_h, I_h, R_h, S_v, I_v) \in {R_+}^5; N_h \leq \frac{\Lambda_h}{\mu_h}, N_v \leq \frac{\Lambda_v}{\mu_v}\right\}. \tag{1}$$

The derivation respect to time of the total population of the model model1 are :
d $N_h \frac{}{dt=\Lambda_h-\mu_h N_h.}$ The solution of $\frac{dN_h}{dt} + \mu_h N_h = \Lambda_h$ is $\frac{\Lambda_h}{\mu_h} - Ce^{\mu_h t}$. If $N_h \leq \frac{\Lambda_h}{\mu_h}$, then $\frac{\Lambda_h}{\mu_h} \geq 0$. If $N_h > \frac{\Lambda_h}{\mu_h}$, then $\frac{\Lambda_h}{\mu_h} < 0$. Then choose the initial value as follows :

1. $N_h(0) = 0$, then the solution is $N_h(t) = \frac{\Lambda_h}{\mu_h}(1 - e^{\mu_h t})$,
2. $N_h(0) = \frac{\Lambda_h}{\mu_h}$, the solution is $N_h(t) = \frac{\Lambda_h}{\mu_h}$,
3. $N_h(0) > 0$, the solution is $N_h(t) = \frac{\Lambda_h}{\mu_h}(1 - e^{\mu_h t}) + N_h(0)e^{\mu_h t}$.

The total population of humans and mosquitoes are in the following : $0 \leq N_h(t) \leq N_h(t) = \frac{\Lambda_h}{\mu_h}(1 - e^{\mu_h t}) + N_h(0)e^{\mu_h t}$, and $0 \leq N_v(t) \leq N_v(t) = \frac{\Lambda_v}{\mu_v}(1 - e^{\mu_v t}) + N_v(0)e^{\mu_v t}$.

In particular : $N_h(t) \leq \frac{\Lambda_h}{\mu_h}, N_v(t) \leq \frac{\Lambda_v}{\mu_v} when N_h(0) \leq \frac{\Lambda_h}{\mu_h}, N_v(0) \leq \frac{\Lambda_v}{\mu_v}$.

Then the area $\left\{\Omega = (S_h, I_h, R_h, S_v, I_v) \in {R_+}^5; N_h \leq \frac{\Lambda_h}{\mu_h}, N_v \leq \frac{\Lambda_v}{\mu_v}\right\}$ is bounded.

Mathematical Analysis

Let the right hand equation of the system by zero. The equilibrium points of the system are disease free equilibrium (DFE) and endemic equilibrium (END).

The disease free equilibrium of the system is

$$DFE = ({N_h}^0, {I_h}^0, {R_h}^0, {N_v}^0, {I_v}^0) = \left(\frac{\Lambda_h}{\mu_h}, 0, 0, \frac{\Lambda_v}{\mu_v}, 0\right). \tag{2}$$

The DFE is always exists.

Basic reproduction ratio is represent the natural compartmented for disease transmission model, established by the system of ordinary differential equation. In this work, the basic reproduction ration compute by NGM as follows.

$$F = \begin{pmatrix} \frac{\beta_1 {N_h}^0}{1 + \alpha_1 {N_h}^0} & \frac{\beta_2 {N_h}^0}{1 + \alpha_3 {N_h}^0} \\ \beta_3 {N_v}^0 & 0 \end{pmatrix}, \quad V = \begin{pmatrix} \gamma + \mu_h & 0 \\ 0 & \mu_v \end{pmatrix}. \tag{3}$$

F is the jacobian of infection matrix with respect to DFE, and V the jacobian matrix which decrease the infection.

$$V^{-1} = \begin{pmatrix} \frac{1}{\gamma + \mu_h} & 0 \\ 0 & \frac{1}{\mu_v} \end{pmatrix}, \quad F.V^{-1} = \begin{pmatrix} \frac{\beta_1 {N_h}^0}{(1 + \alpha_1 {N_h}^0)(\gamma + \mu_h)} & \frac{\beta_2 {N_h}^0}{(1 + \alpha_3 {N_h}^0)\mu_v} \\ \frac{\beta_3 {N_v}^0}{(\gamma + \mu_h)} & 0 \end{pmatrix}. \tag{4}$$

Furthermore, the basic reproduction number is the largest number of eigenvalues of $F.V^{-1}$.

$$R_0 = \frac{R_{01} + \sqrt{R_{01}^2 + 4R_{02}}}{2}; \tag{5}$$

where,
$R_{01} = \beta_1 P_1$,
$R_{02} = \beta_2 \beta_3 P_1 P_2 \frac{N_v}{N_h}$.

Lemma 1 The disease-free equilibrium (DFE) of the system is locally asymptotically stable when $R_0 < 1$, otherwise it is unstable.

The endemic equilibrium of the system is

$$END = (S_h^*, I_h^*, R_h^*, S_v^*, I_v^*). \tag{6}$$

Lemma 2 The endemic equilibrium (END) of the system is exist if $R_0 > 1$ and $\alpha_1 \delta - (\beta_1 e^{-mI_h + \alpha_2} \mu_h) > 0$.

The numerical result used to verify the mathematical analysis. For the purpose of simulation, we choose some parameter value which is satisfy the qualification condition. The following table are provide the parameter description and the parameter value which is used in the numerical simulation.

The sensitivity analysis was performed to determine the relative importance of model parameters of disease transmission. Let choose the parameter value, $\mu_v = 0.0714, \mu_h = 0.00004215, \Lambda_h = 10, \Lambda_v = 20, \beta_1 = 0.001, \beta_2 = 0.02, \beta 3 = 0.01, \alpha_1 = 0.8, \alpha_3 = 0.7, \gamma = 0.1428$. Based on normalization sensitivity index of R_0 and mathematical computation, we have the following result (Table 1).

TABLE 1. Table of sensitivity index for each parameter of the system

Parameter	**Sensitivity Index**	**Interpretation (Increasing or decreasing)**	**Rank**
Λ_h	0.000003021849159	Λ_h by 10%, R_0 by 0.00003%	6
μ_h	-0.00015129107	μ_h by 10%, R_0 by 0.015%	5
α_1	-0.004939244191	α_1 by 10%, R_0 by 0.49%	4
α_2	0	α_2 by 10%, R_0 by 0%	7
α_3	-0.4975273692	α_3 by 10%, R_0 by 49%	3
β_1	0.0049392702	β_1 by 10%, R_0 by 0.49%	4
β_2	0.4975303648	β_2 by 10%, R_0 by 49%	3
β_3	0.4975303648	β_3 by 10%, R_0 by 49%	3
γ	-0.5355979617	γ by 10%, R_0 by 53%	2
Λ_v	0.4975303648	Λ_v by 10%, R_0 by 49%	3
μ_v	-0.9950607298	μ_v by 10%, R_0 by 99%	1

According to Table.1, we can conclude that the reproductive number is most sensitive to μ_v (per capita recovery rate of the infective population) and least sensitive is α_2.

CONCLUSION

To see the effects of social media on the transmission of Zika virus, mathematical models using systems with five nonlinear differential equations were constructed. The boundedness problem is analyzed by ordinary mathematical calculations, and it is proven that the system is bounded. Two types of equilibrium points, namely disease-free and endemic were found with certain existing conditions. The basic reproduction numbers were obtained by using the Next Generation Matrix (NGM), then it became the basis for the conditions of stability and the existence of equilibrium points. Dynamic analysis has been carried out by using supporting theorems such as Descartes and Routh-Hurwitz criteria. Based on the results of the dynamic analysis, local disease-free equilibrium points are obtained when the basic reproduction number was less than unity. Conversely, endemic equilibrium points exist and locally stable when the basic reproduction number is more than unity and certain parameter requirements are satisfied. We also did a sensitivity analysis to see which parameters were the most influential. Based on the results of the analysis, in this matter, the most influential parameter was the death rate og mosquitoes (μ_v), so to reduce the Zika outbreak, eradicating mosquitoes is essential. This can be done by fogging, or 3 M (burying used goods, draining tubs and puddles, closing water storage). The parameter m played an indirect role, namely by reducing the rate of transmission between susceptible humans and infected mosquitoes. This will be shown in the case study presented in the discussion. Numerical simulations of the dynamic behavior of equilibrium points were also presented to complement the analytical results. So it can be concluded that social media have an effect on reducing the spread of the Zika virus.

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