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STABILITY OF THE DYNAMIC MODEL OF SVPR SEXUAL VIOLENCE CASES

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ABSTRACT

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In this study, the stability of the equilibrium points of the Susceptible Violent Punishment Recovered (SVPR) model in the spread of sexual violence cases is analyzed. The model assumes that sexual violence can spread similarly to the transmission of infectious diseases. The constructed model is a system of nonlinear differential equations. The model has two equilibrium points: the equilibrium point with sexual violence-free and the endemic equilibrium point with sexual violence. Stability analysis is then carried out for both fixed points, indicating that the violence-free equilibrium is asymptotically stable if the basic reproduction number $\mathfrak{R}_0 < 1$. Meanwhile, the endemic equilibrium is asymptotically stable if the condition $\mathfrak{R}_0 > 1$ and four other conditions are satisfied. Numerical simulations are required to observe the implementation of the model using MAPLE software. As for this research, we conclude a model that shows the spread of sexual violence is not widespread because it was found that $\mathfrak{R}_0 < 1$.

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1. INTRODUCTION

The phenomenon of sexual violence against women continues to be a serious and concerning issue for most countries worldwide, including Indonesia. The prevalence of news in mass media and social media recently has made society seemingly aware that sexual violence can occur anytime, anywhere, affecting anyone, including close associates, and even in forms previously unimaginable [1]. Sexual violence is one form of direct violence involving others in unwanted sexual activities, either verbally or through actions aimed at controlling or manipulating others. Various forms of sexual violence include child and adult sexual abuse, rape, prostitution, abortion, and forced marriage [2], [3].

According to the annual records of the National Commission on Violence Against Women (Komnas Perempuan) in Indonesia for the year 2022, Gender-Based Violence (GBV) against women reached 338,496 cases throughout 2021. This figure increased by almost 50% from the previous year, which amounted to 226,062 cases. The cases of GBV against women in 2021 represent the highest number in the past ten years [4].

Similar to COVID-19, violence against women has become an epidemic that we must address comprehensively. Mathematical modeling is a representation of real-world phenomena solved mathematically using certain assumptions. One of the phenomena of interest is the phenomenon of disease outbreaks (epidemics) [5], [6]. Kazi Nuzrat Islam and Md. Haider Ali Biswas [7] constructed a dynamic model of sexual violence against women in Bangladesh with the compartmental model $S_1V_1R_1S_2V_2R_2$. Ann Mary Thomas et al. [8] presented a mathematical model of crimes against women in Rajasthan, India, using a polynomial function graph. Batabyal and Beladi [9] created a game theory model of sexual violence, while Isa Abdullahi Baba et al. [10] constructed a mathematical model of rape with possible control modes. In Indonesia, although cases decreased in 2020, sexual violence cases have continued to increase since 2012 until now. Therefore, it is necessary to carry out an analysis to find out whether this increase can become an epidemic or not. Stability analysis is carried out to determine the equilibrium point, which states that there is no change or an increase in the number of sexual violence incidents. The Susceptible, Violent, Punishment, Recovered (SVPR) mathematical model of sexual violence was then constructed. The non-linear model is linearized using the Jacobian matrix, while the stability of the equilibrium point is determined using the Routh-Hurwitz criterion [11], [12]. The behavior of the model around the equilibrium point will be analyzed based on the eigenvalues of the Jacobian matrix. Furthermore, numerical solutions will be simulated using MAPLE software. Maple is a computer-based mathematical application for analytical and numerical mathematical calculations [13].

2. RESEARCH METHODS

The research is conducted in the form of a literature review using materials from scientific journals and books related to the topic. The stages of this research are as follows:

1) Gathering relevant references related to the discussion in this research.
2) Constructing a mathematical model of sexual violence against women.
3) Analyzing the mathematical model of sexual violence against women in a system of nonlinear differential equations.
    a) Determining the equilibrium points of violence-free and endemic equilibrium points in sexual violence
    b) Determining the basic reproduction number ($\mathfrak{R}_0$).
    c) Determining the stability of the violence-free equilibrium point and the endemic equilibrium point of violence.
4) Implementing the model of sexual violence against women in Indonesia.
    a) Collecting the required data and information.
    b) Determining the values of variables and parameters from the acquired data.
    c) Analyzing the stability of the model using the values of variables and parameters obtained from the data.
    d) Providing numerical simulations of the mathematical model of sexual violence against women in Indonesia.
5) Concluding.

3. RESULTS AND DISCUSSION

3.1 Mathematical Model of Sexual Violence

In the issue of sexual violence, the total male population, denoted by N, is divided into four subpopulations: the susceptible class, denoted by S, the violent class, denoted by V, the punishment class, denoted by P, and the recovered class, denoted by R. Individuals in the susceptible class can move to the violent class if they engage in sexual violence. Meanwhile, susceptible individuals who do not commit sexual violence will transition to the recovered class. Subsequently, violents can move to the punishment class if found guilty in court and undergo a corresponding punishment. Violent offenders are found not guilty, and individuals who have completed their sentences can move to recovery class. Furthermore, individuals found not guilty can move to the recovered class after completing their sentence. Lastly, individuals in the recovered class can transit to the susceptible class due to environmental influences.

Based on the case, the diagram of the mathematical model of sexual violence is as follows :

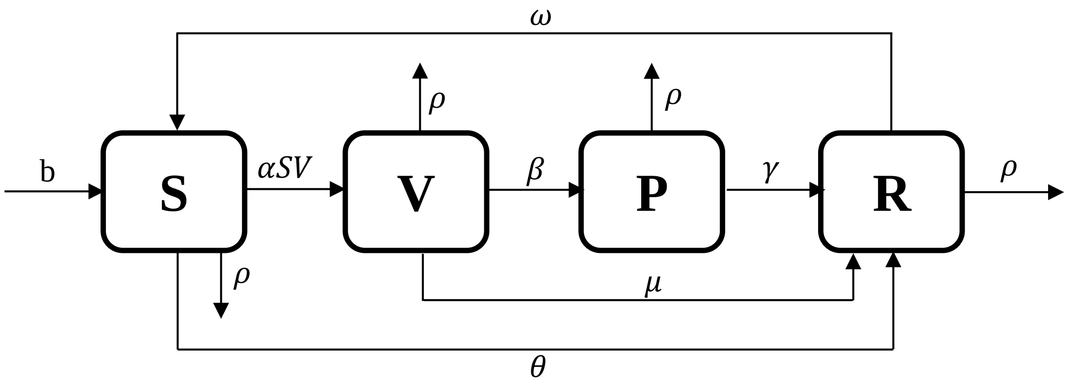

Figure 1 Compartmental Diagram of the Mathematical Model of Sexual Violence

The diagram in **Figure 1** can be expressed in the following system of nonlinear differential equations :

$$\begin{aligned}
\frac{dS}{dt} &= b - \alpha SV - \rho S - \theta S + \omega R\# \\
\frac{dV}{dt} &= \alpha SV - \rho V - \mu V - \beta V \\
\frac{dP}{dt} &= \beta V - \rho P - \gamma P \\
\frac{dR}{dt} &= \gamma P + \mu V + \theta S - \rho R - \omega R
\end{aligned} \tag{1}$$

with initial conditions at $t = 0$ and

$$S(0) \geq 0, P(0) \geq 0, V(0) \geq 0, R(0) \geq 0$$

In this case, the parameters $b, \alpha, \beta, \gamma, \mu, \omega, \theta, \rho$ are positive constants. The description of each parameter can be found in the following **Table 1**

Table 1 The Description of Each Parameter

Parameter	Description
b	Natural birth rate
α	The effective contact rate that spreads sexual violence
β	The transition rate from violent to the punished group.
γ	The rate of transition for individuals who have been punished to the recovered group.
μ	The rate of transition from violent to the recovered group.
ω	The rate of transition for remorseful individuals to the susceptible group.
θ	The rate of transition for susceptible individuals to the recovered group
ρ	The natural death rate

3.2 Analysis of the Model

3.2.1 Violence-free Equilibrium Points

The equilibrium points of a dynamical system describe the qualitative properties of the system [14]. The equilibrium points of the system (1) can be obtained by setting each equation in the system to :

$$\frac{dS}{dt} = 0, \frac{dV}{dt} = 0, \frac{dP}{dt} = 0. \frac{dR}{dt} = 0$$

So that

$$\begin{gathered} b - \alpha SV - \rho S - \theta S + \omega R = 0 \\ \alpha SV - \rho V - \mu V - \beta V = 0 \\ \beta V - \rho P - \gamma P = 0 \\ \gamma P + \mu V + \theta S - \rho R - \omega R = 0 \end{gathered} \tag{2}$$

The violence-free equilibrium point ($E^0 = (S^0, V^0, P^0, R^0)$)) occurs when no population engages in sexual violence, i.e., $V = 0$. As a result, the population of violent undergoing punishment becomes nonexistent, $P = 0$. From Equation (2) we obtain :

$$S^0 = \frac{b(\rho + \omega)}{\rho(\rho + \theta + \omega)}, V^0 = 0, P^0 = 0, R^0 = \frac{\theta b}{\rho(\rho + \theta + \omega)}$$

Thus, the violence-free equilibrium point for the system (1) is :

$$E^0 = \left(\frac{b(\rho + \omega)}{\rho(\rho + \theta + \omega)}, 0,0, \frac{\theta b}{\rho(\rho + \theta + \omega)}\right)$$

3.2.2 Endemic Equilibrium Points

The endemic equilibrium point of sexual violence is denoted as $E^* = (S^*, V^*, P^*, R^*)$ The endemic equilibrium point of sexual violence occurs when there is a population engaged in sexual violence, thus $V > 0$. From Equation (2) we obtain the endemic equilibrium point :

$$S^* = \frac{\rho + \mu + \beta}{\alpha}$$

$$V^* = \frac{(\alpha b\omega + \alpha b\rho - \beta\omega\rho - \beta\rho 2 - \beta\rho\theta - \mu\omega\rho - \mu\rho 2 - \mu\rho\theta - \omega\rho 2 - \rho 3 - \rho 2\theta)(\rho + \gamma)}{\alpha\rho(\beta\gamma + \beta\omega + \beta\rho + \gamma\mu + \gamma\omega + \gamma\rho + \mu\rho + \omega\rho + \rho 2)}$$

$$P^* = \frac{\beta V^*}{\rho + \gamma}$$

$$R^* = \frac{\big(\alpha\gamma\beta + \alpha\mu(\rho + \gamma)\big)V^* + \theta(\rho + \mu + \beta)(\rho + \gamma)}{\alpha(\rho + \gamma)(\rho + \omega)}$$

3.2.3 Basic Reproduction Number

The basic reproduction number is an epidemiologic metric utilized to depict the contagiousness of infectious agents [15] or used to see the spread level of disease in a population [16] . The basic reproduction number ($\Re_0$) in the system is determined using the Next Generation Matrix method [17]. In this case, the subpopulations considered infected with sexual violence are V and P. To determine the basic reproduction number, the changes in both subpopulations, V and P, are considered::

$$\begin{gathered} \frac{dV}{dt} = \alpha SV - \rho V - \mu V - \beta V \\ \frac{dP}{dt} = \beta V - \rho P - \gamma P \end{gathered} \tag{3}$$

Jacobian matrix of the system (3) at the equilibrium point E^0 is

$$J = \begin{pmatrix} \frac{b(\rho+\omega)}{\rho(\rho+\theta+\omega)} - (\rho+\mu+\beta) & 0 \\ \beta & -(\rho+\gamma) \end{pmatrix}$$
$$= \begin{pmatrix} \frac{b(\rho+\omega)}{\rho(\rho+\theta+\omega)} & 0 \\ 0 & 0 \end{pmatrix} + \begin{pmatrix} -(\rho+\mu+\beta) & 0 \\ \beta & -(\rho+\gamma) \end{pmatrix}$$
$$= T + \Sigma$$

Then, the next generation matrix K is

$$K = -T\Sigma^{-1} = \begin{pmatrix} \frac{\alpha b(\rho+\omega)}{\rho(\rho+\theta+\omega)(\rho+\mu+\beta)} & 0 \\ 0 & 0 \end{pmatrix}$$

The basic reproduction number ($\Re_0$) is the spectral radius or the maximum absolute value of the eigenvalues of the next generation matrix K, such that :

$$\det(K - \lambda I) = 0$$
$$\begin{pmatrix} \frac{\alpha b(\rho+\omega)}{\rho(\rho+\theta+\omega)(\rho+\mu+\beta)} - \lambda & 0 \\ 0 & -\lambda \end{pmatrix} = 0$$
$$\left(\lambda - \frac{\alpha b(\rho+\omega)}{\rho(\rho+\theta+\omega)(\rho+\mu+\beta)}\right)\lambda = 0$$
$$\lambda_1 = \frac{\alpha b(\rho+\omega)}{\rho(\rho+\theta+\omega)(\rho+\mu+\beta)}, \lambda_2 = 0$$

Thus, the basic reproduction number is :

$$\Re_0 = \frac{\alpha b(\rho+\omega)}{\rho(\rho+\theta+\omega)(\rho+\mu+\beta)}$$

3.2.4 Stability Analysis at Violence-free Equilibrium Points

The violence-free equilibrium point of the model (1) is asymptotically stable if the eigenvalues of the Jacobian matrix are negative [18] . The Jacobian matrix of the model (1) at a violence-free equilibrium point is given by

$$J_{E^0} = \begin{pmatrix} -(\rho+\theta) & -\frac{\alpha b(\rho+\omega)}{\rho(\rho+\theta+\omega)} & 0 & \omega \\ \alpha V & \frac{\alpha b(\rho+\omega)}{\rho(\rho+\theta+\omega)} - (\rho+\mu+\beta) & 0 & 0 \\ 0 & \beta & -(\rho+\gamma) & 0 \\ \theta & \mu & \gamma & -(\rho+\omega) \end{pmatrix}$$

The characteristic equation can be obtained by $\det(J_{E^0} - \lambda I) = 0$

$$\begin{vmatrix} -(\rho+\theta)-\lambda & -\frac{\alpha b(\rho+\omega)}{\rho(\rho+\theta+\omega)} & 0 & \omega \\ \alpha V & \frac{\alpha b(\rho+\omega)}{\rho(\rho+\theta+\omega)} - (\rho+\mu+\beta) - \lambda & 0 & 0 \\ 0 & \beta & -(\rho+\gamma)-\lambda & 0 \\ \theta & \mu & \gamma & -(\rho+\omega)-\lambda \end{vmatrix} = 0$$

Let $k_1 = \rho+\theta, k_2 = \frac{\alpha b(\rho+\omega)}{\rho(\rho+\theta+\omega)}, k_3 = \rho+\mu+\beta, k_4 = \rho+\gamma, k_5 = \rho+\omega$.

Then we obtain

$$\begin{vmatrix} -k_1-\lambda & -k_2 & 0 & \omega \\ 0 & (k_2-k_3)-\lambda & 0 & 0 \\ 0 & \beta & -k_4-\lambda & 0 \\ \theta & \mu & \gamma & -k_5-\lambda \end{vmatrix} = 0$$

$$\big(\lambda - (k_2 - k_3)\big)(\lambda + k_4)(\lambda^2 + l_1\lambda + l_2) = 0 \tag{4}$$

Where $l_1 = 2\rho + \omega + \theta$ and $l_2 = \rho^2 + \rho(\theta + \omega) + \theta\omega$.

By solving **Equation (4)** the eigenvalues are :

i. $\lambda_1 = k_2 - k_3$. Since $\lambda_1 < 0$ then $k_2 - k_3 < 0$ so that
$$k_2 - k_3 < 0 \frac{\alpha b(\rho + \omega)}{\rho(\rho + \theta + \omega)} < \rho + \mu + \beta \frac{\alpha b(\rho + \omega)}{\rho(\rho + \theta + \omega)(\rho + \mu + \beta)} < 1\Re_0 < 1$$

ii. $\lambda_2 = -k_4 = -(\rho + \gamma)$.

iii. Using the Routh-Hurwitz criterion, the roots of the equation $(\lambda^2 + l_1\lambda + l_2) = 0$, namely λ_3 and λ_4 will always be negative if $l_1 > 0$ and $l_1 l_2 > 0$, which is always satisfied because $l_1 > 0$ and $l_2 > 0$.

Thus, the stability of the violence-free equilibrium point is asymptotically stable if $\Re_0 < 1, -(\rho + \gamma) < 0$, $l_1 > 0, l_1 l_2 > 0$ are all satisfied.

3.2.5 Stability Analysis at Endemic Equilibrium Points

The endemic equilibrium point of sexual violence occurs if $V^* > 0$. From the previous subsection, we have V^* which can be simplified to :

$$V^* = \frac{(\alpha b\omega + \alpha b\rho - \beta\omega\rho - \beta\rho 2 - \beta\rho\theta - \mu\omega\rho - \mu\rho 2 - \mu\rho\theta - \omega\rho 2 - \rho 3 - \rho 2\theta)(\rho + \gamma)}{\alpha\rho(\beta\gamma + \beta\omega + \beta\rho + \gamma\mu + \gamma\omega + \gamma\rho + \mu\rho + \omega\rho + \rho 2)}$$
$$= \frac{\rho(\rho + \omega + \theta)(\rho + \mu + \beta)\left(\frac{\alpha b(\omega + \rho)}{\rho(\rho + \omega + \theta)(\rho + \mu + \beta)} - 1\right)(\rho + \gamma)}{\alpha\rho(\beta\gamma + \beta\omega + \beta\rho + \gamma\mu + \gamma\omega + \gamma\rho + \mu\rho + \omega\rho + \rho^2}$$
$$= \frac{\rho(\rho + \omega + \theta)(\rho + \mu + \beta)(\Re_0 - 1)(\rho + \gamma)}{\alpha\rho(\beta\gamma + \beta\omega + \beta\rho + \gamma\mu + \gamma\omega + \gamma\rho + \mu\rho + \omega\rho + \rho^2}$$

Since $V^* > 0$, it follows $\Re_0 > 1$.

The endemic equilibrium point of the model (1) is asymptotically stable if the eigenvalues of the Jacobian matrix are negative. The Jacobian matrix of the model (1) at the endemic equilibrium point is given by

$$J_{E^*} = \begin{pmatrix} -(\alpha V^* + \rho + \theta) & -\alpha S^* & 0 & \omega \\ \alpha V^* & \alpha S^* - \rho - \mu - \beta & 0 & 0 \\ 0 & \beta & -(\rho + \gamma) & 0 \\ \theta & \mu & \gamma & -(\rho + \omega) \end{pmatrix}$$

Let $r_1 = \alpha V^* + \rho + \theta, r_2 = -(\alpha S^* - \rho - \mu - \beta), r_3 = \rho + \gamma, r_4 = \rho + \omega$

The characteristic equation can be obtained by $\det(J_{E^*} - \lambda I) = 0$

$$\begin{vmatrix} -r_1-\lambda & -\alpha S^* & 0 & \omega \\ \alpha V^* & -r_2-\lambda & 0 & 0 \\ 0 & \beta & -r_3-\lambda & 0 \\ \theta & \mu & \gamma & -r_4-\lambda \end{vmatrix} = 0$$

$$(-r_1 - \lambda)(-r_2 - \lambda)(-r_3 - \lambda)(-r_4 - \lambda) - \alpha V^*(-\alpha S^*(-r_3 - \lambda)(-r_4 - \lambda) + \omega\beta\gamma - (-r_2 - \lambda)\omega\mu)$$
$$- \theta\omega(-r_2 - \lambda)(-r_3 - \lambda) = 0$$
$$\lambda^4 + c_1\lambda^3 + c_2\lambda^2 + c_3\lambda + c_4 = 0 \tag{5}$$

Where

$c_1 = r_1 + r_2 + r_3 + r_4$

$c_2 = r_1 r_2 + r_3 r_4 + (r_1 + r_2)(r_3 + r_4) + \alpha^2 V^* S^* - \theta\omega$

$$c_3 = r_1 r_2 (r_3 + r_4) + r_3 r_4 (r_1 + r_2) + \big((r_3 + r_4)\alpha S^* - \omega\mu\big)\alpha V^* - (r_2 + r_3)\theta\omega$$
$$c_4 = r_1 r_2 r_3 r_4 + \alpha^2 V^* S^* r_3 r_4 - \alpha\omega\beta\gamma V^* - \alpha\omega\mu V^* r_2 - \theta\omega r_2 r_3$$

By using the Routh-Hurwitz criterion, the roots of **Equation (5)** will be negative if :

i. $c_1 = r_1 + r_2 + r_3 + r_4 > 0$
ii. $c_1 c_2 - c_3 > 0 \leftrightarrow \frac{c_1 c_2}{c_3} > 1$
iii. $c_3(c_1 c_2 - c_3) - c_1^2 c_4 > 0 \leftrightarrow \frac{c_3(c_1 c_2 - c_3)}{c_1^2 c_4} > 1$
iv. $c_4 > 0$

Thus, the stability of the violence-free equilibrium point is asymptotically stable if $\Re_0 > 1, c_1 > 0$, $\frac{c_1 c_2}{c_3} > 1, \frac{c_3(c_1 c_2 - c_3)}{c_1^2 c_4} > 1, c_4 > 0$ are all satisfied.

3.3 Numerical Simulation

In this subsection, we will discuss numerical simulations of the sexual violence model in the system (1) using the MAPLE software.

3.3.1 Simulation of the Model at the Violence-Free Equilibrium Point

Below are the parameter values for simulating the model at the violence-free equilibrium point.

Table 2 The Parameter Values at the Violence-Free Equilibrium Point

Parameter	Values	Source
b	0,0032865	Assumption
α	0,0008243766248	Assumption
β	0,04423565217	Assumption
γ	0,05308325223	Assumption
μ	0,004423565217	Assumption
ω	0,4656577416	Assumption
θ	0,00003666046858	Assumption
ρ	0,0032865	[19]

From the parameter values in Table 2, we first calculate the value of $\Re_0$,

$$\Re_0 = 0{,}01586872266 < 1$$

and we obtain $\Re_0 < 1$.

Then, we calculate the value of the violence-free equilibrium point, $E_0 = (0{,}9999218294;\ 0;\ 0;\ 0{,}00007817049354)$.

In the simulation of the violence-free equilibrium point of sexual violence, initial values are used.

$$S(0) = 0{,}9980000805; V(0) = 0{,}001654192887;\ P(0) = 0{,}0003142982585;\ R(0) = 0{,}00003142836236$$

Based on the parameter values and initial values above, graphs for each group against time t are obtained.

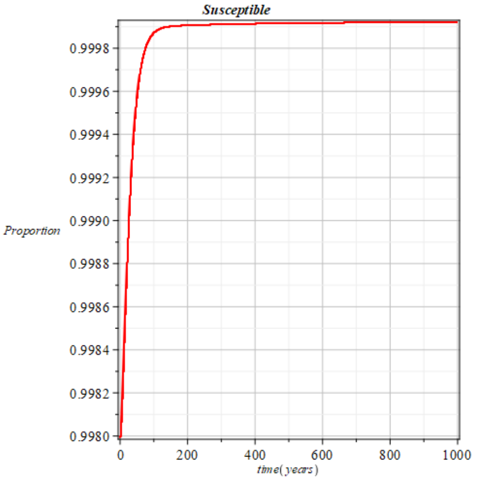

Figure 2 Trajectory of The Susceptible Class ($\boldsymbol{S(t)}$) Compartment at the violence-free equilibrium point

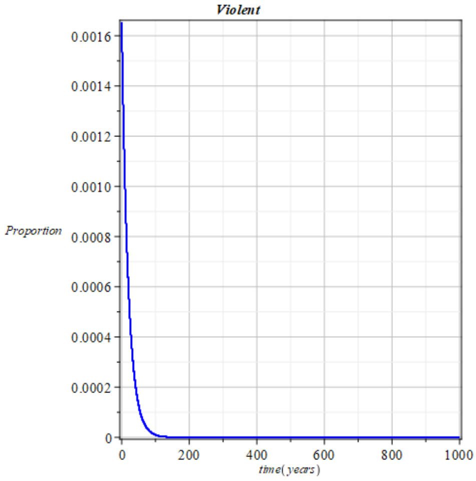

Figure 3 Trajectory of The Violent Class ($\boldsymbol{V(t)}$) Compartment at the violence-free equilibrium point

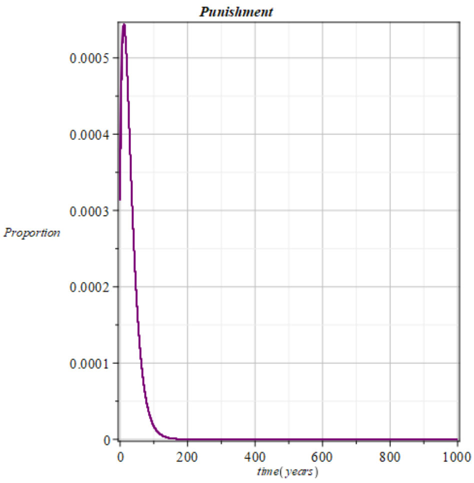

Figure 4 Trajectory of The Punishment Class ($\boldsymbol{P(t)}$) Compartment at the violence-free equilibrium point

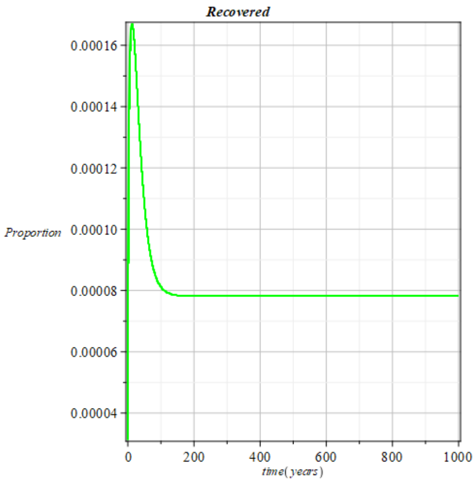

Figure 5 Trajectory of The Recovered Class ($\boldsymbol{R(t)}$) Compartment at the violence-free equilibrium point

In **Figure 2**, **Figure 3**, **Figure 4,** and **Figure 5** it can be observed that the graphs of the subpopulations of susceptible, violent, punishment, and recovered tend to approach the values of the violence-free equilibrium point E_0.

3.3.2 Simulation of the Model at the Endemic Equilibrium Point

Below are the parameter values for simulating the model at the endemic equilibrium point.

Table 3 The Parameter Values at the Endemic Equilibrium Point are as Follows

Parameter	Values	Source
b	0,0032865	Assumption
α^*	0,01648753250	Assumption
β	0.004423565217	Assumption
γ	0,6984540883	Assumption
μ	0,004423565217	Assumption
ω	0,4656577416	Assumption
θ	0,00003666046858	Assumption
ρ	0,0032865	[19]

From the parameter values in **Table 3**, we first calculate the value of $\mathfrak{R}_0$,

$$\mathfrak{R}_0 = 1{,}358723076 > 1$$

and we obtain $\mathfrak{R}_0 > 1$.

Then, we calculate the value of the endemic equilibrium point, $E^* = (0{,}7359276126;\ 0{,}2570043844;\ 0{,}001617458814;\ 0{,}00007817049354)$.

In the simulation of the endemic equilibrium point of sexual violence, initial values are used.

$$S(0) = 0{,}9980000805; V(0) = 0{,}001654192887;$$
$$P(0) = 0{,}0003142982585;\ R(0) = 0{,}00003142836236$$

Based on the parameter values and initial values above, graphs for each group against time t are obtained.

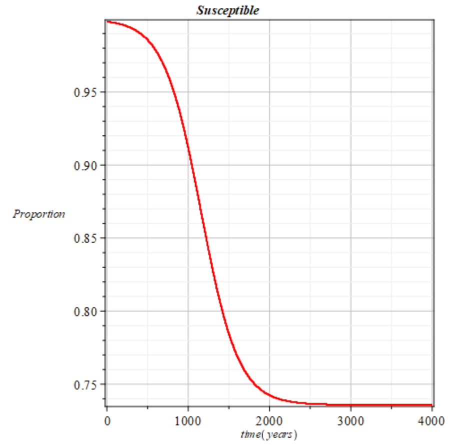

Figure 6 **Trajectory of The Susceptible Class ($S(t)$) Compartment at the endemic equilibrium point**

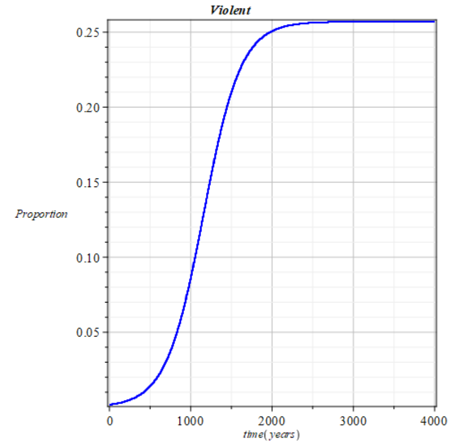

Figure 7 **Trajectory of The Violent Class ($V(t)$) Compartment at the endemic equilibrium point**

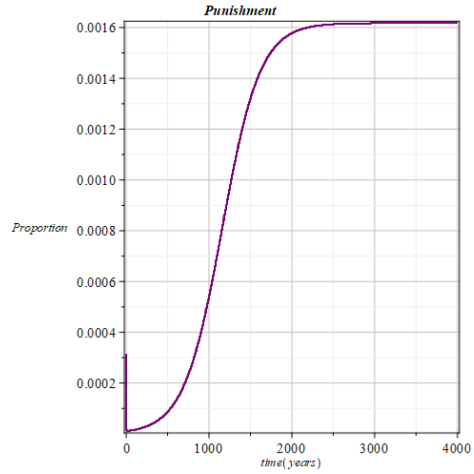

Figure 8 **Trajectory of The Punishment Class ($P(t)$) Compartment at the endemic equilibrium point**

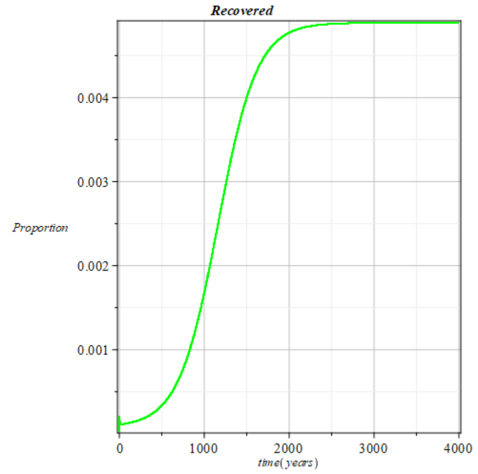

Figure 9 **Trajectory of The Recovered Class ($R(t)$) Compartment at the endemic equilibrium point**

In **Figure 6**, **Figure 7**, **Figure 8**, and **Figure 9** it can be observed that the graphs of the subpopulations of susceptible, violent, punishment, and recovered tend to approach the values of the endemic equilibrium point E^*.

4. CONCLUSIONS

Based on the two simulations conducted, the larger the value of the parameter α, the more sexual violence cases will continue to spread within the population. Conversely, if the value of α can be reduced, then sexual violence cases will not spread, and slowly, the cases will fade away.

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