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A Simulation Model for Sexual and Vectorial Transmission of Zika Virus (ZIKV)

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Abstract

Nowadays the Zika virus (ZIKV) has been one of the most studied vector-borne diseases due to the considerable outbreaks that have generated around the world as well as due to the new transmission mechanisms and health complications originated. According to statistics of the INS-Colombia for July 2016, 68% of the population infected by ZIKV (confirmed cases) are pregnant women. Furthermore, the Quindío department belongs to the states with more than 50% of the total infected persons being pregnant women. Taking into account those characteristics, a theoretical model is proposed and analyzed to describe the population dynamics considering the sexual and vectorial transmission of ZIKV, with special emphasis in the consequences of the non-vectorial transmission in the population. The obtained results with simulations through the beta parameter indicate that the probability of sexual transmission between susceptible women and infected men points out the importance of campaigns to inculcate prevention measures for the safe sexual relationships between ZIKV infected population.

Keywords

ZIKV, Model, Dynamics, Sexual Transmission, Vectorial Transmission

1. Introduction

Recently the concern caused by the Zika virus (ZIKV) has increased, and this infection has been turned in a public health problem in several countries of the American continent. This is mainly due to the relationship with diseases such as: microcephaly and Guillain Barre Syndrome [1] [2] [3] and the discovery of new non-vectorial transmission mechanisms, among them, the vertical, sexual and by blood transfusion ways [4].

It is well known that ZIKV is a disease transmitted by the bite of an infected mosquito (principally the *Aedes aegypti* gender). There are secondary ways of transmission,

although the knowledge of them is limited. The virus has been detected in human saliva, semen and urine [5] [6] [7]. Also there exist documented cases referent to sexual transmission with clinical evidence and serological tests, in Senegal [8], and afterwards in Tahiti and United Kingdom [9] [10]. More recently evidence has been found in France [6], Italia [11] and United States [12]. Therefore, it is very important to give special attention to the non-vectorial transmission since it is being considered a sexually transmitted disease [13], with repercussions in the outbreaks size and geographical expansion of the virus.

Particularly in Colombia, according to the statistics in the "Boletín Epidemiológico Semanal del Instituto Nacional de Salud" [14], 68% of ZIKV infected population corresponds to pregnant women. Figure 1 highlighted the territorial extensions of the

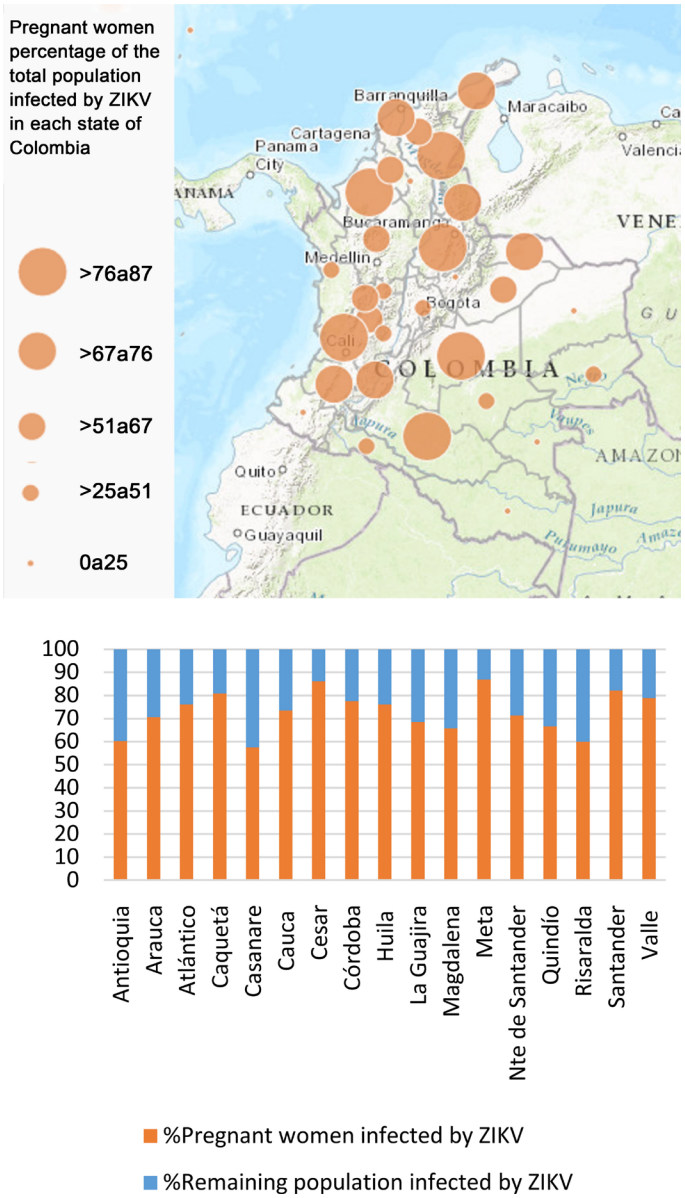

Figure 1. Geospatial distribution of the percentage of pregnant women that are infected by ZIKV in Colombia (upper part). This image has been processed with ArcG is for office software with statistics of the INS [14]. Percentages of the infected pregnant women in each state (lower part).

country with the highest quantity of infected pregnant women (confirmed cases). We divide those percentages into three main groups, each group (sixteen states) with more than fifty percent of infected expectant women (58% - 87%). Then, it is especially important to study and analyze the sexual transmission in those states. Since the Quindío department is one of the most affected by this issue, we will consider it in our investigation.

Taking into account these facts, we propose a model in R^3 which considers the vectorial transmission as well as the sexual transmission of the ZIKV. The basic reproduction number and the stability analysis of the system are obtained. After that, the simulations using the Maple software are carried out to observe the behavior of the epidemic threshold as function of several parameters, the behavior of the sensitivity indexes as well as the transmission probability by sexual way in the human populations. Unlike the model proposed by Gao *et al.* [15], where it is developed a deterministic model of the vectorial and sexual transmission with statistics for Brazil, Colombia and El Salvador. The parameters used in that model include the population divided in symptomatic and asymptomatic populations on the other hand, our model contemplates the population divided in women and men infected by ZIKV, using the average temperature of Armenia-Quindío, Colombia. Also we focus in parameters which contemplate the susceptible women group, due to the possible complications that arise from the transmission to this fraction of the population [16]. The results of both models support the use of campaigns of sexual protection in the intimate relationships of ZIKV infected persons.

It is important to model this dynamics to offer useful information to the public health care institutions in the country, for the application of preventive measures to the sexual transmission of this virus, this is due to the potential propagation of this disease and the collateral effects that may cause. Note that in Colombia almost all the states present high percentages pregnant women infected by ZIKV (see **Figure 1**), emphasizing the relevance of the present study.

2. The Model

It is proposed a simulation model, in R^3, based in non-linear ordinary differential equations following the Sir Ronald Ross formalism to describe the dynamics of the sexual and vectorial ZIKV transmission, accounting the following assumptions: closed populations, variations in time of the ZIKV infected pregnant women population, infected men populations, and the virus-carrier *A. aegypti* mosquitoes, and the constant recovery rate of infected women and infected men. Also, it is considered the ZIKV transmission from the infected men to the susceptible women, assuming promiscuity.

The variables of the model are:

x: fraction of women infected by ZIKV at time t,

y: fraction of men infected by ZIKV at time t and

u: fraction of virus-carrier mosquitoes at time t.

The parameters of the model are shown in **Table 1**.

The differential equations system to describe the infectious process is (**Figure 2**):

$$\frac{\mathrm{d}x(t)}{\mathrm{d}t} = \beta\left(1-x(t)\right)y(t) + \eta\left(1-x(t)\right)u(t) - (\theta+\mu)x(t) \tag{1}$$

Table 1. Parameters of the model.

Parameter	Description
β	Transmission probability by sexual contact between susceptible women and men infected by ZIKV
η	Transmission probability by the bite of virus-carrier mosquitoes to susceptible women
θ	Recovery rate of infected people
μ	Natural mortality rate of the human population
ξ	Transmission probability by the bite of virus-carrier mosquitoes to susceptible men
σ	Transmission probability to non-carrier mosquitoes by the bite to the infected women
δ	Transmission probability to non-carrier mosquitoes by the bite to the infected men
ϵ	Mortality rate of the mosquitoes

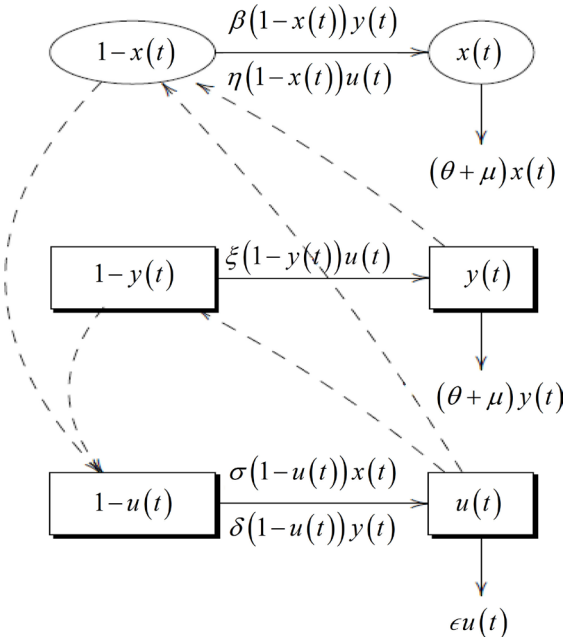

Figure 2. The infectious process diagram.

$$\frac{\mathrm{d}y(t)}{\mathrm{d}t}=\xi(1-y(t))u(t)-(\theta+\mu)y(t) \tag{2}$$

$$\frac{\mathrm{d}u(t)}{\mathrm{d}t}=\sigma(1-u(t))x(t)+\delta(1-u(t))y(t)-\epsilon u(t) \tag{3}$$

where $\theta,\mu,\epsilon>0, 0<\beta,\eta,\xi,\sigma,\delta<1$, with initial conditions $x(0)=x_0$, $y(0)=y_0$ and $u(0)=u_0$.

And, the region where the system trajectories have epidemiological sense is,

$$\Phi=\left\{(x,y,z)\in R_+^3 : 0\le x\le 1, 0\le y\le 1, 0\le u\le 1\right\}$$

3. Stability Analysis

The stability analysis begins calculating the equilibrium points by solving the algebraic system, which is associated to the non-linear differential equations, $\frac{\mathrm{d}x(t)}{\mathrm{d}t}=0$,

$\frac{\mathrm{d}y(t)}{\mathrm{d}t}=0$ and $\frac{\mathrm{d}u(t)}{\mathrm{d}t}=0$;

$$0=\beta\left(1-x(t)\right)y(t)+\eta\left(1-x(t)\right)u(t)-(\theta+\mu)x(t) \tag{4}$$

$$0=\xi\left(1-y(t)\right)u(t)-(\theta+\mu)y(t) \tag{5}$$

$$0=\sigma\left(1-u(t)\right)x(t)+\delta\left(1-u(t)\right)y(t)-\epsilon u(t) \tag{6}$$

Obtaining $y(t)$ from Equation (5), it is obtained the following equation,

$$y(t)=\frac{\xi u(t)}{\left(\theta+\mu+\xi u(t)\right)} \tag{7}$$

Substituting (7) in (4), it is found:

$$\beta\left(1-x(t)\right)\frac{\xi u(t)}{\left(\theta+\mu+\xi u(t)\right)}+\eta u(t)+\eta x(t)u(t)=(\theta+\mu)x(t)$$

Simplifying the previous equation, we have,

$$x(t)=\frac{u(t)\left(\beta\xi+\eta\left(\theta+\mu+\xi u(t)\right)\right)}{\beta\xi u(t)+\left(\theta+\mu+\eta u(t)\right)\left(\theta+\mu+\xi u(t)\right)} \tag{8}$$

Replacing (7) and (8) in (6), we obtain:

$$u(t)\left\{\frac{\sigma\left(1-u(t)\right)\left(\beta\xi+\eta\left(\theta+\mu+\xi u(t)\right)\right)}{\beta\xi u(t)+\left(\theta+\mu+\eta u(t)\right)\left(\theta+\mu+\xi u(t)\right)}+\frac{\delta\left(1-u(t)\right)\xi}{\left(\theta+\mu+\xi u(t)\right)}-\epsilon\right\}=0 \tag{9}$$

where $u(t)=0$;

$$\frac{\sigma\left(1-u((t))\right)\left(\beta\xi+\eta\left(\theta+\mu+\xi u(t)\right)\right)}{\beta\xi u(t)+\left(\theta+\mu+\eta u(t)\right)\left(\theta+\mu+\xi u(t)\right)}+\frac{\delta\left(1-u(t)\right)\xi}{\left(\theta+\mu+\xi u(t)\right)}=\epsilon \tag{10}$$

For $u(t)=0$, it is obtained $y(t)=0$ and $x(t)=0$; then we have the free of infection equilibrium point, $E_0=(0,0,0)$.

Simplifying Equation (10), it is derived the following equation,

$$Au^3+Bu^3+Cu+D=0$$

where,

$$A=\xi^2\sigma\eta+\delta^3\xi^3\eta+\epsilon\eta\xi^2$$

$$B=\sigma\eta\xi(\theta+\mu)-\xi\left[\sigma\eta\xi-\sigma\left(\beta\xi+\eta(\theta+\mu)\right)\right]+\delta^2\xi^2\left[\xi(\beta+\theta+\mu)+\eta(\theta+\mu)\right]+\epsilon\xi\left[(\theta+\mu)(2\eta+\xi)+\xi\beta\right]$$

$$C=-\sigma\xi\left[\beta\xi+\eta(\theta+\mu)\right]-\left[\sigma\eta\xi-\sigma\left[\beta\xi+\eta(\theta+\mu)\right]\right](\theta+\mu)+\left[\delta^2\xi^2(\theta+\mu)^2\right]+\epsilon(\theta+\mu)\left[(\theta+\mu)(2\xi+\eta)+\xi\beta\right]$$

$$D=-\sigma\left[\beta\xi+\eta(\theta+\mu)\right](\theta+\mu)+\epsilon(\theta+\mu)^3$$

Due to $A>0$ and if we assume that at least one of the B, C and D is less than zero, it guarantees a change of sign in the coefficients of the quadratic equation. Following the signs rule of Descartes it is obtained a positive and real root (u), then, we have an infection prevalence equilibrium point, $E_1=(\hat{x},\hat{y},\hat{u})$,

$$\hat{x}(t)=\frac{\hat{u}(t)\left(\beta\xi+\eta\left(\theta+\mu+\xi\hat{u}(t)\right)\right)}{\beta\xi\hat{u}(t)+\left(\theta+\mu+\eta\hat{u}(t)\right)\left(\theta+\mu+\xi\hat{u}(t)\right)}$$

$$\hat{y}=\frac{\xi\hat{u}(t)}{\theta+\mu+\xi\hat{u}(t)}$$

In the linearization process for the non-lineal equations system (1)-(3), is calculated the Jacobian matrix at the generic equilibrium point $E=(\tilde{x},\tilde{y},\tilde{u})$,

$$J(E)=\begin{pmatrix}-(\beta\tilde{y}+\eta\tilde{u}+\mu+\theta) & \beta(1-\tilde{x}) & \eta(1-\tilde{x})\\ 0 & -(\tilde{u}\xi+\mu+\theta) & \xi(1-\tilde{y})\\ \sigma(1-\tilde{u}) & \delta(1-\tilde{u}) & -(\delta\tilde{y}+\sigma\tilde{x}+\epsilon)\end{pmatrix} \tag{11}$$

Evaluating the Jacobian matrix in the free of infection equilibrium point, we obtain:

$$J(E_0)=\begin{pmatrix}-(\mu+\theta) & \beta & \eta\\ 0 & -(\mu+\theta) & \xi\\ \sigma & \delta & \epsilon\end{pmatrix} \tag{12}$$

So, the characteristic equation $\left|J(E_0)-\lambda I\right|=0$ is,

$$\lambda^3+a_1\lambda^2+a_2\lambda+a_3=0 \tag{13}$$

where,

$$a_1=2(\mu+\phi)+\epsilon$$

$$a_2=(\mu+\phi)(\mu+\phi+2\epsilon)+\xi\delta-\sigma\eta$$

$$a_3=1-R_0$$

Under the Routh-Hurwitz criterion, it should be accomplished that $a_1>0, a_3>0$ and $a_1a_2>a_3$. As a consequence the equilibrium point E_0 is local and asymptotically stable.

At the equilibrium point E_1, the characteristic equation $\left|J(E_1)-\lambda I\right|=0$ corresponding to the Jacobian matrix $J(E_1)$ is;

$$\det\begin{pmatrix}-(a+\lambda) & \beta(1-\hat{x}) & \eta(1-\hat{x})\\ 0 & -(b+\lambda) & \xi(1-\hat{y})\\ \sigma(1-\hat{u}) & \delta(1-\hat{u}) & -(c+\lambda)\end{pmatrix}=0 \tag{14}$$

where, $a=\beta\hat{y}+\eta\hat{u}+\mu+\theta$, $b=\xi\hat{u}+\mu+\theta$ and $c=\delta\hat{y}+\eta\sigma+\epsilon$.

Solving by the first column and cofactors, we have,

$$\lambda^3+a_1\lambda^2+a_2\lambda+a_3=0$$

with

$$a_1=a+b+c$$

$$a_2=a(b+c)+bc-\delta\xi(1-\hat{u})(1-\hat{y})$$

$$a_3=abc-a\ \delta\xi(1-\hat{u})(1-\hat{y})-\sigma(1-\hat{u})\beta\xi(1-\hat{x})(1-\hat{y})-\sigma\eta(1-\hat{u})(1-\hat{x})b$$

Applying the Routh-Hurwitz criterion, this equation has 3 roots with negative real part if the inequalities are met $a_1>0, a_3>0$ and $a_1a_2>a_3$, as consequence the equilibrium point E_1 is local and asymptotically stable, if not, the point is unstable.

4. Basic Reproduction Number R_0

The so called epidemic threshold R_0, basic reproduction number, indicates the average number of cases that an infectious person produces during the average time of the infection in a susceptible population [17] [18], this threshold is determined assuming that, at least one of the populations, is fully susceptible. Such fractions are approximated taking into account the presence of the Zika virus, as $1-x\approx 1$, $1-y\approx 1$ and $1-u\approx 1$.

Then doing y in function of u, from Equation (2) is obtained $y=\frac{\xi}{\theta+\mu}u$. Replacing this value in Equation (1), then we have $x=\frac{\beta\xi}{(\theta+\mu)^2}+\frac{\eta}{\theta+\mu}$. Also, u increases $(u>0)$ when $\frac{\mathrm{d}u}{\mathrm{d}t}>0$:

$$\left(\frac{\xi\sigma\beta}{(\theta+\mu)^2}+\frac{\sigma\eta}{\theta+\mu}+\frac{\delta\xi}{\theta+\mu}-\varepsilon\right)u>0$$

so,

$$R_0=\frac{\eta\sigma}{\varepsilon(\theta+\mu)}+\frac{\xi\delta}{\varepsilon(\theta+\mu)}+\frac{\xi\beta\sigma}{\varepsilon(\theta+\mu)^2}=R_0^1+R_0^2+R_0^3$$

where;

R_0^1 is the threshold corresponding to the virus-carrier mosquitoes and infected pregnant women.

R_0^2 is the threshold corresponding to the virus-carrier mosquitoes and infected men.

R_0^3 is the threshold corresponding to the sexual and vectorial transmission.

For a best understanding of the basic reproduction number R_0, the additive and multiplicative effects of R_0 indicate that the vector would be able to transmit the virus to susceptible women and men, the women can acquire the virus by sexual contact, also the vector may get the virus from an infected person.

The terms $\frac{\eta}{\epsilon}$ and $\frac{\xi}{\epsilon}$ indicate the incidence (new cases of ZIKV) in the female and male susceptible populations, respectively, during the lifetime of the vector. These populations generate the quantities $\frac{\sigma}{\theta+\mu}$ and $\frac{\delta}{\theta+\mu}$ of virus-carrier mosquitoes.

The term $\frac{\xi}{\epsilon}\frac{\beta}{\theta+\mu}$ indicates the incidence in the population of susceptible women due to sexual contact between a previously infected man (which gets infected by the bite of a mosquito) and a healthy woman, during a short infectious period of the mosquito or human. This results in a number $\frac{\sigma}{\theta+\mu}$ of infected women.

5. Numerical Analysis of Stability

For an average annual temperature in Armenia-Quindío, Colombia of 19.5˚C, were estimated the transmission probabilities ξ,σ and ϵ, using the functions contained in

[18] [19],

$$\xi = 0.0729T - 0.9037, 12.4^{\circ}\text{C} \le T \le 26.1^{\circ}\text{C}$$

$$\sigma = 0.001044T\left(T - 12.286\right)\left(32.461 - T\right)^{\frac{1}{2}}, 12 - 4^{\circ}\text{C} \le T \le 26.1^{\circ}\text{C} \quad (16)$$

$$\epsilon = 0.8692 - 0.1590T + 0.01116T^2 - 0.0003408T^3 + 0.000003809T^4$$

where $10.54^{\circ}\text{C} \le T \le 33.4^{\circ}\text{C}$, with a life expectancy in Colombia of 75 years, $\mu = \frac{1}{75 \times 365}$, an average period of transmissibility $E\left[x_2\right]$ of 7 days and considering the Poission theory of infectious process in epidemiology $E\left[x_2\right] = \frac{1}{\theta + \mu}$ the parameter θ was estimated; the value of the parameter δ and η are assigned according the literature [16], as described in the Table 2.

The local stability analysis is carried out using the estimated parameters. We start with the calculation of the free of infection and prevalence equilibrium points, which are determined doing the differentiation of the system (1)-(3) equal to zero, and solving the non-linear algebraic system for each demographic variable.

$$\beta\left(1-x\right)y + \left(0.5178\right)\left(1-x\right)u - \left(0.14 + 0.0003\right)x = 0$$

$$\left(0.5178\right)\left(1-y\right)u - \left(0.14 + 0.0003\right)y = 0$$

$$\left(0.52872\right)\left(1-u\right)x + \left(0.52872\right)\left(1-u\right)y - \left(0.03604\right)u = 0$$

Using the MAPLE software the equilibrium points are determined.

- For $\beta = 0.3 : E_0 = \left(0,0,0\right), E_1 = \left(0.838, 0.779, 0.959\right)$
- For $\beta = 0.6 : E_0 = \left(0,0,0\right), E_1 = \left(0.873, 0.779, 0.960\right)$
- For $\beta = 0.8 : E_0 = \left(0,0,0\right), E_1 = \left(0.888, 0.780, 0.960\right)$

With information in the Table 2 and the calculated equilibrium points, we obtain the local sensitivity analysis. Also, using the Jacobian matrix the results of Table 3 are obtained.

6. Local Sensitivity Analysis

Another threshold is obtained using the local sensitivity analysis, this one represents a relative measure of the change in one variable when the value of one parameter changes

Table 2. Estimated parameters for the model.

Parameter	η	θ	μ	ξ	σ	δ	ε	β
Value	0.5178	0.14	0.0003	0.5178	0.52872	0.52872	0.03604	0.3 - 0.6 - 0.8

Table 3. Local stability analysis for each β.

β	Equilibrium point	Eigenvalues	Stability
0.3	(0, 0, 0)	0.7157, −0.3032, −0.7290	Unstable
0.3	(0.838, 0.779, 0.959)	−0.6254, −0.8988, 1.2636	Stable
0.6	(0, 0, 0)	0.7669, −0.5418, −0.5418	Unstable
0.6	(0.873, 0.779, 0.960)	−0.6273, −0.9166, −1.2634	Stable
0.8	(0, 0, 0)	0.7971, −0.5569, −0.5569	Stable
0.8	(0.888, 0.780, 0.960)	−0.6278, −0.9249, −1.2639	Stable

[20] [21] [22]. The sensitivity index for R_0, is calculated with the following expression,

$$I_p^{R_o} = \frac{\partial R_o}{\partial p} \times \frac{p}{R_0}$$

where, p is a parameter. So, the next index have been obtained.

$$\begin{aligned}
I_\xi^{R_o} &= \frac{\left(\delta(\theta+\mu)+\beta\sigma\right)\xi}{\xi(\theta+\mu)\delta+\sigma\left(\beta\xi+\eta(\theta+\mu)\right)} \\
I_\delta^{R_o} &= \frac{\xi(\theta+\mu)\delta}{\left(\delta(\theta+\mu)+\beta\sigma\right)\xi+(\theta+\mu)\eta\sigma} \\
I_\eta^{R_o} &= \frac{(\theta+\mu)\eta\sigma}{\xi(\theta+\mu)\delta+\sigma\left(\beta\xi+\eta(\theta+\mu)\right)} \\
I_\sigma^{R_o} &= \frac{\sigma\left(\beta\xi+\eta(\theta+\mu)\right)}{\xi(\theta+\mu)\delta+\sigma\left(\beta\xi+\eta(\theta+\mu)\right)} \\
I_\epsilon^{R_0} &= -1 \\
I_\theta^{R_o} &= \frac{-\left((2\beta\xi+\eta\mu+\eta\theta)\sigma+\xi(\theta+\mu)\delta\right)\theta}{(\theta+\mu)\left(\sigma(\beta\xi+\eta\mu+\eta\theta)+\xi(\theta+\mu)\delta\right)} \\
I_\mu^{R_o} &= \frac{-\left((2\beta\xi+\eta\mu+\eta\theta)\sigma+\xi(\theta+\mu)\delta\right)\mu}{(\theta+\mu)\left(\sigma(\beta\xi+\eta\mu+\eta\theta)+\xi(\theta+\mu)\delta\right)} \\
I_\beta^{R_o} &= \frac{-\beta\sigma\xi}{\xi(\theta+\mu)\delta+\sigma\left(\beta\xi+\eta(\theta+\mu)\right)}
\end{aligned} \tag{15}$$

The results of the sensitivity analysis of R_0 respect to each parameter are shown in Table 4.

In Figure 3, it is presented the behavior of the basic reproduction number respecting

Table 4. Sensitivity index of R_0 respecting each parameter.

Parameter	ξ	δ	η	σ	ϵ	θ	μ	β
$I_p^{R_0}$	0.758	0.241	0.241	0.758	−1	−1.513	−0.003	0.5167

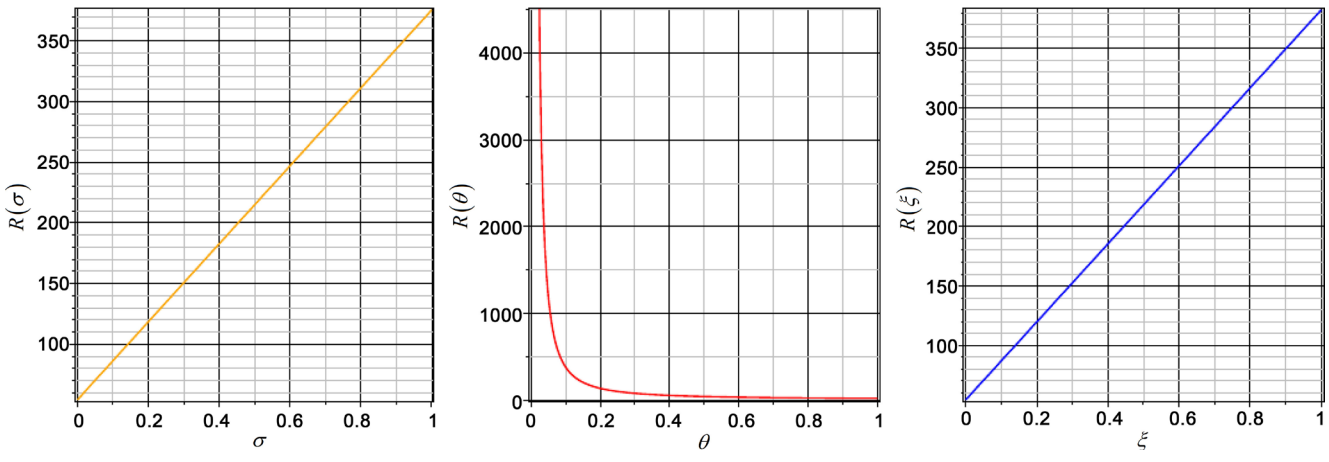

Figure 3. Behavior of the threshold (R_0) respecting to σ, θ, and ξ.

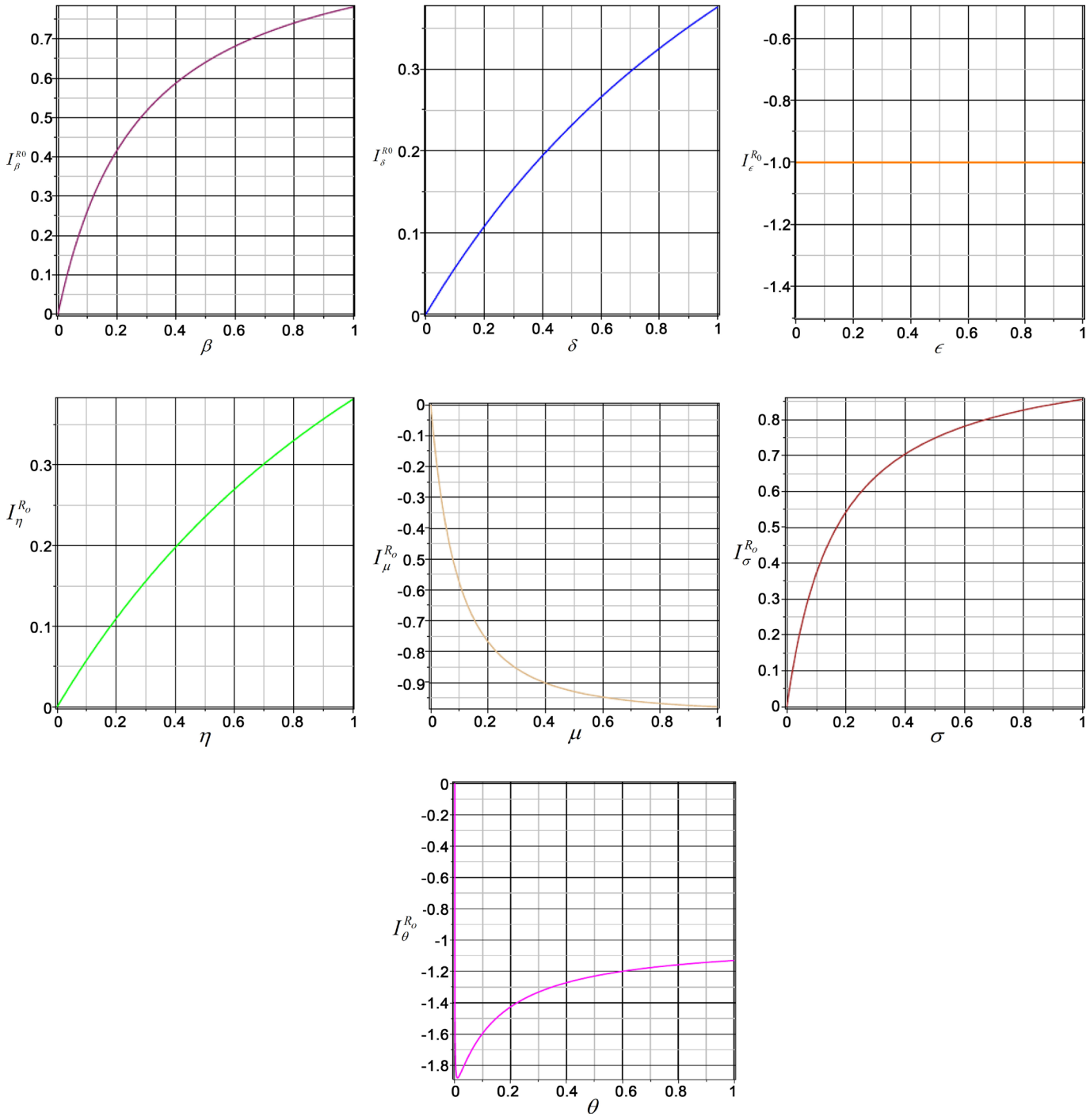

Figure 4. Behavior of the sensitivity indexes for $I_{\beta}^{R_o}, I_{\delta}^{R_o}, I_{f}^{R_o}, I_{\theta}^{R_o}, I_{\mu}^{R_o} y I_{\sigma}^{R_o}$.

to the most sensitive parameters.

In Figure 4, it is shown the behavior for each sensitivity index as function of each parameter.

7. Simulations

The simulations of system (1)-(3) were obtained using the values of the parameters as reported in Table 1 and the MAPLE software.

From the results of the simulations, which are depicted in Figure 5 and Figure 6, it is show that the dynamic system, which describes the dynamics of the infectious process, stabilizes quickly in the first ten days for different values of the ZIKV transmission probability from the infected men to susceptible women, for small, medium and high values of probability. This is to analyze the behavior of the populations, see Table 3. If we consider some preventive measures to decrease the probability to 0.3, the stability level by sexual transmission decreases in almost an 84%.

Figure 6 displayed the behavior of the human and mosquitoes populations for a probability of sexual transmission of 0.8. These ones stabilize in the first ten days of the infectious process.

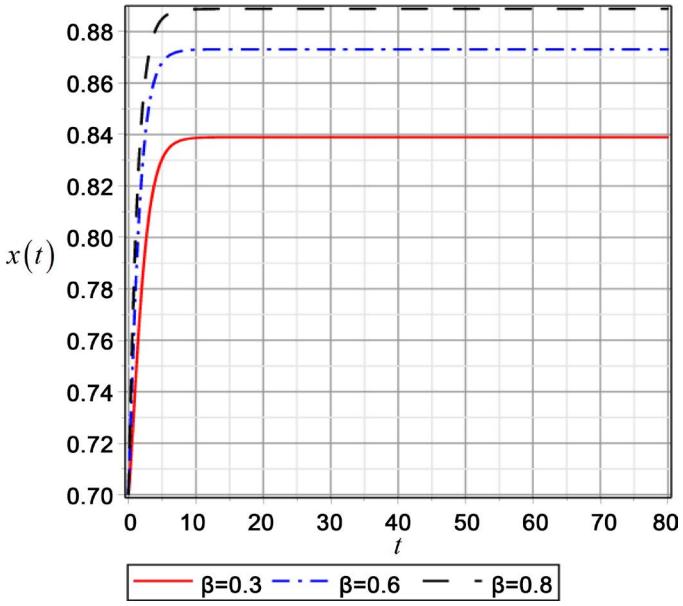

Figure 5. Behavior of the fraction of infected by ZIKV for different β.

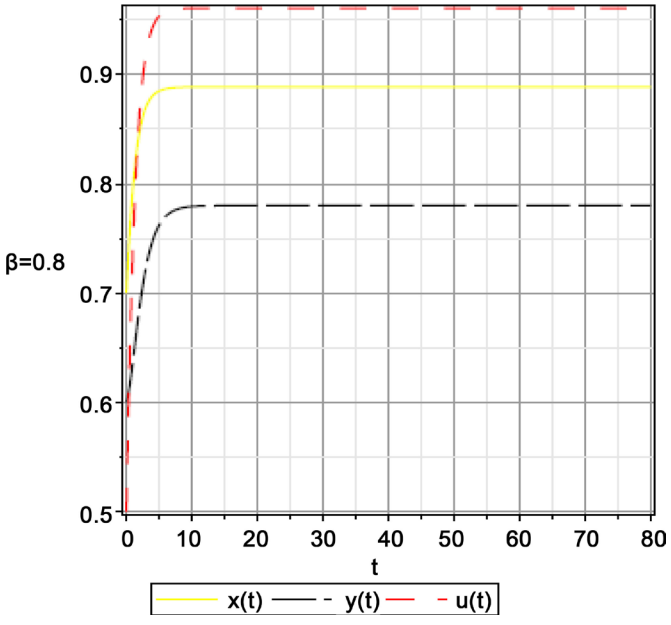

Figure 6. Human and mosquitoes population behavior for $\beta = 0.8$.

8. Conclusions

It is possible to see that upon beta increases, the infected women population increases in a time *t*. Then, it is extremely important to apply prevention measures in the sexual relationships of the infected population, and then help to stop the virus propagation at large scale. Together with these measures, it is expected to have a decrease in the diseases derived by this virus, as congenital microcephaly and Guillian-Barre syndrome.

Figure 6 shows the behavior of the infected women's fraction, infected men's fraction and virus-carrier mosquitoes fraction with a parameter $\beta = 0.8$ from which it is reflected a great quantity of infected men and women as well as a considerable number of virus-carrier mosquitoes, from which, it is evidenced the importance that has the level of the virus transmission by sexual way.

The basic reproduction number is inversely proportional to the recovery rate of the infected persons and the mortality rate of the mosquitoes. That is to say, it is not appropriate to decrease the values of these parameters by treatment and control of the mosquito.

Actually, the Ross-Macdonald formalism is very important to model Vector-Host diseases as Malaria, Dengue, Chagas, Chikungunya and ZIKV, etc. In future works it is important to carry out the goblal stability analysis of the model and add the horizontal transmission in the man as well as the model without considering Sir. Ronald Ross formalism.

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