Impact of Meditation on Suicidal Thoughts: A Mathematical Model

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Abstract

In this paper a non-linear mathematical model for the impact of meditation on suicidal thoughts due to different symptoms has been discussed based on the previous studies. In the modeling process the growth rate of awareness programs impacting the population is assumed to be proportional to the numbers of person who have suicidal thoughts and who have died cause of suicide. The model is analyzed by using stability theory of differential equations. From this analysis and simulation it is found that suicidal thoughts and suicide cases can be prevented, controlled or at least delayed by introducing effective awareness programs. Suicidal thoughts due to the worldwide pandemic is also a serious concern and it can be controlled by Meditation and timely help by suicide prevention helplines that are functioning amidst the pandemic. The numerical simulation analysis of the model confirms the analytical results.

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Keywords: Epidemic Model, Suicidal thoughts, Meditation, Local Stability, Global Stability.

1 Introduction

Suicide has become one of the biggest social problems of the present time, affecting lives in one way or the other. It is a day-to-day experience and everyday news in our surroundings but still remains a silent issue of discussion with less or no efforts being done to prevent or stop such acts. As per previous study according to Durkheim there are four different types of suicide, namely egoistic suicide, altruistic suicide, anomic suicide and fatalistic suicide and all of them have some specific behavior [8]. Stemming from the absence of social integration comes under Egoistic suicide, when social group involvement is too high Altruistic suicide happens, individuals kill themselves for the sake of a religious or political cause. Anomic suicide is caused due to lack of social regulation and it stems from sudden and unexpected changes in situations. When individuals are placed under high expectations or extreme rules which removes a person's sense of self or individuality Fatalistic suicide happens [7, 16].

As per Centers for Disease Control and Prevention (CDC) suicide is a leading cause of death in the United States, more than 47,500 deaths in 2019 due to suicide. Suicide is the eighth-most common reason in India, for deaths as stated by WHO (2017). The number of suicide attempts is at least ten times the number of suicides. As per August 2020 literature shows an increased rate of suicidal deaths during COVID-19 pandemic, which is similar to previous scientific studies on suicide rate during the Influenza, MERS and Severe SARS outbreaks [6, 13, 18, 19].

According to The Economic Times, Suicide was the leading cause for over 300 "non-coronavirus deaths" reported in India due to distress triggered by the nationwide lockdown, revealed a new set of data compiled by a group of researchers. The suicide causalities include fear of COVID-19 infection, financial crisis due to worldwide lockdown, loneliness, social boycott and pressure to be quarantine, COVID-19 positive, COVID-19 work-related stress, unable to come back home due to lockdown, unavailability of alcohol etc [1, 5, 12, 13, 14, 18, 20]. The group, comprising public interest technologist Thejesh GN, activist Kanika Sharma and assistant professor of legal practice at Jindal Global School of Law Aman, concluded that 338 deaths have occurred from March 19 till May 2 and they are related to lockdown. According to the data present in media reports, 80 people killed themselves due to loneliness and fear of being tested positive for the virus. The suicides are followed by migrants dying in accidents on their way back home (51), deaths associated with withdrawal symptoms (45), and those related to starvation and financial distress (36). There have been a staggering number of suicides, caused by fear of infection, loneliness, lack of freedom of movement, and alcohol withdrawal during the lockdown (The Economic Times, 2020).

According to studies relaxation exercises and meditation have a wide range of applications and are especially useful in examining stress and related disorders [2, 9, 10, 11, 12, 18]. According to Sadhguru an Indian yogi and author have put forward his thought about how to overcome from Suicidal thoughts and how it can be reduced by meditation and yoga [17]. The exercise of meditation originated withinside the historic Vedic instances of India and is defined in the ancient Vedic texts[11]. Meditation is a process of self-reflection or self-contemplation, purification mind and thoughts, regular practice of meditation helps development to control over mind so that one can have right views, right actions and behavior can be at peace. The practice of meditation was originated during ancient Vedic times in India and has been described in Vedic texts as well [20]. Meditation is one of the modals used in Ayurveda, the complete, natural health care system that originated in the ancient times of Vedas in India. One of the case studies has revealed a significant, constructive behavioral modification of the human being that practice meditation, thus reducing the number of visits to the physicians by a large extent and the individual is found to save Dollar 200 on the clinician's visit with effective practicing of meditation (J. Achterberg, 1992)[2]. In 1996, Hassed [10] studied that Meditations are the set of techniques that are anticipated to encourage a strengthened state of awareness and focused attention. Meditation has proved to be significant means that helps in reducing stress to a great extent. Further studied by Fortney et.al. in 2010[7], they have shown that meditation has various health benefits and these research findings have sparkled attention in the field of medicine. The rest of this paper is organized as follows: In section 2 gives the formulation of the model. In Section 3, we discuss the boundedness of the solution. In Sections, 4 our model is analyzed with regard to equilibrium point and its local and global stability. In section 5, we present numerical simulation to illustrate the applicability of results obtained. We have concluded with a discussion in section 6.

2 Model Formulation

Let $P, T, S, P_m \text{and} M$ represent the numbers of population whose age greater than 13, number of person who have suicidal thoughts , number of person who have died cause of suicide or attempted to suicide, aware class in a population and the cumulative density of awareness programs driven by the media in that region at time t respectively. $A, \lambda_1, d, \lambda, \lambda_2, \gamma, \nu, \delta, \lambda_0, \mu, \text{and} \mu_0$ are positive parameters. 'A' denotes the incidence rate of population, $'\lambda_1'$ the probability of developing suicidal thoughts, 'd' the natural mortality rate, $'\lambda_2'$ the probability of suicidal thoughts force to suicide, γ the rate at which person try to suicide but save with suicidal thoughts, ν the rate at which person have died caused by suicide become severely disabled, δ the mortality rate due to complications which raised after failing in suicide, λ the dissemination rate of awareness among susceptible class in a population due to which they form a different class, μ the rate with which awareness programs are being implemented, μ_0 the depletion rate of these programs due to ineffectiveness, social problems in the population, λ_0 the rate of transfer of aware class to susceptible class, respectively.

Keeping above consideration and assumption in mind the dynamics of model is governed by the following system of nonlinear ordinary differential equations

(2.1) $$\frac{dP}{dt} = A - (\lambda_1 + d)P - \lambda PM + \lambda_0 P_m,$$

(2.2) $$\frac{dT}{dt} = \lambda_1 P - (\lambda_2 + d)T + \gamma S,$$

(2.3) $$\frac{dS}{dt} = \lambda_2 T - (\gamma + d + \nu + \delta)S,$$

(2.4) $$\frac{dP_m}{dt} = \lambda PM - dP_m - \lambda_0 P_m,$$

(2.5) $$\frac{dM}{dt} = \mu(T + S) - \mu_0 M.$$

where $P(0) > 0, T(0) \geq 0, S(0) \geq 0, P_m(0) \geq 0, M(0) \geq 0.$

3 Boundedness of the solutions of the system

Necessary conditions for the boundedness of the solution of system (2.1)-(2.5) is given by the proceeding Lemma

3.1 Lemma

The set
$\Omega = \{(P, T, S, P_m, M) : 0 \leq P + T + S + P_m \leq \frac{A}{d}, 0 \leq M \leq \frac{2\mu A}{d\mu_0}\},$
is the region of attraction ∀ solutions initiating in interior of the positive octant.

Proof:

Let (P, T, S, P_m, M) be any solution with positive of (2.1)-(2.5) with positive initial conditions $(P_0, T_0, S_0, P_{m0}, M_0)$. Define a function $N = P + T + S + P_m$. Computing the time derivative of along solutions of system (2.1)-(2.5), we get

$$\frac{dN}{dt} = \frac{dS}{dt} + \frac{dT}{dt} + \frac{dS}{dt} + \frac{dP_m}{dt},$$

$$\frac{dN}{dt} \leq A - dN$$

Applying a Lemma on differential inequalities [3], we obtain
$0 \leq N(P, T, S, P_m) \leq \frac{A}{d} + \frac{N(P_0, T_0, S_0, P_{m0})}{\exp(dt)}$ and for $t \to \infty, 0 \leq N \leq \frac{A}{d}$.
Next, taking equation (2.5) and upper bound of N, we get

$$\frac{dM}{dt} \leq \mu(\frac{A}{d} + \frac{A}{d}) - \mu_0 M$$

comparison principle, it follows that $M_{max} = \frac{2\mu A}{d\mu_0}$. From above results, it is assured that the solutions of the system (2.1)-(2.5) is bounded in the region
$\Omega = \{(P, T, S, P_m, M) : 0 \leq P + T + S + P_m \leq \frac{A}{d}, 0 \leq M \leq \frac{2\mu A}{d\mu_0}\},$

4 Equilibrium and Stability Analysis

4.1 Existence of Equilibrium Point

Theorem 4.1. *$\exists$ only one equilibrium point for the system (2.1)-(2.5), as $E^*(P^*, T^*, S^*, P_m^*, M^*)$ if and only if the condition $\lambda q_1 q_2 > \lambda_0 q_3 q_4$ holds.*

Proof. The only equilibrium for the system (2.1)-(2.5) is interior equilibrium $E^*(P^*, T^*, S^*, P_m^*, M^*)$, where $S^* = q_0 T^*$, $M^* = q_1 T^*$, $P^* = q_2 T^*$, $P_m^* = q_3 q_4 T^{*2}$, $q_0 = \frac{\lambda_2}{\gamma+d+\nu+\delta}$, $q_1 = \frac{\mu(\gamma+d+\nu+\delta+\lambda_2)}{\mu+0(\gamma+d+\nu+\delta)}$, $q_2 = \frac{2\gamma\lambda_2+\lambda_2(d+\gamma+\delta)+d(\gamma+d+\nu+\delta)}{\lambda_1}$, $q_3 = \frac{\lambda\mu}{\lambda_1\mu_0(d+\gamma_0)(\gamma+d+\nu+\delta)}$, $q_4 = (\gamma + d + \nu + \delta + \lambda_2)\{2\gamma\lambda_2 + \lambda_2(d + \gamma + \delta) + d(\gamma + d + \nu + \delta)\}$
also,

$$(\lambda q_1 q_2 - \lambda_0 q_3 q_4)T^{*2} + (\lambda_1 + d)q_2 T^* - A = 0. \tag{4.0}$$

$$(\lambda q_1 q_2 > \lambda_0 q_3 q_4). \tag{4.0}$$

In this way T^* is the unique positive root of the equation (4.1) with condition (4.1). □

4.2 Stability Analysis

4.2.1 Local Stability

Theorem 4.2. *Interior equilibrium E^* is locally asymptotically stable if*

$$\begin{aligned}
(\lambda P^*)^2 &< min\{\frac{\mu_0}{2}(\lambda_1 + d + \lambda M^*), \frac{\mu_0}{2}(d + \lambda_0)\}\\
(\lambda_0 + \lambda M^*)^2 &< (\lambda_1 + d + \lambda M^*)(d + \mu_0),\\
\lambda_1^2 &< \frac{2}{3}(\lambda_2 + d)(\lambda_1 + d + \lambda M^*),\\
(\gamma + \lambda_2)^2 &< \frac{2}{3}(\lambda_2 + d)(\gamma + d + \nu + \delta),\\
\mu^2 &< min\{\frac{(\lambda_2 + d)\mu_0}{3}, \frac{(\gamma + d + \nu + \delta)\mu_0}{2}\}.
\end{aligned}$$

holds.

Proof. Local stability of the system is found by linearizing the system (2.1)-(2.5). Let $P = P^* + p_1$, $T = T^* + t_1, S = S^* + s_1$, $P_m = P_m^* + p_{m1}$, and$M = M^* + m_1$ be the small perturbation, after linearizing the system (2.1)-(2.5), we have

$$\begin{aligned}
\frac{dp_1}{dt} &= -(\lambda_1 + d + \lambda M^*)p - \lambda P^* m + \lambda_0 p_{m1},\\
\frac{dt_1}{dt} &= (\lambda_1 p_1 - (\lambda_2 + d)t_1 + \gamma s_1,\\
\frac{ds_1}{dt} &= (\lambda_2 t_1) - (\gamma + d + \nu + \delta)s_1,\\
\frac{p_{m1}}{dt} &= \lambda M^* p_{m1} + \lambda P^* m_1 - dp_{m1} - \lambda_0 p_{m1},\\
\frac{dm_1}{dt} &= \mu(t_1 + s_1) - \mu_0 m_1.
\end{aligned} \tag{4.1}$$

Considering,

$$V = \frac{p_1^2}{2} + \frac{t_1^2}{2} + \frac{s_1^2}{2} + \frac{p_{m1}^2}{2} + \frac{m_1^2}{2} \tag{4.2}$$

as the positive definite Lyapunov function for the interior equilibrium E^*, Differentiating (4.2) with respect to time 't', around the interior equilibrium, we have

$$\begin{aligned}\frac{dv}{dt} &= -\frac{1}{2}(\lambda_1 + d + \lambda M^*)p_1^2 - \frac{(\lambda_2 + d)t_1}{3} - \frac{1}{2}(\gamma + d + \nu + \delta)s_1^2 - \frac{d + \lambda_0}{2}p_{m1}^2 - \frac{\mu_0}{4}m_1^2\\ &-\lambda P^* m_1 p_1 + p_{m1}p_1(\lambda_0 + \lambda M^*) + p_1 t_1 \lambda_1 + s_1 t_1(\gamma + \lambda_2) + \lambda P^* m_1 p_{m1}\\ &+\mu t_1 m_1 + \mu s_1 m_1.\end{aligned} \tag{4.3}$$

Sufficient condition for $\frac{dv}{dt}$ to be negative definite is

$$\begin{aligned}(\lambda P^*)^2 &< min\{\frac{\mu_0}{2}(\lambda_1 + d + \lambda M^*), \frac{\mu_0}{2}(d + \lambda_0)\}\\ &(\lambda_0 + \lambda M^*)^2 < (\lambda_1 + d + \lambda M^*)(d + \mu_0),\\ &\lambda_1^2 < \frac{2}{3}(\lambda_2 + d)(\lambda_1 + d + \lambda M^*),\\ &(\gamma + \lambda_2)^2 < \frac{2}{3}(\lambda_2 + d)(\gamma + d + \nu + \delta),\\ &\mu^2 < min\{\frac{(\lambda_2 + d)\mu_0}{3}, \frac{(\gamma + d + \nu + \delta)\mu_0}{2}\}.\end{aligned} \tag{4.4}$$

in the above equation (4.3) holds. Interior equilibrium E^* is locally asymptotically stable with region of attraction Ω. □

4.2.2 Global Stability [4]

The equilibrium point E^* is non-linearly stable if the following inequalities are satisfied:

$$\begin{aligned}(\lambda P^*)^2 &< min\{\frac{4\mu_0}{9}(\lambda_1 + d + \lambda M^*), \frac{2\mu_0}{3}(d + \lambda_0)\}\\ &(\lambda_0 + \lambda M^*)^2 < \frac{2}{3}(\lambda_1 + d + \lambda M^*)(d + \lambda_0),\\ &\lambda_1^2 < \frac{4}{9}(\lambda_2 + d)(\lambda_1 + d + \lambda M^*),\\ &(\gamma + \lambda_2)^2 < \frac{2}{3}(\lambda_2 + d)(\gamma + d + \nu + \delta),\\ &\mu^2 < min\{\frac{(4\lambda_2 + d)\mu_0}{9}, \frac{2(\gamma + d + \nu + \delta)\mu_0}{3}\}.\end{aligned}$$

Proof 4.2.2

To prove the global stability of the system (2.1)-(2.5), let

$$G = \frac{1}{2}(P - P^*)^2 + \frac{1}{2}(T - T^*)^2 + \frac{1}{2}(S - S^*)^2 + \frac{1}{2}(P_m - P_m^*)^2 + \frac{1}{2}(M - M^*)^2 \tag{4.5}$$

be the positive definite Lyapunov function about the interior equilibrium. Differentiating equation (4.5) with respect to time 't',

$$\frac{dG}{dt} = (P - P^*)\frac{dP}{dt} + (T - T^*)\frac{dT}{dt} + (S - S^*)\frac{dS}{dt} + (P_m - P_m^*)\frac{dP_m}{dt} + (M - M^*)\frac{dM}{dt}. \tag{4.6}$$

Doing some algebraic manipulation, using equations (2.1)-(2.5)and the values of interior equilibrium equation (4.1) can be written as follows

$$\begin{aligned}\frac{dG}{dt} &= -\frac{1}{3}(\lambda_1 + d + M\lambda)(P - P^*)^2 - \frac{1}{3}(\lambda_2 + d)(T - T^*)^2 - \frac{1}{2}(\gamma + d + \nu + \delta)(S - S^*)^2 \\ &-\frac{d + \lambda_0}{2}(P_m - P_m^*)^2 - \frac{\mu_0}{3}(M - M^*)^2 + (\lambda_0 + \lambda M)(P - P^*)(P_m - P_m^*) \\ &+(-\lambda P^*)(M - M^*)(P - P^*) + \lambda_1(P - P^*)(T - T^*) + (\gamma + \lambda_2)(S - S^*)(T - T^*) \\ &+(\lambda + \mu)P^*(M - M^*)(P_m - P_m^*) + \mu(M - M^*)(T - T^*) \\ &+\mu(M - M^*)(S - S^*).\end{aligned} \tag{4.7}$$

Sufficient condition for $\frac{dG}{dt}$ to be negative definite are

$$\begin{aligned}(\lambda P^*)^2 &< min\{\frac{4\mu_0}{9}(\lambda_1 + d + \lambda M^*), \frac{2\mu_0}{3}(d + \lambda_0)\} \\ (\lambda_0 + \lambda M^*)^2 &< \frac{2}{3}(\lambda_1 + d + \lambda M^*)(d + \lambda_0), \\ \lambda_1^2 &< \frac{4}{9}(\lambda_2 + d)(\lambda_1 + d + \lambda M^*), \\ (\gamma + \lambda_2)^2 &< \frac{2}{3}(\lambda_2 + d)(\gamma + d + \nu + \delta), \\ \mu^2 &< min\{\frac{(4\lambda_2 + d)\mu_0}{9}, \frac{2(\gamma + d + \nu + \delta)\mu_0}{3}\}.\end{aligned} \tag{4.8}$$

5 Numerical Simulation

To find the numerical solution, first integrate system (2.1)-(2.5) to substantiate the above analytical results. The proposed model is solved numerically using fourth order Runge-Kutta method under the following set of compatible parameters

$$\begin{aligned}A = 2000;\ \lambda_1 = 0.6;\ d = 0.6;\ \lambda = 1.5;\ \lambda_2 = 1.5;\ \lambda_3 = 0.4;\ \gamma = 0.005; \\ \nu = 1.9; \delta = 1.9; \lambda_0 = 0.2;\ \mu = 0.005; \mu_0 = 0.8; r = 2;\end{aligned} \tag{5.1}$$

with the help of MATLab software. For the set of parameters defined in (5.1), the interior equilibrium point is $E^* = (123293, 352551, 120052, 91.0447, 2.95377$. The characteristic polynomial and eigenvalues corresponding to interior equilibrium point E^* are defined in (5.2) and (5.3) respectively.

$$\psi^5 + 11.364\psi^4 + 46.69\psi^3 + 85.069\psi^2 + 67.992\psi = 19.4539 = 0, \tag{5.2}$$

where

$$\psi_= -4.39567;\ \psi_2 = -3.32506;\ \psi_3 = -2.00484;\ \psi_4 = -0.904545;\ \psi_5 = -0.733957. \tag{5.3}$$

Since all the eigenvalues corresponding to the interior equilibrium E^* are negative, therefore E^* is locally asymptotically stable. Further, to illustrate the global stability of the equilibrium point graphically, numerical simulation is performed for different initial starts and the result is displayed in figure 4.

It is found that all inequalities are satisfied for above parameter values. In figure 1 represents behavior of the population against time, from this figure it is noted that for a given initial values, all the population tend to their corresponding value of equilibrium point E^* and hence coexist in the form of stable steady state, assuring the local stability of E^*. This shows that the system (2.1)-(2.5) is locally and globally stable.

Figures have been plotted between dependent variables and time for different parameter values to show changes occurring in population with time under different conditions. The variations of $'T'$, $'S'$ and $'P_m'$ with respect to time 't' for different values of rate of dissemination $'\lambda'$ is shown in figure 2. From this figure, it can be noted that as the rate of dissemination $'\lambda'$ increases, the density of 'T' and 'S' decrease. This means suicidal thoughts and suicidal cases decreases with an increase in the value of the dissemination rate of awareness. At the same time, aware class in a population increases with rate of dissemination 'λ' increases.

Further, the variations of $'T'$, $'S'$ and $'P_m'$ with respect to time $'t'$ for different values of rate of implementation of awareness programs $'\mu'$ is shown in figure 3. From this figure, it can be noted that as the rate of implementation of awareness programs $'\mu'$ increases the density of 'T' and 'S' decrease. At the same time, aware class in a population increase with rate of implementation of awareness programs $'\mu'$ increases. In figure 4, we may see that all the trajectories initiating inside the region of attraction approach towards the equilibrium value $(P^*, T^*, S^*, P_m^*, M^*)$ for different initial starts, indicating the global stability of interior equilibrium. From the figures presented using the data set, we can conclude that due to awareness programs suicidal thoughts and suicidal cases can be controlled by doing meditation.

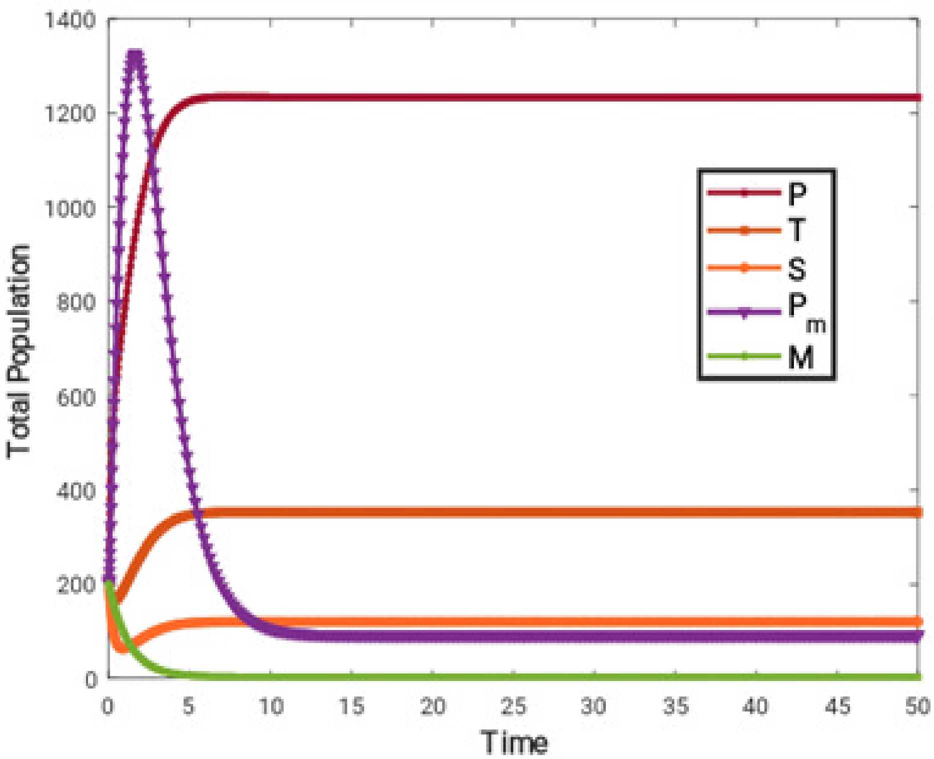

Fig. 1: Stable System

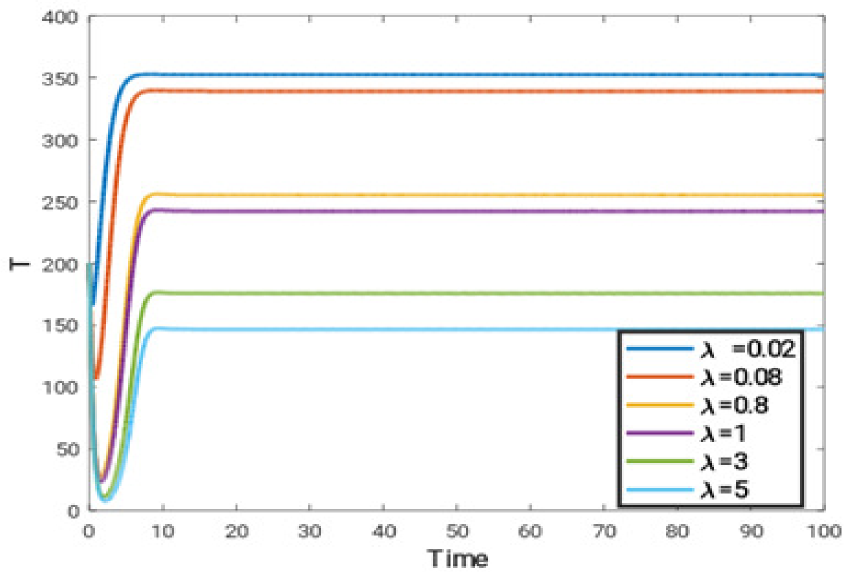

Fig. 2: Effect of λ on T.

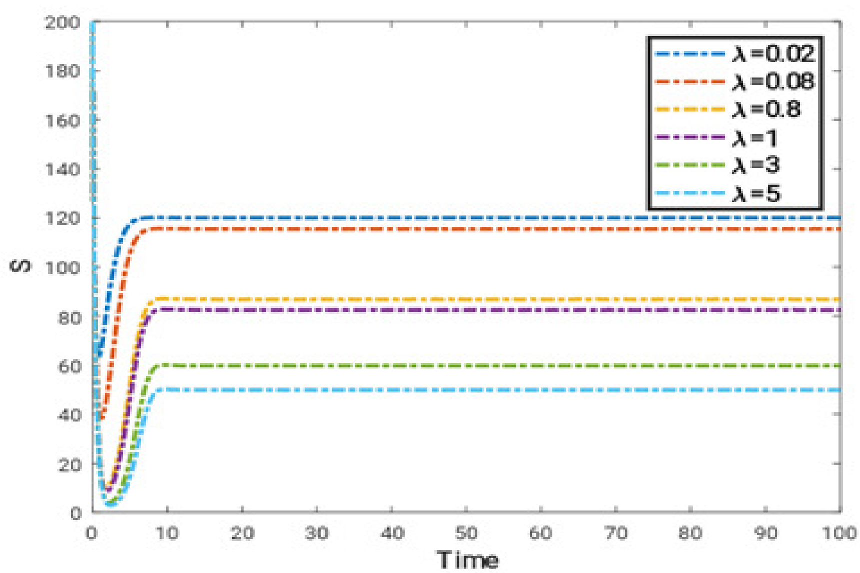

Fig. 3: Effect of λ on S.

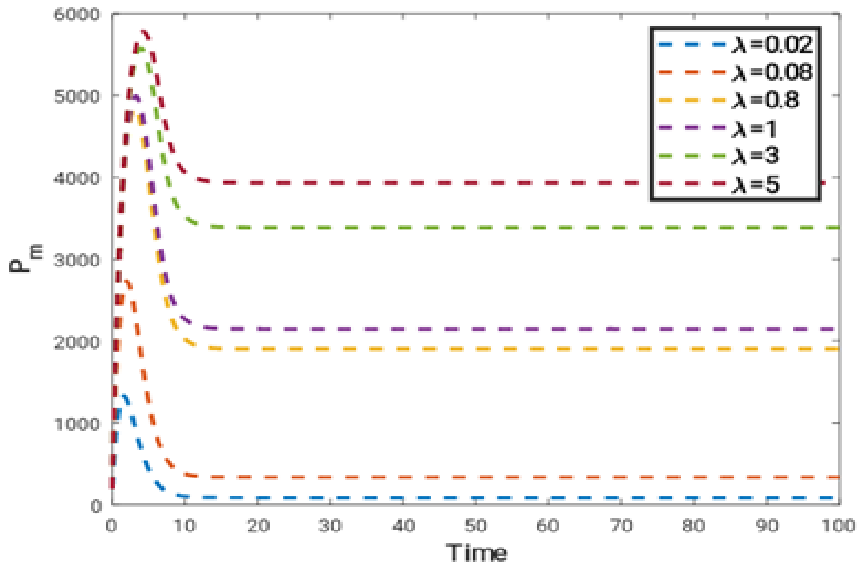

Fig. 4: Effect of λ on P_m.

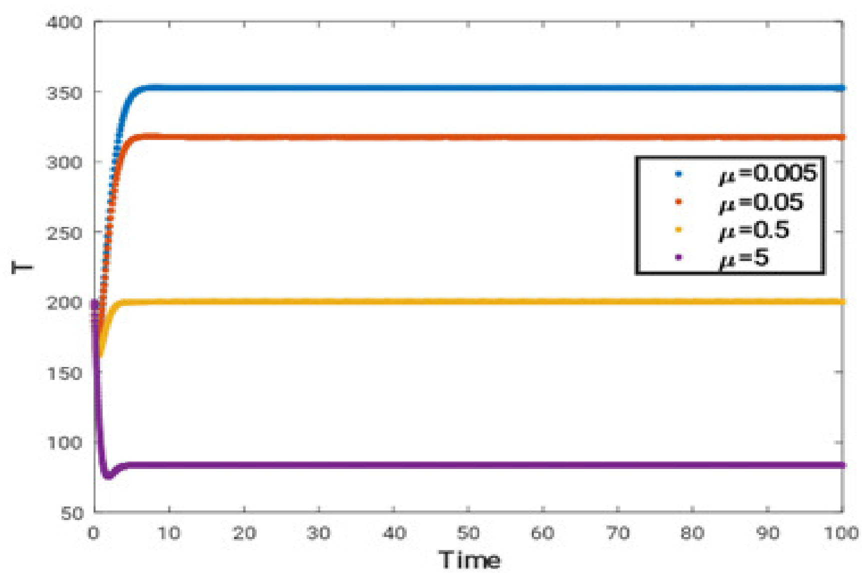

Fig. 5: Effect of μ on T.

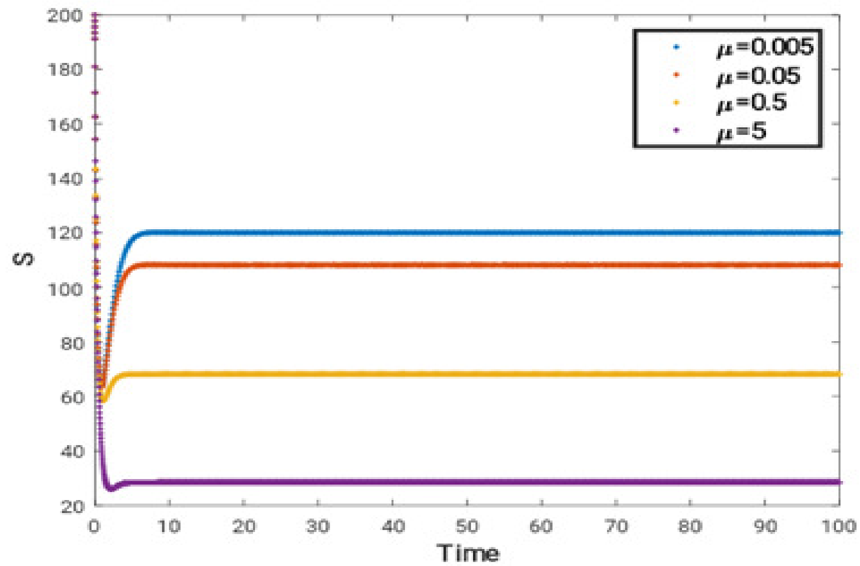

Fig. 6: Effect of μ on S.

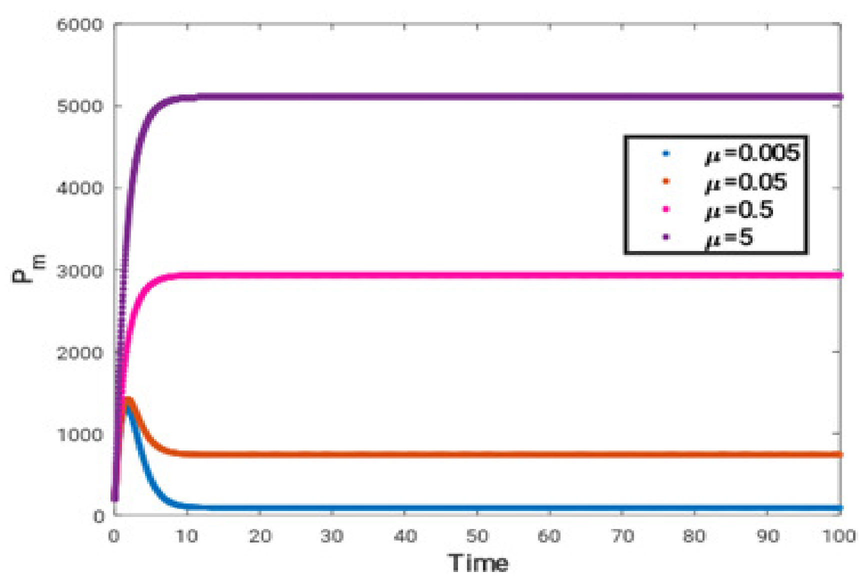

Fig. 7: Effect of μ on P_m.

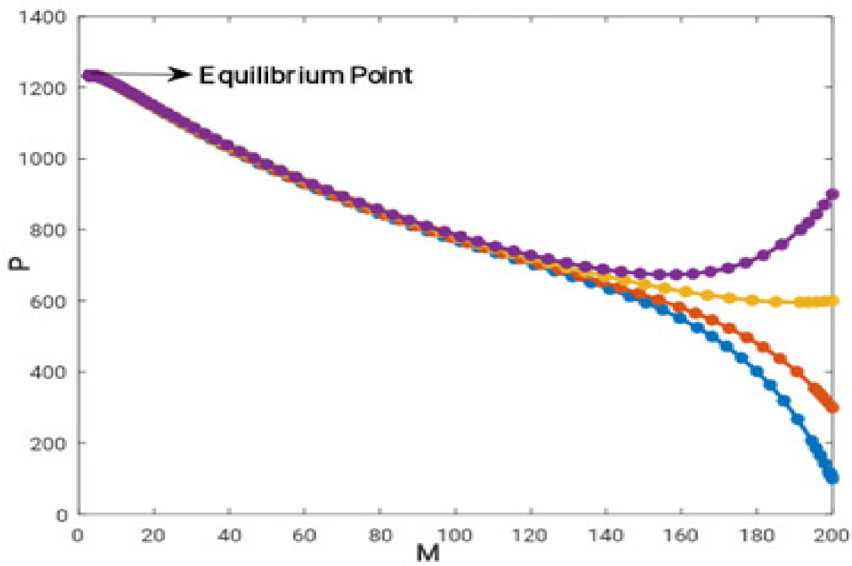

Fig. 8: Equilibrium Point M versus P.

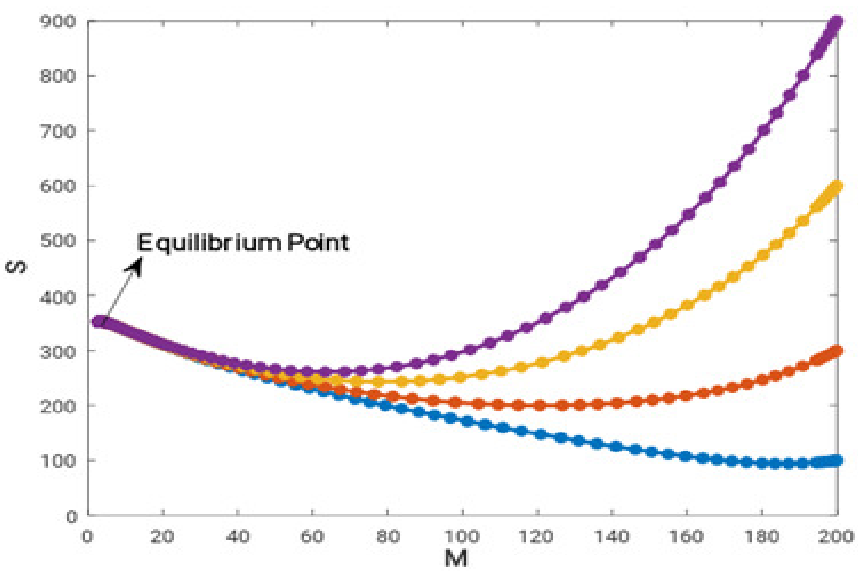

Fig. 9: Equilibrium Point S versus M.

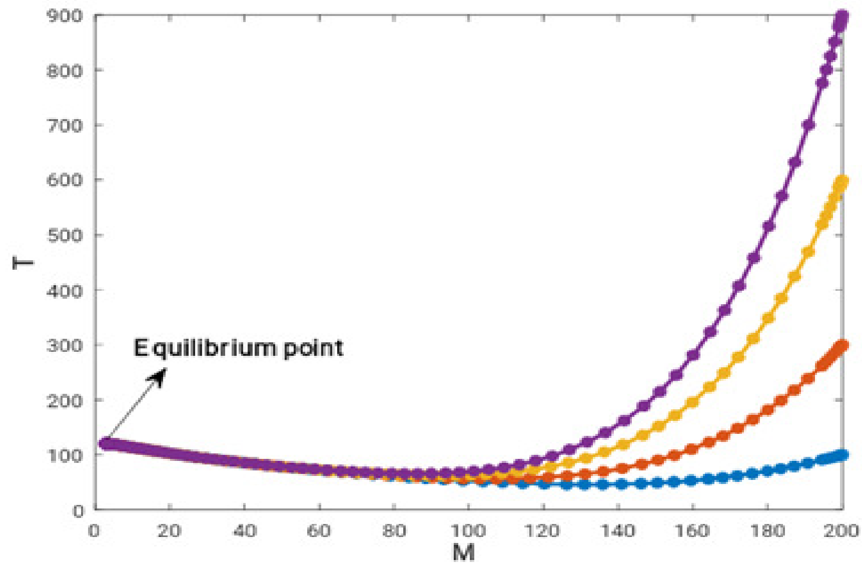

Fig. 10: Equilibrium Point M versus T.

Conclusion

In this paper, a nonlinear mathematical model is proposed and analyzed to see impact of meditation on suicidal thoughts and suicidal cases. It has been considered that the growth rate of awareness programs impacting the population is assumed to be proportional to the numbers of suicidal thoughts and suicidal cases. The analysis showed that awareness programs through the media campaigning are helpful in decreasing the suicidal cases in a population. By awareness programs, at least we could have prevented suicidal thoughts whenever possible and, where not possible, to minimize suicidal cases and maximize quality of life.

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