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Mathematical Modeling of Dengue Virus Control and Vaccination Method

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Abstract

Abstract

Numerical modeling of communicable disease is a device to grow the instrument in what way syndrome pushovers and in what way stately. we have studied numerically the dengue virus. We frame an entirely endless Non-Standard Finite Difference (NSFD) structure for a mathematical model of dengue virus. The familiarize numerical array is bounded, dynamically designate and contain the positivity of the solution, which is one of the important requirements when modeling a prevalent contagious. The comparison between the innovative Non-Standard Finite Alteration structure, Euler method and Runge-Kutta scheme of order four (RK-4) displays the usefulness of the suggested Non-Standard Finite Alteration scheme. NSFD scheme shows convergence to the exact equilibrium facts of the model for any time steps used but Euler and RK-4 fail for large time steps.

Keywords: Dengue Virus; BIREME; Mesh; NLM; Convergence

Abbreviations: DFE: Disease Free Equilibrium; EE: Endemic Equilibrium; NSFD: Non-Standard Finite Difference; SEIT: Susceptible Exposed Infected and Treated; RK-4: Runge-Kutta Scheme of Order Four.

Introduction

The mathematical modeling for dengue skilled insolence to produce the behavior of condition peoples and the basis, nearly talented hearings of the shown to the stop infection [1-5]. Dynamical models for the spread of ailment objects in a public people, recognized the Kermack and McKendrick SEIR traditional endemic model of suggested [6-9] (Figure 1). Now models bring assessments aimed at consecutive progression of verminous lumps in a people [10–14]. Present day build completely convergent to the algebraic model for the broadcast diminuendos for Dengue who saves the dangerous monies of the relentless model [15-17].

Mathematical Model

Variables and Parameters

s(t):	Susceptible entities class at time t.
e(t):	Exposed individuals' class at time t.
i(t):	Infected individuals' class at time t.
r(t):	Recover individuals' class at time t.
μ_h:	Rates per-capita mortality human.
β_h:	Force of infection human susceptible.
γ_h:	Period of virus rate in human.

σ_h: Recover period rate in human.
$M_1(t)$: Ovipositional Rate of treatment.
$M(t)$: Ovipositional induced mortality rate.

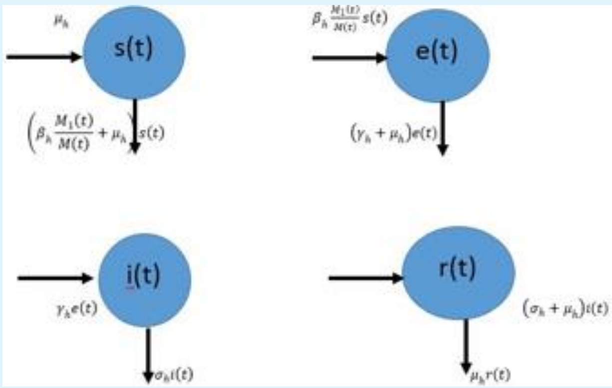

Figure 1: SEIT Dengue Disease Model.

The Scheme of Nonlinear Differential Equations (DE) on behalf of the Typical remains specified by:

$$s'(t) = \mu_h - \left(\beta_h \frac{M_1(t)}{M(t)} + \mu_h\right) s(t)$$
$$e'(t) = \beta_h \frac{M_1(t)}{M(t)} s(t) - (\gamma_h + \mu_h) e(t) \quad (1)$$
$$i'(t) = \gamma_h e(t) - (\sigma_h + \mu_h) i(t)$$
$$r'(t) = \sigma_h i(t) - \mu_h r(t)$$

Analysis of the Model

We describe two equilibrium points of system i.e Disease free equilibrium(DFE) and Endemic equilibrium(EE). $\mathcal{E}_1 = (\beta_h \frac{M_1(t)}{M(t)}, 0,0,0)$ and $\mathcal{E}_2 = (s^*, e^*, i^*, r^*)$ are stability facts of scheme (1), where

$$s^* = \frac{\mu_h}{\beta_h \frac{M_1(t)}{M(t)} + \mu_h}$$
$$e^* = \left(\beta_h \frac{M_1(t)}{M(t)}\right)\left(\frac{\mu_h}{\beta_h \frac{M_1(t)}{M(t)} + \mu_h}\right)\left(\frac{1}{\gamma_h + \mu_h}\right)$$
$$i^* = \left(\beta_h \frac{M_1(t)}{M(t)}\right)\left(\frac{\mu_h}{\beta_h \frac{M_1(t)}{M(t)} + \mu_h}\right)\left(\frac{\gamma_h}{\gamma_h + \mu_h}\right)\left(\frac{1}{\sigma_h + \mu_h}\right)$$
$$r^* = \left(\beta_h \frac{M_1(t)}{M(t)}\right)\left(\frac{1}{\beta_h \frac{M_1(t)}{M(t)} + \mu_h}\right)\left(\frac{\gamma_h}{\gamma_h + \mu_h}\right)\left(\frac{\sigma_h}{\sigma_h + \mu_h}\right)$$

Where $R_0 = \frac{\gamma_h e(t)}{\sigma_h + \mu_h}$

R_0 recognized as Procreative integer who describes the usual number of inferior impurities introduced of the main impurity. $\mathcal{R}_0$ is a beginning influence who describe the disease of the exit or persist? If $\mathcal{R}_0 < 1$ *then* we say that the scheme will be observed disease Free Equilibrium (DFE) and iff $\mathcal{R}_0 > 1$ the scheme to involvement Endemic Equilibrium (EE).

Numerical Modeling

Now we have conferred two standard finite difference structures to unravel the endless dynamical scheme (1) i.e. Euler's Method and Runge-Kutta Method of Order 4 (Figures 2-5).

Characterization of the Euler Technique

The Forward Euler's Structure for the unceasing model (1) certain through:

$$s^{n+1}(t) = s^n(t) + h[\mu_h - \left(\beta_h \frac{M_1(t)}{M(t)} + \mu_h\right) s^n(t)]$$

$$e^{n+1}(t) = e^n(t) + h[\beta_h \frac{M_1(t)}{M(t)} s^n(t) - (\gamma_h + \mu_h) e^n(t)] \quad (2)$$
$$i^{n+1}(t) = i^n(t) + h[\gamma_h e^n(t) - (\sigma_h + \mu_h) i^n(t)]$$
$$r^{n+1}(t) = r^n(t) + h[\sigma_h i^n(t) - \mu_h r^n(t)]$$

Numerical Experiments

Now solve numerical tryouts by expending the values of given parameters Table 1 [6].

Parameters	Values	
	DFE	EE
μ_h	4.2E-05	0.0004
β_h	0.375	0.75
γ_h	0.1	0.2
σ_h	0.143	0.14
$M_1(t)$	1	1
$M(t)$	0.33	0.33

Table 1: Numerical tryouts

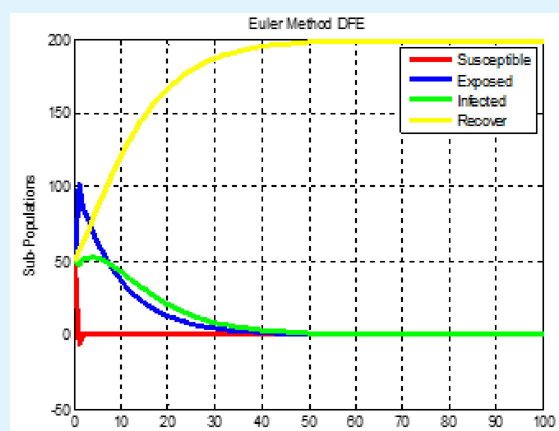

Figure 2: Euler Method (DFE), $h = 1$.

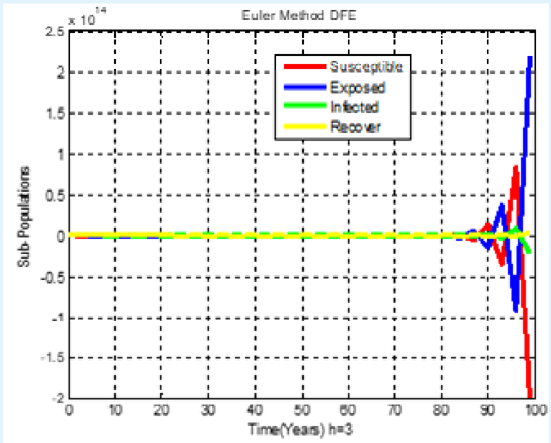

Figure 3: Euler Method (DFE), $h = 3$.

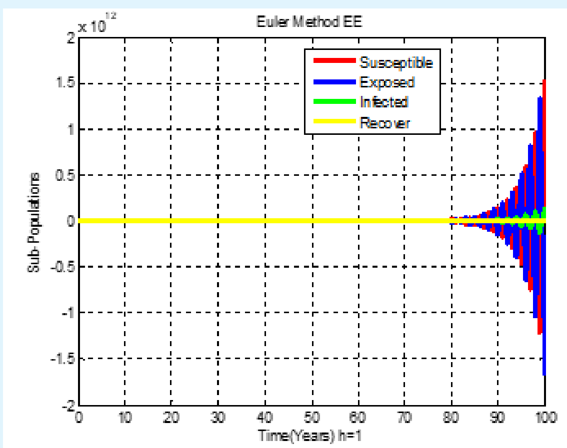

Figure 4: Euler Method (EE), $h = 1$.

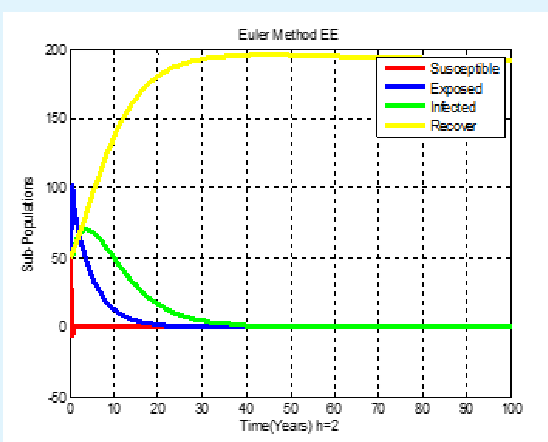

Figure 5: Euler Method (EE), $h = 0.5$.

Characterization of the Fourth Order Runge-Kutta Technique

For Stage-1

$$k_1 = h[\mu_h - \left(\beta_h \frac{M_1(t)}{M(t)} + \mu_h\right) s^n(t)]$$

$$l_1 = h[\beta_h \frac{M_1(t)}{M(t)} s^n(t) - (\gamma_h + \mu_h) e^n(t)] \quad (3)$$

$$m_1 = h[\gamma_h e^n(t) - (\sigma_h + \mu_h) i^n(t)]$$

$$n_1 = h[\sigma_h i^n(t) - \mu_h r^n(t)]$$

For Stage-2

$$k_2 = h[\mu_h - \left(\beta_h \frac{M_1(t)}{M(t)} + \mu_h\right)(s^n(t) + \tfrac{k_1}{2})]$$

$$l_2 = h[\beta_h \frac{M_1(t)}{M(t)}\left(s^n(t) + \tfrac{k_1}{2}\right) - (\gamma_h + \mu_h)\left(e^n(t) + \tfrac{l_1}{2}\right)]$$

$$m_2 = h[\gamma_h (e^n(t) + \tfrac{l_1}{2}) - (\sigma_h + \mu_h)(i^n(t) + \tfrac{m_1}{2})]$$

$$n_2 = h[\sigma_h (i^n(t) + \tfrac{m_1}{2}) - \mu_h (r^n(t) + \tfrac{n_1}{2})]$$

For Stage-3

$$k_3 = h[\mu_h - \left(\beta_h \frac{M_1(t)}{M(t)} + \mu_h\right)(s^n(t) + \tfrac{k_2}{2})]$$

$$l_3 = h[\beta_h \frac{M_1(t)}{M(t)}\left(s^n(t) + \tfrac{k_2}{2}\right) - (\gamma_h + \mu_h)\left(e^n(t) + \tfrac{l_2}{2}\right)]$$

$$m_3 = h[\gamma_h (e^n(t) + \tfrac{l_2}{2}) - (\sigma_h + \mu_h)(i^n(t) + \tfrac{m_2}{2})]$$

$$n_3 = h[\sigma_h (i^n(t) + \tfrac{m_2}{2}) - \mu_h (r^n(t) + \tfrac{n_2}{2})]$$

For Stage-4

$$k_4 = h[\mu_h - \left(\beta_h \frac{M_1(t)}{M(t)} + \mu_h\right)(s^n(t) + k_3)]$$

$$l_4 = h[\beta_h \frac{M_1(t)}{M(t)}(s^n(t) + k_3) - (\gamma_h + \mu_h)(e^n(t) + l_3)]$$

$$m_4 = h[\gamma_h (e^n(t) + l_3) - (\sigma_h + \mu_h)(i^n(t) + m_3)]$$

$$n_3 = h[\sigma_h (i^n(t) + m_3) - \mu_h (r^n(t) + n_3)]$$

Finally

$$s^{n+1} = s^n + \tfrac{1}{6}[k_1 + 2k_2 + 2k_3 + k_4]$$

$$e^{n+1} = e^n + \tfrac{1}{6}[l_1 + 2l_2 + 2l_3 + l_4]$$

$$i^{n+1} = i^n + \tfrac{1}{6}[m_1 + 2m_2 + 2m_3 + m_4] \quad (4)$$

$$r^{n+1} = r^n + \tfrac{1}{6}[n_1 + 2n_2 + 2n_3 + n_4]$$

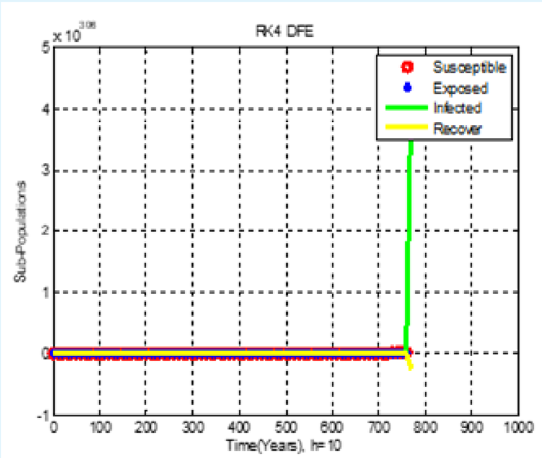

Figure 6: RK-4 Method (DFE), $h = 10$.

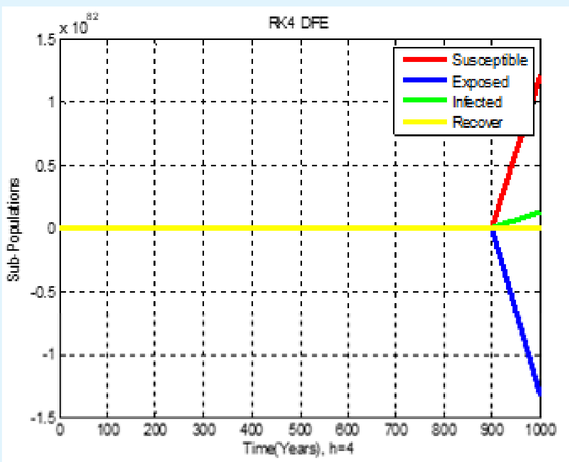

Figure 7: RK-4 Method (DFE), $h = 4$.

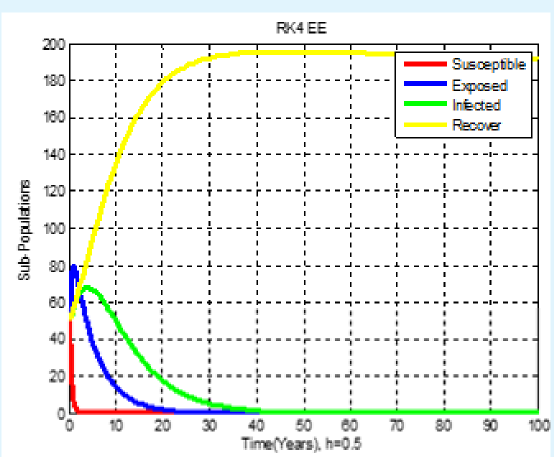

Figure 8: RK-4 Method (EE), $h = 200$.

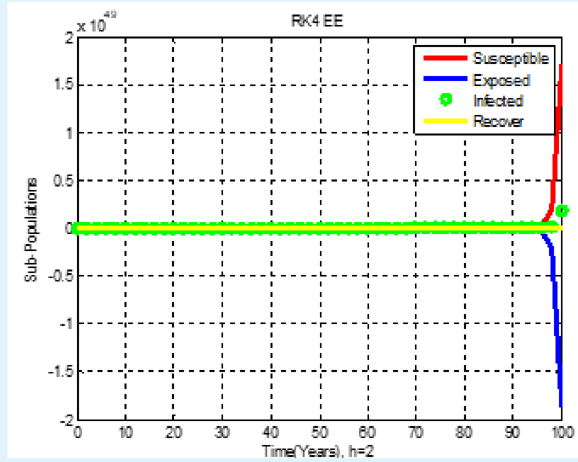

Figure 9: RK-4 Method (EE), $h = 2$.

Non-Standard Finite Difference Model

We display absolutely convergent non-standard finite difference (NSFD). So that the covergenence learning of the recommended building. So

$$s^{n+1} = \frac{s^n(t)+h\mu_h}{1+h\left(\beta_h\frac{M_1(t)}{M(t)}+\mu_h\right)}$$

$$e^{n+1} = \frac{e^n(t)+h\beta_h\frac{M_1(t)}{M(t)}s^n(t)}{1+h(\gamma_h+\mu_h)}$$

$$i^{n+1} = \frac{i^n(t)+h\gamma_h e^n(t)}{1+h(\sigma_h+\mu_h)}$$

$$r^{n+1} = \frac{r^n(t)+h\sigma_h i^n(t)}{1+h\mu_h}$$

Convergence Analysis of NSFD Scheme

Let us define

$$E = \frac{s+h\mu_h}{1+h\left(\beta_h\frac{M_1(t)}{M(t)}+\mu_h\right)}$$

$$F = \frac{e+h\beta_h\frac{M_1(t)}{M(t)}s}{1+h(\gamma_h+\mu_h)}$$

$$G = \frac{i+h\gamma_h e}{1+h(\sigma_h+\mu_h)}$$

$$H = \frac{r+h\sigma_h i}{1+h\mu_h}$$

Now the Jacobian Matrix is given by

$$J=\begin{bmatrix}\frac{\partial E}{\partial s} & \frac{\partial E}{\partial e} & \frac{\partial E}{\partial i} & \frac{\partial E}{\partial r}\\ \frac{\partial F}{\partial s} & \frac{\partial F}{\partial e} & \frac{\partial F}{\partial i} & \frac{\partial F}{\partial r}\\ \frac{\partial G}{\partial s} & \frac{\partial G}{\partial e} & \frac{\partial G}{\partial i} & \frac{\partial G}{\partial r}\\ \frac{\partial H}{\partial s} & \frac{\partial H}{\partial e} & \frac{\partial H}{\partial i} & \frac{\partial H}{\partial r}\end{bmatrix}$$

At DiseaseFree Equilibrium $\mathcal{E}_1=(\beta_h\frac{M_1(t)}{M(t)},0,0,0)$

At Endemic Equilibrium

$$\mathcal{E}_1=\Big(\frac{\mu_h}{\beta_h\frac{M_1(t)}{M(t)}+\mu_h},\left(\beta_h\frac{M_1(t)}{M(t)}\right)\left(\frac{\mu_h}{\beta_h\frac{M_1(t)}{M(t)}+\mu_h}\right)\left(\frac{1}{\gamma_h+\mu_h}\right),\left(\beta_h\frac{M_1(t)}{M(t)}\right)\left(\frac{\mu_h}{\beta_h\frac{M_1(t)}{M(t)}+\mu_h}\right)\left(\frac{\gamma_h}{\gamma_h+\mu_h}\right)\left(\frac{1}{\sigma_h+\mu_h}\right),$$
$$\left(\beta_h\frac{M_1(t)}{M(t)}\right)\left(\frac{1}{\beta_h\frac{M_1(t)}{M(t)}+\mu_h}\right)\left(\frac{\gamma_h}{\gamma_h+\mu_h}\right)\left(\frac{\sigma_h}{\sigma_h+\mu_h}\right)\Big)$$

Numerical Experiments

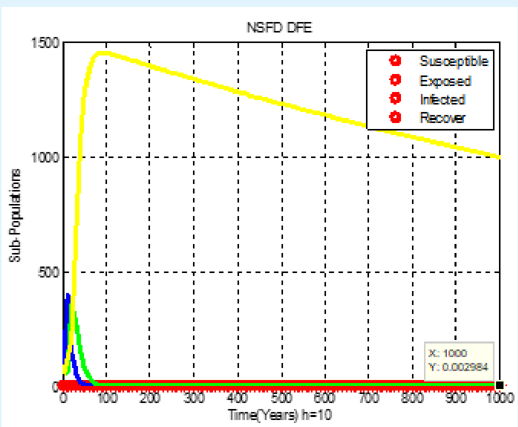

Figure 10: NSFD Method (DFE), $h=10$.

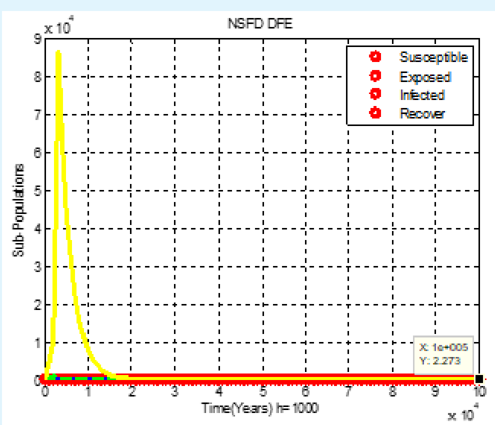

Figure 11: NSFD Method (DFE), $h=1000$.

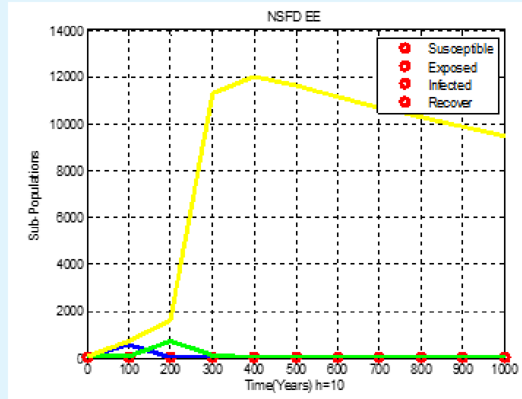

Figure 12: NSFD Method (EE), $h=10$.

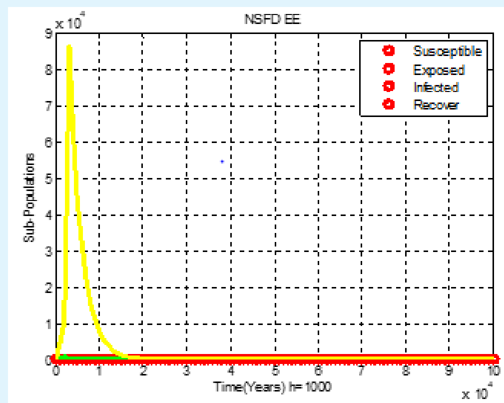

Figure 13: NSFD Method (EE), $h=1000$.

Comparison Analysis

In this section, we see the comparison among of two standard difference schemes and non-standard difference scheme in epidemiology (Figures 14-19).

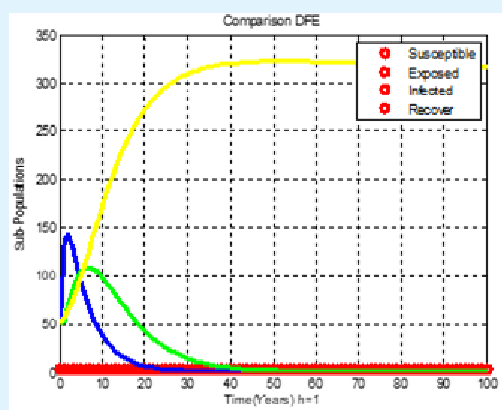

Figure 14: Comparison (DFE), h=1.

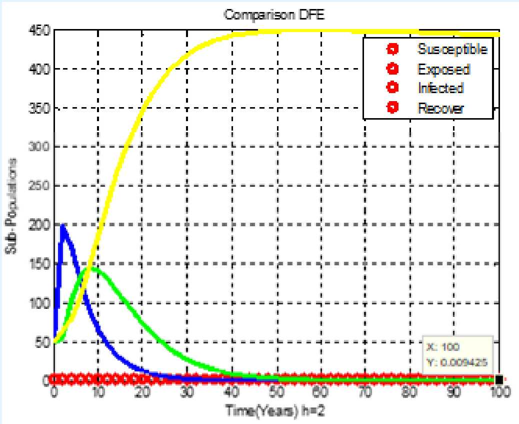

Figure 15: Comparison (DFE), h=2.

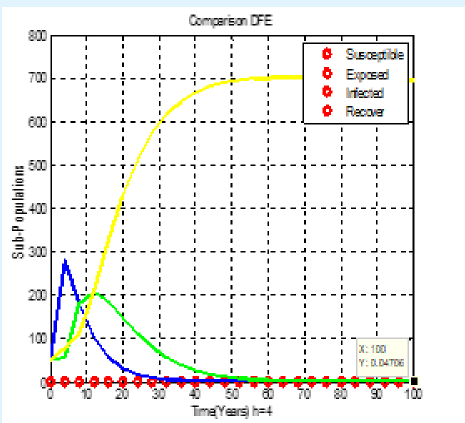

Figure 16: Comparison (DFE), h=4.

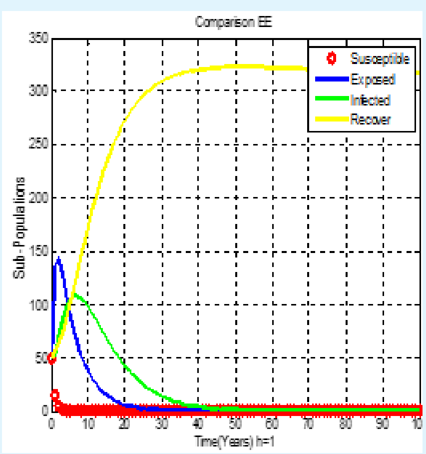

Figure 17: Comparison (EE), h=1.

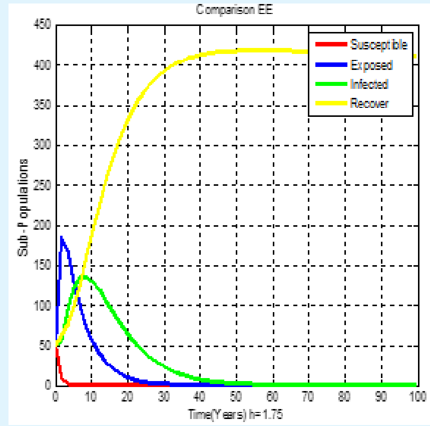

Figure 18: Comparison (EE), h=1.75.

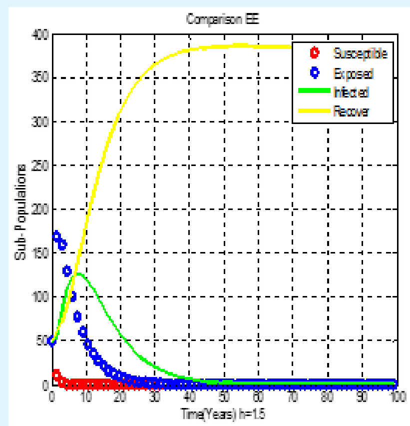

Figure 19: Comparison (EE), h=1.5.

Results and Discussion

The model of dengue consumes introduced expending SEIT Model. (i.e Susceptible, Exposed, Infected and Treated). The loyalty of firm spots i.e the Disease free equilibrium(DFE) and Endemic equilibrium truths(EE) thought arithmetically. So label an unqualifiedly endless Non-Standard Finite Difference (NSFD) arrangement the continual dynamical scheme.The optional construction happens dynamical consistant, arithmetically secure and grips athentic possessions of the relentless model. The outcomes equaled well known standard finite difference schemes i.e Euler's and Runge-Kutta method of order 4 (RK-4). The Euler and RK-4 be influenced by step size 'h' while the constructed NSFD scheme for every assessment used to scums convergent.

Deduction

The Non-Standard Finite Difference Scheme shaped aimed at dengue Euler and RK-4 are failed because they be depend value h. So Euler and RK-4 are temporarily convergent. Euler and RK-4 are divergent and change answer via value of h. But Non Standard Finite Difference Scheme is independent on value h. Improbability the step size in hundreds and thousands then NSFD still convergent. NSFD Scehme satisfy all convergent properties. The graphical behaviour Euler, RK-4 and NSFD schemes are in Figureure no.1 to 19. The compassion of differences the condensed amount of than the other assemblies. So sign that NSFD is unswerving.

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