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Research Article

Mathematical Model Analysis of Marriage Divorce Incorporating Counselling and Medical Attention

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Abstract

This paper has investigated the mathematical model analysis of marriage divorce taking into consideration the effect of counselling and medical attention in order to minimize the divorce cases. The research aimed at developing the deterministic mathematical model of marriage divorce incorporating the counselling and medical attention(treatment), determining the divorce free and endemic equilibrium points, determining the sensitivity analysis and finding numerical simulation. The system of the differential equations of the model was proved to be well posed which showed that the mathematical model of marriage divorce was re-searchable. The differential equations were linearized using Jacobean matrix and It was found that the divorce free equilibrium point to be locally asymptotically stable when the reproduction number is less than one, $R_0 < 1$ and divorce endemic equilibrium point to be globally asymptotically unstable when the reproduction number is greater than one, $R_0 > 1$. The sensitivity analysis was done to get the numerical values of the parameters involved in the model. The numerical simulations were done using Runge Kutta fourth order and MATLAB in order to generate the graphs. It was found that the number of divorced individuals reduced as results of individuals got counselling sessions and medical attention (treatment). It was equally observed, the active interaction between married and divorced individuals resulted in the increase of the divorced individuals due to the fact that the reproduction number is greater than one. The number of married individuals increased as a result of individuals got counselling sessions and separated individuals renewed their relationship. This research is of the great help of the community that with good communication, assume responsibility in the family, fidelity as couples, considering diversity in family and avoiding violence of any kind in the family as key factors of avoiding divorce in marriage.

Keywords

Mathematical Model, Marriage Divorce, Reproduction Number, Counselling, Medical Attention, Numerical Simulation

1. Introduction

Marriage is the legally or formally recognized union of two people as partners in a personal relationship that is historically and in some jurisdiction specifically a union between individuals. Divorce is the legal dissolution of a marriage by a court or other competent body.

Divorce can be modeled using various approaches, including social, economic and mathematical perspectives. These models aims at understanding the factors influencing divorce

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trends and predict potential outcomes. Mathematical models, like compartmental models and Ordinary differential equation models, analyze divorce dynamics, considering factors such as marriage, separation, divorce, and remarriage and their interactions within a population.

Mathematical model of marriage and divorce can help analyze divorce dynamics and potentially identify factors that contribute to its spread or reduction. There are some factors which are bases of divorce such as infidelity that is extramarital affairs can lead to marital breakdown, lack of commitment that is weakening of the bond and dedication between partners, communication problems involve difficulty in expressing needs and resolving conflicts, incompatibility that is differences in values, goals and life style choices, substance abuse this includes addiction which can negatively impact relationship and domestic violation that is physical or emotional abuse which is a major factor in divorce.

A study on mathematical analysis of marriage and divorce was done and it was discovered that when the reproduction number is less than one the divorce rate was minimized even though there is small break in marriage [2, 8, 9]. It was found that small number of divorce got broken but do not go to divorce compartment because the individuals renew their marriage and continue their relationship. It was observed that when the reproduction number is greater than one the divorced married individuals increase.

A Numerical Investigation of Marriage Divorce Model was conducted and analyzed [1]. It was observed that there is a little or no percentage of divorce marriage recorded when $R_0 < 1$. With increasing periods of time, it shows that only a small number of divorce marriage population go broken but many of such classes quickly resolved their differences and continue to maintain their relationship. Also the number of married individuals seems to be increasing for up to 25 years of marriage. The number of broken and divorced married individuals increases with time /year due to the fact that $R_0 > 1$.

Due to partial contact with married individuals and broken marriage classes, the number of divorced marriage population increase with time and the number of married individuals decreases due to their contact with divorced class of people who are always willing to drag the married people to join them.

Investigation on Mathematical model for marriage divorce was conducted [3]. They discovered that the interventions such as reconciliation programs and counselling initiatives can significantly reduce divorce rates and stabilize family structures.

Considering the previous studies done on marriage divorce, are based on marriage, broken, divorce and counselling compartments. The current paper has investigated the minimizing divorce in marriage using the combination of counselling and medical attention.

The mathematical modelling has become an effective means of analyzing the dynamics of infectious diseases. It gives the predictions using the reproductive number.[4-7]

The study aimed at developing SMPDCH mathematical model, determining the reproduction number, The divorce Free and Endemic equilibrium points, sensitivity analysis, simulation and suggest effective strategies to mitigate rising divorce rate.

2. Mathematical Model Analysis of Marriage Divorce

2.1. Model Description and Mathematical Formulation

The total number of the population is subdivided into six compartments which include the individuals who are susceptible at time t, S(t) who are single individuals at time t, Married individuals at time t, M(t), the separated individuals at time t, P(t), the divorced individuals at time t, D(t), individuals undergoing the counselling at time t, C(t) and individuals under medical care at time t, H(t).

The recruitment rate is represented by Λwhich are individuals reaching the age of marriage. The individuals got married at the rate β. The individuals broke their marriage and entered in the broken marriage compartment at the rate α. The broken individuals can renew their marriage at the rate ρ. The broken individuals got divorced at the rate δ. The separated individuals and divorced individuals got counselling at the rates θ, ψ respectively.

The young couples with problems of communication, small misunderstanding resolved their problems through counselling at the rate of γ. The individuals who have got medical care at the rate ω. The divorce individuals can become single individuals at the rate $\sigma$and seek medical attention at the rate λ. The individuals who got medical attention join counselling at the rate η. Some of the divorced individuals will die due to divorce at the rate Θ. The whole population has μ as an average of death rate.

2.2. Equations

The differential equations of the model are given below

$$\frac{dS(t)}{dt} = \Lambda + \sigma D - (\mu + \beta)S \quad (1)$$

$$\frac{dM(t)}{dt} = \beta S + \gamma C + \rho P - (\theta + \alpha + \mu)M \quad (2)$$

$$\frac{dP(t)}{dt} = \alpha M - (\mu + \theta + \delta + \rho)P \quad (3)$$

$$\frac{dD(t)}{dt} = \delta P - (\Theta + \mu + \sigma + \lambda + \psi)D \quad (4)$$

$$\frac{dC(t)}{dt} = \theta P + \eta H + \psi D - (\gamma + \mu + \omega)C \quad (5)$$

$$\frac{dH(t)}{dt} = \omega C + \lambda D - (\eta + \mu)H \qquad (6)$$

2.3. Figures

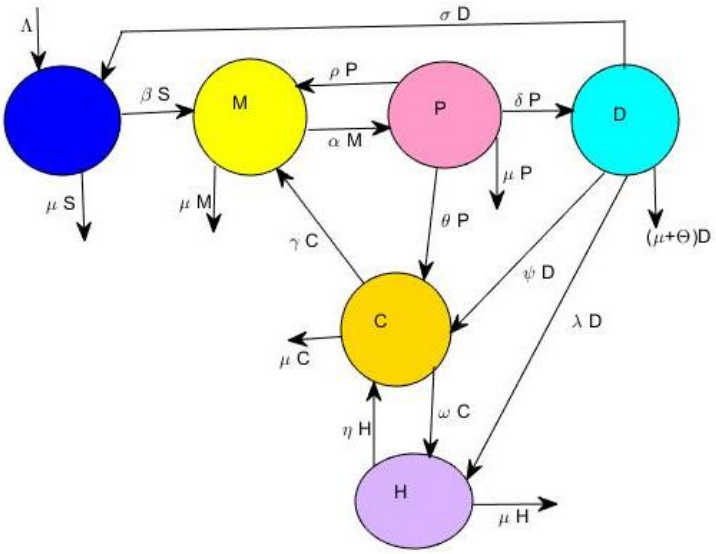

Figure 1. *Mathematical Model of Divorce in Marriage.*

2.4. Tables

Table 1. *Variables State and Parameters Description.*

Variables and Parameters	Description
S(t)	Number of people who get age of marriage at time t
M(t)	Number of people who are married at time t
P(t)	Number of individuals who are separated at time t
D(t)	Number of divorced individuals at time t.
C(t)	Number of individuals who got counselling at time t
H(t)	Number of individuals who got medical treatment
Λ	Recruitment rate of individuals to the age of single
B	The rete of single individuals who got married
Σ	Rate of divorced individuals who became single
A	The contact rate of divorced with married individuals
Θ	Death rate of individuals due to divorce
P	Rate of separated individuals who renewed their previous marriage
Δ	Rate of separated individuals who got divorced
Λ	Rate of divorced individuals who got medical treatment
Ψ	Rate of divorced individuals who got counselling

Variables and Parameters	Description
Θ	Rate of separated individuals who got counselling
Γ	Rate of individuals who renewed their previous marriage after counselling.
Ω	Rate of individuals who got medical attention after counselling
M	Natural death rate of individuals
η	Rate of individuals who went to counselling after being treated.

Table 2. Variable State and Parameters Description.

Parameters	Values	Sources
Λ	0.4	Assumed
B	0.04	[2]
P	0.03	[2]
A	0.03	Assumed
Δ	0.01	[8]
Σ	0.04	[9]
Θ	0.01	Assumed
Ψ	0.002	Assumed
Λ	0.01	[9]
Θ	0.3	[8]
Γ	0.001	[3]
H	0.02	[1]
Ω	0.01	[3]
M	0.015	[2]

3. Materials and Methods

3.1. Invariant Region

The model which is made of SMPDCH with differential equations, Λ, the variables and parameters of the model that are assumed $vt \geq 0$. The invariant region is calculated using the theorem below. The set Θ attracts all the solutions in $R^6{}_+$ and is positively invariant. The proof is shown.

$$N(t) = S(t) + M(t) + P(t) + D(t) + C(t) + H(t)$$

$$DN(t) = \frac{dS(t)}{dt} + \frac{dM(t)}{dt} + \frac{dP(t)}{dt} + \frac{dD(t)}{dt} + \frac{dC(t)}{dt} + \frac{dH(t)}{dt}$$

By simplification, we get

$$\frac{dN(t)}{dt} \leq -\mu N$$

By integration as $t \to \bowtie$ we get.

$$\Theta = \left\{(S, M, P, D, C, H)\epsilon R^6{}_+ \ : \ 0 \leq N(t) \leq \frac{\Lambda}{\mu}\right\}$$

The solution set of the dynamic system of the equations in the model is bounded in the region. This implies that the dynamic system of the model in the region is well posed.

3.2. Positivity of the Solution

The solution of the system remains positive at any point in time, if the initial values of the variables are positive.

$\Psi = \{(S(t), M(t), P(t), D(t), C(t), H(t))\epsilon R^6{}_+ : \ S(0) > 0, M(0) > 0, P(0) > 0, D(0) > 0, C(0) > 0, H(0) > 0\}$ are

positive for $t \geq 0$

3.3. Divorce Free Equilibrium Point

In the absence of divorce, that is $D = P = 0$, then the divorce free equilibrium happens and is found by equating the right hand side of the differential equations to zero, hence the divorce free equilibrium is found to be,

$$E_0 = (S^0, M^0, P^0, D^0, C^0, H^0) = \left(\frac{\Lambda}{\mu+\beta}, \frac{\Lambda\beta}{(\mu+\beta)(\theta+\alpha+\mu)}, 0,0,0,0\right) \quad (7)$$

Equation (7) represents divorce free equilibrium and this means that the state in which there is no divorce in marriage.

3.4. Basic Reproduction Number

The Next Generation Matrix is used to calculate the basic reproduction number which is the spectral radius of the Next Generation Matrix. sing Jacobean matrix at divorce free equilibrium [10-12] we obtain F and V with respect to P and D.

$$FV^{-1} = \begin{bmatrix} 0 & \frac{\alpha\Lambda\beta}{(\mu+\beta)(\theta+\alpha+\mu)} \\ \delta & 0 \end{bmatrix} \begin{bmatrix} \frac{1}{(\mu+\theta+\delta+\rho)} & 0 \\ 0 & \frac{1}{(\omega+\psi+\delta+\lambda+\mu)} \end{bmatrix}$$

The reproduction number is given by

$$R_0 = \frac{\alpha\beta\Lambda\delta}{(\mu+\beta)(\theta+\alpha+\mu)(\omega+\psi+\delta+\lambda+\mu)(\mu+\theta+\delta+\rho)}$$

3.5. Local Stability of Divorce Free Equilibrium Point.

The divorce free equilibrium is locally asymptotically stable if $R_0 < 1$ and unstable if $R_0 > 1$. Finding the Jacobean matrix.

Table 3. *Eigenvalues.*

—($\mu+\beta$)	**0**	**0**	**σ**	**θ**	**θ**
β	—(μ + α +θ)	ρ	0	θ	0
0	0	—($\mu+\theta+\delta$ +ρ)	$\Lambda\beta/\mu$	0	0
0	0	δ	—($\omega+\mu+\sigma+\psi$ +λ)	0	0
0	θ	θ	ψ	—($\gamma+\mu+\omega$)	0
0	0	0	λ	ψ	—(η + μ)

Since all the eigenvalues are negative, therefore Divorce Free equilibrium is locally asymptotically stable if $R_0 < 1$.

3.6. Endemic Equilibrium

To calculate the Divorce Endemic Equilibrium point, all variables in the system of the differential equations are taken into consideration. The Divorce Endemic Equilibrium Point is given by $EE = (S^*, M^*, P^*, D^*, C^*, H^*)$. From the differential equations of the system,

$$\frac{dS(t)}{dt} = \Lambda + \sigma D - (\mu+\beta)S$$

$$\text{or } \Lambda + \sigma D - (\mu+\beta)S = 0 \quad S^* = \frac{\Lambda}{(\mu+\beta)} + \left(\frac{\theta\delta\alpha\rho\sigma}{(\theta+\mu+\Psi)(\omega+\mu+\sigma+\lambda+\psi)(\mu+\theta+\delta+\rho)-\theta(\omega+\mu+\delta+\lambda+\psi)-\alpha\theta^2(\omega+\mu+\delta+\lambda+\psi)}\right)$$

$$\frac{dM(t)}{dt} = \beta S + \gamma C + \rho P - (\theta+\alpha+\mu)M \text{ or}$$

$$\beta S + \gamma C + \rho P - (\theta+\alpha+\mu)M = 0$$

$$M^* = \frac{\gamma}{(\mu+\alpha+\theta)}\left(\frac{\rho(\mu+\delta+\rho)}{(\theta+\mu+\Psi)(\mu+\theta+\delta+\rho)-\theta(\omega+\mu+\delta+\lambda+\psi)+\gamma(\omega+\mu+\delta+\lambda+\psi)-\alpha\theta\gamma(\omega+\mu+\delta+\lambda+\psi)}\right)+$$

$$+\alpha\gamma\rho\left(\frac{\rho(\omega+\mu+\delta+\psi)}{(\theta+\mu+\Psi)(\mu+\theta+\delta+\rho)(\omega+\mu+\sigma+\lambda+\psi)}\right)$$

$$\frac{dP(t)}{dt} = \alpha M - (\mu+\theta+\delta+\rho)P \text{ or}$$

$$\alpha M - (\mu+\theta+\delta+\rho)P = 0$$

$$P^* = \frac{\alpha\theta}{(\mu+\alpha+\theta)}\left(\frac{\gamma\rho(\omega+\mu+\delta+\psi)}{(\theta+\mu+\Psi)(\omega+\mu+\delta+\lambda+\psi)(\mu+\theta+\delta+\rho)-\theta\gamma(\omega+\mu+\delta+\lambda+\psi)+\psi(\omega+\mu+\delta+\lambda+\psi)}\right)$$

$$\frac{dD(t)}{dt} = \delta P - (\Theta+\mu+\sigma+\lambda+\psi)D \text{ or}$$

$$\delta P - (\Theta+\mu+\sigma+\lambda+\psi)D = 0$$

$$D^* = \left(\frac{\gamma\rho\alpha\theta\delta}{(\theta+\mu+\Psi)(\omega+\mu+\delta+\lambda+\psi)(\mu+\theta+\delta+\rho)-\theta\gamma(\omega+\mu+\delta+\lambda+\psi)(\mu+\theta+\delta+\rho)}\right)$$

$$\frac{dC(t)}{dt} = \theta P + \eta H + \psi D - (\gamma+\mu+\omega)C \text{ or}$$

$$\theta P + \eta H + \psi D - (\gamma+\mu+\omega)C = 0$$

$$C^* = \left(\frac{\gamma\rho\left((\omega+\mu+\delta+\lambda+\psi)(\mu+\theta+\delta+\rho)\right)}{(\theta+\mu+\Psi)(\omega+\mu+\delta+\lambda+\psi)(\mu+\theta+\delta+\rho)-\theta\gamma(\omega+\mu+\delta+\lambda+\psi)(\mu+\theta+\delta+\rho)}\right)$$

$$\frac{dH(t)}{dt} = \omega C + \lambda D - (\eta+\mu)H \text{ or}$$

$$\omega C + \lambda D - (\eta+\mu)H = 0$$

$$H^* = \left(\frac{\alpha^2\gamma\rho}{(\theta+\mu+\Psi)(\omega+\mu+\delta+\lambda+\psi)(\mu+\theta+\delta+\rho)-\theta\gamma(\omega+\mu+\delta+\lambda+\psi)(\mu+\theta+\delta+\rho)}\right)$$

The Endemic Equilibrium of the system of the differential equations is given by the above computations

$$\mathrm{EE} = (\mathrm{S}^*, \mathrm{M}^*, \mathrm{P}^*, \mathrm{D}^*, \mathrm{C}^*, \mathrm{H}^*)$$

3.7. Stability Analysis

The analysis of stability indicates the behaviour of endemic near the equilibrium points. Kerobeinikov and Wake proposed the logarithmic Lyapunov function to prove the global stability of Endemic Equilibrium for epidemiological system of differential equations.[13, 14]

Theorem: The Endemic Equilibrium point Z^* is globally asymptotically stable when $R_0 > 1$ and unstable when $R_0 < 1$.

Proof: The logarithmic Lyapunov function is utilized to analyze the stability of the Endemic Equilibrium.

$Z^* = \sum_{i=1}^{6} b_i\left[y_i - y^*{}_i log(y_i)\right]$ where $b_i$represents a positive constant, the free divorce in the compartment iis represented by y_i and $y^*{}_i$ represents the free divorces in compartment i at equilibrium point. The system of differential equations is written as

$$Z^*(SMPDCH) = \lambda_1\left(S - S^*log(S)\right) + \lambda_2\left(M - M^*log(M)\right) + \lambda_3\left(P - P^*log(P)\right) + \lambda_4\left(D - D^*log(D)\right) + \lambda_5\left(C - C^*log(C)\right) + \lambda_6\left(H - H^*log(H)\right)$$

Where $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6$ are non negative constants and $Z^*$is considered to be continuous derivatives.
Consider the derivative with respect to each compartment.

$$\mathrm{dZ} = \left\{\lambda_1\left(1-\frac{\mathrm{S}^*}{\mathrm{S}}\right) + \lambda_2\left(1-\frac{\mathrm{M}^*}{\mathrm{M}}\right) + \lambda_3\left(1-\frac{\mathrm{P}^*}{\mathrm{P}}\right) + \lambda_4\left(1-\frac{\mathrm{D}^*}{\mathrm{D}}\right) + \lambda_5\left(1-\frac{\mathrm{C}^*}{\mathrm{C}}\right) + \lambda_6\left(1-\frac{\mathrm{H}^*}{\mathrm{H}}\right)\right\}$$

At Endemic Equilibrium oint

$$\frac{dZ}{dt} = \lambda_1\left(\frac{S^*-S}{S}\right)[(\mu+\beta)(S^*-S)] + \lambda_2\left(\frac{M^*-M}{M}\right)[(\theta+\alpha+\mu)(M^*-M)] + \lambda_3\left(\frac{P^*-P}{P}\right)[(\mu+\delta+\rho)(P^*-P)] + \lambda_4\left(\frac{D^*-D}{D}\right)[(\omega+\mu+\sigma+\lambda+\psi)(D^*-D)] + \lambda_5\left(\frac{C^*-C}{C}\right)[(\theta+\mu+\Psi)(C^*-C)] + \lambda_6\left(\frac{H^*-H}{H}\right)[(\mu)(H^*-H)]$$

$$\frac{dZ}{dt} = -\lambda_1\left(\frac{S^*-S}{S}\right)^2(\mu+\beta) - \lambda_2\left(\frac{M^*-M}{M}\right)^2(\theta+\alpha+\mu) - 3\left(\frac{P^*-P}{P}\right)^2(\mu+\delta+\rho) - \lambda_4\left(\frac{D^*-D}{D}\right)^2(\omega+\mu+\sigma+\lambda+\psi) - \lambda_5\left(\frac{C^*-C}{C}\right)^2(\theta+\mu+\Psi) - \lambda_6\left(\frac{H^*-H}{H}\right)^2(\mu)$$

Considering S→ S*,M→ M*, P → P*,D→ D*,C→ C*,H→ H*,

Therefore $\frac{dZ}{dt} \ll 0$ and the function Z^* is negative when $Z(SMPDCH) \geq 0$. The largest invariant set N is a singleton set Z which is the Endemic Equilibrium point, with this invariant principle, Z is globally asymptotically stable when $R_0 > 1$ in N.

3.8. Sensitivity Analysis

The sensitivity analysis is used to show the relationship between reproduction number and each parameter involved in the differential equations. The sensitivity index was computed to show the importance of the most sensitive parameters which determine how divorce is spread in the compartments. In the determination of the sensitivity indices, the errors are so small and sometimes the values are assumed. The equation that is standard for sensitivity analysis of R_0 is given the following relationship and the values of parameters are given in Table 1.

$$S^{R_0}{}_P = \frac{\partial R_0}{\partial P} * \frac{P}{R_0}$$

4. Numerical Simulation

The SMPDCH model was analyzed. The reproduction number was determined and divorce Free and Endemic equilibrium points were performed. The previous studies focused on the marriage, separated, divorce and counselling compartments. The researcher brings innovation by combining counselling and medical attention to minimize the divorce in marriage. The different parameters included in the differential equations are used to check the dynamics of the divorce in marriage. Some of the causes of divorce in marriage include the infertility of one of the couple. It may be as a result of sickness and with medical attention, one can get treated and get back to normal life. The values of different parameters are given in the table below.

Figure 2. *Divorce Dynamics in Marriage.*

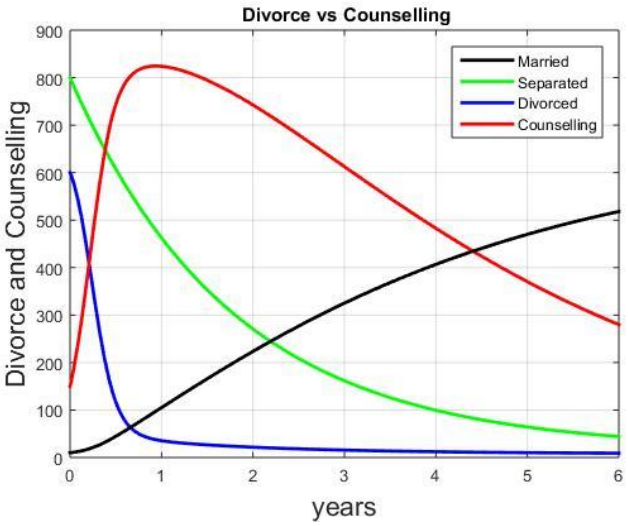

Figure 3. *Divorce and Counselling.*

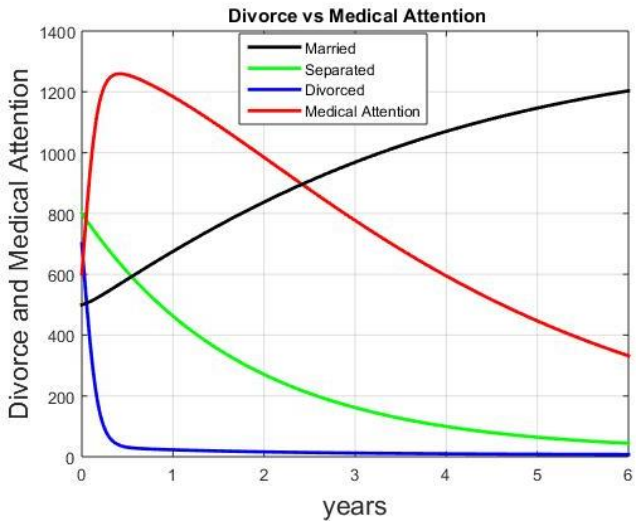

Figure 4. *Divorce and Medical Attention.*

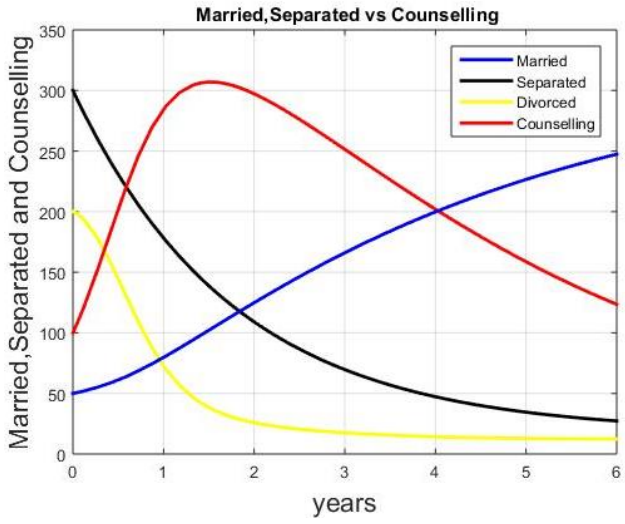

Figure 5. *Married, Separated vs Counselling.*

5. Discussion

5.1. Divorce Dynamics in Marriage

From Figure 2: There are many factors that cause separation from the couples. Some of them are communication problems, violence and lack of commitments. When the couples experience these problems and they separate. After separation, some couples experience difficulties like how to take care of children, heartbreak, emotional and physical distress, hence the couple divorce as a result from the problems mentioned above. From the figure it is observed that as the counselling and medical attention initiatives are intensified results in reducing the divorce and separated married individuals.

5.2. Divorce and Counselling

From Figure 3: The divorced married individuals experience challenges even some of them die as result of divorce. The number of divorce married individuals reduces as a result of counselling.

5.3. Divorce and Medical Attention

From Figure 4: Some married individuals get divorced as a result of infertility. If one of the partners is infertile may cause misunderstanding in relationship. These individuals need medical attention. The number of divorced married individuals decreases as the number of individuals who got medical attention has increased.

5.4. Married, Separated and Counselling

From Figure 5: The individuals who are broken, may get remarry as they resolve the differences or as a result of counselling. The number of individuals who renew or get remarried increases as result of counselling.

In this section, authors are advised to provide a thorough analysis of the results and make comparisons with relevant literature, not a short summary or conclusion. Any future research directions could also be stated in the discussion.

6. Conclusions

This paper investigated the mathematical model dynamics of divorce in marriage including counselling and medical attention. The deterministic SMPDCH model was analyzed. The reproduction number was determined. The divorce Free and Endemic Equilibrium points were computed and analyzed. The values of different parameters were given from different sources.

It is observed that the number of the separated and divorced individuals decreases as the number of individuals getting counselling and medical attention increases. This is due to the fact that the reproduction numbers is less than one $R_0 < 1$.

It is noted that as the number of divorced married individuals reduces because of increasing number of individuals that are treated in different medical facilities.

This paper has studied the impact of the counselling and medical attention on the minimizing the divorce cases. Researchers may investigate the minimization of divorce cases by considering the factors such as cultural influences, economic, awareness campaigns and legal reforms. The conclusion section should precisely articulate the main findings of the article, emphasizing its significance and relevance. In the conclusion, it is highly recommended that authors avoid referencing figures or tables. Instead, these should be appropriately referenced within the body of the paper.

Abbreviations

SMPDCH	Susceptible, Married, Separated, Divorce, Counselling, Medical Attention
R_0	Reproduction Number
EE	Endemic Equilibrium
JE_0	Jacobean Matrix at Divorce Free Equilibrium

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Author Contributions

Felicien Habiyaremye: Conceptualization, Formal Analysis, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Conflicts of Interest

The author declares no conflicts of interest.

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