On The Analysis of Saturation Terms on Mathematical Models for Malaria Transmission

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***Abstract: -* In this paper, the behavior of saturation term on malaria transmission was investigated.Basic reproduction number of the modified models was found using next generation matrix. Theorems were also used to prove the disease free and endemic equilibria with Local and Global Stabilities. Numerical Simulation of the effect of the sociological and psychological parameters or other mechanisms was done for both human and vectors using Runge-Kutta of order 4 method. Our results reveal that for proper treatment and eradication of malaria, saturation term and other factors cannot be over emphasized.**

***Keywords:* Saturation Term, Local and Global Stabilities, Basic Reproduction Number, Endemic Equilibrium.**

I. INTRODUCTION

Malaria is a life threatening disease caused by parasites that are transmitted to people through the bites of infected female Anopheles mosquito. In [1], simple mathematical model for malaria transmission was modified. Also, [2] and [3] considered SEIR model and simulation between human and vector.

[4] Considered a mathematical model for endemic with variable human and mosquito population and results showed that disease free equilibrium is locally asymptotically stable if the basic reproduction number is less than one.[5],[6],[7] and [8] discussed the control and simulation of malaria transmission.

In this paper, we studied behavioral of saturation terms on mathematical models of malaria transmission for human and vector. Numerical simulation shows the effect of both sociological and physiological of some important parameters in the model.

II. THE BASIC MATHEMATICAL MODEL

In this paper, model [1] was adopted and modified by incorporating an incidence rate which include saturation term m

The Existing model MOJEEB (2017)

$$\frac{dS_H}{dt} = \wedge_H - \beta_H S_H I_H - \mu_H S_H$$
$$\frac{dE_H}{dt} = \beta_H S_H I_H - (\alpha_{1H} + \mu_H)E_H$$
$$\frac{dI_H}{dt} = \alpha_{1H} E_H - (\alpha_{2H} + \mu_H + \delta)I_H$$
$$\frac{dR_H}{dt} = \alpha_{2H} I_H - \mu_H R_H$$
$$\frac{dS_V}{dt} = \wedge_V - \beta_v S_V I_V - \mu_V S_V$$
$$\frac{dE_V}{dt} = \beta_v S_V I_V - (\alpha_{1V} + \mu_V)E_V$$
$$\frac{dI_V}{dt} = \alpha_{1V} E_V - \mu_V I_V \qquad (1)$$

2.1 Proposed model

$$\frac{dS_H}{dt} = \wedge_H - \frac{\beta_H S_H I_H}{1+mS_H} - \mu_H S_H$$
$$\frac{dE_H}{dt} = \frac{\beta_H S_H I_H}{1+mS_H} - (\alpha_{1H} + \mu_H)E_H$$
$$\frac{dI_H}{dt} = \alpha_{1H} E_H - (\alpha_{2H} + \mu_H + \delta)I_H$$
$$\frac{dR_H}{dt} = \alpha_{2H} I_H - \mu_H R_H$$
$$\frac{dS_V}{dt} = \wedge_V - \frac{\beta_v S_V I_V}{1+mS_V} - \mu_V S_V$$
$$\frac{dE_V}{dt} = \frac{\beta_V S_V I_V}{1+mS_V} - (\alpha_{1V} + \mu_V)E_V$$
$$\frac{dI_V}{dt} = \alpha_{1V} E_V - \mu_V I_V \qquad (2)$$

2.2 Disease Free Equilibrium (DFE)

At Disease Free Equilibrium,

$$\mathrm{I}_H = 0, E_H = 0, R_H, I_V = 0, E_V = 0$$

From equation (2),

$$\wedge_H - \frac{\beta_H S_H I_H}{1+mS} - \mu_H S_H = 0$$

$$\wedge_H - \mu_H S_H = 0$$

$$S_H = \frac{\wedge_H}{\mu_H} \qquad (3)$$

$$\wedge_V - \frac{\beta_v S_V I_V}{1+mS_V} - \mu_V S_V = 0$$

$$\wedge_V - \mu_V S_V = 0$$

$$S_V = \frac{\wedge_V}{\mu_V} \qquad (4)$$

$$E_{0HV} = (S_H, E_H, I_H, R_H, S_V, E_V, I_V) = (\frac{\wedge_H}{\mu_H}, 0,0,0, \frac{\wedge_V}{\mu_V}, 0,0) \qquad (5)$$

2.3 The Endemic Equilibrium

At endemic equilibrium,

$I_H \neq 0, E_H \neq 0, I_V \neq 0, E_V \neq 0$

Therefore, from equation (2), we have;

$$\alpha_1 E_H^* - (\alpha_{2H} + \mu_H + \delta) I_H^* = 0$$

$$\alpha_1 E_H^* = (\alpha_{2H} + \mu_H + \delta) I_H^*$$

$$E_H^* = \frac{(\alpha_{2H} + \mu_H + \delta)}{\alpha_{1H}} [\frac{\wedge_H \alpha_{1H} \beta_H - (\wedge_H m + \mu_H)(\alpha_{1H} + \mu_H)(\alpha_{2H} + \mu_H + \delta)}{\alpha_{1H} - m(\alpha_{1H} + \mu_H)^2 (\alpha_{2H} + \mu_H + \delta)^2}] \qquad (6)$$

Also to get S_H^* from equation (2), we say,

$$\frac{\beta_H S_H^* I_H^*}{1+mS_H^*} - (\alpha_{1H} + \mu_H) E_H^* = 0$$

$$\frac{\beta_H S_H^* I_H^*}{1+mS_H^*} = (\alpha_{1H} + \mu_H) E_H^*$$

$$\beta_H S_H^* I_H^* = (1+mS_H^*)(\alpha_{1H} + \mu_H) E_H^*$$

$$S_H^* = \frac{(\alpha_{1H} + \mu_H)(\alpha_{2H} + \mu_H + \delta)}{\alpha_{1H} \beta_H - m(\alpha_{1H} + \mu_H)(\alpha_{2H} + \mu_H + \delta)} \qquad (7)$$

Also to get I_H^* from equation (2), we say;

$$\wedge_H - \frac{\beta_H S_H^* I_H^*}{1+mS_H^*} - \mu_H S_H^* = 0$$

$$\wedge_H - \mu_H S_H^* = \frac{\beta_H S_H^* I_H^*}{1+mS_H^*}$$

$$I_H^* = \alpha_{1H} [\frac{\wedge_H \alpha_{1H} \beta_H - (\wedge_H m + \mu_H)(\alpha_{1H} + \mu_H)(\alpha_{2H} + \mu_H + \delta)}{\alpha_{1H} - m(\alpha_{1H} + \mu_H)^2 (\alpha_{2H} + \mu_H + \delta)^2}] \qquad (8)$$

Also to get R_H^* from equation (2) we say,

$$\alpha_{2H} I_H^* - \mu_H R_H^* = 0$$

$$R_H^* = \frac{\alpha_{2H} I_H^*}{\mu_H}$$

$$R_H^* = \frac{\alpha_{2H} \alpha_{1H}}{\mu_H} [\frac{\wedge_H \alpha_{1H} \beta_H - (\wedge_H m + \mu_H)(\alpha_{1H} + \mu_H)(\alpha_{2H} + \mu_H + \delta)}{\alpha_{1H} - m(\alpha_{1H} + \mu_H)^2 (\alpha_{2H} + \mu_H + \delta)^2}] \qquad (9)$$

To get S_V^* from equation (2),we get;

$$\frac{\beta_V S_V^* I_V^*}{1+mS_V^*} - (\alpha_{1V} + \mu_V) E_V^* = 0$$

$$\frac{\beta_V S_V^* I_V^*}{1+mS_V^*} = (\alpha_{1V} + \mu_V) E_V^*$$

$$\beta_V S_V^* I_V^* = (1+mS_V^*)(\alpha_{1V} + \mu_V) E_V^*$$

$$S_V^* = \frac{\mu_V (\alpha_{1V} + \mu_V)}{\alpha_{1V} \beta_V - m\mu_V \beta_V (\alpha_{1V} + \mu_V)} \qquad (10)$$

To get E_V^* from equation (2), we obtain;

$$\alpha_{1V} E_V^* - (\alpha_{2V} + \mu_V + \delta) I_V^* = 0$$

$$\alpha_1 E_V^* = (\alpha_{2V} + \mu_V + \delta) I_V^*$$

$$E_V^* = \frac{(\alpha_{2V} + \mu_V + \delta)}{\alpha_{1V}} I_V^* \qquad (11)$$

To get I_V^* from equation (2), we get;

$$\wedge_V - \frac{\beta_V S_V^* I_V^*}{1+mS_V^*} - \mu_V S_V^* = 0$$

$$\wedge_V - \mu_V S_V^* = \frac{\beta_V S_V^* I_V^*}{1+mS_V^*} \qquad (12)$$

2.4 Basic Reproduction Number R_{0HV}

Using next generation matrix

$$R_{0HV} = FV^{-1} \qquad (13)$$

The inverse of V is obtained because

$$V^{-1} = \begin{bmatrix} \frac{1}{(\alpha_{1H} + \mu_H)} & 0 & 0 & 0 \\ \frac{\alpha_{1H}}{(\alpha_{1H} + \mu_H)(\alpha_{2H} + \mu_H + \delta)} & \frac{1}{(\alpha_{2H} + \mu_H + \delta)} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{\alpha_{1V}}{\mu_V (\alpha_{1V} + \mu_V)} & \frac{1}{\mu_V} \end{bmatrix} \qquad (14)$$

Hence, $R_{0HV} = F.V^{-1}$

$$R_1 = \sqrt{\left(\frac{\beta_H \wedge_H \alpha_{1H}}{(\mu_H + m\wedge_H)(\alpha_{1H}+\mu_H)(\alpha_{2H}+\mu_H+\delta)}\right)\left(\frac{\beta_V \wedge_V \alpha_{1V}}{\mu_V(\mu_V+m\wedge_V)(\alpha_{1V}+\mu_V)}\right)} \quad (15)$$

$$R_1 = \sqrt{R_{0H} R_{0V}}$$

Where

$$R_H = \frac{\beta_H \wedge_H \alpha_{1H}}{(\mu_H + m\wedge_H)(\alpha_{1H}+\mu_H)(\alpha_{2H}+\mu_H+\delta)}$$

$$R_V = \frac{\beta_V \wedge_V \alpha_{1V}}{\mu_V(\mu_V + m\wedge_V)(\alpha_{1V}+\mu_V)}$$

$$R_1 = \sqrt{\left(\frac{\beta_H \beta_V \alpha_{1H} \alpha_{1V} \wedge_V \wedge_H}{\mu_V(\mu_V+m\wedge_V)(\alpha_{1V}+\mu_V)(\mu_H+m\wedge_H)(\alpha_{1H}+\mu_H)(\alpha_{2H}+\mu_H+\delta)}\right)} \quad ..16$$

2.5 Local Stability of Disease Free Equilibrium

The Jacobian matrix becomes,

$$J(E_0) = \begin{bmatrix} -\mu_H & 0 & \frac{-\beta_H S_H}{1+mS_H} & 0 & 0 & 0 & 0 \\ 0 & -(\alpha_{1H}+\mu_H) & \frac{\beta_H S_H}{1+mS_H} & 0 & 0 & 0 & 0 \\ 0 & \alpha_{1H} & -(\alpha_{2H}+\mu_H+\delta) & 0 & 0 & 0 & 0 \\ 0 & 0 & \alpha_{2H} & -\mu_H & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -\mu_V & 0 & \frac{-\beta_V S_V}{1+mS_V} \\ 0 & 0 & 0 & 0 & 0 & -(\alpha_{1V}+\mu_V) & \frac{\beta_V S_V}{1+mS_V} \\ 0 & 0 & 0 & 0 & 0 & \alpha_{1V} & -\mu_V \end{bmatrix} \quad (17)$$

The determinant of the matrix becomes,

$$\begin{vmatrix} -\mu_H & 0 & \frac{-\beta_H S_H}{1+mS_H} & 0 & 0 & 0 & 0 \\ 0 & -(\alpha_{1H}+\mu_H) & \frac{\beta_H S_H}{1+mS_H} & 0 & 0 & 0 & 0 \\ 0 & \alpha_{1H} & -(\alpha_{2H}+\mu_H+\delta) & 0 & 0 & 0 & 0 \\ 0 & 0 & \alpha_{2H} & -\mu_H & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -\mu_V & 0 & \frac{-\beta_V S_V}{1+mS_V} \\ 0 & 0 & 0 & 0 & 0 & -(\alpha_{1V}+\mu_V) & \frac{\beta_V S_V}{1+mS_V} \\ 0 & 0 & 0 & 0 & 0 & \alpha_{1V} & -\mu_V \end{vmatrix}$$

Therefore,

$$\lambda_1 = -\alpha_{2V} - \mu_V$$

$$\lambda_2 = -\mu_H$$

$$\lambda_3 = -\mu_H$$

$$\lambda_4 = -\mu_V$$

$$\lambda_5 = -\mu_V$$

$$\lambda_6 = -\frac{1}{2}\left(\frac{1}{1+mS_H}\right)\begin{pmatrix} 2\mu_H m S_H + mS_H\delta + mS_H\alpha_{1H} + mS_H\alpha_{2H} + 2\mu_H \\ -\begin{pmatrix} m^2 S_H{}^2\delta^2 - 2m^2 S_H{}^2\delta\alpha_{1H} + 2m^2 S_H{}^2\delta\alpha_{2H} + m^2 S_H{}^2\alpha_{1H}{}^2 - 2m^2 S_H{}^2\alpha_{1H}\alpha_{2H} \\ + m^2 S_H{}^2\alpha_{2H}{}^2 + 4mS_H{}^2\beta_H\alpha_{1H} + 2mS_H\delta^2 - 4mS_H\delta\alpha_{1H} + 4mS_H\delta\alpha_{2H} + 2mS_H\alpha_{1H}{}^2 \\ -4mS_H\alpha_{1H}\alpha_{2H} + 2mS_H\alpha_{2H}{}^2 + 4S_H\alpha_{1H}\beta_H + \delta^2 - 2\delta\alpha_{1H} + 2\delta\alpha_{2H} + \alpha_{1H}{}^2 - 2\alpha_{1H}\alpha_{2H} + \alpha_{2H}{}^2 \end{pmatrix}^{\frac{1}{2}} \\ + \delta + \alpha_{1H} + \alpha_{2H} \end{pmatrix}$$

$$\lambda_7 = -\frac{1}{2}\left(\frac{1}{1+mS_H}\right)\begin{pmatrix} 2\mu_H m S_H + mS_H\delta + mS_H\alpha_{1H} + mS_H\alpha_{2H} + 2\mu_H \\ -\begin{pmatrix} m^2 S_H{}^2\delta^2 - 2m^2 S_H{}^2\delta\alpha_{1H} + 2m^2 S_H{}^2\delta\alpha_{2H} + m^2 S_H{}^2\alpha_{1H}{}^2 - 2m^2 S_H{}^2\alpha_{1H}\alpha_{2H} \\ + m^2 S_H{}^2\alpha_{2H}{}^2 + 4mS_H{}^2\beta_H\alpha_{1H} + 2mS_H\delta^2 - 4mS_H\delta\alpha_{1H} + 4mS_H\delta\alpha_{2H} + 2mS_H\alpha_{1H}{}^2 \\ -4mS_H\alpha_{1H}\alpha_{2H} + 2mS_H\alpha_{2H}{}^2 + 4S_H\alpha_{1H}\beta_H + \delta^2 - 2\delta\alpha_{1H} + 2\delta\alpha_{2H} + \alpha_{1H}{}^2 - 2\alpha_{1H}\alpha_{2H} + \alpha_{2H}{}^2 \end{pmatrix}^{\frac{1}{2}} \\ + \delta + \alpha_{1H} + \alpha_{2H} \end{pmatrix} \quad (18)$$

All Eigen values solved at the equilibrium points contain negative real part therefore the system is locally asymptotically stable.

2.6 Global Stability of Disease Free Equilibrium

We consider the Lyapunov function,

$$\frac{dE_H}{dt} = \frac{\beta_H S_H I_H}{1+mS_H} - (\alpha_{1H} + \mu_H)E_H$$

$$\frac{dI_H}{dt} = \alpha_{1H}E_H - (\alpha_{2H} + \mu_H + \delta)I_H$$

$$\frac{dE_V}{dt} = \frac{\beta_V S_V I_V}{1+mS_V} - (\alpha_{1V} + \mu_V)E_V$$

$$\frac{dI_V}{dt} = \alpha_{1V}E_V - \mu_V I_V$$

$$\frac{dV}{dt} = \alpha_{1H}\frac{dE_H}{dt} + (\alpha_{1H} + \mu_H)\frac{dI_H}{dt} + \alpha_{1V}\frac{dE_V}{dt} + (\alpha_{1V} + \mu_V)\frac{dI_V}{dt}$$

$$\frac{dV}{dt} = \alpha_{1H}\left[\frac{\beta_H S_H I_H}{1+mS_H} - (\alpha_{1H} + \mu_H)E_H\right]$$

$$+ (\alpha_{1H} + \mu_H)\left[\alpha_{1H}E_H - (\alpha_{2H} + \mu_H + \delta)I_H\right]$$

$$+ \alpha_{1V}\left[\frac{\beta_V S_V I_V}{1+mS_V} - (\alpha_{1V} + \mu_V)E_V\right] + (\alpha_{1V} + \mu_V)\left[\alpha_{1V}E_V - \mu_V I_V\right]$$

$$\frac{dv}{dt} = (\alpha_{2H} + \mu_H + \delta)\left[\frac{\beta_H S_H I_H \alpha_{1H}}{(1+mS_H)(\alpha_{2H} + \mu_H + \delta)} - 1\right]$$

$$+ \mu_V(\alpha_{1V} + \mu_V)\left[\frac{\beta_V S_V I_V \alpha_{1V}}{(1+mS_V)\mu_V(\alpha_{1V} + \mu_V)} - 1\right]$$

$$= (\alpha_{2H} + \mu_H + \delta)\left[\frac{\beta_H S_H I_H \alpha_{1H}}{(1+mS_H)(\alpha_{2H} + \mu_H + \delta)} - 1\right]$$

$$+ \mu_V(\alpha_{1V} + \mu_V)\left[\frac{\beta_V S_V I_V \alpha_{1V}}{(1+mS_V)\mu_V(\alpha_{1V} + \mu_V)} - 1\right]$$

$$= (\alpha_{2H} + \mu_H + \delta)[R_{0H} - 1] + \mu_V(\alpha_{1V} + \mu_V)[R_{0V} - 1]$$

$$if \quad R_{0HV} \le 1$$

$$L^1 \le 0 \quad (19)$$

Hence the disease free equilibrium is globally asymptotically stable.

2.7 Local Stability of Endemic Equilibrium

Let

$$S_H - S_H^* = A, E_H - E_H^* = B, I_H - I_H^* = C, R_H - R_H^* = D,$$
$$S_V - S_V^* = E, E_V - E_V^* = F, I_V - I_V^* = G$$

$$\frac{dA}{dt} = -\frac{\beta_H (A + S_H^*)(C + I_H^*)}{1 + m(A + S_H^*)} - \mu_H (A + S_H^*)$$
$$\frac{dB}{dt} = \frac{\beta_H (A + S_H^*)(C + I_H^*)}{1 + m(A + S_H^*)} - (\alpha_{1H} + \mu_H)(B + E_H^*)$$
$$\frac{dC}{dt} = \alpha_{1H}(B + E_H^*) - (\alpha_{2H} + \mu_H + \delta)(C + I_H^*)$$
$$\frac{dD}{dt} = \alpha_{2H}(C + I_H^*) - \mu_H (D + R_H^*)$$
$$\frac{dE}{dt} = \wedge_V - \frac{\beta_v (E + S_V^*)(G + I_V^*)}{1 + m(E + S_V^*)} - \mu_V (E + S_V^*)$$
$$\frac{dF}{dt} = \frac{\beta_v (E + S_V^*)(G + I_V^*)}{1 + m(E + S_V^*)} - (\alpha_{1V} + \mu_V)(F + E_V^*)$$
$$\frac{dG}{dt} = \alpha_{1V}(F + E_V^*) - \mu_V (G + I_V^*) \qquad (20)$$

By linearizing, we get

$$\frac{dA}{dt} = (-\beta_H I_H^* - \mu_H)A - \beta_H S_H^* C + nonlinearterms$$
$$\frac{dB}{dt} = \beta_H S_H^* C - (\alpha_{1H} + \mu_H)B + \beta_H I_H^* + nonlinearterms$$
$$\frac{dC}{dt} = \alpha_{1H} B - (\alpha_{2H} + \mu_H + \delta)C + nonlinearterms$$
$$\frac{dD}{dt} = \alpha_{2H} C - \mu_H D + nonlinearterms$$
$$\frac{dE}{dt} = -\beta_v I_V^* - \mu_V E - \beta_v S_V^* G + nonlinearterms$$
$$\frac{dF}{dt} = \beta_v S_V^* G - (\alpha_{1V} + \mu_V)F + \beta_v I_V^* E + nonlinearterms$$
$$\frac{dG}{dt} = \alpha_{1V} F - \mu_V G + nonlinearterms$$

(21)

The Jacobian matrix becomes,

$$J(E) = \begin{bmatrix} -\beta_H I_H^* - \mu_H & 0 & -\beta_H S_H^* & 0 & 0 & 0 & 0 \\ 0 & -(\alpha_{1H} + \mu_H) & \beta_H S_H^* & 0 & 0 & 0 & 0 \\ 0 & \alpha_{1H} & -(\alpha_{2H} + \mu_H + \delta) & 0 & 0 & 0 & 0 \\ 0 & 0 & \alpha_{2H} & -\mu_H & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -\beta_V I_V^* - \mu_V & 0 & -\beta_V S_V^* \\ 0 & 0 & 0 & 0 & 0 & -(\alpha_{1V} + \mu_V) & \beta_V S_V^* \\ 0 & 0 & 0 & 0 & 0 & \alpha_{1V} & -\mu_V \end{bmatrix} \qquad (22)$$

Therefore the Eigen values become,

$$\lambda_1 = -\mu_H,$$
$$\lambda_2 = -\beta_H I_H^* - \mu_H,$$
$$\lambda_3 = -\beta_V I_V^* - \mu_V,$$
$$\lambda_4 = -\mu_V - \frac{1}{2}\alpha_{1V} + \frac{1}{2}\sqrt{4\alpha_{1V}\beta_V S_V^* + \alpha_{1V}^2},$$
$$\lambda_5 = -\mu_V - \frac{1}{2}\alpha_{1V} - \frac{1}{2}\sqrt{4\alpha_{1V}\beta_V S_V^* + \alpha_{1V}^2},$$
$$\lambda_6 = -\mu_H - \frac{1}{2}\delta - \frac{1}{2}\alpha_{1H} - \frac{1}{2}\alpha_{2H} + \frac{1}{2}\sqrt{4\alpha_{1H}\beta_H S_H^* + \delta^2 - 2\delta\alpha_{1H} + 2\delta\alpha_{2H} + \alpha_{1H}^2 - 2\alpha_{1H}\alpha_{2H} + \alpha_{2H}^2},$$
$$\lambda_7 = -\mu_H - \frac{1}{2}\delta - \frac{1}{2}\alpha_{1H} - \frac{1}{2}\alpha_{2H} + \frac{1}{2}\sqrt{4\alpha_{1H}\beta_H S_H^* + \delta^2 - 2\delta\alpha_{1H} + 2\delta\alpha_{2H} + \alpha_{1H}^2 - 2\alpha_{1H}\alpha_{2H} + \alpha_{2H}^2}$$

All Eigen values solved at the endemic equilibrium contain negative real part. Therefore, the system is locally asymptotically stable

III. RESULTS AND DISCUSSION

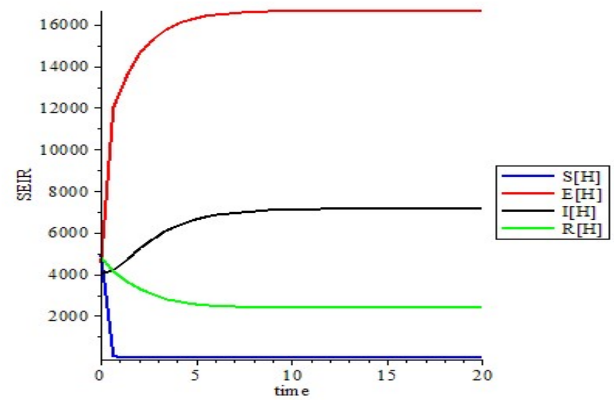

Figure 1: Graph of Susceptible (SH), Exposed (EH), Infected (IH), Recovered (RH) against time (t) with

$\beta = 0.1,\ \wedge = 10000,\ \mu = 0.3,\ \delta = 0.2,\ m = 0.01,$
$\alpha_{1H} = 0.3,\ \alpha_{2H} = 0.1$

The graph shows that the lower the saturation term, the lower the susceptible for human compartment

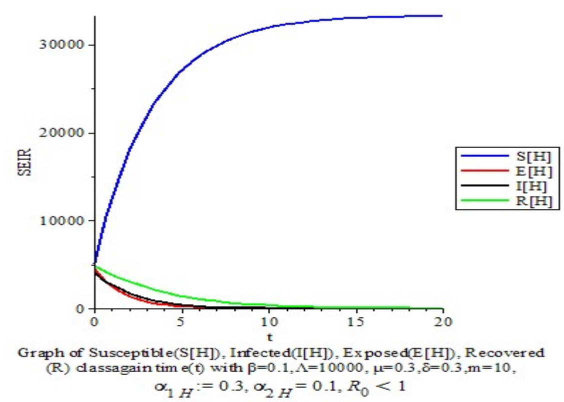

Figure 2: Graph of Susceptible (SH), Exposed (EH), Infected (IH), Recovered (RH) against time (t) with

$\beta = 0.1,\ \wedge = 10000,\ \mu = 0.3,\ \delta = 0.2,\ m = 1.0$
$\alpha_{1H} = 0.3,\ \alpha_{2H} = 0.1$

The graph shows that the higher the saturation term the higher the susceptible for human compartment

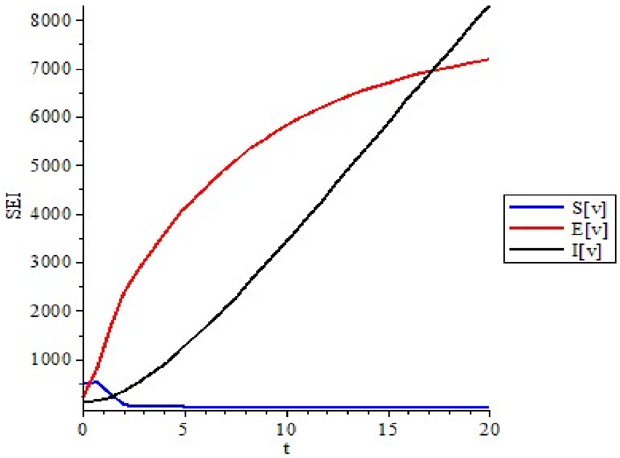

Figure 3: Graph of Susceptible (Sv), Exposed (Ev), Infected (Iv) against time (t) with

$$\beta = 0.1, \wedge = 10000, \ \mu = 0.3, \ \delta = 0.2, \ m = 0.01,$$
$$\alpha_{1v} = 0.3, \ \alpha_{2v} = 0.1$$

The graph shows that the saturation term is low that makes the susceptible for vector to become lower because the vectors are the carrier.

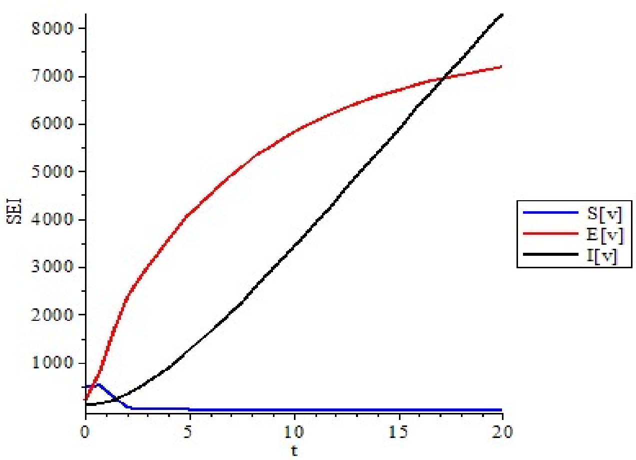

Figure 4: Graph of Susceptible (Sv), Exposed (Ev), Infected (Iv) against time (t) with

$$\beta = 0.1, \wedge = 10000, \ \mu = 0.3, \ \delta = 0.2, \ m = 0.02,$$
$$\alpha_{1v} = 0.3, \ \alpha_{2v} = 0.1$$

The graph shows that the saturation term is low that makes the susceptible for vector to become lower because the vectors are the carrier.

IV. CONCLUSION

In this paper, we showed that the model is locally asymptotically stable if the basic reproduction number is greater than unity and unstable otherwise. According to our results, we discovered that malaria can be controlled by increasing the saturation term, by reducing the infection rate between humans and vectors, and through proper sensitization by health workers, giving out bed nets, insecticide and active anti malaria drugs.

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