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Analysis of a Zika Virus Disease Model with treatment and Vector Control.

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Abstract

In this work, a system of nonlinear ordinary differential equations is used to present a structured compartmental-based deterministic model for zika virus disease. The model incorporates treatment and vector control using sterile-insect technology. The analysis of the model by Jacobian linearization and Castillo-Chavez invariant region approach shows that the zika-free equilibrium (ZFE) point is both locally and globally asymptotically stable when the control reproduction number, R_z is less than one, and unstable otherwise. The global stability of the ZFE is a confirmation that there exists a unique endemic equilibrium point in the system and the absence of backward bifurcation in the model. Plots are presented to show the dynamics of the disease under the controls considered. The results showed that using sterile insect technique is an effective way of controlling the disease. It also shows that treatment does not reduce the spread of the disease significantly due to the high possibility of asymptomatic cases. Human contact rate with mosquitoes and occurence of asymptomatic cases were shown to increase the endemicity of the disease. In conclusion, the work suggests that while employing SIT helps to reduce and control the spread of the disease, efforts should also be made to ensure that human contact with mosquitoes is eliminated.

Keywords: Zika virus, sterile-insect technology stability analysis, asymptomatic occurrence.
2020 Mathematics Subject Classification: 93A30, 34B60, 34D20, 34D23.

1 Introduction

Zika virus disease is a *flavivirus disease* caused by the zika virus, and transmitted to humans through the bites of an infectious Aedes aegypti mosquito (Lamwong and Pongsumpun, 2018; Anyanwu et al. 2020). It is also passed to humans through sex, blood transfusion and during pregnancy. Newborns infected by the disease during pregnancy can suffer congenital abnormalities of the brain such as microcephaly and the Guillain-Barre syndrome (Lormeau and Guillain, 2016; Anyanwu et al. 2020; Biswas, 2024). This is one of the reasons the disease is of great concern. Further details

of the epidemiology of the disease can be found in the following articles (WHO, 2016; Lamwong and Pongsumpun, 2018; Gonzalez-Parra and Benincasa, 2019; Rakkiyappan et al., 2019; CDC, 2022; WHO, 2022). Recently, there have been many works on mathematical modelling of zika virus disease transmission. Some authors such as (Atokolo and Mbah, 2020; Agudelo and Ventresca, 2022; Alfwzan et al., 2023; Ibrahim and Denes, 2023; Dotia et al., 2024; Wang et al., 2024) developed their models using nonlinear ordinary differential equations while some authors like (Rezapour et al., 2020; Helikumi et al., 2024; Kouidere et al., 2024) used fractional-order approach to model the disease. (Aldila et al., 2021; Ibrahim and Denes, 2023) incorporated symptomatic and asymptomatic cases but not use of sterile insect technique. Optimal control analysis was explored by the following authors (Falowo et al., 2022; Helikumi et al., 2024; Kouidere et al., 2024; Odeh et al., 2024).
In this work, a transmission model of the disease presented in Duru et al. (2025) is further discussed. The model incorporates treatment and use of sterile insect technology as control measures. It also highlights the cases of asymptomatic occurrence and mosquito contact rate with humans and their effects. The sterile insect technology, (SIT) is one of the ways targeted at controlling the population of mosquitoes where sterile males are introduced into the wild to mate with the females (Dyck et al., 2021). For more on use of sterile insect technique and where it has been applied, see (UN FAO (1997); UN FAO (2014); Atokolo and Mbah, 2020;). Unlike in Duru et al. (2025) where the numerical solution of the model was provided, this work offers more analysis of the reproduction number to understand the impact of asymptomatic occurence and human contact rate with mosquitoes. It also provides further numerical simulations to understand the effects of the proposed controls. The work is organized in the following way; the model is presented in section 2 and shown to be well-posed epidemiologically. The zika-free equilibrium (ZFE) and the control reproduction number for the system was also obtained in this section. In section 3, the local and global stability of the ZFE was discussed while in section 4, we looked at the existence of endemic equilibrium while sensitivity analysis of parameters of the zika reproduction number was performed in section 5. In section 6, numerical simulations were carried out and the work was concluded in section 7.

2 Materials and Methods

A new mathematical model for the zika virus disease with ten (10) compartments made up of the human and mosquito populations is presented. The human population is divided into six (6) compartments; Susceptible humans S_h, Exposed humans E_{hz}, Symptomatic infectious humans I_{hzS}, Asymptomatic infectious humans I_{hzA}, Infectious humans undergoing treatment I_{hzT}, and Recovered humans R_h. The female Aedes mosquito population is subdivided into three (3) compartments; Susceptible mosquitoes S_{zv}, Exposed mosquitoes E_{zv}, Infectious Mosquitoes I_{zv} while the SIT mosquito population, I_{SIT} completes the system. The goal of this research is to propose using sterile insect technique to control the population of Aedes mosquitoes and consequently reduce the spread of zika virus disease. Also, the study aims to highlight the health burdens associated with occurrence of asymptomatic cases in zika transmission dynamics as well as the place of treatment in

controlling the disease.The disease dynamics has been explained in details in Duru et al. (2025).

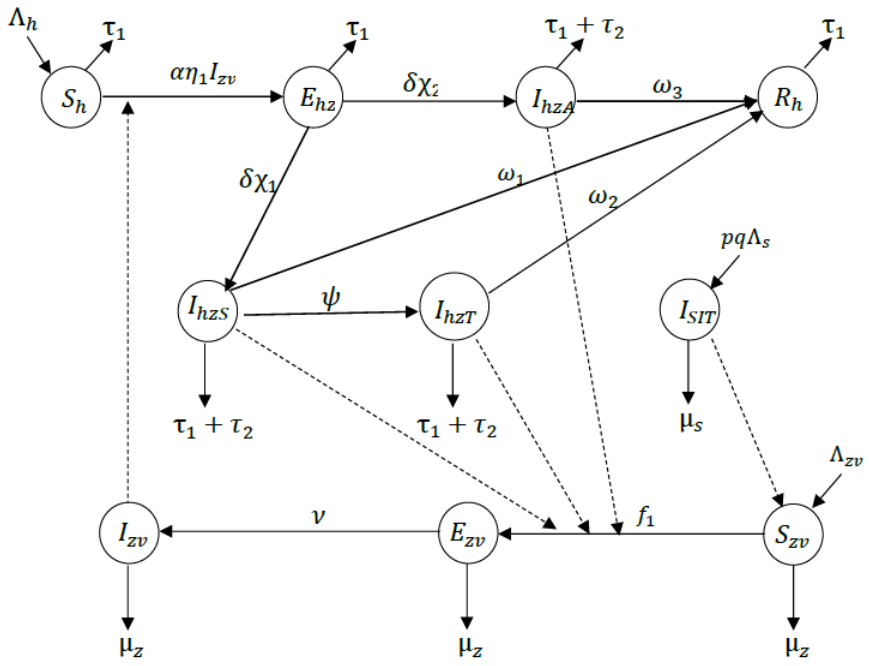


Figure 1: Flow diagram for the disease transmission

The model for the system is giving by the following system of nonlinear ordinary differential equation;

$$
\begin{aligned}
\frac{dS_h}{dt} &= \Lambda_h - (\alpha\eta_1 I_{zv} + \tau_1)S_h, \\
\frac{dE_{hz}}{dt} &= \alpha\eta_1 I_{zv} S_h - ((\chi_1 + \chi_2)\delta + \tau_1)E_{hz}, \\
\frac{dI_{hzS}}{dt} &= \delta\chi_1 E_{hz} - (\tau_1 + \tau_2 + \psi + \omega_1)I_{hzS}, \\
\frac{dI_{hzA}}{dt} &= \delta\chi_2 E_{hz} - (\tau_1 + \tau_2 + \omega_3)I_{hzA}, \\
\frac{dI_{hzT}}{dt} &= \psi I_{hzS} - (\tau_1 + \tau_2 + \omega_2)I_{hzT}, \\
\frac{dR_h}{dt} &= \omega_1 I_{hzS} + \omega_2 I_{hzT} + \omega_3 I_{hzA} - \tau_1 R_h, \\
\frac{dS_{zv}}{dt} &= \Lambda_{zv} - \alpha(\eta_2 I_{hzS} + \eta_3 I_{hzA} + \eta_4 I_{hzT})S_{zv} - (\kappa I_{SIT} + \mu_z)S_{zv}, \\
\frac{dE_{zv}}{dt} &= \alpha(\eta_2 I_{hzS} + \eta_3 I_{hzA} + \eta_4 I_{hzT})S_{zv} - (\nu + \mu_z)E_{zv},
\end{aligned}
\tag{1}
$$

$$\frac{dI_{zv}}{dt} = \nu E_{zv} - \mu_z I_{zv},$$
$$\frac{dI_{SIT}}{dt} = pq\Lambda_s - \mu_s I_{SIT},$$

where $S_h(0) = S_h^0, E_{hz}(0) = E_{hz}^0, I_{hzS}(0) = I_{hzS}^0, I_{hzA}(0) = I_{hzA}^0, I_{hzT}(0) = I_{hzT}^0, R_h(0) = R_h^0, S_{zv}(0) = S_{zv}^0, E_{zv}(0) = E_{zv}^0, I_{zv}(0) = I_{zv}^0, I_{SIT}(0) = I_{SIT}^0$ are the initial conditions for the system. The total human and mosquito population are respectively given by

$$N_h = S_h + E_{hz} + I_{hzS} + I_{hzA} + I_{hzT} + R_h$$

and

$$N_{zv} = S_{zv} + E_{zv} + I_{zv}.$$

The solution to the system exists in the region $\Omega = \Omega_1 \times \Omega_2 \times \Omega_3$ described by

$$\begin{aligned}
\Omega_1 &= \left\{ (S_h, E_{hz}, I_{hzS}, I_{hzA}, I_{hzT}, R_h) \in \mathbb{R}_+^6 : N_h \leq \frac{\Lambda}{\tau_1} \right\}, \\
\Omega_2 &= \left\{ (S_{zv}, E_{zv}, I_{zv}) \in \mathbb{R}_+^3 : N_{zv} \leq \frac{\Lambda}{\mu_z} \right\} \\
\Omega_3 &= \left\{ I_{SIT} \in \mathbb{R} : I_{SIT} \leq \frac{pq\Lambda_s}{\mu_s} \right\}.
\end{aligned} \tag{2}$$

respectively.

Table 1: Description of Parameters.

Parameters	Description	Values	Source
Λ_h	Rate of recruitment of humans	50	Assumed
Λ_{zv}	Rate of recruitment of Aedes mosquitoes	100	Assumed
Λ_s	Rate of recruitment of SIT mosquitoes	100	Assumed
α	Biting rate of mosquitoes with humans	0.4	Duru et al. (2024)
η_1	Probability of transmission from I_{zv} to S_h	0.0009	Lamwong and Pongsumpun (2018)
η_2	Probability of transmission from I_{hzS} to S_{zv}	0.07	Duru et al. (2024)
η_3	Probability of transmission from I_{hzA} to S_{zv}	0.07	Lamwong and Pongsumpun (2018)
η_4	Probability of transmission fromI_{hzT} to S_{zv}	0.05	Assumed
δ	Rate of development of infectiousness in E_{hz}	0.3333	Anyanwu et al. (2020)
ν	Rate of development of infectiousness in E_{zv}	0.1111	Anyanwu et al. (2020)
τ_1	Natural death rate of humans	0.00004	Gonzalez-Parra and Benincasa (2019)
τ_2	Death rate due to disease	0.0003	Assumed
μ_z	Natural death rate of mosquitoes	0.0556	Lamwong and Pongsumpun (2018)
μ_s	Natural death rate of SIT mosquitoes	0.0278	Assumed
χ_1	proportion of symptomatic humans	0.31	Duru et al. (2024)
χ_2	proportion of asymptomatic humans	0.62	Duru et al. (2024)
ω_1	Rate at which I_{hzS} recovers naturally	0.1429	Andayani et al. (2019)
ω_2	Rate at which I_{hzS} recovers from treatment	0.1667	Lamwong and Pongsumpun (2018)
ω_3	Rate at which asymptomatic humans recovers	0.118	Dantas et al. (2017);
κ	Mating rate of SIT mosquitoes with Aedes	0.5	Assumed
ψ	Rate at which I_{hzS} accepts trearment	0.85	Duru et al. (2024)
p	Proportion of I_{SIT} that joins the wild mosquitoes	0.7	Assumed
q	Mean mating competitiveness of I_{SIT}	0.5	Assumed

2.1 Positivity and boundedness of solutions

Lemma 1: Let the initial data set for the model be $\{S_h^0, E_{hz}^0, I_{hzS}^0, I_{hzA}^0, I_{hzT}^0, R_h^0, S_{zv}^0, E_{zv}^0, I_{zv}^0, I_{SIT}^0\}$ at $t = 0$. Then, the solution set $(S_h(t), E_{hz}(t), I_{hzS}(t), I_{hzA}(t), I_{hzT}(t), R_h(t), S_{zv}(t), E_{zv}(t), I_{zv}(t), I_{SIT}(t))$ of the model with the given initial data will remain positive for all time $t > 0$.

Proof. See (Duru et al., 2025).

Lemma 2: The region Ω is positively invariant and is an attractor of all positive solution to the system.

Proof. See (Duru et al., 2025).

Lemmas (1) and (2) guarantee that the system, (1) is mathematically and epidemiologically well-posed in the region Ω, hence can be studied and analyzed.

2.2 Zika-free equilibrium of the system

The zika-free equilibrium (ZFE) of the model is the steady state solution of (1) when there is no zika viral infection in the human and mosquito populations. If we denote the ZFE by E^0, then we have

$$E^0 = \left(\frac{\Lambda_h}{\tau_1}, 0, 0, 0, 0, 0, \frac{\Lambda_{zv}}{\mu_z}, 0, 0, 0\right).$$

2.3 The zika control number

The zika control number, R_z is defined as the average number of secondary infections that can be caused by one infectious index case introduced into an entirely susceptible population (Duru et al., 2024). It is a threshold parameter such that when it is less than one, the disease will be expected to die out and when it is greater than one, the disease will persist in the system (Van Den Driessche and Watmough2002). The method for obtaining the zika control number is defined by Diekmann et al., (2010). For our zika model, the infectious class corresponds to the state variables with the following differebtial equations;

$$\begin{aligned}
\frac{dE_{hz}}{dt} &= \alpha\eta_1 I_{zv} S_h - ((\chi_1 + \chi_2)\delta + \tau_1)E_{hz},\\
\frac{dI_{hzS}}{dt} &= \delta\chi_1 E_{hz} - (\tau_1 + \tau_2 + \psi + \omega_1)I_{hzS},\\
\frac{dI_{hzA}}{dt} &= \delta\chi_2 E_{hz} - (\tau_1 + \tau_2 + \omega_3)I_{hzA},\\
\frac{dI_{hzT}}{dt} &= \psi I_{hzS} - (\tau_1 + \tau_2 + \omega_2)I_{hzT},\\
\frac{dE_{zv}}{dt} &= \alpha(\eta_2 I_{hzS} + \eta_3 I_{hzA} + \eta_4 I_{hzT})S_{zv} - (\nu + \mu_z)E_{zv},\\
\frac{dI_{zv}}{dt} &= \nu E_{zv} - \mu_z I_{zv}.
\end{aligned}$$

Let $\mathcal{F}$ denote the rate of appearance of new infection in the system and $\mathcal{V}$ denote the movement into and out of the compartments by other means, then

$$\mathcal{F}=\begin{bmatrix} \alpha\eta_1 I_{zv}S_h \\ 0 \\ 0 \\ 0 \\ \alpha(\eta_2 I_{hzS}+\eta_3 I_{hzA}+\eta_4 I_{hzT})S_{zv} \\ 0 \end{bmatrix} \quad \text{and} \quad \mathcal{V}=\begin{bmatrix} ((\chi_1+\chi_2)\delta+\tau_1)E_{hz} \\ -\delta\chi_1 E_{hz}+(\tau_1+\tau_2+\psi+\omega_1)I_{hzS} \\ -\delta\chi_2 E_{hz}+(\tau_1+\tau_2+\omega_3)I_{hzA} \\ -\psi I_{hzS}+(\tau_1+\tau_2+\omega_2)I_{hzT} \\ (\nu+\mu_z)E_{zv} \\ -\nu E_{zv}+\mu_z I_{zv} \end{bmatrix}.$$

$$\text{Thus, } F=\frac{\partial\mathcal{F}}{\partial Y}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & C_1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & C_2 & C_3 & C_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \text{ and } V=\frac{\partial\mathcal{V}}{\partial Y}=\begin{bmatrix} D_1 & 0 & 0 & 0 & 0 & 0 \\ -\chi_1\delta & D_2 & 0 & 0 & 0 & 0 \\ -\chi_2\delta & 0 & D_3 & 0 & 0 & 0 \\ 0 & -\psi & 0 & D_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & D_5 & 0 \\ 0 & 0 & 0 & 0 & -\nu & \mu_z \end{bmatrix}$$

where $C_1=\frac{\alpha\eta_1\Lambda_h}{\tau_1}$, $C_2=\frac{\alpha\eta_2\Lambda_{zv}}{\mu_z}$, $C_3=\frac{\alpha\eta_3\Lambda_{zv}}{\mu_z}$, $C_4=\frac{\alpha\eta_4\Lambda_{zv}}{\mu_z}$, $D_1=(\chi_1+\chi_2)\delta+\tau_1$, $D_2=\tau_1+\tau_2+\psi+\omega_1, D_3=\tau_1+\tau_2+\omega_3$, $D_4=\tau_1+\tau_2+\omega_2$, $D_5=\nu+\mu_z$.

The zika control number which corresponds to the dominant eigenvalue of FV^{-1} denoted in this work by R_z is given by

$$R_z=\left(\frac{C_1\nu\delta(C_2\chi_1D_3D_4+C_3\chi_2D_2D_4+C_4\chi_1\psi D_3)}{\mu_z D_1D_2D_3D_4D_5}\right)\frac{1}{2}.$$

The first term in the summation is the total expected population of humans that will be infected at the zika-free equilibrium by one newly symptomatic infectious human before entering treatment, the second term is the total expected number of humans that will be infected at the ZFE by one newly asymptomatic infectious human while the third term is the total expected number of humans that will be infected at the ZFE by one newly infectious human whilst they are undergoing treatment for zika.

3 Stability of zika-free equilibrium point

3.1 Global stability of the zika-free equilibrium

The globally asymptotically stable (GAS) of the ZFE is investigated using the method in Castillo-Chavez and Song (2004).

Theorem 2. Consider the system of differential equations

$$\frac{dX}{dt}=F_1(X,0) \tag{3}$$

$$\frac{dY}{dt}=F_2(X,Y), F_2(X,0)=0 \tag{4}$$

where (3) is the system of differential equations, satisfied by non-diseased classes such that $X = (S_h, R_h, S_{zv}, I_{SIT})$ and (4) is the system of differential equations satisfied by the diseased classes so that $Y = (E_{hz}, I_{hzS}, I_{hzA}, I_{hzT}, E_{zv}, I_{zv})$. The ZFE, E^0 is GAS if (3) is GAS, and if in (4), $BX_2 - F_2(X, Y) \geq 0$, where B is the Jacobian matrix of $F_2(X, Y)$, evaluated at E^0.

Proof. From the system (1), F_1 and F_2 which represent the right-hand side of (3) and (4) respectively is given by

$$F_1 = \begin{pmatrix} \Lambda_h - (\alpha\eta_1 I_{zv} + \tau_1)S_h \\ \omega_1 I_{hzS} + \omega_2 I_{hzT} + \omega_3 I_{hzA} - \tau_1 R_h \\ \Lambda_{zv} - \alpha(\eta_2 I_{hzS} + \eta_3 I_{hzA} + \eta_4 I_{hzT} + \kappa I_{SIT} + \mu)S_{zv} \\ pq\Lambda_s - \mu_s I_{SIT} \end{pmatrix}$$

and

$$F_2 = \begin{pmatrix} \alpha\eta_1 I_{zv} S_h - ((\chi_1 + \chi_2)\delta + \tau_1)E_{hz} \\ \delta\chi_1 E_{hz} - (\tau_1 + \tau_2 + \psi + \omega_1)I_{hzS} \\ \delta\chi_2 E_{hz} - (\tau_1 + \tau_2 + \omega_3)I_{hzA} \\ \psi I_{hzS} - (\tau_1 + \tau_2 + \omega_2)I_{hzT} \\ \alpha(\eta_2 I_{hzS} + \eta_3 I_{hzA} + \eta_4 I_{hzT})S_{zv} - (\nu + \mu_z)E_{zv} \\ \nu E_{zv} - \mu_z I_{zv}. \end{pmatrix}$$

Solving the resulting equation of (3) at the ZFE gives

$$S_h = \frac{\Lambda_h}{\tau_1} + \left(S_h^0 - \frac{\Lambda_h}{\tau_1}\right)e^{-\tau_1 t}, \qquad R_h = R_h^0 e^{-\tau_1 t},$$
$$S_{zv} = \frac{\Lambda_{zv}}{\mu_z} + \left(S_{zv}^0 - \frac{\Lambda_{zv}}{\mu_z}\right)e^{-\mu_z t}, \quad I_{SIT}(t) = \frac{pq\Lambda_s}{\mu_s} + \left(I_{SIT}^0 - \frac{pq\Lambda_s}{\mu_s}\right)e^{-\mu_s t}$$

As $t \to \infty$ and $\Lambda_s = 0$ at the ZFE, we will have $S_h \to \frac{\Lambda_h}{\tau_1}$, $R_h \to 0$, $S_{zv} \to \frac{\Lambda_{mv}}{\mu_z}$ and $I_{SIT} \to 0$ respectively which corresponds to the values of these state variables at the ZFE. Also, the matrix B corresponds to the Jacobian submatrix J_1 given in section 2.4.

Hence,

$$BY - F_2(X, Y) = \begin{bmatrix} \alpha\eta_1\left(\frac{\Lambda_h}{\tau_1} - S_h\right)I_{zv} \\ 0 \\ 0 \\ 0 \\ \alpha\left(\frac{\Lambda_{zv}}{\mu_z} - S_{zv}\right)(\eta_2 I_{hzS} + \eta_3 I_{hzA} + \eta_4 I_{hzT}) \\ 0 \end{bmatrix}$$

It is obvious to see that $S_h(t) \leq \frac{\Lambda_h}{\tau_1}$ and $S_{zv}(t) \leq \frac{\Lambda_{zv}}{\mu_z}$. Hence, we are certain of non-negativity of all the rows in the matrix showing that $BX - F_2(X, Y) \geq 0$ is satisfied. Hence, the ZFE is globally asymptotically stable. This means that irrespective of the initial sizes of the infected population, having $R_z < 1$ is sufficient to eliminate zika virus disease from the system.

4 Results and Discussion

In this section, we perform simulation analysis on the zika model using the following assumed initial state values; $S_h = 500, E_{hz} = 110, I_{hzS} = 20, I_{hzA} = 40, I_{hzT} = 15, R_h = 10, S_{zv} = 1000, E_{mv} = 95, I_{mv} = 70, I_{SIT} = 300$ and the parameter values in Table 1.

4.1 Effect of SIT in the system

Here, we investigate how the application of sterile insect technique will affect the various population studied especially the Aedes mosquito population. The major target of SIT is to reduce the population of mosquitoes and thus reduce the rate of infection. The Figures 2-4 shows the effect of the sterile insect technique on the various population studied.

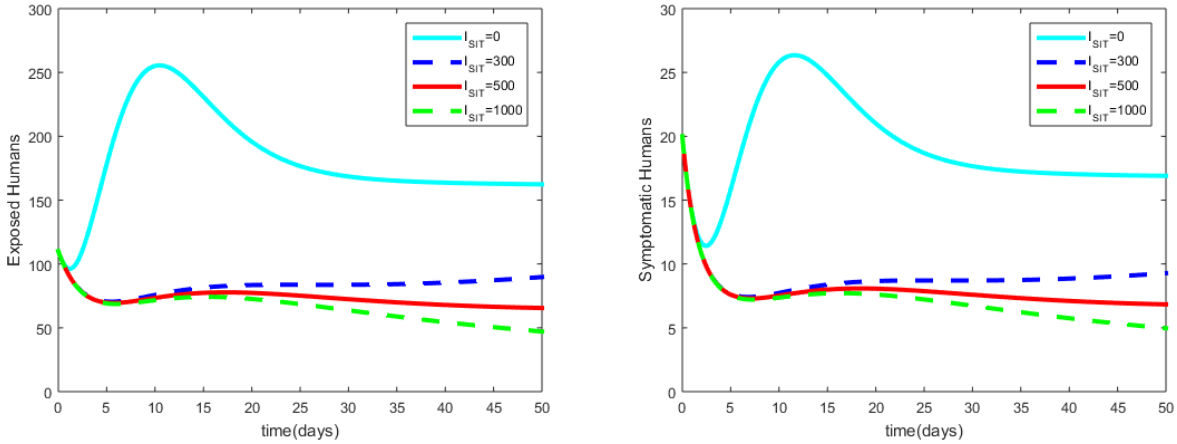


Figure 2: (i) Exposed Humans and (ii) Symptomatic Humans under SIT control

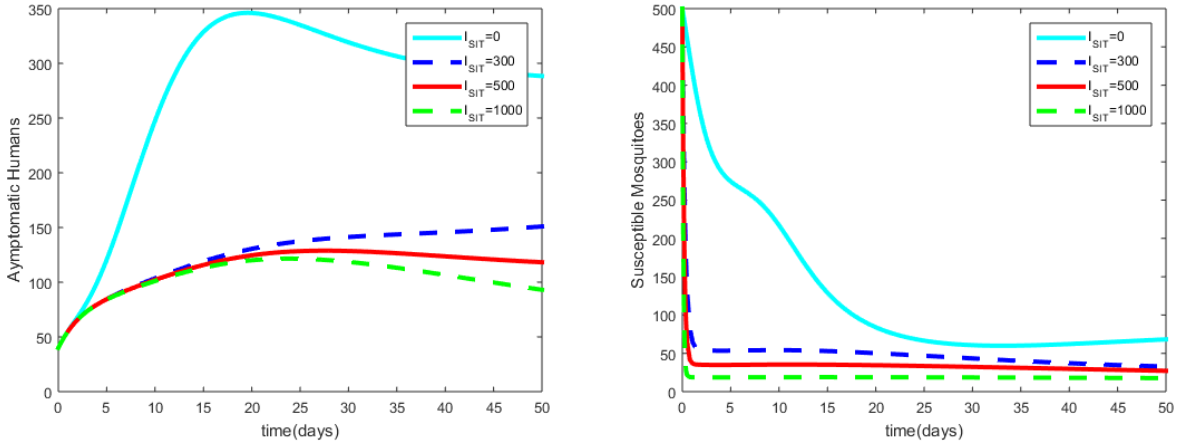


Figure 3: (i) Asymptomatic Human and (ii) Susceptible Mosquitoes under SIT control

The exposed humans shown in Figure 2i experiences a sharp decrease under SIT compared to when

there was no SIT. It is expected that sterile insect technique which reduces the number of Aedes mosquitoes will affect the exposed population as the number of mosquitoes which can cause the disease is reduced with time. Hence, the application of SIT has been shown to have great effect is reducing the spread of infection. The reduction in the exposed population consequently causes a reduction in the population of the symptomatic infectious humans shown in Figure 2ii when sterile insect technique is applied. As the number of exposed humans are reduced, expectedly the number of infectious humans will also reduce too. Similar scenario is obtained in the asymptomatic infectious humans in Figure 3i.

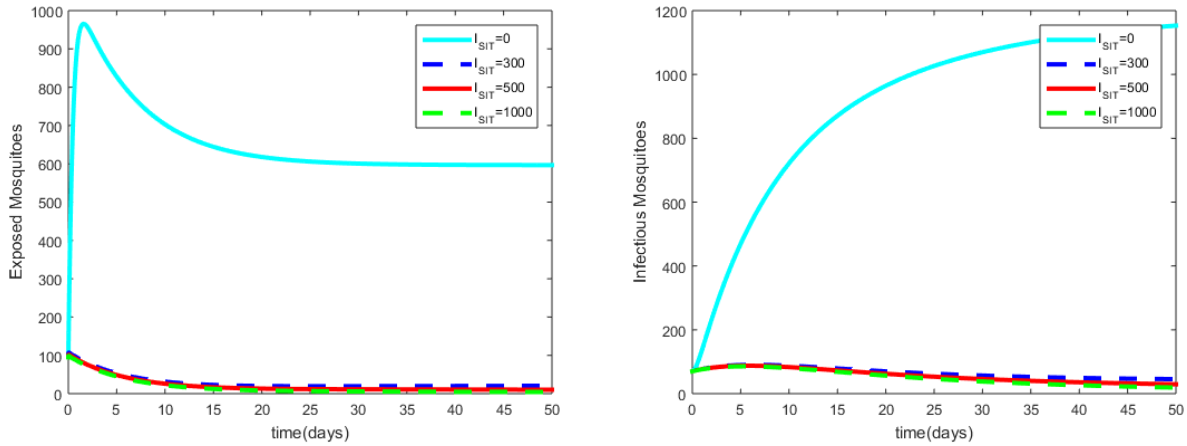


Figure 4: (i) Exposed Mosquitoes and (ii) Infectious Mosquitoes under SIT control

This reduction is because applying SIT reduces the number of mosquitoes and consequently reduces the infectious human population. The susceptible mosquitoes (Figure 3ii) shows that the more SIT mosquitoes are interacting with females in the target population, the population of the Aedes mosquitoes will continue to reduce and possibly eliminated from the environment. The interaction between the Aedes mosquitoes and the sterile insect mosquitoes leads to decay as it ensures that none of the Aedes mosquitoes mating with SIT mosquitoes contribute to the repopulation of the Aedes mosquitoes. The exposed mosquitoes shown in Figure 4i also experienced a sharp decrease in population due to sterile insect technique because more mosquitoes are not borne. The application of SIT ensures that every egg laid by the Aedes mosquitoes that mates with the sterile mosquitoes will not hatch. The infectious mosquitoes in Figure 4ii also reduce sharply with time which is also as a result of sterile insect technique. These reduction in the mosquito population signifies that with more sterile males circulating in the wild and mating with the Aedes mosquitoes, the population of the mosquitoes will be drastically reduced or wiped out thus leading to a reduction or elimination of zika virus from the population.

4.2 Effect of treatment in the system

Furthermore, we also looked at how treating infectious humans will affect the system and control of the disease using the same parameter values from Table 1. Figures 5-6 show the effect of treatment

on some of the compartments. The symptomatic humans in Figure 5ii which is where the treatment is primarily applied reduces sharply under treatment when compared to the no treatment scenario. We could also see that as the rate of treatment increases, the population of symptomatic humans reduces too.

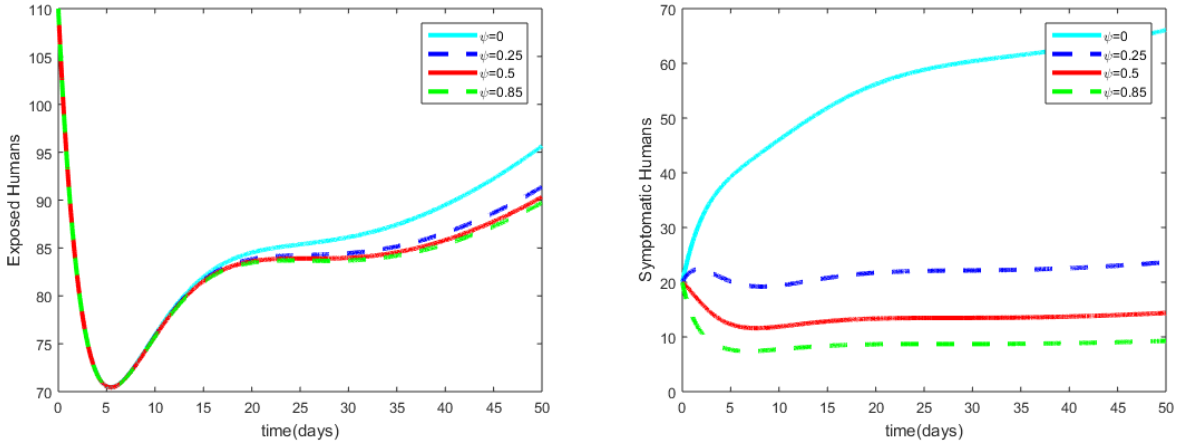


Figure 5: (i) Exposed Humans and (ii) symptomatic Humans

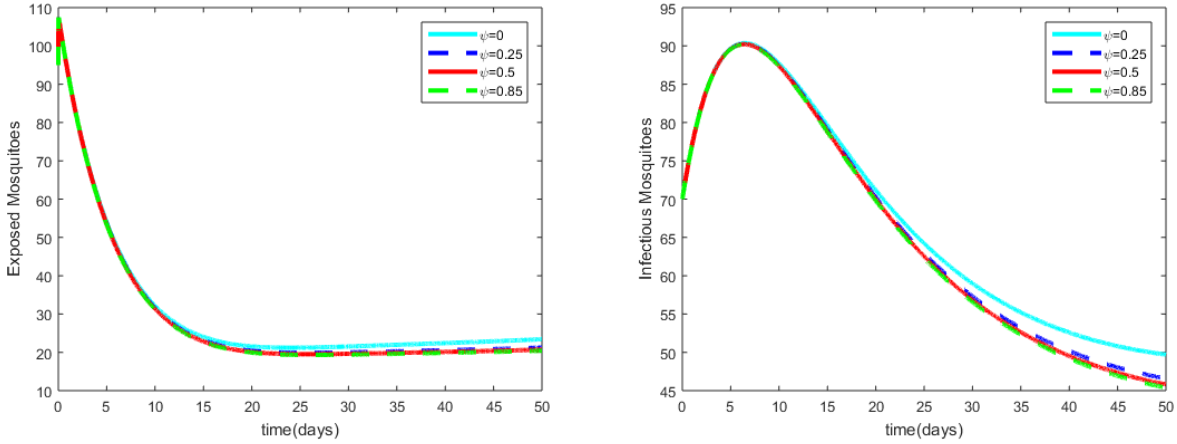


Figure 6: (i) Exposed Mosquitoes and (ii) infectious Mosquitoes

The exposed human population (Figure 5i), the exposed mosquito population (Figure 6i) and the infectious mosquito population (Figure 6ii) all experienced a slight decrease in population as more people are treated for zika. This is because treatment is only applied to the symptomatic humans while asymptomatic humans continues to significantly contribute to infection of both humans and the mosquitoes. Thus, treatment alone can reduce the spread of the disease but can not eradicate it as long as there are cases of asymptomatic humans who are infectious.

4.3 Effect of asymptomatic occurence on the system

The effect of the occurence of asymptomatic cases was also investigated using the values in Table 1. The results are shown in Figures 7-8. The results showed that an increase in the occurence of asymptomatic cases will lead to an increase in the number of exposed humans and mosquitoes to zika virus disease.

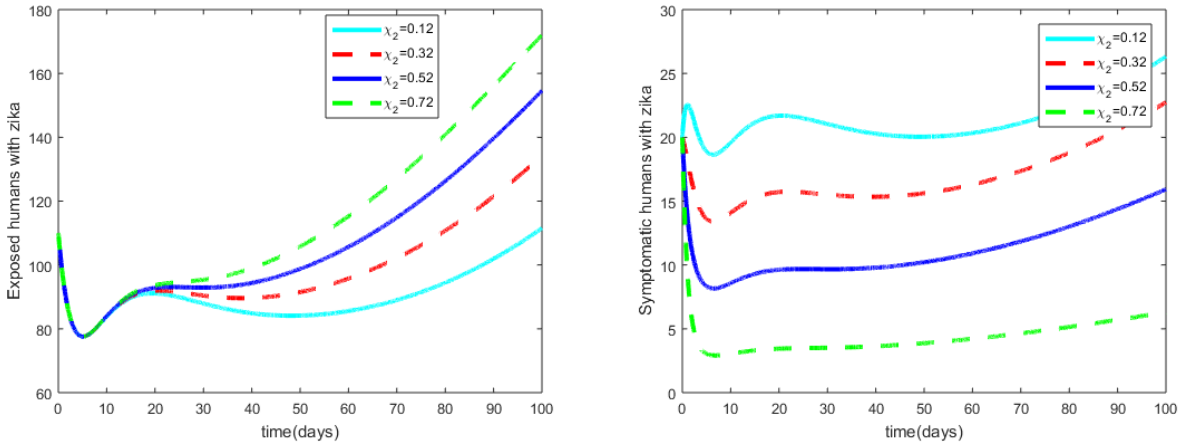


Figure 7: (i) exposed humans and (ii) symptomatic humans

This occurs because asymptomatic humans are not treated and can transfer the virus to mosquitoes unhindered. The more the mosquitoes are infected, the higher the probability of infecting more humans. Consequently, the number of infectious human and mosquitoes also increased due to the increase in the occurence of asymptomatic cases. The occurence of asymptomatic cases cannot be stopped or controlled as long as zika virus is in circulation. Hence, the best option is to apply measures that will eradicate zika virus disease from the system.

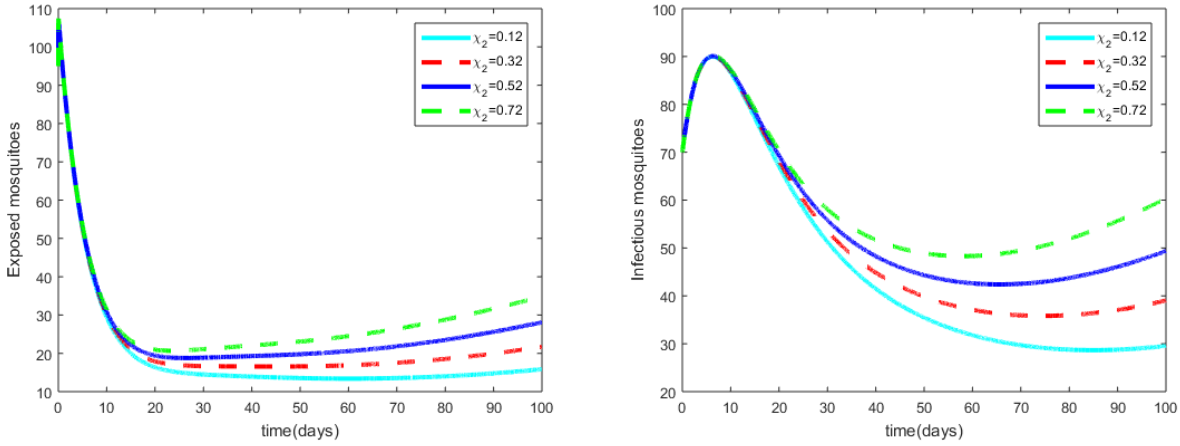


Figure 8: (i) exposed Mosquitoes and (ii) infectious Mosquitoes

4.4 Effect of mosquito contact with humans

The rate of contacts between humans and mosquitoes as shown in the sensitivity analysis affects the endemicity of the disease. This is shown in Figures 9-11 below. The graphs showed that the more mosquitoes come in contact with humans, the infectious classes experience an increase in population. The exposed human and mosquito population shown in Figures 9i and 10ii increases

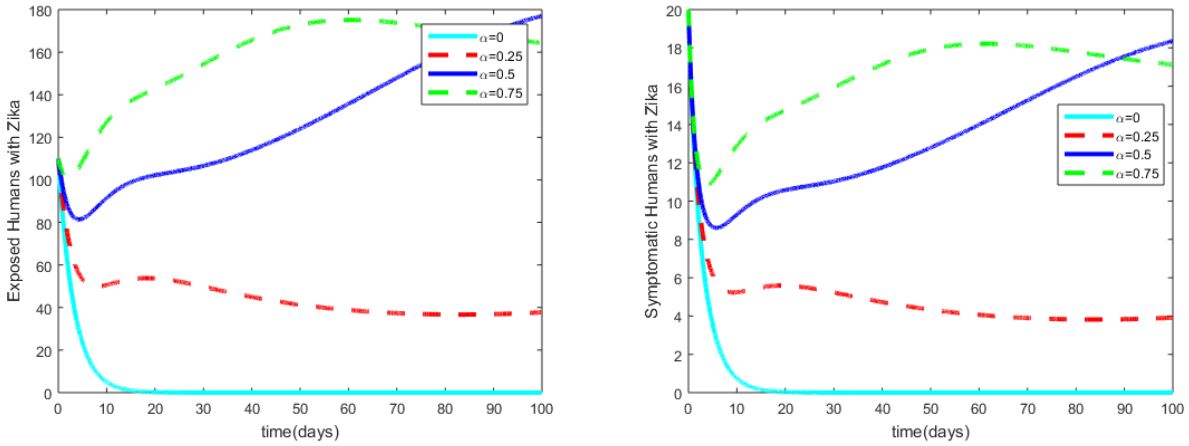


Figure 9: (i) exposed humans and (ii) symptomatic humans

as the probalities of infection increases as a result of increase in contact rate of mosquitoes with humans. Consequently, the symptomatic and asymptomatic human population shown in Figures 9ii and 10i also increases greatly as the rate of contact between mosquitoes and humans increases too. The dynamics of the infectious mosquitoes is shown in Figure 11 describing how an increase in the contact rate of mosquitoes with humans will lead to an increase in the number of infectious mosquitoes. This effect of the human contact rate with mosquitoes shows that zika virus can be effectively eradicated by taking up measures that will ensure that humans have less contact with mosquitoes. One of them is sterile insect technique proposed in this work.

5 Conclusion

A new mathematical model for the transmission of zika virus which incorporated treatment of infectious humans and sterile insect technique was studied in this work. The model was analyzed and the analyses showed that the zika-free equilibrium of the model is both locally and globally asymptotically stable when the control reproduction number, R_z is less than one and unstable otherwise. Plots were used to show the dynamics of the disease. The population of the Aedes mosquitoes was seen to be significantly reduced with SIT causing a reduction in the spread of zika virus with time. The effect of treatment was shown in the work and was seen to have little effect in controlling the disease since there are more occurence of asymptomatic cases which are not treated. Furthermore, we showed the effect of increase in the level of contact between humans

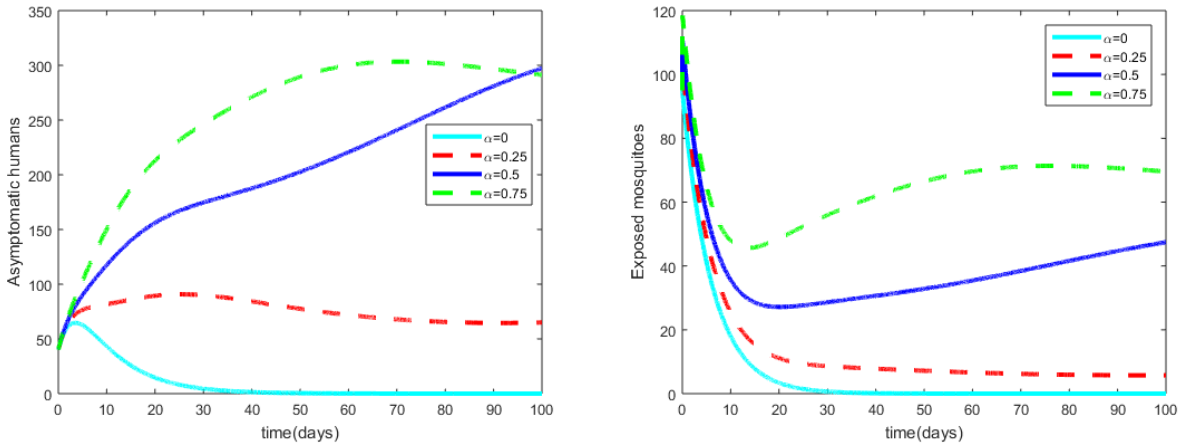


Figure 10: (i) asymptomatic humans and (ii) exposed Mosquitoes

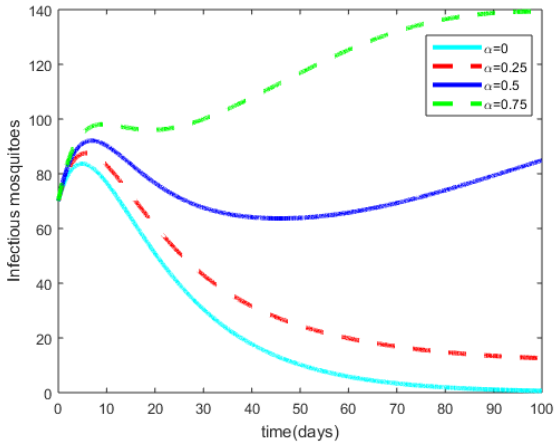


Figure 11: Infectious Mosquitoes

and mosquitoes. The effect of increase in the rate of asymptomatic cases was shown too. Since zika virus can be asymptomatic and causes severe health complications for newborns infected by their mothers, efforts should be made to reduce and control the spread of the disease. Conclusively, employing SIT and treatment will help to control the Aedes mosquito population as well as the spread of zika virus disease as shown in this work. Further research in this regard can investigate the possibility of combining physical and biological control measures as well as comparing them to ascertain their effectiveness

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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