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A Mathematical Model on the Dynamics of Student-Lecturer-Sex on Campuses

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Mathematical models for disease spread are mostly based on differential equations with an in-built threshold that determines the behaviour of the system. This study investigates student-lecturer-sex (SELEX) on campus by an epidemiological model. The dynamics of these activities among female students and male lecturers are analyzed by the usual Susceptible-Infected-Recovered (SIR) model. The model suggests that, admitting and recruitment of new members play a significant role in reduction of SELEX on campus. It was revealed that, the basic reproductive numbers are not enough to predict whether or not SELEX will persist on university campus, but minimizing the admitting and recruitment of infected students and lecturers reduces the spread of the disease-SELEX.

Keywords: Epidemiology; SIR model; student-lecturer-sex; university campus.

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1 INTRODUCTION

Modelling has become a predictive tool which helps to determine the existence and treatment strategies of certain diseases. It has become the need to develop useful models which will give practitioners and academia valuable predictions. Mathematical models for disease spread are mostly based on differential equations with an in-built threshold that determine the behaviour of the system. Several research work have tried to model and analyze sexual activities outside marriage using ordinary differential equation because of it relevance to policymakers and stakeholders. Among these include: Hardit [1], who predicted sexual aggression among college men. He examined various components of the confluence model on sexual aggression with a population of contemporary college men. The confluence model was a constituent of two intercorrelated pathways: hostile masculinity; composed of negative attitudes and beliefs towards women, and impersonal sex; characterized by engaging in sexual relationships that lack emotional closeness. Hierarchical regression analyses revealed partial support for components of the confluence model. Significant mediating and moderating effects of confluence model variables were present. Contrary to his hypotheses, the level of consumption of sexualized media did not moderate any of the pathways to sexual aggression. Membership in a fraternity was associated with higher levels of reported sexual aggression. The finding highlighted on the importance of certain male peer group membership as one factor in sexual aggression among college men. An epidemiological model depicting the dynamics of campus sex among students is also investigated [2]. The SIR model was used in analyzing the dynamics of sexual activities among students. Two equilibrium points were found, a disease-free equilibrium and an endemic equilibrium point. It was evident that, admitting new students without the infection plays a significant role in the reduction of sexual activities among students on campus.

An epidemiological model capturing the dynamics of campus drinking was used to study how the ‘disease’ of drinking is spread on campus. The model suggests that the reproductive numbers are not sufficient to predict whether drinking behavior will persist on campus and that the pattern of recruiting new members plays a significant role in the reduction of campus alcohol problems. They assumed that, problem drinkers can recruit both non-drinkers and social drinkers. This allows to transition to the problem drinking state both directly and via progression through social drinking. In the limit case, they modified this assumption and allowed problem drinkers to only recruit social drinkers, and that, non-drinkers may transit to the problem drinking class only after progressing through social drinking. As a result, the dynamics of campus drinking are significantly impacted. Surprisingly, in the limiting case, even with a large reproductive number R1 , the proportion of both social and problems drinkers is reduced. This suggests that one possible strategy for reducing drinking problems on campus is to modify the recruitment patterns [3]. Oduwole and Shehu [4] proposed a compartmental mathematical model to track the dynamic of poverty and prostitution. They introduced a non-violent compartment that focuses on rehabilitating both male and female prostitutes. They showed that the dynamics of prostitution relates to many forms of poverty and crime. In the model of Busenberg, the disease spread was mainly due to the sexual interaction between a core group of female prostitutes and young unmarried males [5]. Threshold parameters were obtained that determine persistence of endemic proportions, persistence of total population, and the persistence of infective population given the extinction of endemic proportions in a population tending to infinity. Conditions were given for the existence of multiple endemic equilibria as well as the existence of multiple stable equilibria with separatrix.

Gani [6] considered the differential-difference equations of the SIR model with constant population size and gives the partial differential equation which the associated probability generating function satisfies and outlines a mathematical method for solving it. However, the mathematics involved is so complicated that it limits its success in the SIR model varying the population sizes of at most 3 individuals. Andersson [7] studied the epidemics on configuration model networks, considering a closed population without births, deaths and migration. By constructing a configuration model network it was possible for them to investigate when the epidemic may become large and when it will stay small with probability one, and how the distribution of the infectious period affects the outbreak. They answered these questions by using generating functions and percolation theory. They observed that the early stages of an epidemic outbreak can be approximated by a branching process, also this approximation is possible until approximately the $\sqrt{n}th$ infection in a population that consists of n individuals. They concluded that the transmission of the disease depend on the infectious periods, if the infectious periods are fixed for all individuals the transmission is independent and identically distributed whereas if the infectious periods are random this is not the case. Davidoff et al. [8] studied the demand and supply systems among sex workers. Two mathematical models were constructed to explore the dynamics of the sex industry: one for the males who provide demand and another for the females who provide the supply. With a preliminary study by Sachdev on the attitudes and behaviour of university students, it provided baseline information on the sexual attitudes and behaviour of young students from two Universities in Delhi [9]. The findings by and large confirm the general trend favoring more liberal sexual attitudes. It was evident that female respondents beginning to cast off traditional moral restraints experience their own sexuality. However, significant gender differences in sexual attitudes and behaviour still persist. The study shows that while attitudes are changing, behaviour lags behind. It was apparent that more Indian college women are likely to engage in this sexual behaviour as cultural forces give them more freedom to express their sexuality. Other research work on EPQ inventory model for non-instantaneous deteriorating items under trade credit policy [10], inventory model for non-instantaneous deteriorating items with quadratic demand rate and shortages under trade credit policy [11], and approximations of functions in banach spaces [12] have also been investigated.

One of the challenges affecting the academic field of study is sexual activities among students and their teaching staffs. It is therefore imperative to address the situation within the ambit of mathematical models. In this study we categorize student-lecturer-sex (SELEX) as a disease on university campus. The term SELEX is considered as engaging in a sexual act when not married for any reason or having sexual act outside your marriage partner. An epidemiological model capturing the dynamics of SELEX among female students and male lecturers on university campus is illustrated with an SIR model. The model together with the scenario in question is a hypothetical case but not real issue based on actual data.

2 THE MODEL

These mathematical model was formulated using SIR framework, where the individuals in the population are divided into six compartments. Non infected students (S_S) are the susceptible group, non infected lecturers (S_L) - the susceptible lecturers group recruited in the school; thus, population without the disease SELEX. Infected students (P_S), infected lecturers (P_L), are those whose sexual activities/habits and associated behaviour have negative consequence. The recovered group: recovered students (R_S) and recovered lecturers (R_L) are those who has stopped illegal sex for a minimum of twelve months. The students and lecturers join the campus in any two state as either susceptible $(S_S$ or $S_L)$ or infected $(P_S$ or $P_L)$. Once on campus, a student or lecturer may move from any of the state to the other. In the model, αN is the number of students admitted into the system every academic year, ωN is the number of lecturers recruited by the university, α and ω are the entering and departure rate from campus environment by female students and male lecturer respectively. The rate at which a lecturer influences a female students into sex is denoted by ϕ, and ψ as the vice versa. γ and ϵ are the recovery rates from SELEX by a student and a lecturer respectively. κ and π are the relapse rates from recovered to infected. σ and η are the entering rate of infected student and a lecturer respectively. S_SP_L and S_LP_S shows the interaction between infected and non-infected. The conversion from infected to recovery is assumed to be the result of a recovery process and is executed by the terms γP_S and

ϵP_L. Recovered may only relapse to infected class or leave the campus. Parameters ϕ, β, μ; ψ; κ; π are the transmission rates and measure the effectiveness of the interactions between non-infected and infected, recovered and SELEX state. The transition to a lower state is assumed to be a recovery.

Assumptions

- Constant population size.
- Non infected includes never and recovered admitted.
- Recovered can only relapse.
- The rate at which the disease is acquire is proportional to the product of susceptible and infective present.
- The effects of breaks and vacations are not considered.
- The rate at which female student and male lecturers are admitted and recruited in the university is proportional to the size of the female students and male lecturers population.
- The rate which susceptible leaves the campus is proportional to group/class of female students and male lecturers population.

The dynamics are modelled using the following differential equations where S_s, S_l, P_s, P_l, R_s and R_l have being rescaled proportionally:

$$\begin{aligned}
\frac{ds_s}{dt} &= \alpha - \beta s_s p_s - \phi s_s p_l - \alpha s_s \\
\frac{dp_s}{dt} &= \sigma p_s + \beta s_s p_s + \kappa p_s r_s + \psi s_l p_s - \gamma p_s - u p_s \\
\frac{dr_s}{dt} &= \gamma p_s - \kappa p_s r_s - \alpha r_s \\
\frac{ds_l}{dt} &= \omega - \mu s_l p_l - \omega s_l - \psi s_l p_s \\
\frac{dp_l}{dt} &= \eta p_l + \mu s_l p_l + \pi p_l r_l + \phi s_s p_l - \epsilon p_l - v p_l \\
\frac{dr_l}{dt} &= \epsilon p_l - \pi p_l r_l - \omega r_l
\end{aligned} \tag{2.1}$$

where $s_s + p_s + r_s = 1, s_l + p_l + r_l = 1, u = \alpha + \sigma + \psi, v = \eta + \omega + \phi$

3 MODEL ANALYSIS AND DISCUSSIONS

To determine the various equilibria, a local stability analysis is performed to check whether the SELEX will die out or not. At the equilibrium, the Jacobian matrix for the equations is:

$$J_{DFE} = \begin{bmatrix} -\alpha - \beta p_s - \phi p_l & -\beta s_s & 0 & 0 & -\phi s_s & 0 \\ \beta p_s & n & \kappa p_s & \psi p_s & 0 & 0 \\ 0 & \gamma - \kappa r_s & -\kappa p_s - \alpha & 0 & 0 & 0 \\ 0 & -\psi s_l & 0 & q & -\mu s_l & 0 \\ \phi p_l & 0 & 0 & \mu p_l & m & \pi p_l \\ 0 & 0 & 0 & 0 & \epsilon - \pi r_l & -\pi p_l - \omega \end{bmatrix} \tag{3.1}$$

where $n = \beta s_s + \psi s_l + \kappa r_s - \alpha - \psi - \gamma$
$m = \mu s_l + \phi s_s + \pi r_l - \omega - \phi - \epsilon$
$q = -\omega - \mu p_l - \psi p_s$

The eigenvalues at the disease-free equilibrium are:

$\lambda_1 = \lambda_2 = -\alpha, \lambda_3 = -\alpha - \gamma$
$\lambda_4 = \lambda_5 = -\omega, \lambda_6 = -\omega - \epsilon.$

There are two levels of infectives on the disease-free equilibrium R_0^s and R_0^l. The first reproductive number R_0^s is defined as the average number of secondary cases caused by a typical female student with SELEX in a non-infected campus environment. The basic reproductive number R_0^s is calculated as:

$$R_0^s = (\beta - \alpha - \gamma)\left(\frac{1}{\gamma + \alpha}\right) + 1 = \frac{\beta}{\alpha + \gamma}$$

The second reproductive number R_0^l is defined as the average number of secondary cases caused by a typical male lecturer with SELEX in a non-infected campus environment. The basic reproductive number R_0^l is given as:

$$R_0^l = \frac{\mu}{\omega + \epsilon}$$

At the disease-free equilibrium, the disease is stable when, $\frac{\beta}{\alpha+\gamma} < 1$ and $\frac{\mu}{\epsilon+\omega} < 1$. But unstable when, $\beta > \alpha + \gamma$ and $\mu > \epsilon + \omega$. The R_0's obtained reveals that the transmission rates β and μ relative to the recovery rates γ, ϵ, and the departure rate α, ω plays a significant role in determining whether or not SELEX becomes established on campus. From $R_0^s = \frac{\beta}{\alpha+\gamma}$ and $R_0^l = \frac{\mu}{\epsilon+\omega}$, it can be seen that an increase in β and μ increases R_0^s and R_0^l respectively. While an increase in α, ω and γ, ϵ decreases R_0^s and R_0^l respectively. In the case when the infectious interaction between student and lecturer are zero, that is $\beta = \mu = 0$, then:

$$R_0^s = \frac{\phi}{\alpha+\gamma} \quad \text{and} \quad R_0^l = \frac{\psi}{\epsilon+\omega}$$

The endemic equilibrium point is given as $(s_s, p_s, r_s, s_l, p_l, r_l)$ where

$$s_s = \frac{\alpha}{\alpha + \phi p_l + \beta p_s}, r_s = \frac{\gamma p_s}{\kappa p_s + \alpha}, s_l = \frac{\omega}{\omega + \psi p_s + \mu p_l}, r_l = \frac{\epsilon p_l}{\pi p_l + \omega}$$

$$p_s = \frac{\sqrt[3]{(\sqrt{(-27a^2d + 9abc - 2b^3)^2 - 4(3ac - b^2)^3} - 27a^2d + 9abc - 2b^3)}}{3(\sqrt[3]{2}a)}$$
$$- \frac{\sqrt[3]{2}(3ac - b^2)}{\sqrt[3]{(\sqrt{(-27a^2d + 9abc - 2b^3)^2 - 4(3ac - b^2)^3} - 27a^2d + 9abc - 2b^3)}} - \frac{b}{3a}$$

$a = \kappa\beta\psi + \kappa\beta\alpha\psi + \psi^2 - \beta\kappa\gamma\psi$

$b = \kappa\alpha^2\psi + \kappa\alpha\psi^2 + \beta\alpha\omega + \gamma\psi\beta\alpha + \alpha^2\psi\beta + \omega^2\alpha\beta - \beta\alpha\psi\kappa + \kappa\phi\alpha\psi + \kappa\phi + \psi^2 + \kappa\beta\alpha\mu$

$c = \kappa\alpha^2\omega + \alpha^3\gamma\psi + \alpha^3\psi + \alpha^2\psi^2 + \alpha\gamma\beta\omega + \alpha^2\omega\beta - \alpha\beta\omega\kappa - \alpha^2\beta\psi + \kappa\alpha^2\mu + \kappa\alpha\mu\mu\psi + \kappa\phi\gamma\psi + \alpha^2\phi\psi + \alpha\psi^2\phi + \alpha\gamma\mu\beta + \alpha^2\mu\beta + \psi\mu\alpha\beta - \alpha\beta\kappa\mu + \kappa\phi\alpha\mu + \kappa\phi\psi\mu$

$d = \alpha^2\gamma\mu + \alpha^3\mu + \alpha^2\psi\mu + \alpha\gamma\phi\omega + \alpha^2\phi\omega - \alpha^2\beta\mu + \alpha\phi\gamma\mu + \alpha^2\phi\mu + \alpha\phi\psi\mu + \alpha^2\gamma\omega + \alpha^3\omega - \alpha^2\beta\omega$

$$p_l = \frac{\sqrt[3]{(\sqrt{(-27\vartheta^2d + 9\vartheta\varphi\varrho - 2\varphi^3)^2 - 4(3\vartheta\varrho - \varphi^2)^3} - 27\vartheta^2d + 9\vartheta\varphi\varrho - 2\varphi^3)}}{3(\sqrt[3]{2}\vartheta)}$$
$$- \frac{\sqrt[3]{2}(3\vartheta\varrho - \varphi^2)}{\sqrt[3]{(\sqrt{(-27\vartheta^2d + 9\vartheta\varphi\varrho - 2\varphi^3)^2 - 4(3\vartheta\varrho - \varphi^2)^3} - 27\vartheta^2d + 9\vartheta\varphi\varrho - 2\varphi^3)}} - \frac{\varphi}{3\vartheta}$$

$\vartheta = \phi^2\mu\pi + \omega\pi\mu\phi$

$\varphi = \omega\phi^2\mu + \omega^2\pi\phi + \phi^2\omega\pi + \omega\pi\alpha\mu + \omega^2\phi\mu + \omega\epsilon\phi\mu + \omega\pi\beta + \phi\beta\mu\pi + \omega\pi\phi\psi + \phi^2\psi\pi - \omega\phi\mu\pi - \psi\phi\pi\epsilon$

$\varrho = \omega^2\phi + \omega^2\pi\alpha + \omega^3\phi + \omega^2\alpha\mu + \omega\epsilon\alpha\mu + \omega^2\epsilon\phi + \omega\epsilon\phi\psi + \phi\alpha\psi\pi + \omega\pi\beta\psi + \omega\phi\beta\pi + \omega\phi\beta\mu + \omega\phi^2\psi + \omega^2\pi\beta + \alpha\phi\psi\pi + \omega\alpha\pi\psi + \omega^2\phi\psi + \omega^2\beta\mu + \omega\epsilon\beta\mu - \phi\alpha\pi - \omega\mu^2\beta - \omega^2\phi\mu - \omega\mu\alpha\pi$

$d = \omega\epsilon\beta\psi + \omega^2\beta\psi + \phi\beta\psi\omega + \omega\epsilon\psi + \omega^2\epsilon\beta + \omega^2\alpha\psi + \omega^3\beta + \omega^2\phi\beta + \omega^2\alpha\epsilon + \omega^3\alpha - \omega^2\mu\beta - \omega^2\mu\alpha$

Using the Routh-Hurwitz Criteria a method for determining whether a linear system is stable or not we obtain:

$$\begin{bmatrix} a & -\beta s_s & 0 & 0 & -\phi s_s & 0 \\ \beta p_s & b & \kappa p_s & \psi p_s & 0 & 0 \\ 0 & \gamma - \kappa r_s & -\kappa p_s - \alpha & 0 & 0 & 0 \\ 0 & -\psi s_l & 0 & c & -\mu s_l & 0 \\ \phi p_l & 0 & 0 & \mu p_l & d & \pi p_l \\ 0 & 0 & 0 & 0 & \epsilon - \pi r_l & -\pi p_l - \omega \end{bmatrix}$$

as the Jacobian matrix. This implies

$$(\lambda + A_1)(\lambda + A_2)(\lambda + A_3)(\lambda + A_4)(\lambda + A_5)(\lambda + A_6) - K = 0$$
$$\lambda^6 + B_1\lambda^5 + B_2\lambda^4 + B_3\lambda^3 + B_4\lambda^2 + B_5\lambda + B_6 = 0$$

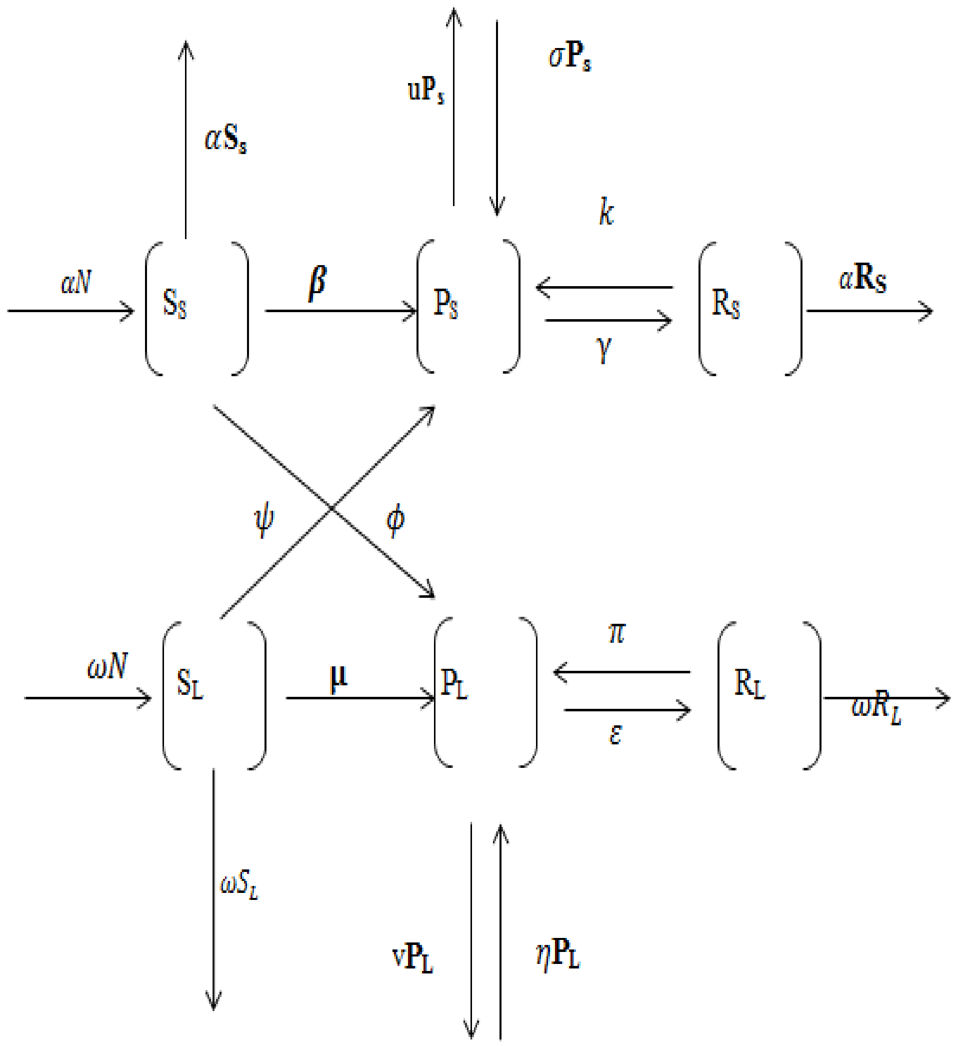

Fig. 1. Compartmental diagram for female students and male lecturers

where $A_1 = \alpha + \beta p_s + \phi p_l$, $A_2 = -\beta s_s - \psi s_l - \kappa r_s + \alpha + \psi + \gamma$, $A_3 = \kappa p_s + \alpha$, $A_4 = \omega + \mu p_l + \psi p_s$, $A_5 = \mu s_l - \phi s_s - \pi r_l + \omega + \phi + \epsilon$, $A_6 = \pi r_l + \omega$, $K = (\pi \epsilon r_l - \pi^2 r_l^2 - \epsilon\omega + \pi\omega r_l)(\phi\mu\psi\beta s_s s_l p_s p_l)^2(\gamma\pi\kappa r_l p_s - \pi\kappa^2 p_s r_s r_l) = 0$, $B_1 = A_6 + A_5 + A_4 + A_3 + A_2 + A_1$, $B_2 = A_4(A_3+A_2+A_1)+A_3(A_2+A_1)+A_2A_1+A_5A_6$, $B_3 = A_5(A_4+A_3+A_2+A_1)+A_4(A_3+A_2+A_1)+A_3(A_2+A_1)+A_4A_5A_6+A_2A_1$ ...... $B_6 = A_6A_5A_4A_3A_2A_1 - K$. Considering the characteristic equation $\lambda^6 + B_1\lambda^5 + B_2\lambda^4 + B_3\lambda^3 + B_4\lambda^2 + B_5\lambda + B_6 = 0$ where n=6, The Routh-Hurwitz Criteria are $B_1 > 0, B_2 > 0, B_3 > 0, B_4 > 0, B_5 > 0, B_6 > 0$. For

$$
\begin{aligned}
\det(H_1) &= B_1 && > 0\\
\det(H_2) &= \begin{pmatrix} B_1 & 1\\ 0 & B_2 \end{pmatrix} && = B_1 B_2 > 0\\
\det(H_3) &= \begin{matrix} B_1 & 1 & 0\\ B_3 & B_2 & B_1\\ 0 & 0 & B_3 \end{matrix} && = B_1 B_2 - B_3 > 0\\
&\vdots && \vdots\\
&\vdots && \vdots\\
\det(H_6) &= \begin{matrix} B_1 & 1 & 0 & 0 & 0 & 0\\ B_3 & B_2 & B_1 & 1 & 0 & 0\\ 0 & 0 & B_3 & B_2 & B_1 & 0\\ 0 & 0 & 0 & B_4 & B_3 & B_2\\ 0 & 0 & 0 & 0 & B_5 & B_4\\ 0 & 0 & 0 & 0 & 0 & B_6 \end{matrix} && = B_i > 0, i = 1,2,3,4,5,6
\end{aligned}
$$

The determinants of the Hurwitz matrices are $\det(H_1) > 0, \det(H_2) > 0, \det(H_3) > 0, \det(H_4) > 0, \det(H_5) > 0$ and $\det(H_6) > 0$ which implies all the eigenvalues of the endemic point have negative real part. Therefore, endemic equilibrium state is stable.

The following values are selected to illustrate the graphical presentation of the model equations: $\alpha = 0.06, \omega = 0.02, \beta = 0.48, \mu = 0.48, \gamma = 0.11, \epsilon = 0.13, \kappa = 0.20, \pi = 0.20, \psi = 0.33, \phi = 0.32, \eta = 0.07, \sigma = 0.10$. This is illustrated in Fig. 2.

It can be observed that, the infectious population is increasing whiles the susceptible and recoveries are decreasing. This confirms the accession made by Reymond [13], that the males which are the demand group, when targeted could reduce the spread of the disease.

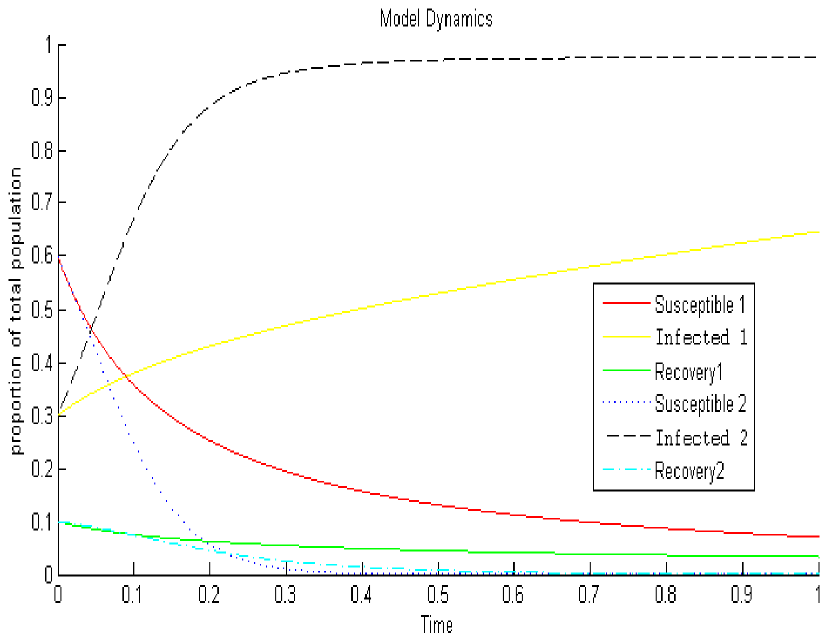

Fig. 2. Model dynamics

4 CONCLUSION

An SIR model capturing the dynamics of student-lecturer-sex (SELEX) on campus is studied. The stability conditions of the disease-free point resulted in an unstable equilibrium state, and a stable state in the case of endemic equilibrium. The results showed that, the disease SELEX is more dependent on the infectious rate than the other parameters. This suggests one possible technique in reducing SELEX on campus is to modify the admitting and recruitment patterns. This may be accomplished by designing effective control strategies and systems to limit the factor demand and supply among students and lecturers. This research can also be practically performed with sets of real data, because this was purely based on assumptions.

COMPETING INTERESTS

The authors declare that no competing interests exist.

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