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A Graphical Analysis of Mosquito Infection Model with Host and Vector Population

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Abstract: A mosquito infection model was formulated consisting of SIR (Susceptible-Infectious-Recovered) with exposed and carrier class for humans as host and SI (Susceptible-Infectious) with exposed class for mosquitoes as vector. Numerical simulations were carried out for the diseases Malaria, Dengue and Chikungunya. The graphs on susceptible, exposed, carrier, infectious and recovered were given for the different values of parameters involved in the model. The comparative graphical study was done on the state variables.

Keywords: Mosquitoes, Malaria, Dengue, Chikungunya, *Anopheles*, *Aedes aegypti*, Infection model

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Introduction

Mosquito is an insect which is common in the world. There are more than 3,500 types of mosquitoes worldwide. When a mosquito bites an infected person or animal, it gets infected. Those can spread germs by a bite to others. A mosquito pierces the skin to suck up blood and it inserts saliva in the skin. Our body gets a bump and itching because of a bite. Some have a mild reaction while most of them has more strong reaction.

A bite of an infected mosquito spreads the Mosquito-borne diseases such as Zika virus, West

Nile virus, Chikungunya virus, Dengue, and Malaria. Not everyone infected with a mosquito-borne germ gets sick, but mosquito-borne diseases can cause death in severe cases. We can prevent mosquito bites by using mosquito repellents on skin and clothing, in indoors using bed nets in sleeping areas that are not screened and working outdoors during day times, wear long-sleeved shirts and long pants.

Malaria, Dengue and Chikungunya are the predominant diseases caused by mosquitoes in India. Mathematical models are widely used for

the mosquito-borne diseases especially for these predominant diseases. Ngwa and Shu (2000) analysed the differential equation model for Malaria with human and mosquito populations. Dumont and Chiroleu (2010) proposed and analysed SEIR model with aquatic state for vector. Mandal *et al.* (2011) formulated a SEIR model for malaria and analysed for different period such as latent, incubation and symptomatic. Nita and Jyothi (2013) has analysed the vector borne diseases by SEIR model.

Guo *et al.* (2013) has proposed a dengue disease epidemic model with nonlinear incidence. Manore *et al.* (2014) compared the emergence and endemic transmission of Dengue and Chikungunya. Augusto *et al.* (2016) developed a new age- structured deterministic model for the transmission of Chikungunya. Bakary *et al.* (2017) formulated a mathematical model describing the Dynamics of Malaria with age structure for vector population.

Chanprasopchai *et al.*, (2018) has investigated the SIR model for dengue fever with effect of dengue vaccination. El-Moneam *et al.* (2019) has studied the dynamical behaviour of the mathematical model for dengue in the Jazan region. In this study we formulated a mosquito infection model consisting of SIR with exposed and carrier class for humans as host and SI with exposed class for mosquitoes as vector. We analysed and compared the diseases Malaria, Dengue and Chikungunya by numerical stimulation.

Formulation of Model:

The mosquito reinfection model is defined as the following ordinary differential equations--

$$\frac{dS_h}{dt} = \omega_h - \sigma_h S_h I_h - \mu_h S_h$$

$$\frac{dE_h}{dt} = \eta \sigma_h S_h I_h - \sigma_{h_1} E_h - \mu_h E_h$$

$$\frac{dI_h}{dt} = \sigma_{h_1} E_h + \sigma_{h_2} C_h - \gamma I_h - \mu_h I_h - dI_h$$

$$\frac{dC_h}{dt} = (1 - \eta) \beta_h S_h I_h - \sigma_{h_2} C_h - \delta C_h - \mu_h C_h \quad (1)$$

$$\frac{dR_h}{dt} = \gamma I_h + \delta C_h - \mu_h R_h$$

$$\frac{dS_v}{dt} = \omega_v - \sigma_v S_v I_v - \mu_v S_v$$

$$\frac{dE_v}{dt} = \sigma_v S_v I_v - \alpha_v E_v - \mu_v E_v$$

$$\frac{dI_v}{dt} = \alpha_v E_v - \mu_v I_v$$

The description of variables is given in the Table 1.

Here $N_h = S_h + E_h + I_h + C_h + R_h$, is the human population and $N_v = S_v + E_v + I_v$, is the mosquito population. Figure 1 shows the mosquito infection model.

The description of parameters is given in the Table 2.

Numerical Analysis:

Malaria:

Malaria is a life-threatening blood disease that is caused by a female *Anopheles* mosquito bite. After infection, the parasite multiplies in the liver and the red blood cells. Severe malaria produces fever, headache, vomiting and other flu-like symptoms. In India, malaria is reported annually from the eastern and central part and also, from states which have large forest, hilly and tribal areas.

Table 3 gives the data for India. The values given in Table 4 are taken from Nita and Jyothi (2013), Olaniyi and Obabiyi (2013) and Osman and Adu (2017).

Table 5 gives the assumed value of the parameters.

Figure 2 shows the flow of the variables of the host and the vector with respect to time. From Figure 3, it is clear that whenever the infection from mosquito to humans increases, the susceptible individuals of human decreases. Figure 4 clears that the individuals in exposed

Table 1: Description of Variables

Variables	Description	Variables	Description
S_h	Susceptible class of host	E_h	Exposed class of host
I_h	Infectious class of host	C_h	Carrier class of host
R_h	Recovered class of host	S_v	Susceptible class of vector
E_v	Exposed class of vector	I_v	Infectious class of vector

Table 2: Description of Parameters

Parameters	Description	Parameters	Description
ω_h	Average birth rate for humans	α_{h_1}	Exposed rate of humans from E_h
ω_v	Recruitment rate of mosquitoes	α_{h_2}	Exposed rate of humans from C_h
β_h	Infection rate in humans	α_v	Exposed rate of mosquitoes
β_v	Infectious rate of mosquitoes	γ	Recovery rate in humans
μ_h	Average death rate in humans	η	fraction who has symptoms
μ_v	Natural death rate for mosquitoes	θ	Mosquitoes bite rate
$\sigma_h = \frac{\beta_h}{\theta}$ [7]	Probability of infection from mosquitoes to humans	$\sigma_v = \frac{\beta_v}{\theta}$ [7]	Probability of infection from humans to mosquitoes
d	disease induced rate	δ	Immunity rate in humans

Table 3: Data of India

Parameter	Value	Parameter	Value
ω_h	0.0488	μ_h	0.0199
β_h	0.0025	d	0.00023

Table 4: Data from Reference papers

Parameter	Value	Parameter	Value	Parameter	Value
σ_h	0.0208	σ_v	0.24	α_v	0.083
β_v	0.0288	μ_v	0.05	θ	0.12

Table 5: Assumed data

Parameter	Value	Parameter	Value	Parameter	Value
ω_v	0.6	δ	0.2	γ	0.75
α_{h_1}	0.02	α_{h_2}	0.015	η	0.4

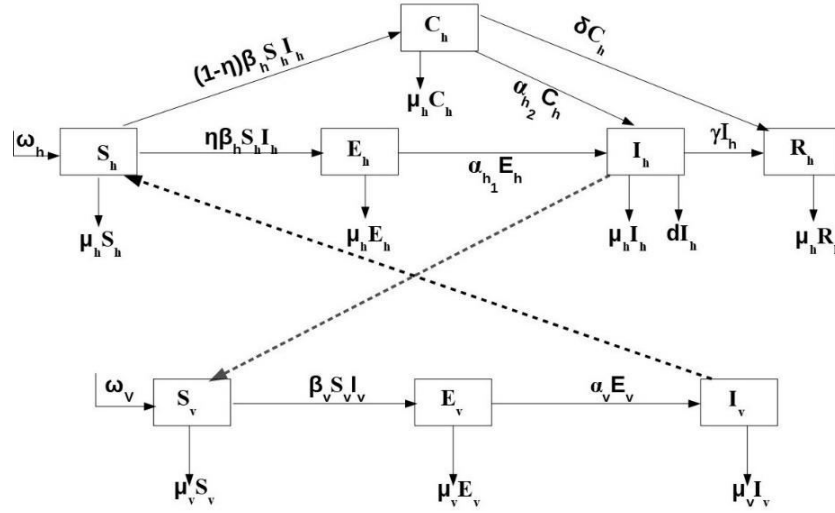


Fig. 1: Mosquito infection model: The infection between the host and the vector indicated by dotted lines.

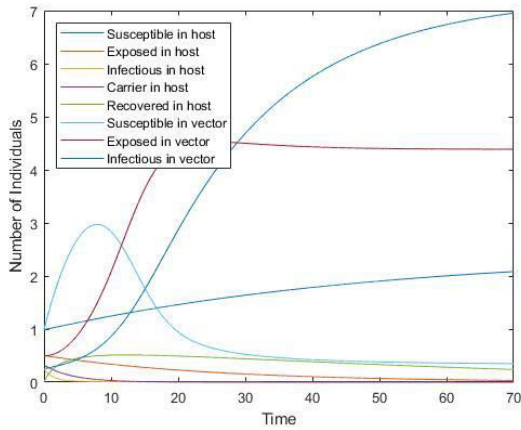


Fig. 2: Flow of variables with respect to time for Malaria.

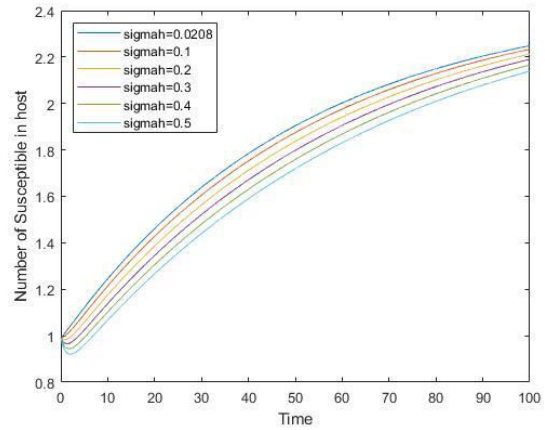


Fig. 3: Susceptible class of the host for different values of σ_h of Malaria.

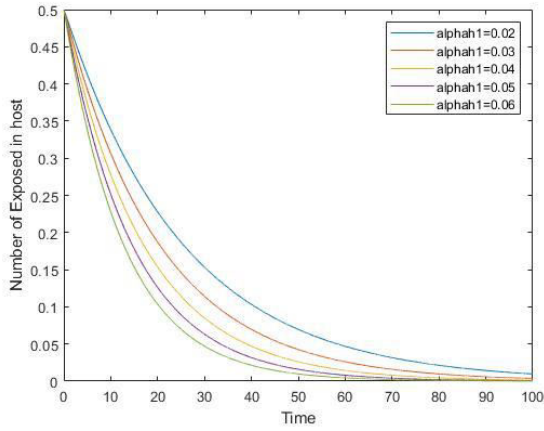


Fig. 4: Exposed class of the host for different values of α_{h_1} of Malaria.

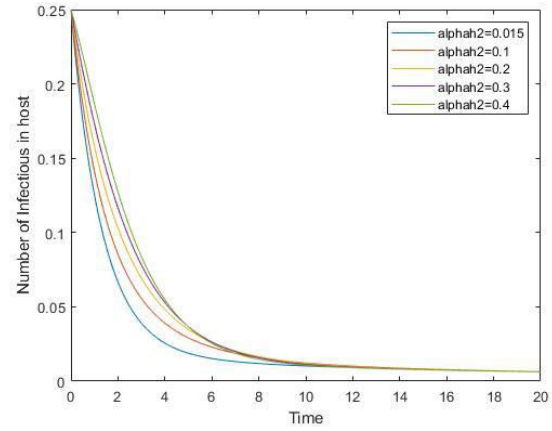


Fig. 5: Infectious class of the host for different values of α_{h_2} of Malaria.

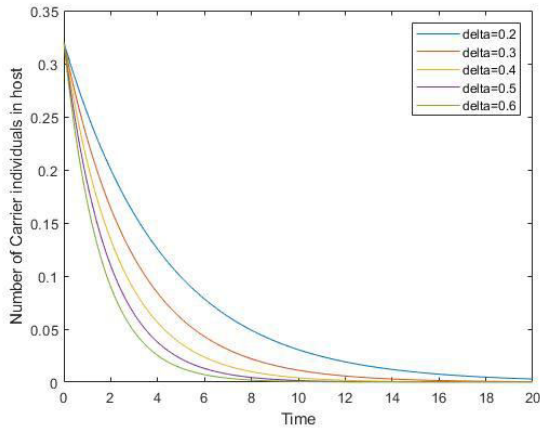


Fig. 6: Carrier class of the host for different values of δ of Malaria.

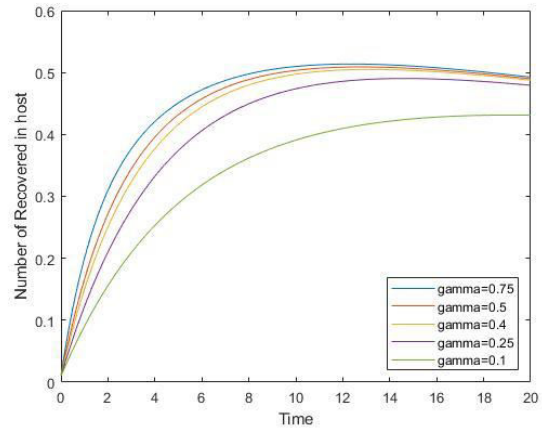


Fig. 7: Recovered class of the host for different values of γ of Malaria.

class of the humans decreases whenever the exposed rate of humans from E_h increases and Figure 5 shows that the individuals in infectious class increases whenever the exposed rate of humans from C_h increases. From Figure 6, it is clear that whenever the immunity rate in humans increases, the individuals in carrier class decreases and Figure 7 clears that whenever recovery rate of humans decreases, the recovered individuals of human decreases.

Dengue:

Dengue fever is a viral infection, caused by DEN-1, DEN-2, DEN-3, and DEN-4. The infection is caused by a bite of the female mosquitoes namely *Aedes aegypti*. Dengue fever is also known as the break-bone fever due to the severe muscle and joint pain which feels like the breaking of bones. It generally starts with a fever. The symptoms are high fever, severe muscle and joint pain, severe headache, rashes on the chest, back, or stomach, nausea and

Table 6: Data from References papers

Parameter	Value	Parameter	Value	Parameter	Value
η	0.18	θ	0.45	β_v	0.6
α_{h_1}	0.065	β_h	0.5	μ_v	0.0514
σ_h	1.11	σ_v	1.33	γ	0.2

Table 7: Assumed data

Parameter	Value	Parameter	Value
ω_v	0.6	α_{h_2}	0.075
δ	0.2	α_v	0.4

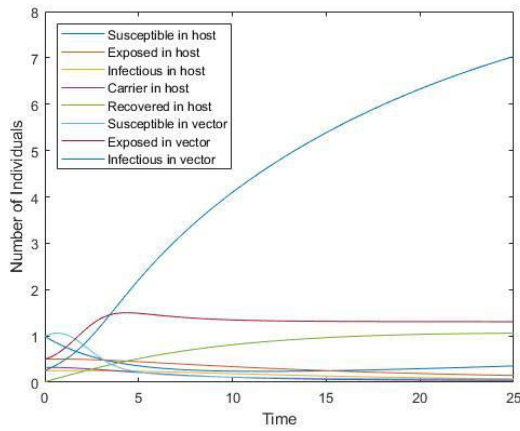
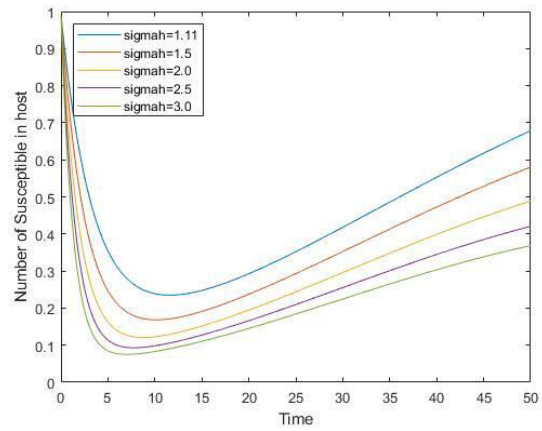


Fig. 8: Flow of variables with respect to time for Dengue.

Fig. 9: Susceptible class of the host for different values of σ_h of Dengue.

vomiting and diarrhoea. For India, $\omega_h=0.0488$, $\mu_h=0.0199$, $d=0.001$.

The values given in the Table 6 are taken from Endy *et al.* (2002); Gao *et al.* (2016) and Musa *et al.* (2019).

Table 7 gives the assumed value of the parameters.

The flow of the state variables with respect to time of vector and host is shown in Figure 8. From Figure 9, it is clear that whenever the probability of infection from mosquito to humans increases, the susceptible individuals of human decreases. Figure 10 shows that whenever the exposed rate

of humans from E_h increases, the exposed individuals of humans decreases and Figure 11 shows that whenever the exposed rate of humans from C_h increases, the individuals in infectious class of human increases. From Figure 12, it is clear that whenever the immunity rate increases, the individuals in the carrier class of humans decreases and Figure 13 shows that the recovered individuals of the human increases when the recovery rate of humans increases.

Chikungunya:

Chikungunya is spread in the day time by the bite of an *Aedes* mosquito which cannot be spread by the infectious person directly. The common

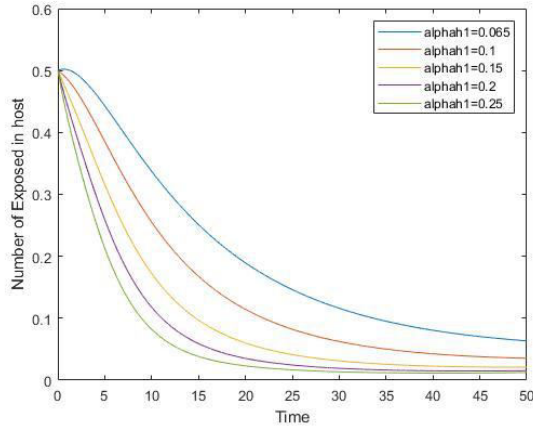


Fig. 10: Exposed class of the host for different values of α_{h_1} of Dengue.

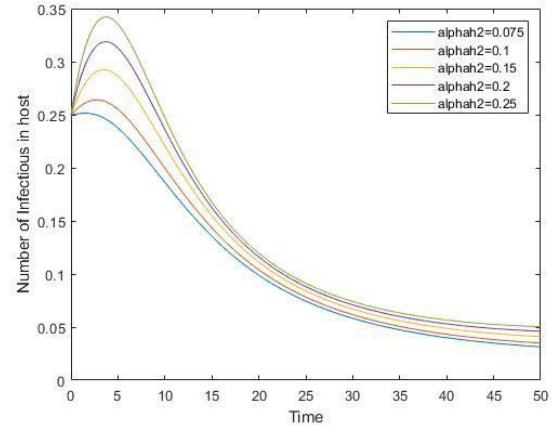


Fig. 11: Infectious class of the host for different values of α_{h_2} of Dengue.

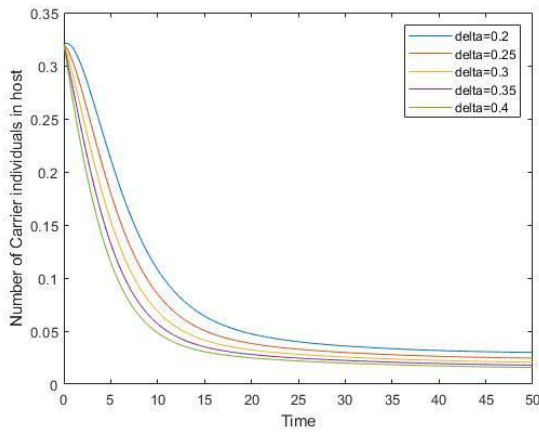


Fig.12: Carrier class of the host for different values of δ of Dengue.

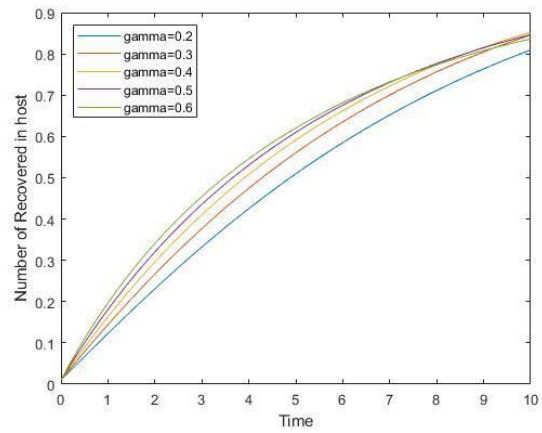


Fig. 13: Recovered class of the host for different values of γ of Dengue.

Table 8: Data from References papers

Parameter	Value	Parameter	Value
ω_v	0.07	θ	0.25
α_{h_1}	0.285	β_h	0.24
σ_v	0.285	β_v	0.24
μ_v	0.0714	σ_h	0.96
γ	0.6	σ_v	0.96

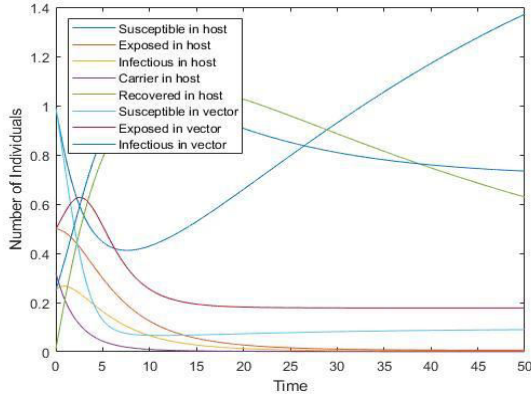


Fig. 14: Flow of variables with respect to time for Chikungunya.

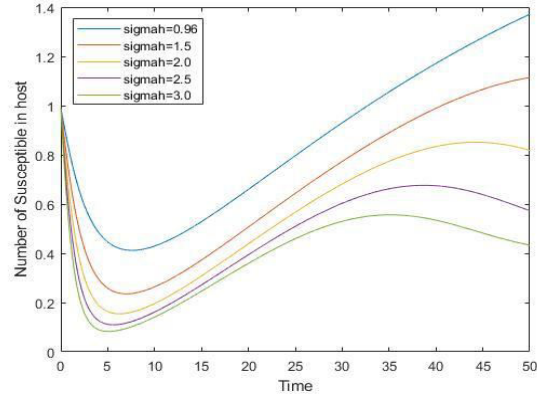


Fig. 15: Susceptible class of the host for different values of σ_h of Chikungunya.

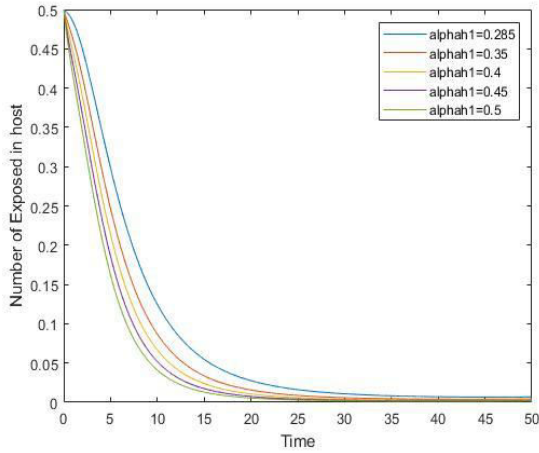


Fig. 16: Exposed class of the host for different values of α_{h_1} of Chikungunya.

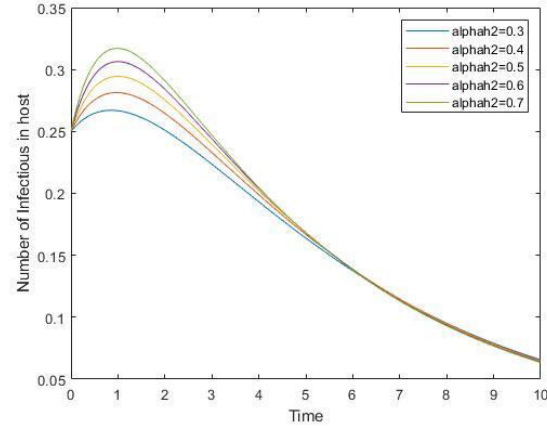


Fig. 17: Infectious class of the host for different values of α_{h_2} of Chikungunya.

symptoms include high fever, joint pain affecting multiple joints, headache and loss of appetite. Chikungunya usually occurs in Africa, India and Southeast Asia. In India, epidemic of Chikungunya fever was reported in 1963, 1965 and 1973. The states affected are Andhra Pradesh, Karnataka, Maharashtra, Madhya Pradesh, Tamil Nadu, Gujarat and Kerala. There is no specific treatment for chikungunya. In India $\omega_h=0.0488$, $\mu_h=0.0199$, $d=0.149$ and we assume the vales for $\eta=0.6$, $\alpha_{h_2}=0.3$, $\delta=0.2$.

The values given in Table 8 are taken as from Dumont and Chiroleu (2010), Manore *et al.* (2014) and Augusto *et al.* (2016).

Figure 14 gives a clear view about the flow of variables with respect to time of host and vector and Figure 15 shows that the individuals in the susceptible class of host decreases when the probability of infection from mosquito to humans increases. From Figure 16, it is clear that the exposed individuals in host decreases when the exposed rate of humans from E_h increases and Figure 17 shows that the individuals in infectious class of the host increases whenever the exposed rate of humans from C_h increases. Figure 18 shows that whenever the immunity rate of host increases, the individuals in the carrier class of the host decreases and Figure 19 shows that the individuals in the recovered class of the host

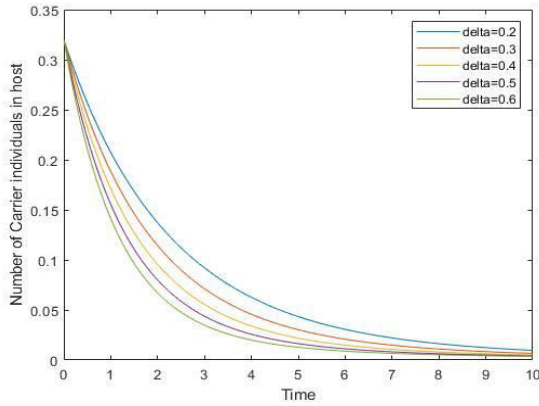


Fig.18: Carrier class of the host for different values of δ of Chikungunya.

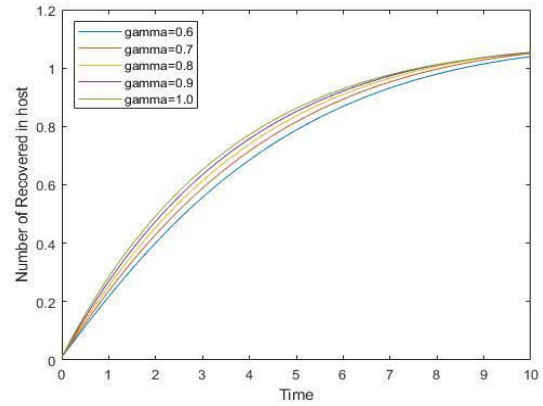


Fig. 19: Recovered class of the host for different values of γ of Chikungunya.

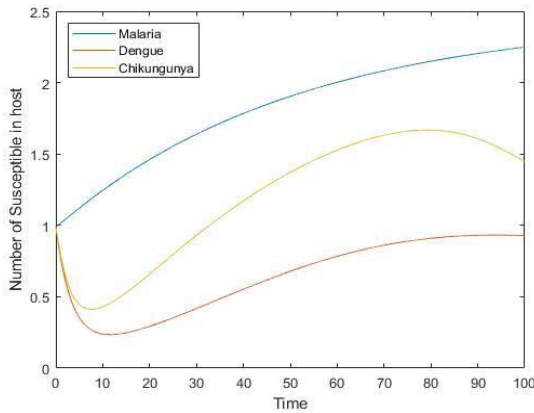


Fig. 20: Susceptible class of the host for Malaria, Dengue and Chikungunya.

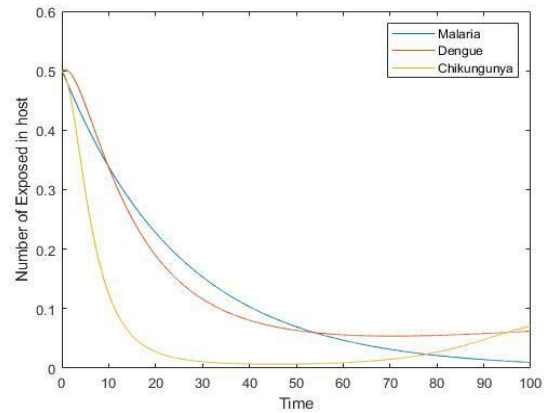


Fig. 21: Exposed class of the host for Malaria, Dengue and Chikungunya.

increases whenever the recovery rate of the host increases.

Comparative Study:

Here we compare the mosquito infection diseases Malaria, Dengue and Chikungunya for the variables of the host. From Figure 20, Malaria has the maximum number of individuals in the susceptible class of host while Dengue has the least. Figure 21 that Chikungunya has the minimum number of individuals in the exposed class of host while Malaria and Dengue are maximum in number. From Figure 22, Dengue has the maximum number of individuals in the infectious class of host while Malaria has the least. From Figure 23, Dengue has the maximum number of individuals in the carrier class of host

while Chikungunya has the least. Figure 24 shows that Chikungunya has the maximum number of individuals in the recovery class of host while Malaria has the least.

According to National Center for Vector Borne Disease Control, in August 2022 the confirmed cases of Malaria is 46809, Dengue is 30627 and Chikungunya is 3429. Number of deaths caused by Malaria is 6, Dengue is 12 and Chikungunya is 0. Hence, the most susceptible is Malaria compared to other two while Chikungunya is least exposed than other two. As Chikungunya has no deaths, it is highly recovered than other two.

Conclusion

A mosquito infection model consists of SIR with

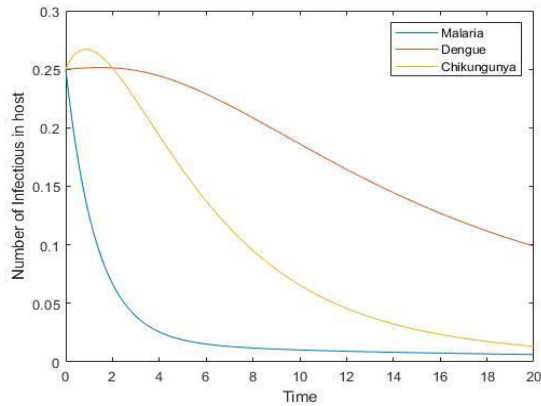


Fig. 22: Infectious class of the host for Malaria, Dengue and Chikungunya.

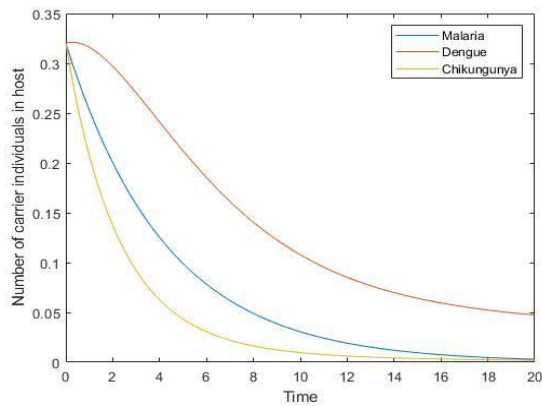


Fig. 23: Carrier class of the host for Malaria, Dengue and Chikungunya.

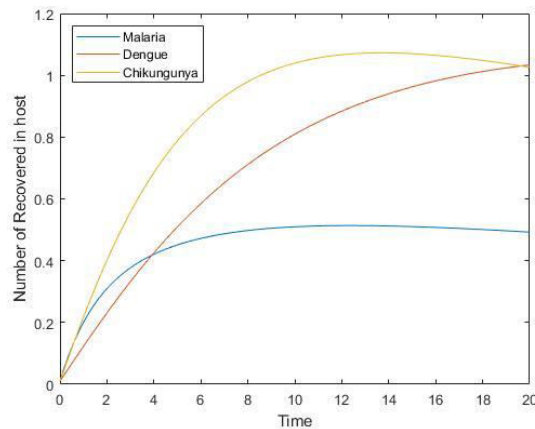


Fig. 24: Recovered class of the host for Malaria, Dengue and Chikungunya.

exposed and carrier class for humans as host and SI with exposed class for mosquitoes as vector was formulated. Numerical simulations were carried out for the predominant mosquito infection diseases Malaria, Dengue and Chikungunya to explore the flow of variables. By the comparison of these diseases, Malaria was highly susceptible. Without clinical symptoms, Dengue spreads maximum while Chikungunya spreads least. Chikungunya was the least exposed disease. Dengue was the highly infectious while Malaria was least infectious. Chikungunya was the highly recovered while Malaria was the least recovered.

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