Modelling Typhoid Fever with General Knowledge, Vaccination and Treatment for Susceptible Individual

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Abstract. **The Paper Investigates The Significance Of General Knowledge In The Control Of Typhoid Fever In Endemic Environment. Saturated Incidence Rate Was Introduced To Study The General Knowledge Of The Disease. The Basic Reproduction Number Of The Resulting Model Was Determined By Using Next Generation Matrix.The Paper Also Analyzed The Control Strategies For The Disease Free Equilibriumof The Infected And Vaccinated Model. The Paper Studies The Local And Global Stabilities Of Disease Free And Endemic Equilibrium. We Provide A Numerical Simulation Of The Model Using Runge-Kutta Of Order 4. Our Results Show That General Knowledge Of The Typhoid Disease Has Appreciable Effect In The Model.**

Keywords: **Treatment, Basic Reproduction Number, Vaccination, Lyapunov Function.**

I. INTRODUCTION

Typhoid Fever, Also Known As Enteric Fever, Is A Potential Fatal Multisystemic Illness Caused Primarily By Salmonella Enteric Serotype Typhi. The Classic Presentation Is Fever, Malaise, Diffuse Abdominal Pain And Constipation [1]. In [2] Typhoid Fever With Education, Vaccination And Treatment Was Studied To Know The Significant Effects.[3] Studiedthe Numerical Effect Of Saturation Term On Susceptible Individual In Susceptible-Exposed-Infected-Recovered Epidemic Model Their Model Show That Saturation Term Plays A Vital Role. [4] Investigated The Behavioral Analysis Of Seirs Epidemic Model With A Saturated Incidence Rate. The Effect Of Disease Induced Death On Seirs Epidemic Model Was Studied By [5]. Their Model Reveals That Disease Induced Death Is Not A Better Measure For Disease Eradication. Effect Of Disease Transmission Coefficient Was Studied By [6] Which Reveal That Disease Is Better Eradicated With Higher Transmission Coefficient.In Our Own Paper, The Work Of Was Modified To Incorporate A Saturated Incidence Rate $\frac{\beta SI}{1+mS}$, M Being The General Knowledge For The Susceptible Individuals.

II. THE BASIC MATHEMATICAL MODEL

In This Paper, The Model In Equation (1) Was Adopted And Modified By Incorporating An Incidence Rate Which Include General Knowledge Parameter m

Existing Model

$$\begin{aligned}
\frac{dS}{dt} &= \Lambda + \omega_1 V + \omega_2 R - (\theta + \mu + (1-\psi_e)(\beta I + \gamma I_C)S \\
\frac{dV}{dt} &= \theta S - (\omega_1 + \mu)v \\
\frac{dI}{dt} &= (1-\rho)(1-\psi_e)(\beta I + \gamma I_C)S - (\eta + d_2 + \mu)I + \alpha(1-\psi_e)I_C \\
\frac{dI_C}{dt} &= \rho(\beta I + \gamma I_C)S - (\mu + d_1)I_C - \alpha I_C \\
\frac{dR}{dt} &= \eta I - (\omega_2 + \mu)R
\end{aligned} \tag{1}$$

2.1 Modified Model of Equation

We Obtain 5-Demensional Non-Linear System Of Ordinary Differential Equations Describing The Transmission Of Typhoid Fever.

$$\begin{aligned}
\frac{dS}{dt} &= \Lambda + \omega_1 V + \omega_2 R - (\theta + \mu + (1-\psi_e)\frac{(\beta I + \gamma I_C)}{1+mS}S \\
\frac{dV}{dt} &= \theta S - (\omega_1 + \mu)v \\
\frac{dI}{dt} &= (1-\rho)(1-\psi_e)\frac{(\beta I + \gamma I_C)S}{1+mS} - (\eta + d_2 + \mu)I + \alpha(1-\psi_e)I_C \\
\frac{dI_C}{dt} &= \rho\frac{(\beta I + \gamma I_C)S}{1+mS} - (\mu + d_1)I_C - \alpha I_C \\
\frac{dR}{dt} &= \eta I - (\omega_2 + \mu)R
\end{aligned} \tag{2}$$

2.2 Disease-Free Equilibrium (Dfe)

The Modified Model In Equation (2) Is Therefore Solved For The Following:

$$\frac{dS}{dt} = \frac{dV}{dt} = \frac{dI}{dt} = \frac{dI_C}{dt} = \frac{dR}{dt} = 0$$

$$\Lambda + \omega_1 V + \omega_2 R - \theta S - \mu S - \frac{(\beta I + \gamma I_C)S}{1+mS} = 0 \tag{3.1}$$

$$\theta S - (\omega_1 + \mu)v = 0 \tag{3.2}$$

$$(1-\rho)\frac{(\beta I + \gamma I_C)S}{1+mS} - (\eta + d_2 + \mu)I - \alpha I_C = 0 \tag{3.3}$$

$$\frac{\rho(\beta I + \gamma I_C)S}{1+mS} - (\mu + d_1)I_C - \alpha I_C = 0 \tag{3.4}$$

$$\eta I - (\omega_2 + \mu)R \tag{3.5}$$

At Equilibrium,

At Disease-Free Equilibrium $I = I_C = 0$

From Equation (3.5)

$$\eta(0) - (\omega_2 + \mu)R = 0$$

$$R^0 = 0$$

From Equation (3.2)

$$\theta S - (\omega_1 + \mu)v = 0$$

$$\frac{\theta S}{\omega_1 + \mu} = \frac{(\omega_1 + \mu)V}{\omega_1 + \mu}$$

$$V = \frac{\theta S}{(\omega_1 + \mu)} \qquad (3.6)$$

Substitute $V = \dfrac{\theta S}{(\omega_1 + \mu)}$ and R = 0 into (3.1)

Also From (3.1) With Various Substitution

hence,

$$S = -\Lambda \div \frac{\theta\omega_1 - \theta(\omega_1 + \mu) - \mu(\omega_1 + \mu)}{\omega_1 + \mu}$$

i.e

$$S^0 = \frac{\wedge(\omega_1 + \mu)}{\mu(\omega_1 + \theta + \mu)} \qquad (3.7)$$

Putting Equation (3.6) Into (3.7)

$$V = \frac{\theta}{\omega_1 + \mu}\left(\frac{\wedge(\omega_1 + \mu)}{\mu(\theta + \omega_1 + \mu)}\right) = \frac{\theta\wedge}{\mu(\theta + \omega_1 + \mu)} \qquad (3.8)$$

Model System (2) Has A Disease Free Equilibrium

$$E_0 = (S^0, V^0, I^0, I_C{}^0, R^0)\left(\frac{\Lambda(\omega_1 + \mu)}{\mu(\theta + \omega_1 + \mu)}, \frac{\theta\Lambda}{\mu(\theta + \omega_1 + \mu)}, 0,0,0\right) \quad (3.9)$$

2.3 *Endemic Equilibrium*

At Endemic Equilibrium, If We Let

$E^* = (S^*, V^*, I^*, I_C{}^*, R^*)$ Satisfies $(S, V, I, I_C, R) > 0$

From Equation (3.5)

$$\eta I - (\omega_2 + \mu)R = 0$$

$$\frac{\eta I}{(\omega_2 + \mu)} = \frac{(\omega_2 + \mu)R}{(\omega_2 + \mu)}$$

$$R^* = \frac{\eta I^*}{\omega_2 + \mu}$$

From Equation (3.2)

$$\theta S - (\omega_1 + \mu)v = 0$$

$$\theta S = (\omega_1 + \mu)v$$

$$V^* = \frac{\theta S^*}{\omega_1 + \mu}$$

From Equation (3.3)

$$(1-P)\frac{(\beta I + \gamma I_c)S}{1 + mS} - (\eta + d_2 + \mu)I + \alpha I_c = 0$$

$$\rho\frac{(\beta I + \gamma I_C)S}{1 + mS} - (\mu + d_1)I_C - \alpha I_C = 0 \qquad (4.1)$$

From eqn (3.3)

$$(1-P)\frac{PI + \gamma I_c)S}{1 + mS} = (\eta + d_2 + \mu)I - \alpha I_c$$

$$\Rightarrow (1-P)(\beta I + \gamma I_C)S = (\eta + d_2 + \mu)I - \alpha I_c + \left((\eta + d_2 + \mu)I - \alpha I_c\right)mS$$

$$\Rightarrow (1-P)(\beta I + \gamma I_C)S - \left[(\eta + d_2 + \mu)I - \alpha I_c\right]mS = (\eta + d_2 + \mu)I - \alpha I_c$$

$$S = \left[(1-P)(\beta I + \gamma I_C) - \left[(\eta + d_2 + \mu)I - \alpha I_c\right]m\right] = (\eta + d_2 + \mu)I - \alpha I_c$$

$$S^* = \frac{(\eta + d_2 + \mu)I - \alpha I_c}{\left[(1-P)(\beta I + \gamma I_C) - \left[(\eta + d_2 + \mu)I - \alpha I_c\right]m\right]} \qquad (4.2)$$

From Equation (3.4)

$$\frac{\rho(\beta I + \gamma I_C)S}{1 + mS} = (\mu + d_1)I_C - \alpha I_C$$

$$\rho(\beta I + \gamma I_C)S = \left((\mu + d_1)I_C - \alpha I_C(1 + mS)\right)$$

$$\rho(\beta I + \gamma I_C)S - \left[(\mu + d_1)I_C - \alpha I_C\right]mS = (\mu + d_1)I_C + \alpha I_C$$

$$S\left[\rho(\beta I + \gamma I_C) - \left[(\mu + d_1)I_C - \alpha I_C\right]m\right] = (\mu + d_1)I_C + \alpha I_C$$

$$S = \frac{(\mu + d_1 + \alpha)I_C}{\left[\rho(\beta I + \gamma I_C) - \left[(\mu + d_1)I_C - \alpha I_C\right]m\right]} \qquad (4.3)$$

Equating (3.3) And (3.4)

$$\frac{(\mu+d_1+\alpha)I_C}{\left[\rho(\beta I+\gamma I_C)-\left[(\mu+d_1)I_C-\alpha I_C\right]m\right]} = \frac{(\eta+d_2+\mu)I-\alpha I_c}{\left[(1-P)(\beta I+\gamma I_C)-\left[(\eta+d_2+\mu)I-\alpha I_c\right]m\right]}$$

$$(\mu+d_1+\alpha)I_C\left[(1-P)(\beta I+\gamma I_C)-\left[(\eta+d_2+\mu)I-\alpha I_c\right]m\right]=(\eta+d_2+\mu)I-\alpha I_c\left[\rho(\beta I+\gamma I_C)-\left[(\mu+d_1)I_C-\alpha I_C\right]m\right]$$

$$(\mu+d_1+\alpha)I_C(1-P)(\beta I+\gamma I_C)-(\mu+d_1+\alpha)I_C m\left((\eta+d_2+\mu)I-\alpha I_c\right)=\rho(\beta I+\gamma I_C)\left[(\eta+d_2+\mu)I-\alpha I_c\right]- \left((\mu+d_1+\alpha)I_C m\right)\left((\eta+d_2+\mu)I-\alpha I_c\right)$$

Adding $\left[\left((\mu+d_1+\alpha)I_C m\right)\left((\eta+d_2+\mu)I-\alpha I_c\right)\right]$ *to both sides*

$$(\mu+d_1+\alpha)I_C(1-p)(\beta I+\gamma I_C)=P(\beta I+\gamma I_C)\left[(\eta+d_2+\mu)I-\alpha I_c\right]$$

Dividethroughby $(\beta I+\gamma I_C)$

$$(\mu+d_1+\alpha)I_C(1-p)=P(\beta I+\gamma I_C)I-\alpha I_c$$

$$(\mu+d_1+\alpha)I_C(1-p)+\alpha PI_c=P(\mu+d_1+\alpha)I$$

$$I_c\left[(\mu+d_1+\alpha)(1-P)+\alpha P\right]=P(\eta+d_2+\mu)I$$

$$I_c\left[(\mu+d_1+\alpha)-\mu P-Pd_1-\alpha P+\alpha P\right]=P(\eta+d_2+\mu)I$$

$$I_c\left[(1-P)(\mu+d_1)+\alpha\right]=P(\eta+d_2+\mu)I$$

$$I_c^* = \frac{P(\eta+d_2+\mu)I}{(1-P)(\mu+d_1)+\alpha}$$

$$\frac{-\left[\mu(\omega_1+\theta+\mu)\left[P(\beta I+\gamma I_c)-\left((\mu+d_1)I_c+\alpha I_c\right)m\right]\right]P+\dfrac{\wedge P}{(\mu+d_1+\alpha)}+\dfrac{\eta+\omega_2 IP}{(\omega_2+\mu)(\mu+d_1+\alpha)}=I_c^*}{(\omega_1+\mu)(\mu+d_1+\alpha)^2 I_c}$$

$$\frac{-\mu(\omega_1+\theta+\mu)\left[P\beta I+P\gamma I_c-(\mu+d_1+\alpha)I_c m\right]P}{(\omega_1+\mu)(\mu+d_1+\alpha)^2 I_c}+\frac{\wedge P}{(\mu+d_1+\alpha)}+\frac{\eta+\omega_2 IP}{(\omega_2+\mu)(\mu+d_1+\alpha)}=I_c^*$$

$$\frac{-\left[\mu(\omega_1+\theta+\mu)(P\beta I+I_c\left(P\gamma-(\mu+d_1+\alpha)M\right)\right]P}{(\omega_1+\mu)(\mu+d_1+\alpha)^2 I_c}+\frac{\wedge P}{(\mu+d_1+\alpha)}+\frac{\eta+\omega_2 IP}{(\omega_2+\mu)(\mu+d_1+\alpha)}=I_c^*$$

$$\frac{-\mu(\omega_1+\theta+\mu)P^2\beta I}{(\omega_1+\mu)(\mu+d_1+\alpha)^2 I_c}-\frac{\mu(\omega_1+\theta+\mu)P(P\gamma-(\mu+d_1+\alpha)M}{(\omega_1+\mu)(\mu+d_1+\alpha)^2}+\frac{\wedge P}{(\mu+d_1+\alpha)}+\frac{\eta+\omega_2 IP}{(\omega_2+\mu)(\mu+d_1+\alpha)}=I_c^*$$

$$\frac{-(\mu(\omega_1+\theta+\mu)P(P\gamma-(\mu+d_1+\alpha))M)}{(\omega_1+\mu)(\mu+d_1+\alpha)^2}+\frac{\wedge P}{(\mu+d_1+\alpha)}+\frac{\eta+\omega_2 IP}{(\omega_2+\mu)(\mu+d_1+\alpha)}=\frac{I_c^*+\mu(\omega_1+\theta+\mu)P^2\beta}{(\omega_1+\mu)(\mu+d_1+\alpha)^2 I_c}$$

Multiply through by I_c

$$\frac{(-\mu(\omega_1+\theta+\mu)P(P\gamma-(\mu+d_1+\alpha))m)}{(\omega_1+\mu)(\mu+d_1+\alpha)^2}+\frac{\wedge P}{(\mu+d_1+\alpha)}-I_c^*=I\left[\frac{-\eta\omega_2 P}{(\omega_2+\mu)(\mu+d_1+\alpha)}+\frac{\mu(\omega_2+\theta)\mu P^2\beta}{(\omega_2+\mu)(\mu+d_1+\alpha)^2}\right]$$

$$I=\frac{(-\mu(\omega_1+\theta+\mu)P(P\gamma-(\mu+d_1+\alpha))m)+\wedge P(\omega_1+\mu)(\mu+d_1+\alpha)-I_c(\omega_2+\mu)(\mu+d_1+\alpha)^2}{(\omega_1+\mu)(\mu+d_1+\alpha)^2}$$

$$I=\frac{-\eta\omega_2 P(\omega_1+\mu)(\mu+d_1+\alpha)I_c+\mu(\omega_1+\theta+\mu)P^2\beta(\omega_2+\mu)}{(\omega_2+\mu)(\omega_1+\mu)(\mu+d_1+\alpha)^2 I_c}$$

$$I=\frac{I_c(\omega_2+\mu)(-\mu(\omega_1+\theta+\mu)P(P\gamma-(\mu+d_1+\alpha))m)+\wedge P(\omega_1+\mu)(\mu+d_1+\alpha)-I_c(\omega_1+\mu)(\mu+d_1+\alpha)^2}{-\eta\omega_2 P(\omega_1+\mu)(\mu+d_1+\alpha)I_c+\mu(\omega_1+\theta+\mu)P^2\beta(\omega_2+\mu)}$$

$$=\frac{((1-P)(\mu+d_1)+\alpha)I_c^*}{P(\eta+d_2+\mu)}$$

Dividing through by I_c^**; gives*

$$\frac{(\omega_2+\mu)(-\mu(\omega_1+\theta+\mu)P(P\gamma-(\mu+d_1+\alpha))m)+\wedge P(\omega_1+\mu)(\mu+d_1+\alpha)-I_c(\omega_1+\mu)(\mu+d_1+\alpha)}{-\eta\omega_2 P(\omega_1+\mu)(\mu+d_1+\alpha)I_c+\mu(\omega_1+\theta+\mu)}$$

$$=\frac{((1-P)(\mu+d_1)+\alpha}{P(\eta+d_2+\mu)}$$

$$\Rightarrow P(\eta+d_2+\mu)(\omega_2+\mu)(-\mu(\omega_1+\theta+\mu)P(P\gamma-(-\mu+d_1+\alpha))M+\wedge P(\omega_1+\mu)(\mu+d_1+\alpha)$$

$$-P(\eta+d_2+\mu)(\omega_2+\mu)I_c(\omega_1+\mu)(\mu+d_1+\alpha)]=((1-P)(\mu+d_1)+\alpha)$$

$$(-\eta\omega_2 P)(\omega_1+\mu)(\mu+d_1+\alpha)I_c((1-P)((1-P)(\mu+d_1)+\alpha)(\mu(\omega_1+\theta+\mu))$$

$$I_c\left[-P(\eta+d_2+\mu)(\omega_2+\mu)(\omega_1+\mu)(\mu+d_1+\alpha)+\eta\omega_2 P(\omega_1+\mu)(\mu+d_1+\alpha)^2(1-P)\right]$$

$$=-P(\eta+d_2+\mu)(\omega_2+\mu)\left[(-\mu(\omega_1+\theta+\mu)P(P\gamma-(-\mu+d_1+\alpha))m+\wedge P(\omega_1+\mu)(\mu+d_1+\alpha))\right]+((1-P)(\mu+d_1+\alpha)$$
$$\left(\mu(\omega_1+\theta+\mu)\right)$$

$$I_c^*=\frac{-P(\eta+d_2+\mu)(\omega_2+\mu)(-\mu(\omega_1+\theta+\mu)(P\gamma-(\mu+d_1+\alpha))mP-P\wedge(\omega_1+\mu)(\mu+d_1+\alpha))+((1-P)(\mu+d_1+\alpha)(\mu(\omega_1+\theta+\mu)}{-P-(\eta+d_2+\mu)(\omega_2+\mu)(\omega_1+\mu)(\mu+d_1+\alpha)+\eta\omega_2 P(\omega_1+\mu)(\mu+d_1+\alpha)^2(1-P)}$$

$$I_c^*=\frac{-(\eta+d_2+\mu)(\omega_2+\mu)(-\mu(\omega_1+\theta+\mu)(P\gamma-(\mu+d_1+\alpha))mP-P\wedge(\omega_1+\mu)(\mu+d_1+\alpha))+((1-P)(\mu+d_1+\alpha)(\mu(\omega_1+\theta+\mu)}{-(\eta+d_2+\mu)(\omega_2+\mu)(\omega_1+\mu)(\mu+d_1+\alpha)+\eta\omega_2 P(\omega_1+\mu)(\mu+d_1+\alpha)^2(1-P)} \quad (44)$$

If we substitute I_c^* into 3.1 we have I^*

$$I^*=\frac{-(1-P)(\mu+d_1+\alpha)(\omega_2+\mu)(-\mu(\omega_1+\theta+\mu)(P\gamma-(\mu+d_1+\alpha))mP-P\wedge(\omega_1+\mu)(\mu+d_1+\alpha))+((1-P)(\mu+d_1+\alpha)(\mu(\omega_1+\theta+\mu)}{-P-(\eta+d_2+\mu)(\omega_2+\mu)(\omega_1+\mu)(\mu+d_1+\alpha)+\eta\omega_2 P(\omega_1+\mu)(\mu+d_1+\alpha)^2(1-P)}$$

i.e

$$I^*=\frac{-P(\eta+d_2+\mu)(\omega_2+\mu)(-\mu(\omega_1+\theta+\mu)(P\gamma-(\mu+d_1+\alpha))mP-P\wedge(\omega_1+\mu)(\mu+d_1+\alpha))+((1-P)(\mu+d_1+\alpha)(\mu(\omega_1+\theta+\mu)}{-(\eta+d_2+\mu)(\omega_2+\mu)(\omega_1+\mu)(\mu+d_1+\alpha)+\eta\omega_2 P(\omega_1+\mu)(\mu+d_1+\alpha)^2(1-P)}$$

gives w

$$I^*=\frac{-(1-P)(\mu+d_1+\alpha)(\omega_2+\mu)(-\mu(\omega_1+\theta+\mu)(P\gamma-(\mu+d_1+\alpha))mP-P\wedge(\omega_1+\mu)(\mu+d_1+\alpha))+((1-P)(\mu+d_1+\alpha)(\mu(\omega_1+\theta+\mu)}{-P-(\eta+d_2+\mu)(\omega_2+\mu)(\omega_1+\mu)(\mu+d_1+\alpha)+\eta\omega_2 P(\omega_1+\mu)(\mu+d_1+\alpha)^2(1-P)}$$

Now putting I^* *in* $R^*=\dfrac{\eta I^*}{(\omega_2+\mu)}$ *gives new* R^*, I^*, I_c^* *in*

Hence

$$S^*=\frac{(\eta+d_2+\mu)I-\alpha I_c}{[(I-P)(\beta I+\alpha I_c)-(P\eta+d_2+\mu)I-\alpha I_c]\alpha} \quad (4.5)$$

2.4 Basic Reproduction Number

We Apply The Next Generation Matrix Technique

Then, If $G=FV^{-1}$

$$G=FV^{-1}$$

$$F=\begin{pmatrix}(I-P)\dfrac{(\beta I+\gamma I_c)S}{I+mS}\\ \dfrac{P(\beta I+\gamma I_c)S}{I+mS}\end{pmatrix} \quad \exp anding$$

$$V=\begin{pmatrix}-(\eta+d_2+\mu)I+\alpha I_c\\ -(\mu+d_1)I_c+\alpha I_c\end{pmatrix} \quad \exp anding$$

$$F=\begin{pmatrix}\dfrac{\delta f_1}{\delta I} & \dfrac{\delta f_1}{\delta I_c}\\ \dfrac{\delta f_2}{\delta I} & \dfrac{\delta f_2}{\delta I_c}\end{pmatrix}=\begin{pmatrix}\dfrac{(I-P)\beta S}{1+mS} & \dfrac{(I-P)\delta S}{1+mS}\\ \dfrac{P\beta S}{1+mS} & \dfrac{P\delta S}{1+mS}\end{pmatrix}$$

$$V=\begin{pmatrix}\dfrac{\delta V_1}{\delta I} & \dfrac{\delta V_1}{\delta I_c}\\ \dfrac{\delta V_2}{\delta I} & \dfrac{\delta V_2}{\delta I_c}\end{pmatrix}=\begin{pmatrix}-(\eta+d_2+\mu) & \alpha\\ 0 & -(\mu+d_1+\alpha)\end{pmatrix}$$

$$Since\ F=\begin{pmatrix}\dfrac{(I-P)\beta S}{1+mS} & \dfrac{(I-P)\delta S}{1+mS}\\ \dfrac{P\beta S}{1+mS} & \dfrac{P\delta S}{1+mS}\end{pmatrix}$$

$$and\ V=\begin{pmatrix}-(\eta+d_2+\mu) & \alpha\\ 0 & -(\mu+d_1+\alpha)\end{pmatrix}$$

simplifying

$$V^{-1}=\begin{pmatrix}\dfrac{-1}{(\eta+d2+\mu)} & \dfrac{-\alpha}{(\eta+d2+\mu)(\mu+d1+\alpha)}\\ 0 & \dfrac{-1}{(\mu+d1+\alpha)}\end{pmatrix}$$

substitute the value into

$$G=FV^{-1}$$

$$=\begin{pmatrix}\dfrac{(1-P)\beta S}{1+mS} & \dfrac{(1-P)\gamma S}{1+mS}\\ \dfrac{P\beta S}{1+mS} & \dfrac{P\gamma S}{1+mS}\end{pmatrix}\begin{pmatrix}\dfrac{-1}{(\eta+d2+\mu)} & \dfrac{-\alpha}{(\eta+d2+\mu)(\mu+d1+\alpha)}\\ 0 & \dfrac{-1}{(\mu+d1+\alpha)}\end{pmatrix} \quad (5.1)$$

The characteristics equation of (5.1)

$$=\begin{vmatrix}\dfrac{(P-1)\beta S}{1+mS(\eta+d2+\mu)}-\lambda & \dfrac{+\alpha(P-1)\beta S+(P-1)\gamma S(\eta+d2+\mu)}{(1+mS)(\eta+d2+\mu)(\mu+d1+\alpha)}\\ \dfrac{-P\beta S}{1+mS(\eta+d2+\mu)} & \dfrac{-\alpha P\beta S-P\gamma S(\eta+d2+\mu)}{(1+mS)(\eta+d2+\mu)(\mu+d1+\alpha)}-\lambda\end{vmatrix} \quad (5.2)$$

The Dominant Eigen Value Of 5.2 Is The Ro After Substituting The Value Of S^{o}i.E

$$R_0=\frac{\alpha(P-1)\beta(\wedge(\omega_1+\mu))+(P-1)\gamma\wedge(\omega_1+\mu)(\eta+d_2+\mu)}{(\mu(\theta+\omega_1+\mu)+m\wedge(\omega_1+\mu))(\eta+d_2+\mu)(\mu+d_1+\alpha)} \quad (5.3)$$

VI. LOCAL STABILITY OF DISEASE FREE EQUILIBRIUM

$$J(E_0)=\begin{bmatrix}\dfrac{d\dot S}{dS} & \dfrac{d\dot S}{dV} & \dfrac{d\dot S}{dI} & \dfrac{d\dot S}{dIc}\\ \dfrac{d\dot V}{dS} & \dfrac{d\dot V}{dV} & \dfrac{d\dot V}{dI} & \dfrac{d\dot V}{dIc}\\ \dfrac{d\dot{Ic}}{dS} & \dfrac{d\dot{Ic}}{dV} & \dfrac{d\dot{Ic}}{dI} & \dfrac{d\dot{Ic}}{dIc}\\ \dfrac{d\dot I}{dS} & \dfrac{d\dot I}{dV} & \dfrac{d\dot I}{d\dot{Ic}} & \dfrac{d\dot I}{dI}\end{bmatrix} \quad (6.1)$$

So That,

$$J(E_0)=\begin{vmatrix} -(\theta+\mu) & \theta & 0 & 0 \\ \omega_1 & -(\omega_1+\mu) & 0 & 0 \\ -\beta S & 0 & (1-\rho)\beta S^0-(\eta+d_2+\mu) & (1-\rho)\gamma s^0 \\ -\gamma S^0 & 0 & (1-\rho)\gamma S^0+\alpha & \rho\gamma S^0-(\eta+d_2+\mu) \end{vmatrix} \quad (6.2)$$

Let

$a=(1-\rho)\beta S^0-(\eta+d_2+\mu)$

$b=(1-\rho)\gamma S^0+\alpha$

$c=(1-\rho)\gamma s^0$

$d=\rho\gamma S^0-(\eta+d_2+\mu)$

Hence,

$$J(E_0)=\begin{vmatrix} -(\theta+\mu) & \omega_1 & -\beta S^0 & -\gamma S^0 \\ 0 & -(\omega_1+\mu) & 0 & 0 \\ 0 & 0 & (1-\rho)\beta S^0-(\eta+d_2+\mu) & (1-\rho)\gamma S^0+\alpha \\ 0 & 0 & \rho(\beta S) & \rho(\gamma S^0)-(\mu+d_1+\alpha) \end{vmatrix} \quad (6.3)$$

$$\text{Tr } J(E_0)=(1-\rho)\beta S^0+\rho(\gamma S^0)-(\mu+d_1+\alpha)-(\eta+d_2+\mu)-(\theta+\mu)-(\omega_1+\mu)$$
$$=(1-\rho)\beta S^0+\rho(\gamma S^0)-(4\mu+\omega_1+\eta+d_1+d_2+\alpha)+\omega_1+\eta+d_1+d_2+\alpha)$$

We Want To Show When $R_e<1$, That The "Routh-Hurwith Condition Hold, Namely Tr $(J(E_0)) < 0$ And Det $(J(E_0)) <0$ And Det $(J(E_0))>0$ If

$$(1-\rho)\beta S^0+\rho(\gamma S^0)<(4\mu+\theta+\omega_1+\eta+d_1+d_2+\alpha)$$

Then $Tr(J(E_0))<0$

$$J(E_0)=-(\theta+\mu)\begin{vmatrix} -(\theta+\mu) & 0 & 0 \\ 0 & a & c \\ 0 & b & d \end{vmatrix}-\theta\begin{vmatrix} \omega_1 & 0 & 0 \\ -\beta S & a & c \\ -\gamma S^0 & b & d \end{vmatrix}+0 \quad (6.4)$$

$$|J(E_0)|=(\theta+\mu)(\omega_1+\mu)(ad-bc)-\theta\omega_1(ad-bc)$$
$$=(ad-bc)\left[\theta\omega_1+\theta\mu+\mu\omega_1+\mu^2-\theta\omega_1\right]$$
$$=(ad-bc)\left[\mu(\theta+\omega_1+\mu)\right]$$

$$\text{Det } (J(E_0))=\mu(\theta+\omega_1+\mu)(\text{ad - bc})$$

Simplification gives

$$(\text{ad - bc})=\text{ad}\left(1-\frac{\text{bc}}{\text{ad}}\right)$$

$$\text{So, det}\left(J(E_0)\right)\mu(\theta+\omega_1+\mu)(ad-bc)=\mu(\theta+\omega_1+\mu)ad\left(1-\frac{bc}{ad}\right)$$

$$Where\ R_e=\frac{bc}{ad}$$

$$\det\left[J(E_0)\right]=\mu(\theta+\omega_1+\mu)(ad-bc)=\mu(\theta+\omega_1+\mu)ad\left(1-\frac{bc}{ad}\right)$$

$$Therefore\ \det\left[J(E_0)\right]>0\ if\ and\ only\ if\ R_e<1$$

VII. LOCAL STABILITY OF ENDEMIC EQUILIBRIUM

If We Let

$$J(E^*)=\begin{bmatrix} \frac{d\dot S}{dS} & \frac{d\dot S}{dV} & \frac{d\dot S}{dI} & \frac{d\dot S}{dIc} \\ \frac{d\dot V}{dS} & \frac{d\dot V}{dV} & \frac{d\dot V}{dI} & \frac{d\dot V}{dIc} \\ \frac{d\dot{I}c}{dS} & \frac{d\dot{I}c}{dV} & \frac{d\dot{I}c}{dI} & \frac{d\dot{I}c}{dIc} \\ \frac{d\dot I}{dS} & \frac{d\dot I}{dV} & \frac{d\dot I}{d\dot{I}c} & \frac{d\dot I}{dIc} \end{bmatrix} \quad (7.1)$$

$$J(E^*)=\begin{vmatrix} -(\theta+\mu) & \omega_1 & \frac{-\gamma S^*}{1+mS^*} & \frac{-\beta S^*}{(1+mS^*)} \\ \theta & -(\omega_1+\mu) & 0 & 0 \\ 0 & 0 & \frac{PS^*\gamma}{1+mS^*}-(\mu+d_1+\alpha) & \frac{P\beta S^*}{1+mS^*} \\ 0 & 0 & \frac{(1-\rho)\gamma S^*}{1+mS^*}+\alpha & \frac{(1-\rho)\beta S^*}{(1+mS^*)}-(\eta+d_2+\mu) \end{vmatrix} \quad (7.2)$$

$$\text{Tr } J(E^*)=\frac{(1-P)\beta S^*}{1+mS^*}+\frac{\rho\gamma S^*}{1+mS^*}-(\eta+d_1+\mu)-(\eta+d_2+\mu)-(\omega_1+\mu)-(\theta+\mu)$$
$$=\frac{(1\text{-p})\,\beta S^*}{1+mS^*}+\frac{\rho\gamma S^*}{1+mS^*}-(4\mu+\theta+\omega\ \ +\eta+d_1+d_2+\alpha)$$

We Want To Show, That $R_e<1$ That The Routh-Hurwith Condition Hold Namely Tr $(J(E^*)) <0$ And Dettr $(J(E^*))>0$ If

$$\frac{(1\text{-p})\,\beta S^*}{1+mS^*}+\frac{\rho\gamma S^*}{1+mS^*}<4(\mu+\theta+\omega\ \ +\eta+d_1+d_2+\alpha)$$

Then Tr $(J(E^*))<0$

Also,

$$J(E^*)=\begin{vmatrix} -(\theta+\mu) & \omega_1 & \frac{-\gamma S^*}{1+mS^*} & \frac{-\beta S}{1+mS^*} \\ 0 & -(\omega_1+\mu) & 0 & 0 \\ 0 & 0 & \frac{PS^*\gamma}{1+mS^*}-(\mu+d_1+\alpha) & \frac{(I-P)\gamma S^*}{1+mS^*}+\alpha \\ 0 & 0 & \frac{\rho\beta S^*}{1+mS^*} & \frac{(I-P)\beta S^*}{1+mS^*}-(\eta+d_2+\mu) \end{vmatrix} \quad (7.3)$$

Change Of Row And Column By Determinant Properties So,

$$J(E^*)=\begin{vmatrix} -(\theta+\mu) & \theta & 0 & 0 \\ \omega_1 & -(\omega_1+\mu) & 0 & 0 \\ \frac{-\gamma S^*}{1+mS^*} & 0 & \frac{PS^*\gamma}{1+mS^*}-(\mu+d_1+\alpha) & \frac{(I-P)\gamma S^*}{1+mS^*}+\alpha \\ \frac{-\beta S}{1+'mS^*} & 0 & \frac{P\beta S^*}{1+mS^*} & \frac{(I-P)\beta S^*}{1+mS^*}-(\eta+d_2+\mu) \end{vmatrix}$$

.

.

$$Let\ e=\frac{PS^*\gamma}{1+mS^*}-(\mu+d_1+\alpha)$$

$$f=\frac{P\beta S^*}{1+mS^*}$$

$$g=\frac{(I-P)\gamma S^*}{1+mS^*}+\alpha$$

$$h=\frac{(I-P)\beta S^*}{1+mS^*}-(\eta+d_2+\mu)$$

$$|J(E^*)|=\begin{vmatrix} -(\theta+\mu) & \theta & 0 & 0 \\ \omega_1 & -(\omega_1+\mu) & 0 & 0 \\ \frac{-\gamma S^*}{1+mS^*} & 0 & e & g \\ \frac{-\beta S}{1+mS^*} & 0 & f & h \end{vmatrix} \quad (7.4)$$

$$\left|J(E^*)\right| = (\theta+\mu)(\omega_1+\mu)(eh-fg) - \theta\omega_1(eh-fg)$$

$$= (eh-fg)\left[\theta\omega_1 + \theta\mu + \mu\omega_1 + \mu^2 - \theta\omega_1\right]$$

$$= (eh-fg)\left[\mu(\theta+\omega_1+\mu)\right]$$

$$\det(J(E^*)) = \mu(\theta+\omega_1+\mu)(eh-fg)$$

Simplification gives

$$(eh-fg) = eh\left(1-\frac{fg}{eh}\right)$$

$$So, \det(J(E^*)) = \mu(\theta+\omega_1+\mu)(eh-fg) = \mu(\theta+\omega_1+\mu)eh\left(1-\frac{fg}{eh}\right)$$

$$Where\ R_e = \frac{fg}{eh}$$

$$\det(J(E^*)) = \mu(\theta+\omega_1+\mu)eh(1-R_e)$$

Therefore, $\det(J(E^*)) > 0$ if and only if $R_e < 1$

VIII. GLOBAL STABILITY

Note : $\frac{dv}{dt} = V_x \cdot x + V_y \cdot y$

Disease Free-Equilibrium At Global Stability

To Investigate The Global Stability Of X_0, Consider The Lyapunov Function.

$$L(I_c, I) = I + \varepsilon I_c \qquad (8.1)$$

We Take Asymptotic Infectious And Symptomatic Infectious, $L(I_c, I) \le 0$ For $R_0 \le 1$

We Take The Derivative Of Equation (8.1) Gives

$$\dot{L}(I_c, I) = \dot{I} + \varepsilon \dot{I}_c$$

$$If\ we\ substitute\ \dot{I} = \frac{dI}{dt} = \frac{(1-p)(\beta I + \gamma I_c)}{1+mS} - (\eta + d_2 + \mu)I + \alpha I_c$$

$$And\ I_c = \frac{(\beta I + \gamma I_c)S}{1+mI} - (\eta + d_2 + \mu)I \text{ into} \qquad (8.2)$$

$$\dot{L}(I_c, I) = \frac{(1-p)(\beta I + \gamma I_c)S}{1+ms} - (\eta + d_2 + \mu)I + \alpha I_c + \varepsilon\left[\frac{p(\beta I + \gamma I_c)S}{1+ms} - (\alpha + d_2 + \mu)I_c\right]$$

$$\frac{dL}{dt} = \frac{(\beta I + \gamma I_c)S}{(1+mS^*)} - \frac{p(\beta I + \gamma I_c)S}{1+ms} - (\eta + d_2 + \mu)I + \alpha I_c + \frac{p(\beta I + \gamma I_c)S}{1+ms} - (\mu + d_1 + \alpha)I_c\varepsilon$$

$$\frac{dL}{dt} = \frac{(\beta I + \gamma I_c)\wedge(\omega_1+\mu)(1-P) + P\varepsilon}{\mu(1+mS)(\theta+\omega_1+\mu)} - (\eta + d_2 + \mu)I - \left((\mu + d_1 + \alpha)\varepsilon - \alpha\right)I_c$$

$$Let\ \frac{(\beta I + \gamma I_c)\wedge(\omega_1+\mu)(1-P) + P\varepsilon}{\mu(1+mS)(\theta+\omega_1+\mu)} = 0$$

$$\Rightarrow (\beta I + \gamma I_c)\wedge(\omega_1+\mu)(1-P) + P\varepsilon = 0$$

$$then\ \wedge = 0,\ (\beta I + \gamma I_c) = 0,\ (\omega_1+\mu) = 0,\ 1 - P + P\varepsilon = 0$$

Note: If Abcd=0 Then A=0, B=0, C=0, D=0.

$$\omega_1 + \mu = 0 \qquad \mu = -\omega_1$$

$$\frac{dL}{dt} = -(\eta + d_2 + \omega_1)I - ((-\omega_1 + d_1 + \alpha)\varepsilon - \alpha)I_c$$

Since $\varepsilon > 0$ And Sufficiently Small And $\delta > 0$ Then

$$\frac{dL}{dt} = -(\eta + d_2 + \omega_1)I - ((-\omega_1 + d_1 + \alpha)\varepsilon - \alpha)I_c \le \delta L$$

Then $\dot{L} < 0 \ \forall\ L \ne L^*$

Thus $\dot{L}^*$ Is Globally Stable For All Initial Conditions

$$L(t) \to L^*\ as\ t \to \infty$$

IX. ANALYSIS OF CONTROL STRATEGIES FOR DISEASE FREE EQUILIBRIUM

$$R_e = \frac{bc}{ad} = \frac{\left[(1-P)\gamma S^0 + \alpha\right]\left[P\beta S^0\right]}{\left[(1-P)\beta S^0 - (\eta+d_2+\mu)\right]\left[P\gamma S^0 - (\eta+d_1+\alpha)\right]} \qquad (9.1)$$

$$= \frac{(1-P)P\beta S^0\gamma + \alpha P\beta S^0}{(1-P)\beta S^0 P\gamma - P\gamma S^0(\eta+d_2+\mu) - (1-P)\beta S^0(\eta+d_1+\alpha) + (\eta+d_1+\alpha)(\eta+d_2+\mu)}$$

$$\frac{\delta R_e}{\delta\gamma} = \frac{(1-P)\beta S^0 P\gamma - P\gamma S^0(\eta+d_2+\mu) + (1-P)\beta S^0 - (\eta+d_2+\alpha) + (\eta+d_2+\mu) + \eta + d_2(1-P)P\beta S}{\left[(1-P)\beta S^0 P\gamma - P\gamma S^0(\eta+d_2+\mu) - (1-P)\beta S^0(\eta+d_1+\alpha) + (\eta+d_1+\alpha)(\eta+d_2+\mu)\right]^2} \qquad (9.2)$$

$$\frac{\delta R_e}{\delta\gamma} = \frac{\left[1-(1-P)^2\beta^2 S^{0^2} P(\eta+d_1+\alpha) + (1-P)P\beta S^0(\eta+d_1+\alpha) + (\eta+d_2+\mu)\right] - \alpha P\beta S^0(1-P)\beta^2 S^0 P - pS^0(\eta+d_2+\alpha)}{\left[(1-P)\beta S^0 P\gamma - P\gamma S^0(\eta+d_2+\mu) - (1-P)\beta S^0(\eta+d_1+\alpha) + (\eta+d_1+\alpha)(\eta+d_2+\mu)\right]}$$

$$= \frac{S^0\beta P\left[\left[-(1-P)^2\beta S^0(\eta+d_1+\alpha) + (1-P)(\eta+d_1+\alpha) + (\eta+d_2+\mu)\right] - \alpha(1-P)\beta S^0 P - pS^0(\eta+d_2+\alpha)\right]}{S^0\left[(1-P)\beta S^0 P\gamma - P\gamma(\eta+d_2+\mu) - (1-P)\beta(\eta+d_1+\alpha) + (\eta+d_1+\alpha)(\eta+d_2+\mu\times\frac{1}{S^0})^2\right]} \qquad (9.3)$$

It is really clear that R_e increases as γ increases. This agrees with the *believe* that higher transimibility increases the basic reproduction number.

To see the effect of P on R_e *we note that,*

$$\frac{\delta R_e}{\delta p} = (1-P)\beta S^0 - (\eta+d_2+\mu)\left[P\gamma S^0 - (\eta+d_1+\alpha)(1-P)\gamma S^0 + \alpha\right]\beta S^0 + \left[P\beta S^0\right]\left[\gamma S^0\right] - (1-P)\gamma S^0 + \alpha]$$

$$= P\beta S^0 - (\eta+d_2+\mu)\left[\gamma S^0\right] + P\gamma S^0 - (\eta+d_1+\alpha)\left[\beta S^0\right]$$

$$\frac{\delta R_e}{\delta p} = \frac{\wedge(\omega_1+\mu)}{\mu(\theta+\omega_1+\mu)}\left(\frac{\gamma}{\mu+d_1+\alpha} + \frac{\alpha\beta}{(\mu+d_2+\mu)(\mu+d_1+\alpha)} - \frac{\beta}{(\mu+d_2+\mu)}\right)$$

$$\frac{\delta R_e}{\delta p} = \frac{\wedge(\omega_1+\mu)}{\mu(\theta+\omega_1+\mu)}\left(\frac{\gamma(\mu+d_2+\mu) + \alpha\beta(-\beta(\mu+d_1+\alpha)}{(\mu+d_1+\alpha)(\mu+d_2+\mu)}\right)$$

$$Thus,\ \frac{\delta R_e}{\delta p} > 0\ provided\ \gamma > \frac{\beta(\mu+d_1) - \alpha(1-\beta)}{(\mu+d_2+\mu)} \qquad (9.4)$$

Also from equation (2) after inputting the value of $S^0 = \frac{\wedge(\omega_1+\mu)}{\mu(\theta+\omega_1+\mu)}$ *we have,*

$$\frac{\delta R_e}{\delta p} = \frac{-k(a+b+c)}{(\theta+\omega_1+\mu)} \qquad (9.5)$$

$$Where\ k = \frac{\wedge(\omega_1+\mu)}{\mu(\theta+\omega_1+\mu)}$$

$$a = \frac{(1-P)\beta}{(\mu+d_2+\eta)}$$

$$b = \frac{P\gamma}{(\mu+d_1+\alpha)}$$

$$c = \frac{P\alpha\beta}{(\mu+d_2+\eta)(\mu+d_1+\alpha)}$$

X.SENSITIVITY ANALYSIS OF Re

$$\gamma_{\theta}^{R_e}=\frac{\delta R_e}{\delta\theta}\times\frac{\theta}{R_e}$$

$$=\frac{-k(a+b+c)}{(\theta+\omega_1+\mu)^2}\times\left[\frac{\frac{\theta}{\wedge(\omega_1+\mu)}}{\mu(\theta+\omega_1+\mu)\left[\frac{(1-P)\beta}{(\mu+d_2+\eta)}+P\frac{\gamma}{(\mu+d_1+\alpha)}+\frac{\alpha\beta}{(\mu+d_2+\eta)(\mu+d_1+\alpha)}\right]}\right] \quad (101)$$

$$=\left(\frac{\wedge(\omega_1+\mu)(1-P)\beta}{(\mu+d_2+\eta)\mu(\theta+\omega_1+\mu)^3}+\frac{P\gamma\wedge(\omega_1+\mu)}{\mu(\theta+\omega_1+\mu)^3(\mu+d_1+\alpha)}+\frac{P\gamma\beta\wedge(\omega_1+\mu)}{(\mu+d_2+\eta)(\mu+d_1+\alpha)\mu(\theta+\omega_1+\mu)^3}\right)$$

$$\times$$

$$\left(\frac{\theta}{\frac{\wedge(\omega_1+\mu)(1-P)\beta}{(\mu+d_2+\eta)\mu(\theta+\omega_1+\mu)^3}+\frac{P\gamma\wedge(\omega_1+\mu)}{\mu(\theta+\omega_1+\mu)^3(\mu+d_1+\alpha)}+\frac{P\gamma\beta\wedge(\omega_1+\mu)}{(\mu+d_2+\eta)(\mu+d_1+\alpha)\mu(\theta+\omega_1+\mu)^3}}\right)$$

$$=\frac{\wedge(\omega_1+\mu)(1-P)\beta P\gamma\wedge(\omega_1+\mu)(\mu+d_2+\eta)+P\alpha\beta\wedge(\omega_1+\mu)}{\mu(\theta+\omega_1+\mu)^3(\mu+d_2+\eta)(\mu+d_1+\alpha)}$$

$$\times$$

$$\left(\frac{\theta}{\frac{\wedge(\omega_1+\mu)(1-P)\beta P\gamma\wedge(\omega_1+\mu)(\mu+d_2+\eta)+P\alpha\beta\wedge(\omega_1+\mu)}{\mu(\theta+\omega_1+\mu)^3(\mu+d_2+\eta)(\mu+d_1+\alpha)}}\right) \quad (102)$$

$$\gamma_{\theta}^{R_e}=\frac{\theta}{\mu(\theta+\omega_1+\mu)^2}=\frac{\theta}{(\theta+\omega_1+\mu)^2}$$

$$Hence\,\gamma_{\theta}^{R_e}=\frac{\theta}{(\theta+\omega_1+\mu)^2} \quad (103)$$

XI. RESULTS AND DISCUSSION

11.1 Results

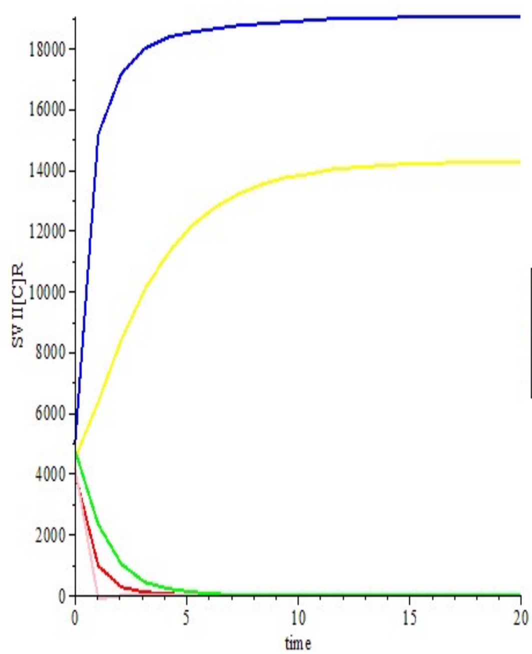

Figure 1: M=0.01

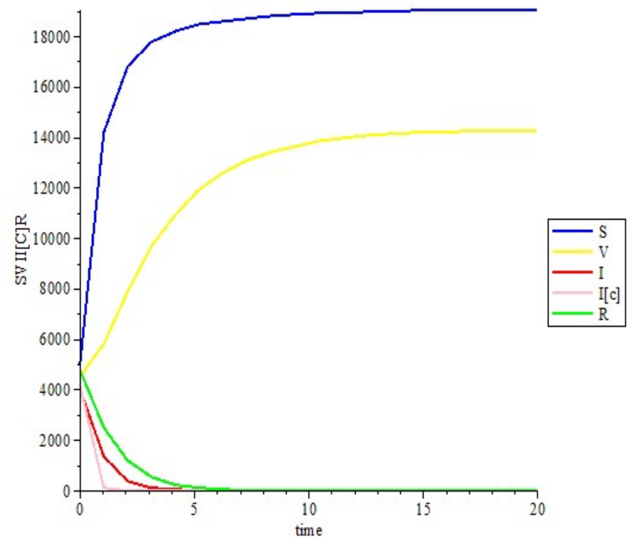

Figure 2: M=0.5

At M=10

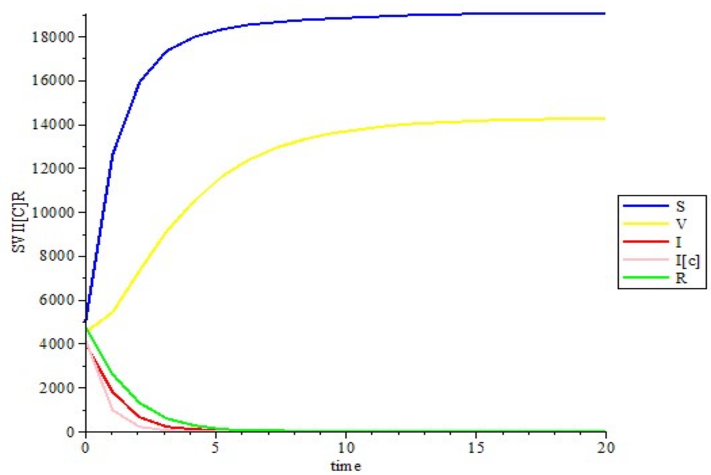

Figure 3: M=1.0

11.2 Discussion

Figure 1-3, Reveals The Effect Of General Knowledge In Eradicating Typhoid Fever. It Implies That At M=0.01, The Susceptible Class Increases Slightly. But At M=0.5 And 1.0, The Susceptibleclass Increases Drastically While Infected Reduces To The Minimum.

XII. CONCLUSIONS

The Simulation Results Reveals The Effect Of The General Knowledge, That Is The Lower The General Knowledge m The Little Higher The Susceptible Compartment, Because Of The Presence Of Other Parameters. Also, The Higher The General Knowledge The Highest Level Of Susceptible Class Is Observed. This Means, When There's Presence Of Vaccination, Treatment And General Knowledge, There Is High Tendency For Disease Eradication. It Is Also Clearly

Show That General Knowledge Play Vital Role Than Education In Disease Eradication. Hence Education Is More Than Schooling.

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