Mathematical Analysis of Alcoholism with Effect of Awareness through Media in Developing Countries

Laxman Bahadur Kunwar and Vijai Shanker Verma

Abstract—**In this paper, we have proposed a non-linear deterministic mathematical model for the spread of alcoholism as a communicable disease. Some properties of the solution to the model including positivity, existence and stability of equilibrium points are analyzed. The expression for basic reproduction number for the spread of alcoholism, a threshold value (R_0) is determined by the next generation matrix approach. It has been found that the system has two equilibria states ; one drinking-free equilibrium ; second drinkung-present equilibrium. It has been shown that the drinking-free equilibrium is stable if $R_0 < 1$ and drinking-present equilibrium is stable if $R_0 > 1$. The results are analyzed using numerical simulation. It has been observed that though awareness program is an effective measure in reducing drinking problem, it can not eradicate the problem totally. Simulation results indicate that the problem can be eliminated by reducing transmission coefficient to certain level together with the implementation of effective awareness programs.**

Index Terms—**alcoholism, basic reproduction number, equilibrium points, stability analysis.**

I. Introduction

MENTAL neurological and substance (MNS) use disorders are the leading causes of disability worldwide, contributing to 14% of the global burden of disease [1]. The magnitude of depression and alcohol use disorder varies across different regions and age groups; however, depression and alcohol used diseases have been reported to be the second and third leading causes of years lived with disability [2]. The study results indicate that heavy alcohol consumption increases the relative risk of any stroke while light or moderate alcohol consumption may be protective against ischemic stroke [3]. Heavy or harmful drinking is defined as drinking more than 40 grams of pure alcohol per day for men and 20 grams of pure alcohol per day for women. In addition to the average volume of alcohol, patterns of drinking- especially irregular heavy-drinking occasions, or binge drinking (defined as drinking at least 60 grams of pure alcohol or five standard drinks in one sitting), markedly contribute to the associated burden of disease and injury [4]. The harmful consumption of alcohol is considered to be the major cause of global burden for large diseases, social and economic burden in societies. Overall, infectious diseases like cancer, diabetes, neuropsychiatric disease, cardiovascular disease, diseases related to liver and pancreas, any type of injury intentional or unintential of different categories are impacted by harmful or heavy alcohol consumption [5]. The latest causal relationships are those between harmful drinking and the incidence of infectious diseases such as tuberculosis as well as the incidence and course of HIV/AIDS. Alcohol consumption by an expectant mother may cause fatal alcohol syndrome and pre-term birth complications [6]. It has been realized by survey team of WHO that approximately 3 million deaths every year worldwide result from harmful use of alcohol which represents 5.3 % of all deaths. The report shows that overall 5.1 % of the global burden of disease and injury is attributable to alcohol, as measured in disability-adjusted life years.

It has been observed that in developing country Nepal, one out of five women attending primary care services have depression due to alcohol consumption, and one out of five men have alcohol use disorder [7]. In a survey of non-communicable disease (NCD) carried out in 2019 [8] by WHO and Nepal Health Research Council (NHRC) regarding alcohol consumption, it was found that 23.9 % (4.8 million) of the adults in which 38.6 % (3.7 million) of men and 10.8 % (1.1 million) of women were current drinkers. Almost 1 in 8 men were engaged in drinking on daily or almost daily basis. This was equivalent to 1.4 million adults (1.1 million men and 0.3 million women). It was found that 6.8 % of adults (12.4 % men, 1.7 % of women) are heavy drinkers (consumed 6 standard drinks or 60 g of pure alcohol or more drinks on any single occasion in the past 30 days). The study revealed that more than one-fourth (28.4 %) of drinkers (32.2 % men, 16.2 % women) are engaged in heavy episodic drinking. Khanal & Chataut [9] have found that smoker is more likely to be alcohol consumer and vice versa. According to their study, alcohol consumption habit is found to be independently associated with smoking habit, sex, and occupation. People who smoke are more likely to be alcohol consumers and vice versa. Drinking alcohol in Nepal is socially and culturally conventional in many ethnic groups, the consumption has been growing over the year throughout all ethnicities and age groups [10].

Once a group of people consuming alcohol harmfully is generated in a community, it spreads like a communicable disease in the society. The epidemic models such as SIQR model [11], HIV viral transmission model [12] may be foundations for the development of models to describe dynamics of alcoholism. Radio, Newspaper, T.V., and Internet are the main modes of communication for the success of the awareness programs. Observing the influence of aware-

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ness program through the media, the impact of awareness programs by media on dynamics of drinking behavior has been incorporated in many mathematical models. Studies suggested that media coverage campaigns play tremendous impact on controlling the spread of infectious diseases [13] and smoking problems [14],[15]. However, most of these studies assumed that the media reduces the contact rate of susceptible with infective individuals. In addition, these studies assumed that the cumulative density of awareness programs is constant in models. Hence, it is more reasonable to consider that the cumulative density of the awareness program varies. Misra et al. [16] explicitly incorporated the cumulative density of awareness program in the modelling process, which is a separate dynamics variable whose growth depends on the size of an epidemic. Huo and Wang [17] extended the model of Misra et al. via including a treatment class and established some sufficient conditions for stability of the alcohol-free and alcohol-present equilibrium points. Sharma and Samanta [18] developed a mathematical model consisting of four compartments corresponding to four population classes namely, moderate and occasional drinkers, heavy drinkers, drinkers in treatment, and temporarily recovered class. Recently, Khajji et al. [19] presented a continuous mathematical model $PMHT^rT^pQ$ of alcohol drinking with the influence of private and public addiction treatment centers including six compartments : potential drinkers $P(t)$, moderate drinkers $M(t)$, heavy drinkers $H(t)$, rich heavy drinkers $T^r(t)$, poor heavy drinkers $T^p(t)$, and quitters of drinking Q(t). They concluded that the reproductive numbers are not sufficient to persist whether drinking behavior would persist on campus and further they observed that the pattern of recruiting new members played a significant role in the reduction of alcohol problems in campus.

In this study, we have assumed that the impact of the awareness programs, quantified by the growth rate of the cumulative density of awareness programs, is proportional to the number of deaths induced by heavy drinking. Due to the influence of the programs, a fraction of the susceptible population will keep away themselves from the heavy drinkers and they are converted into the recovered populations in which they are non-drinkers or moderate drinkers. Also, a fraction of heavy drinkers can be recovered from heavy alcohol drinking due to the impact of awareness campaigns. A fraction of the aware population or recovered population will re-join the susceptible population whereas the rest will remain as the aware population. The objective of the study is to develop a mathematical model to study the dynamics of heavy alcohol drinking as an epidemiological model, and analyze the effectiveness of the awareness programs on the alcohol drinking distribution. However, the model has been numerically simulated using the data of Nepal, the model may also be useful to other developing countries such as India, Bhutan, Bangladesh, etc.

II. Mathematical Model

In this model, the total population is divided into three compartments namely; the susceptibles, who are prone to be alcoholic, denoted by $S(t)$; those who are aware of the risk and avoid drinking, denoted by $X(t)$; those who drink heavily, denoted by $A(t)$. The fourth compartment is the cumulative density of the awareness programs, denoted by $M(t)$. It is considered that, due to the awareness programs, non-drinkers avoid contact with heavy drinkers. We only consider the interaction from the awareness program between heavy drinkers and non-drinkers. The total number of population at any time t is denoted by $P(t)$. The transmission dynamics of alcoholism is expressed by the following system of nonlinear ordinary differential equations:

$$\left.\begin{aligned}
\frac{dS(t)}{dt} &= \Lambda - \beta S(t)A(t) + \sigma X(t) + (1-p)\gamma A(t) \\
&\quad - \lambda S(t)M(t) - \delta S(t) \\
\frac{dA(t)}{dt} &= \beta S(t)A(t) - (\gamma+\delta+\alpha)A(t) \\
\frac{dX(t)}{dt} &= \lambda S(t)M(t) + p\gamma A(t) - (\delta+\sigma)X(t) \\
\frac{dM(t)}{dt} &= \kappa\alpha A(t) - mM(t)
\end{aligned}\right\} \tag{1}$$

with following initial conditions :
$S(0) > 0, A(0) \geq 0, X(0) \geq 0, M(0) \geq 0$

Using $P(t) = S(t) + A(t) + X(t)$, i. e. $S(t) = P(t) - A(t) - X(t)$, the system (1) can be rewritten as follows:

$$\left.\begin{aligned}
\frac{dA(t)}{dt} &= \beta[P(t) - A(t) - X(t)]A(t) - (\gamma+\delta+\alpha)A(t) \\
\frac{dX(t)}{dt} &= \lambda[P(t) - A(t) - X(t)]M(t) + p\gamma A(t) - \\
&\quad (\delta+\sigma)X(t) \\
\frac{dP(t)}{dt} &= \Lambda - \delta P(t) - \alpha A(t) \\
\frac{dM(t)}{dt} &= \kappa\alpha A(t) - mM(t)
\end{aligned}\right\} \tag{2}$$

Now, we analyze the system (2) consisting of four equations. The schematic diagram for the proposed model is shown in Figure 1.

TABLE I: Description of the model parameters.

Parameter	Desription
Λ	Recruitment rate of susceptible individuals who do not drink or drink only moderately.
β	Transmission coefficient of the infection for the susceptible individuals from the heavy drinkers.
λ	Dissemination rate of awareness programs among the susceptible population.
γ	Recovery rate of heavy drinkers due to media awareness programs.
δ	Natural death rate of the general population in the model.
σ	Transmission rate of transferring from aware to the unaware susceptible population due to fading of memory or certain factor.
α	Death rate due to heavy alcohol consumption.
κ	Implementation rate of awareness programs.
m	Depletion rate of awareness programs due to ineffectiveness such as social and psychological factors in the population.
p	Fraction of the recovered individuals joining the aware class.
$(1-p)$	Fraction of the recovered individuals joining the unaware susceptible class.

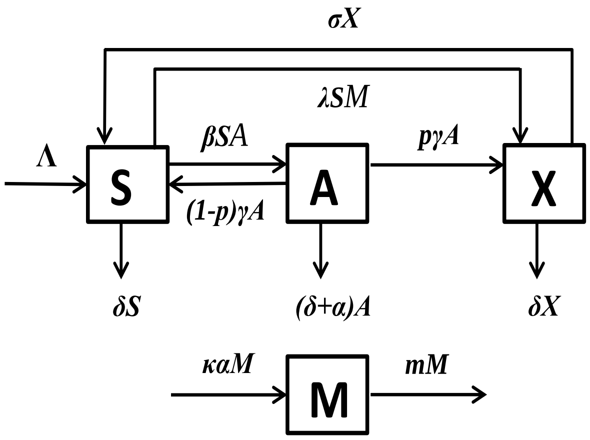

Fig. 1: Schematic diagram of the model.

III. Basic Properties of the Model

A. Boundedness

To analyze the above model, we need the bounds on the dependent variables involved. For this, we find the feasible region of attraction in the following theorem:

Theorem 1. *The feasible region of the system of equations* (2) *is given by a set* Ω*, which is defined as* $\left\{(A, X, P, M) \in R_+^4 : 0 \leq A, X \leq P \leq \frac{\Lambda}{\delta}, 0 \leq M \leq \frac{\kappa\alpha\Lambda}{m\delta}\right\}$ *and it is positively invariant with respect to the system.*

Proof: Taking third equation of system (2) of the model, we have

$$\frac{dP(t)}{d(t)} + \delta P(t) = \Lambda - \alpha A(t)$$

It is a linear differential equation in $P(t)$ whose solution is given by

$$P(t) = \frac{\Lambda}{\delta} - \frac{Q(t)}{e^{\delta t}}$$

where

$$Q(t) = \frac{\alpha}{\delta} \int A(t) e^{\delta t} dt$$

This implies that

$$\lim_{t \to \infty} P(t) = \frac{\Lambda}{\delta} \Rightarrow \lim_{t \to \infty} SupP(t) \leq \frac{\Lambda}{\delta} \tag{3}$$

From above, we conclude that $\frac{\Lambda}{\delta}$ is the maximum possible value for $S(t), A(t)$, and $X(t)$. Again, we conclude that

$$S(t) + X(t) + A(t) \leq \frac{\Lambda}{\delta}$$

so that

$$0 \leq A, X \leq P \leq \frac{\Lambda}{\delta} \tag{4}$$

Since system (2) monitors human population, it is plausible to assume that all its variables and parameters are non-negative for all $t \geq 0$. Again, taking fourth equation of the system (2), we have

$$\frac{dM(t)}{dt} + mM(t) = \kappa\alpha A(t)$$

Solving and taking limit as $t \to \infty$, we get

$$\lim_{t \to \infty} M(t) = \frac{\kappa\alpha\Lambda}{m\delta} \implies \lim_{t \to \infty} SupM(t) \leq \frac{\kappa\alpha\Lambda}{m\delta} \tag{5}$$

Hence, feasible region of the system (2) is given by the set Ω and it is positively invariant with respect to the system. ■

IV. Basic Reproduction Number

In epidemiology, basic reproduction number is the number of infectious cases that one infectious case generates on an average through out its infectious period. In our study, term “infection” refers to the conversion of a non-drinker or moderate drinker to a heavy drinker. Using next generation matrix method [20], the basic reproduction number of the alcohol consumption model is given by the following expression :

$$R_0 = \frac{\beta\Lambda}{\delta(\gamma + \delta + \alpha)} \tag{6}$$

The value of R_0 acts as a threshold of the spread of alcoholism in the community.

V. Equilibrium Analysis

We compute and analyze two equilibria states of the system (2); first drinking-free equilibrium; second drinking-present equilibrium.

A. The Drinking-Free Equilibrium

At the drinking-free equilibrium point $E_0\left(A^0, X^0, P^0, M^0\right)$, we have $A^0 = 0$ and

$$\tfrac{dA}{dt} = 0, \tfrac{dX}{dt} = 0, \tfrac{dP}{dt} = 0, \tfrac{dM}{dt} = 0.$$

Solving these equations, we get

$$A^0 = 0, M^0 = 0, P^0 = \tfrac{\Lambda}{\delta} \text{ and } X^0 = 0$$

Therefore, the drinking-free equilibrium point is $E_0\left(A^0, X^0, P^0, M^0\right) = E_0\left(0, 0, \frac{\Lambda}{\delta}, 0\right)$.

B. The Drinking- Present Equilibrium

At the drinking-present equilibrium point $E_1(A^*, X^*, P^*, M^*)$, we have $A^* \neq 0$ and

$$\tfrac{dA}{dt} = 0, \tfrac{dX}{dt} = 0, \tfrac{dP}{dt} = 0, \tfrac{dM}{dt} = 0$$

From $\frac{dA(t)}{dt}|_{E_1} = 0$, we get

$$\beta(P^* - A^* - X^*) - (\gamma + \delta + \alpha) = 0 \tag{7}$$

From $\frac{dX(t)}{dt}|_{E_1} = 0$, we get

$$\lambda(P^* - A^* - X^*) M^* + p\gamma A^* - (\delta + \sigma) X^* = 0 \tag{8}$$

From $\frac{dP(t)}{dt}|_{E_1} = 0$, we have

$$\Lambda - \delta P^* - \delta A^* = 0 \tag{9}$$

From$\frac{dM(t)}{dt}|_{E_1} = 0$, we have

$$\kappa\alpha A^* - mM^* = 0 \tag{10}$$

Now, from (9) and (10), we have

$$P^* = \frac{\Lambda - \alpha A^*}{\delta} \tag{11}$$

$$M^* = \frac{\kappa\alpha A^*}{m} \tag{12}$$

Substituting the value P^* from (11) in (7), we get

$$X^* = \frac{\Lambda - \alpha A^* - \delta A^*}{\delta} - \frac{\gamma + \delta + \alpha}{\beta} \tag{13}$$

Hence, the drinking-present equilibrium point is $E_1 \left(A^*, \frac{\Lambda - \alpha A^* - \delta A^*}{\delta} - \frac{\gamma+\delta+\alpha}{\beta}, \frac{\Lambda - \alpha A^*}{\delta}, \frac{\kappa\alpha A^*}{m} \right)$.

For uniqueness of E_1, substituting the values of P^*, X^*, M^* from $(11), (12)$ and (13) in equation (8) and simplifying, we have

$$a_1 \left(A^*\right)^2 + a_2 \left(A^*\right) + a_3 = 0 \tag{14}$$

where

$$\begin{aligned} a_1 &= \frac{\kappa\alpha}{m} \left[\frac{\alpha\lambda}{\delta} + \lambda - \frac{\alpha\lambda}{\delta} - \lambda \right], \\ a_2 &= p\gamma + \frac{\kappa\alpha\lambda \left(\gamma + \delta + \alpha\right)}{\beta m} + \frac{\left(\alpha + \delta\right)\left(\delta + \sigma\right)}{\sigma}, \\ a_3 &= \frac{\left(\delta + \sigma\right)\left(\gamma + \delta + \alpha\right)}{\delta} \left(1 - R_0\right) \end{aligned}$$

The solution of the quardatic equation (14) is $A^* = -\frac{a_3}{a_2}$. Obviously, a_2 is positive. Clearly, $a_3 > 0$ if $R_0 < 1$ and $a_3 < 0$ if $R_0 > 1$. Hence, the equation (14) yields unique positive value of A^* if $R_0 > 1$. Then, the values of other components P^*, X^* and M^* can be determined. The result implies that the existence of equilibrium E_1 is equivalent to the existence of A^*. Therefore, system (2) has a unique drinking-present equilibrium E_1 if $R_0 > 1$.

VI. Stability Analysis

We use the variational matrix method for the local stability analysis of both the drinking-free and drinking-present equilibrium points in the following theorems:

Theorem 2. *The drinking-free equilibrium E_0 is locally asymptotically stable if $R_0 < 1$ and unstable otherwise.*

Proof: The variational matrix $V(E)$ at the arbitrary point E of the system (2) is given by

$$V(E) = \begin{bmatrix} \beta\left(P - 2A - X\right) - \left(\gamma + \delta + \alpha\right) & -\beta A & \beta A & 0 \\ p\gamma - \lambda M & -\lambda M - \left(\delta + \sigma\right) & \lambda M & \lambda\left(P - A - X\right) \\ -\alpha & 0 & -\delta & 0 \\ \alpha\kappa & 0 & 0 & -m \end{bmatrix}$$

So, the variational matrix at the drinking-free equilibrium $E_0 \left(0, 0, \frac{\Lambda}{\delta}, 0\right)$ can be written as

$$V(E_0) = \begin{bmatrix} \beta\frac{\Lambda}{\delta} - \left(\gamma + \delta + \alpha\right) & 0 & 0 & 0 \\ p\gamma & -\left(\delta + \sigma\right) & 0 & \frac{\lambda\Lambda}{\delta} \\ -\alpha & 0 & -\delta & 0 \\ \alpha\kappa & 0 & 0 & -m \end{bmatrix}$$

The four eigenvalues of the characteristic equation of the matrix $V(E_0)$ are :

$\phi_1 = -\left(\delta + \sigma\right) < 0,$

$\phi_2 = -\delta < 0,$

$\phi_3 = -m < 0,$

$\phi_4 = \left(\gamma + \delta + \alpha\right)\left(R_0 - 1\right).$

It is clear that $\phi_4 < 0$ if $R_0 < 1$. Hence, every eigenvalues of $V(E_0)$ have negative real part whenever $R_0 < 1$. Therefore, the drinking-free equilibrium E_0 of the system (2) is locally asymptotically stable if $R_0 < 1$. Again, if $R_0 > 1$, then the drinking-free equilibrium is a saddle point and so the equilibrium of the system is unstable. ■

Theorem 3. *The drinking-present equilibrium E_1 is locally asymptotically stable if the coefficients of the characteristic equation of system (2) at E_1 satisfy the Routh-Hurwitz criterion.*

Proof: The variational matrix at the drinking-present equilibrium E_1 is given by

$$V(E_1) = \begin{bmatrix} x_{11} & x_{12} & x_{13} & 0 \\ x_{21} & x_{22} & x_{23} & x_{24} \\ x_{31} & 0 & x_{33} & 0 \\ x_{41} & 0 & 0 & x_{44} \end{bmatrix}$$

where $x_{11} = \beta\left(P^* - 2A^* - X^*\right) - \left(\gamma + \delta + \alpha\right), x_{12} = -\beta A^*, x_{13} = \beta A^*, x_{21} = p\gamma - \lambda M^*, x_{22} = -\lambda M^* - \left(\delta + \sigma\right), x_{23} = \lambda M^*, x_{24} = \lambda\left(P^* - A^* - X^*\right), x_{31} = -\alpha, x_{33} = -\delta, x_{41} = \alpha\kappa, x_{44} = -m$

The characteristic equation of the system (2) at E_1 is $|\phi I - V(E_1)| = 0$, where I is the identity matrix of order 4 and ϕ is the eigenvalue of matrix $V(E_1)$. By simple computation, the characteristic equation can be expressed in the following form:

$$\phi^4 + b_1\phi^3 + b_2\phi^2 + b_3\phi + b_4 = 0 \tag{15}$$

where

$$b_1 = -\left(x_{11} + x_{22} + x_{33} + x_{44}\right),$$

$$\begin{aligned} b_2 = {} & x_{11}x_{22} + x_{11}x_{33} + x_{11}x_{44} + x_{22}x_{33} + x_{22}x_{44} + x_{33}x_{44} \\ & - \left(x_{12}x_{21} + x_{13}x_{31}\right), \end{aligned}$$

$$\begin{aligned} b_3 = {} & x_{12}x_{21}x_{33} + x_{12}x_{21}x_{44} + x_{13}x_{31}x_{22} + x_{13}x_{31}x_{44} \\ & - (x_{11}x_{22}x_{33} + x_{11}x_{22}x_{44} + x_{11}x_{33}x_{44} + x_{22}x_{33}x_{44} \\ & + x_{12}x_{24}x_{41} + x_{12}x_{31}x_{23}), \end{aligned}$$

$$\begin{aligned} b_4 = {} & x_{11}x_{22}x_{33}x_{44} + x_{12}x_{23}x_{31}x_{44} + x_{12}x_{24}x_{33}x_{41} - x_{12}x_{21} \\ & x_{33}x_{44} - x_{13}x_{22}x_{31}x_{44} \end{aligned}$$

Now, when $R_0 > 1$, the drinking-present equilibrium point exists. Furthermore, benefitting the Routh-Hurwitz criterion [21], all the eigenvalues of characteristic equation (15) have negative real parts if the conditions given below hold:

$$b_i > 0 \left(i = 1, 2, 3, 4\right), \; b_1 b_2 - b_3 > 0 \text{ and}$$
$$b_1 b_2 b_3 - b_3^2 - b_1^2 b_4 > 0$$

Therefore, the drinking-present equilibrium E_1 is locally asymptotically stable if $R_0 > 1$ and above conditions are satisfied. ■

VII. Sensitivity Analysis and Numerical Simulation

The probability that an individual in Nepal be a heavy alcohol drinker is 0.239 since the current adult drinkers is 23.9 % there, and this allows the use of $\beta = 0.239$, which represents the probability of becoming a drinker following prolonged contact with an individual who consumes alcohol [8]. The number of times an individual is in a company of alcohol drinking people enough to be let him/her get the temptation to drink varies with individuals. To carry out numerical simulations, we consider the number of contact between the people who drink and do not drink to convince non-drinker to drink as one. The rate at which moderate drinkers become alcoholic again (σ) depends on several factors including one's genetic makeup and drinking patterns among a host of other factors, but here $\sigma = 0.001year^{-1}$ is used. Alcohol- related deaths are not documented in most developing countries, so we use 3.5%, estimated by Mokdad *et al.* in 2004 for the United States of America [22] although developing countries like Nepal, India, etc may have lesser value. The WHO STEPS survey showed that only 4% of the adults were former drinkers (who drank in past but did not consume in the last 12 months), so it is reasonable to take $p = 0.04$. Assuming the total population 100 % , we choose initial population as : $S(0) = 70, A(0) = 23, X(0) = 7$ and $M(0) = 20$.

TABLE II: The values of parameters used for simulation.

Parameter & Value	Source
$\Lambda = 5\ person(year)^{-1}$	Assumed
$\beta = 0.239\ year^{-1}$	[8]
$\sigma = 0.001\ year^{-1}$	[17]
$\delta = 0.25\ year^{-1}$	[18]
$\alpha = 0.035\ year^{-1}$	[22]
$\kappa = 2.5$	Assumed
$m = 0.05\ year^{-1}$	[17]
$\lambda = 0.02\ year^{-1}$	[17]
$\gamma = 0.2\ year^{-1}$	Assumed

Using Table II, the basic reproduction number is obtained as $R_0 = 9.8557 > 1$. Calculating values of a_1, a_2 and a_3 using Table II and then substituting in the equation (14), population of heavy drinking individuals is obtained as $A^* = 0.06021$. Substituting this value of A^* in (11), (12) and (13), other components of drinking-present equilibrium E_1 of the system (2) is obtained as follows : $A^* = 0.06021, X^* = 17.9021, P^* = 19.9916, M^* = 0.1054$.

The mathematical expressions for the normalized forward sensitivity indices of R_0 with respect to the parameters involved in it are obtained as:

$$S_{\alpha}^{R_0} = \frac{-\alpha}{(\alpha+\delta+\gamma)} < 0;\ S_{\beta}^{R_0} = 1 > 0;\ S_{\Lambda}^{R_0} = 1 > 0,$$

$$S_{\gamma}^{R_0} = \frac{-\gamma}{(\alpha+\delta+\gamma)} < 0;\ S_{\delta}^{R_0} = \frac{-(\alpha+\gamma+2\delta)}{\delta(\alpha+\delta+\gamma)} < 0$$

Bar plot in Figure 2 displays the normalized sensitivity indices of R_0 related to the parameters for the model, evaluated at the baseline parameter values given in Table II. The most sensitive parameters are the transmission rate (β) and recruitment rate (Λ) of the susceptible in Nepal. The least sensitive parameter is γ.

Figure 3 (left panel) shows that as the value of β and Λ increases, the value of R_0 also increases. Symmetrical shape of the plot indicates that β and Λ play equal significant role in ensuring that the alcohol problem occurs. Again, the Figure 3 (right panel) illustrates that the increment in the value of β magnifies R_0 more rapidly than γ. Contour plots (Figure 4) justify the fact that (i) increase in both β and Λ increases R_0 symmetrically; (ii) increase in the value of β together with decrease in the value of γ yields the rapidly raise in the value of R_0.

Figure 5 demonstrates the effect of the awareness programs on alcohol consumption behavior in one of developing countries Nepal. Awareness programs are the effective measures in controlling heavy drinking problems. It is observed that the aware population $X(t)$ increases whereas the heavy drinker population $A(t)$ decreases with an increase in the value of dissemination rate λ of the awareness program among susceptible population while the other parameters remain unchanged. Hence, it can be concluded that the drinking problem could be controlled through the proper execution of awareness programs through the media.

Graphical illustration comparing the trends of the behavior of the population in the absence and presence of media awareness program (Figure 6 (left panel)) shows that in the absence of a media awareness program, a decrease of the susceptible population to an asymptotically low level is accompanied by an increase in the population of heavy alcohol drinking population. However, in the presence of media awareness program, (Figure 6 (right panel)), the aware population $X(t)$ increases to their corresponding asymptotic states while the heavy alcohol consuming population declines to their asymptotic level. Furthermore, the increment in the frequency of media awareness programs is not a sufficient measure to eliminate a drinking culture in the community, it only partially alleviates the issue.

Simulation results carried out by taking different values of the parameters β and λ (Figure 7) show that implimentation of controlling measures to supress transmission rate and to increase dissemination rate of awareness program simultaneously, control the population of heavy drinkers significantly. Consequently, the model forcasts that effective awareness programs and avoidance of regular contact of non-drinkers with heavy drinkers in drinking environment eliminate the drinking problem.

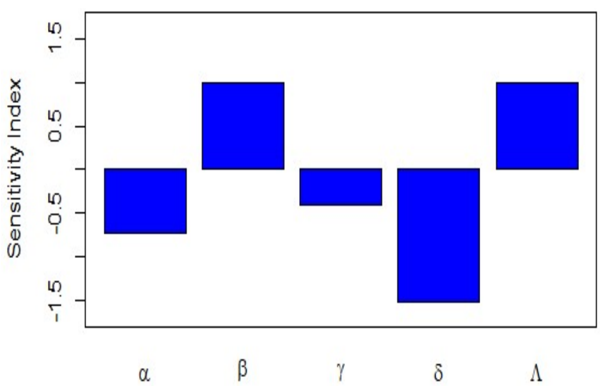

Fig. 2: Normalized sensitivity indices of R_0.

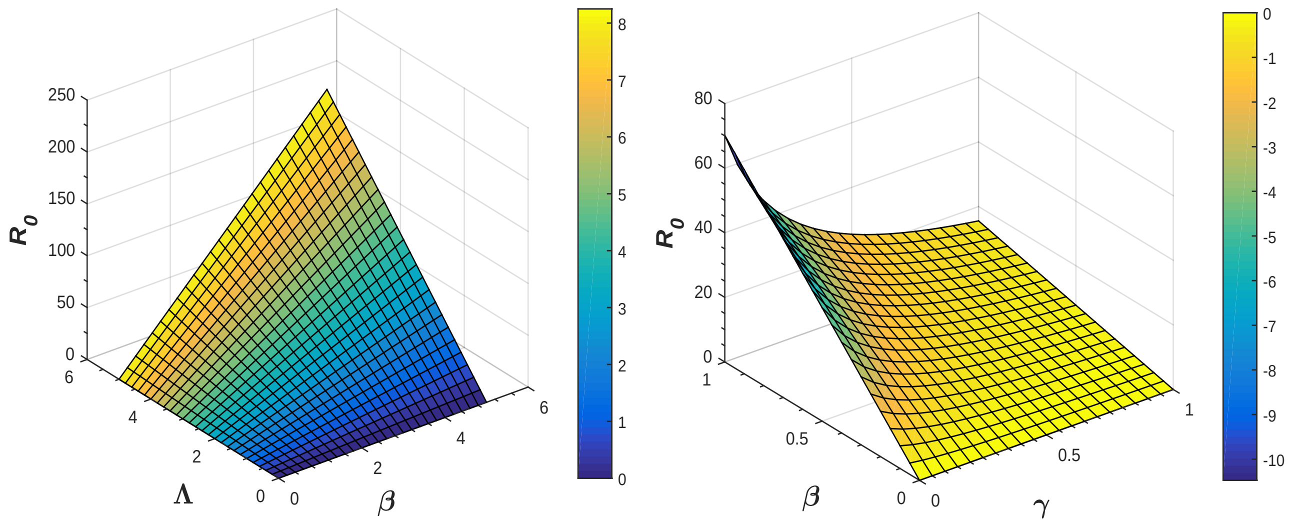

Fig. 3: Variation of R_0 with (i) Λ and β (left panel), (ii) β and γ (right panel).

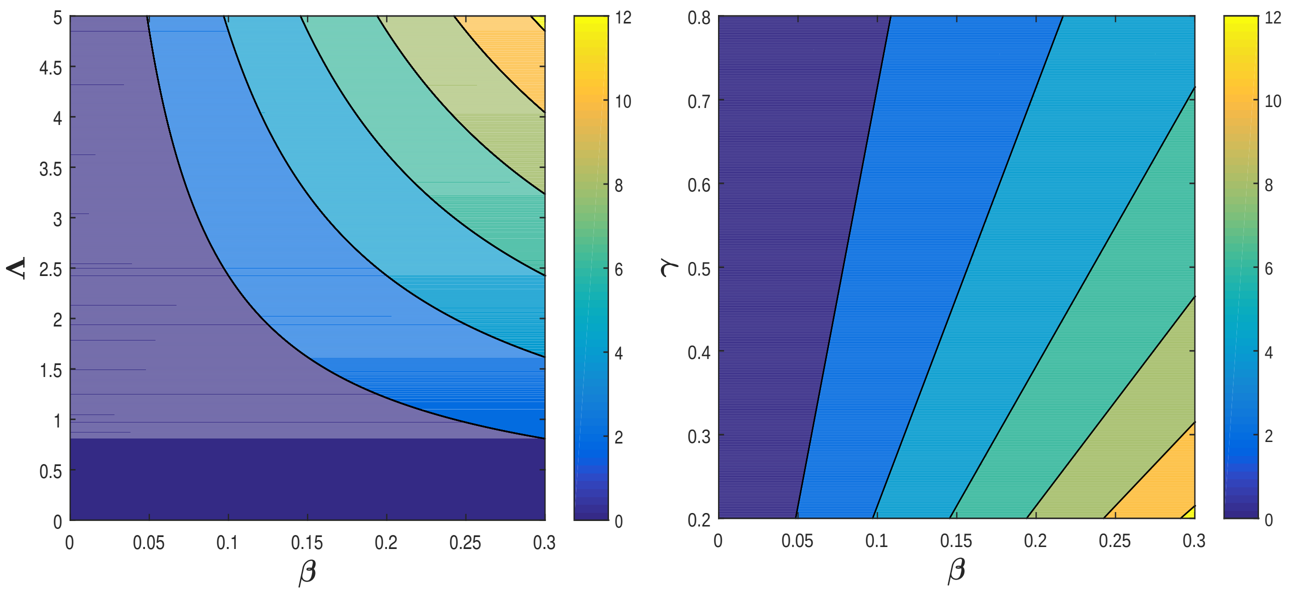

Fig. 4: Contour plot of R_0 as a function of (i) β and Λ (left panel), (ii) β and γ (right panel).

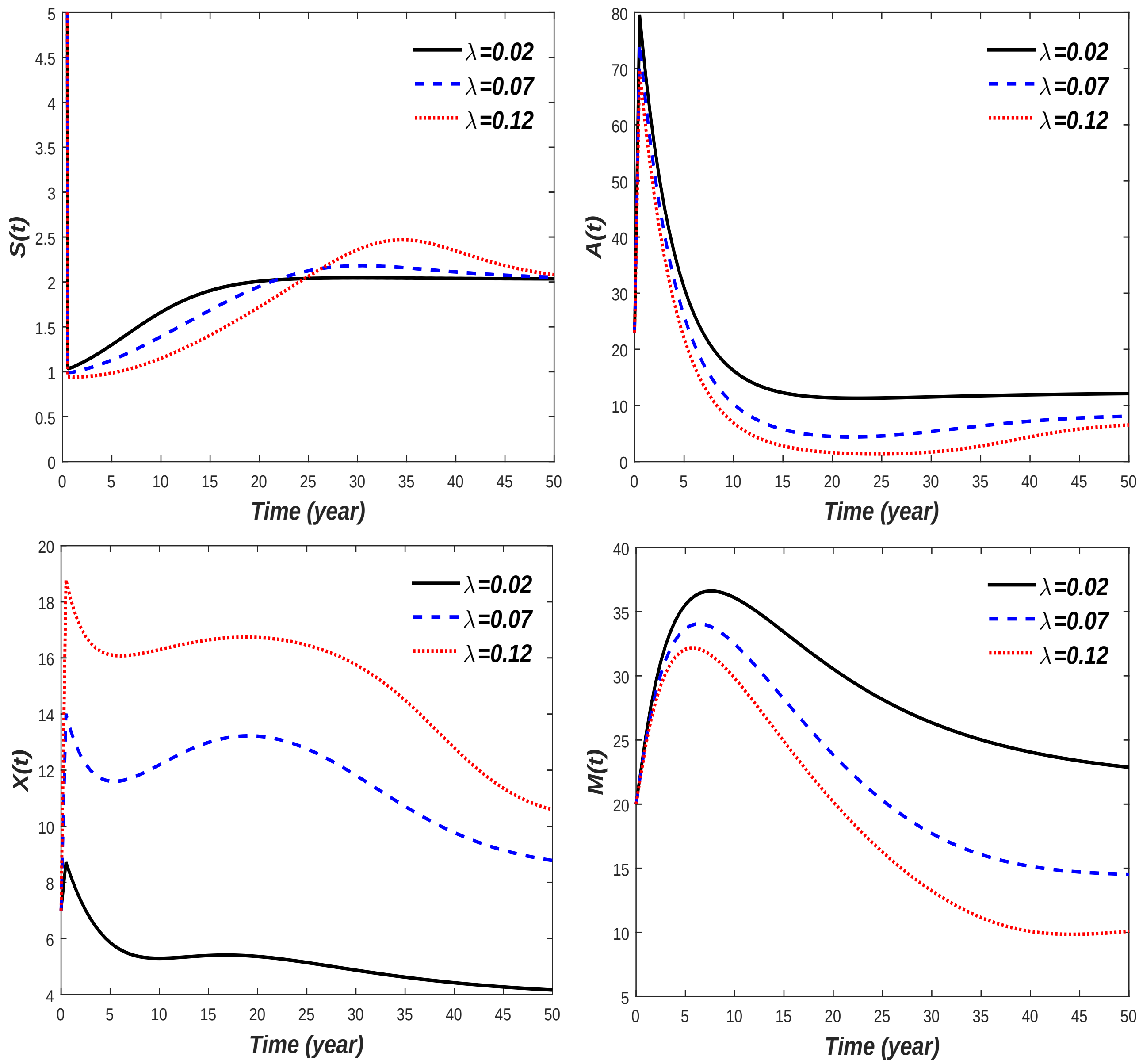

Fig. 5: Dynamics of human population for different values of dissemination rate of awareness program (λ).

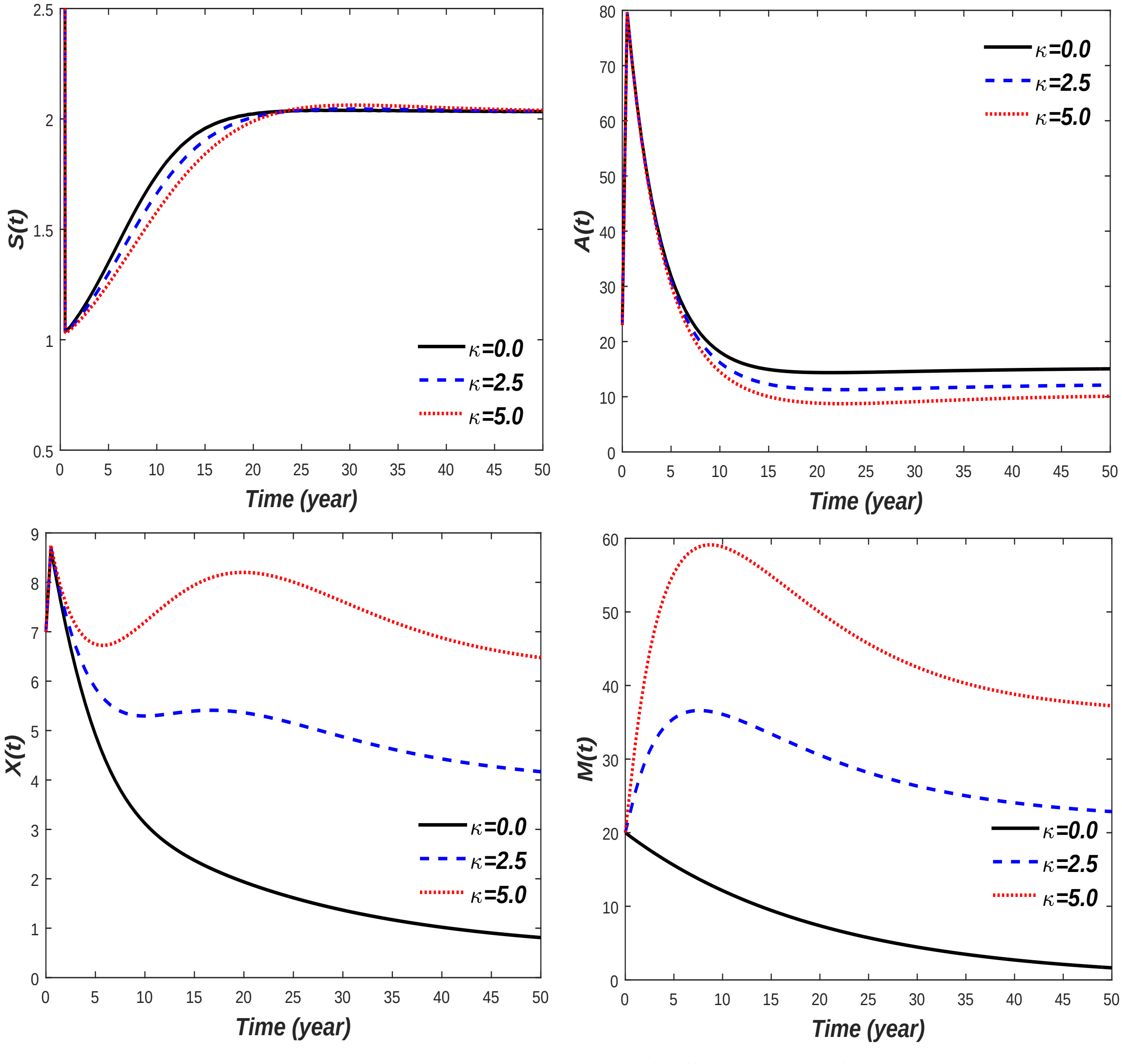

Fig. 6: Dynamics of human populations in the absence and presence of different degrees (frequencies) of media awareness programs (κ).

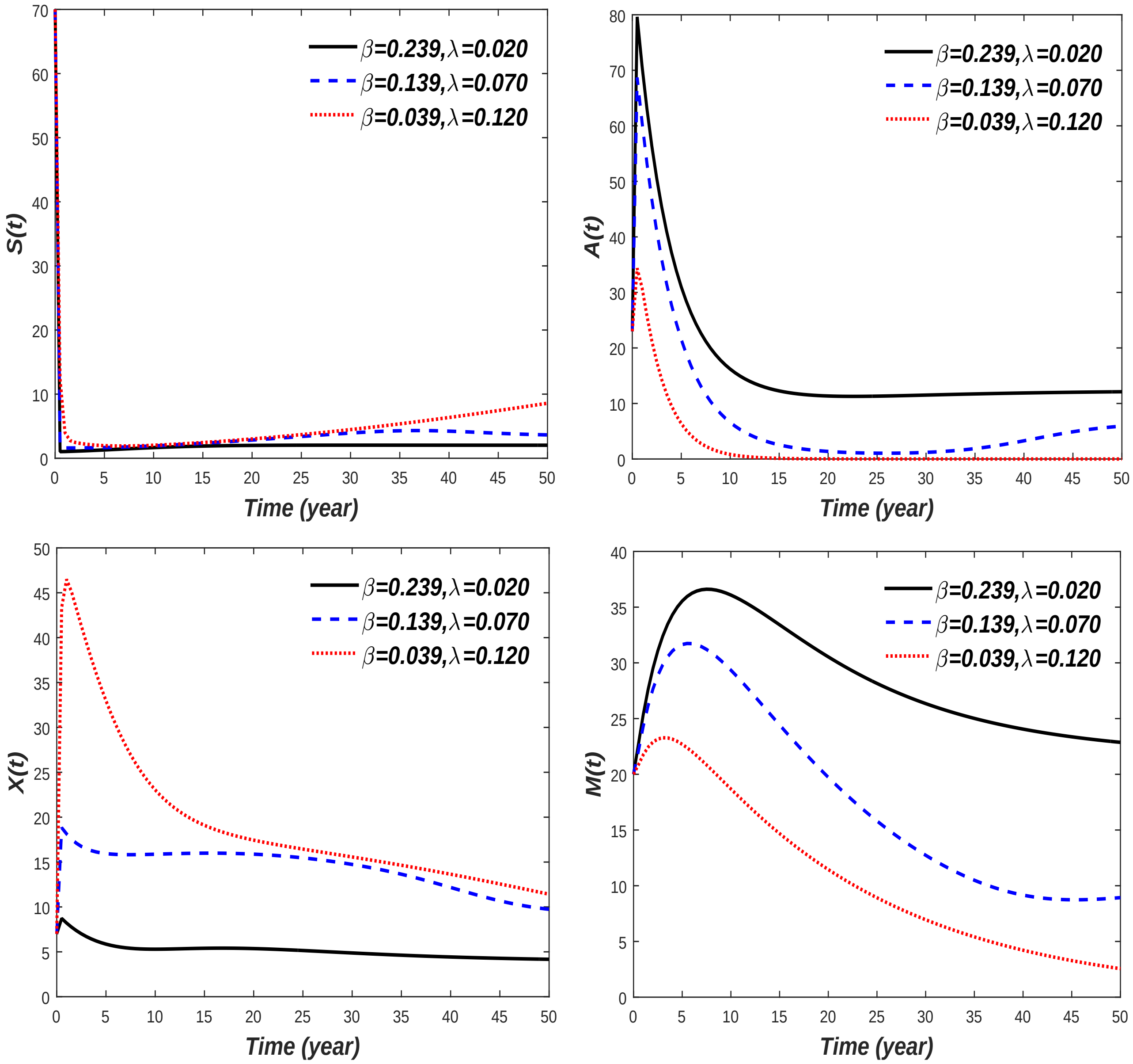

Fig. 7: Variation in population for different levels of dissemination rate of awareness program and transmission coefficient of the infection for the susceptible individuals.

VIII. Results and Discussion

The research shows that an awareness program is an effective measure in controlling the heavy drinking problem. It may be applied to study the dynamics of drinking behavior in developing countries like Nepal, India, etc. Definitely, it has some limitations; the model can be modified by introducing one more compartment including the individual who is under the treatment. Conversion of non-drinkers or moderate drinkers into heavy drinkers is a time- consuming process as it does not happen suddenly after the interaction between heavy drinkers and non-drinkers or moderate drinkers. So, it will be more realistic to introduce time delay in the model [23],[24]. In future, we shall study mathematical models by introducing other social and environmental perturbations for other developing countries [25]. The results are not exhaustive to understand the drinking problems of society fully. How and to which degree heavy alcohol consumption is affecting nationally and globally, intensive studies must be conducted among children and young people at different geographical, economic, cultural, and social levels.

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