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# MODELING THE IMPACT OF COMMUNITY AWARENESS ON THE DYNAMICS OF CARDIOVASCULAR DISEASES

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## ABSTRACT

Cardiovascular disease (CVD) is caused due to high blood pressure, diabetes, poor diet and lack of exercises. Awareness about cause and preventive measures of the disease play a key role to control the prevalence of CVD in the communities. In this article a non-linear mathematical model is proposed and analyzed in which the number of CVD people in the communities is controlled by the awareness disseminated through the word of mouth. Aware people change their lifestyle that includes daily physical exercises, taking healthy food timely and live stress-free life etc. thereby preventing the onset of CVD and its complications. The awareness generation number R0 is calculated and it is found that the system undergoes transcritical bifurcation. Equilibria analysis and stability analysis are performed. Numerical analyses are performed to validate the analytical findings. The analysis of the model and the outcomes reveal that the density of the CVD people can be significantly reduced by community awareness through word of mouth.

***Key Words:*** *community awareness, CVD, R0, stability, transcritical bifurcation.*

## INTRODUCTION

Cardiovascular disease (CVD) has emerged as a significant global epidemic, imposing a substantial burden on health, society, and the economy. The prevalence of CVD continues to rise, with an estimated 62 million people affected by cardiovascular disease NHLBI morbidity and mortality chartbook, (2002). Moreover, CVD remains the leading cause of mortality worldwide, accounting for approximately 30% of all global deaths Mendis et al. (2011). As such, understanding the factors that contribute to the development and prevention of CVD is of utmost importance. Over the years, concerns have been raised regarding the potential influence of mouth to mouth and community awareness, particularly those disseminated through interpersonal communication and community events, on individuals' health behaviors and lifestyle choices. While numerous studies have explored the impact of awareness on various health outcomes, such as obesity, smoking, and alcohol consumption. Limited research has specifically focused on the effects of this awareness on CVD. To effectively address the prevention and management of CVD, predictive models incorporating multiple risk factors have been developed. These models consider factors such as age, smoking status, sex, blood pressure (BP), and cholesterol levels to estimate the risk of cardiovascular events and mortality Agostino et al. (2008); Hippisley-Cox et al. (2008). Additionally, dietary and lifestyle interventions play a crucial role in reducing cardiovascular risk Eilat-Adar et al. (2013); Stuart-Shor et al. (2012). Notably, CVD is largely preventable through two key strategies: primordial prevention and primary prevention. Primordial prevention aims to prevent the development of risk factors in the first place, while primary prevention focuses on interventions designed to modify adverse levels of risk factors once they are present, with the goal of preventing an initial CVD event Lloyd-Jones et al. (2006). The importance of both primordial and primary prevention approaches has been highlighted by population-based studies and clinical research Strasser, (1978); Kavey et al. (2003); Claude, (1996); Dubey et al. (2016). In the context of raising awareness about CVD, mouth to mouth and community awareness have become prominent sources of health information. These sources serve as channels for disseminating knowledge about disease prevalence and prevention, enabling individuals

To access information and share it with their family, relatives, and friends. As a result, attitudes and lifestyles can be positively influenced, fostering a greater understanding of the seriousness of long-standing conditions such as CVD. Motivated by the importance of awareness in mitigating the risk of CVD, this research aims to develop a comprehensive mathematical model. The model considers the transmission of awareness solely through word-of-mouth communication, assuming that individuals become aware of CVD and independently adopt preventive measures to reduce the likelihood of developing the disease. In conclusion, this research paper endeavors to model the effects of mouth to mouth and community awareness on cardiovascular disease. By exploring the role of awareness campaigns in raising awareness and promoting preventive measures, we aim to contribute valuable insights that can inform effective strategies for CVD prevention and management. Through a comprehensive analysis of the effects of mouth to mouth and community awareness, we hope to provide a deeper understanding of their potential contributions to reducing the burden of CVD on a global scale.

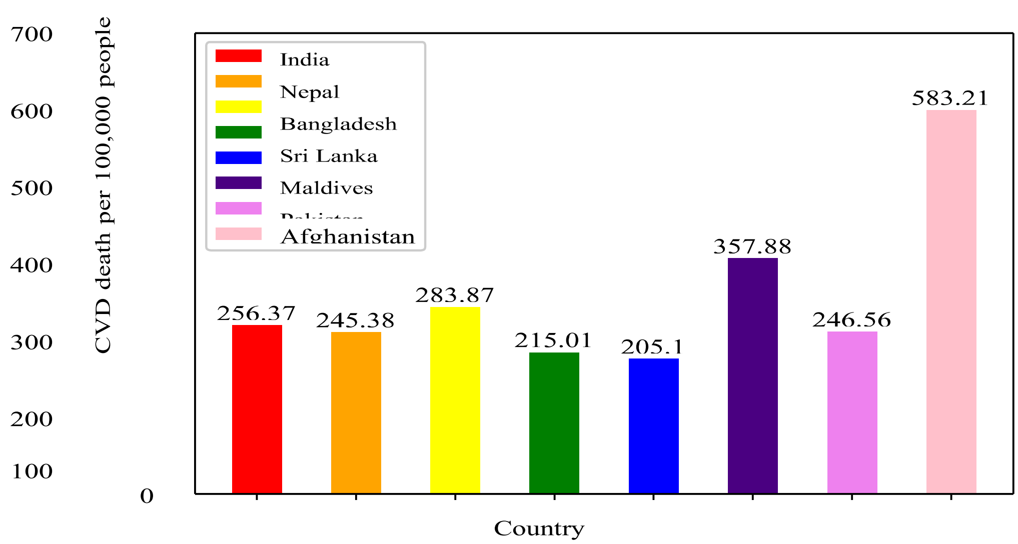


**Figure 1:** CVD death per 100,000 people by country in South Asia in 2019
*Source: IHME, Global Burden of Disease (2019)*

## THE MATHEMATICAL MODEL

In the model formulation the susceptible individuals are divided into unaware susceptible Sh(t) and aware susceptible Ah(t). Ch(t) denotes the number of individuals suffering through the cardiovascular disease (CVD). The unaware susceptible individuals are assumed to be recruited at the constant immigration rate λ and suffer through CVD at a rate γ whereas aware individual at a lower γ0γ, 0 < γ0 < 1 as they adopt preventive measures. Aware people disseminate awareness about the disease through word of mouth and make unaware people aware at the rate γ. Also, aware people may lose their awareness due to memory fading and other social reasons and joins the unaware class which is represented in the model by λ0A. Since the people In the Ch(t) class have weak immune system so they suffer through disease induced mortality at the rate dc. On the basis of above assumptions, the proposed model is given as:

$$\frac{dS_h}{dt} = \lambda - \gamma S_h - \beta A_h S_h + \lambda_0 A_h - d_n S_h$$

$$\frac{dA_h}{dt} = \beta A_h S_h - \gamma_0 \gamma A_h - \lambda_0 A_h - d_n A_h \tag{1}$$

$$\frac{dC_h}{dt} = \gamma S_h + \gamma_0 \gamma A_h - d_c C_h - d_n C_h$$

with the initial condition $S_h(0) > 0$, $A_h(0) \geq 0$ and $C_h(0) \geq 0$and $N_h = S_h + A_h + C_h$ is the total human population.

## MATHEMATICAL ANALYSIS

### Region of Biological Interest

**Theorem 1.** The region in which every solution of model system (1) that begins in the positive space confined is given by:

$$\Omega = \left\{ (S_h, A_h, C_h) \in R_+^3 : 0 \leq S_h, A_h, C_h \leq N_h \leq \lambda \frac{\lambda}{d_n} \right\},$$

The region Ω is closed and bounded in positive three-dimensional space.

### Feasibility of Equilibria

The system has two equilibria awareness free equilibrium $E_{afe}$ and interior equilibrium $E_{ie}$, which are obtained by solving the equilibrium equations of system (1). The awareness free equilibrium is

$$E_{afe} = \left( \frac{\lambda}{\gamma + d_n}, 0, \frac{\lambda\gamma}{(\gamma + d_n)(d_c + d_n)} \right)$$

### Basic Reproduction Number

The basic reproduction number is obtained from next generation matrix approach Diekmann et al. (2010). The awareness generating matrix and transition matrix at awareness free equilibrium of subsystem of system (1) are respectively,

$$T_m = \begin{bmatrix} 0 & 0 \\ 0 & \frac{\lambda\beta}{\gamma + d_n} \end{bmatrix} \text{ and } T_s = \begin{bmatrix} (\gamma + d_n) & \left( \frac{\beta\lambda}{\gamma + d_n} - \lambda_0 \right) \\ 0 & (\gamma_0\gamma + \lambda_0 + d_n) \end{bmatrix}$$

The basic reproduction is defined as $R_0 = \rho(-T_m T_s^{-1}) = \sup \{|\Phi| : \Phi \, \mathcal{E} \, \sigma(-T_m T_s^{-1})\}$, where $\sigma$ is the spectrum and $\rho$ is the spectral radius of the matrix $T_m T_s^{-1}$. Thus,

$$R_0 = \frac{\beta\lambda}{(\gamma + d_n)(\gamma_0\gamma + \lambda_0 + d_n)}$$

$R_0$ defines the average number of individuals that are made aware about the CVD in the society by an aware people during his entire life through word of mouth when enter in to the susceptible and unaware communities of CVD.

The interior equilibrium is, $E_{ie} = \left( \frac{\gamma_0\gamma + \lambda_0 + \lambda}{\beta}, \frac{R_0 - 1}{R_0(\gamma_0\gamma + d_n)}, \frac{\frac{\gamma(\gamma_0\gamma+\lambda_0+\lambda)}{\beta} + \frac{\gamma\gamma_0(R_0-1)}{R_0(\gamma_0\gamma+d_n)}}{d_c + d_h} \right)$. The interior equilibrium exists if $R_0 > 1$.

**Stability Analysis**

In this section, we study the extent to which a small disturbance in equilibrium solutions affect thebehavior of the solutions of system (1). The Jacobian matrix of the system (1) is,

$$J = \begin{bmatrix} -(\gamma + \beta A_h + d_n) & -(\beta S_h - \lambda 0) & 0 \\ \beta A_h & (\beta S_h - \gamma_0\gamma - \lambda 0 - d_n) & 0 \\ \gamma & \gamma_0\gamma & -(d_c + d_n) \end{bmatrix}$$

The Jacobian matrix at awareness free equilibrium is,

$$J_{E_{afe}} = \begin{bmatrix} -(\gamma + d_n) & -\left(\frac{\beta}{\gamma+d_n} - \lambda_0\right) & 0 \\ 0 & (R_0 - 1)(\gamma_0\gamma + \lambda_0 + d_n) & 0 \\ \gamma & \gamma_0\gamma & -(d_c + d_n) \end{bmatrix}$$

The eigenvalues of the matrix $J_{Eafe}$ are $-(\gamma + d_n)$, $(R_0 - 1)(\gamma_0\gamma + \lambda_0 + d_n)$, and $-(d_c + d_n)$ which areall negative if $R_0 < 1$. Therefore, the awareness free equilibrium is asymptotically stable if $R_0 < 1$.

The Jacobian matrix at interior equilibrium is,

$$J_{E_{ie}} = \begin{bmatrix} a_{11} & -(\gamma_0\gamma + d_n) & 0 \\ a_{21} & 0 & 0 \\ \gamma & \gamma_0\gamma & -(d_c + d_n) \end{bmatrix}$$

where $a_{11} = \left(\gamma + \frac{\beta(R_0-1)}{R_0(\gamma_0\gamma+d_n)} + d_n\right)$ and $a_{21} \frac{\beta(R_0-1)}{R_0(\gamma_0\gamma+d_n)}$

One eigenvalue $-(d_c + d_n)$ is negative and other two eigenvalues are obtained from the matrix

$$\begin{bmatrix} a_{11} & -(\gamma_0\gamma + d_n) \\ a_{21} & 0 \end{bmatrix}$$

The characteristic polynomial with $\zeta$ as eigenvalue is,

$$\zeta^2 + c_1\zeta + c_2. \tag{2}$$

where $c_1 = \begin{bmatrix} a_{11} & -(\gamma_0\gamma + d_n) \\ a_{21} & 0 \end{bmatrix}$ and $c_2 = \beta(R_0 - 1)$. Here, $c_1 > 0$ and $c_2 > 0$ for $R_0 > 1$. By using Routh-Hurwitz criteria we can say that both the roots of the equation (2) are real negative or complexwith negative real part. The interior equilibrium $E_{ie}$ is asymptotically stable if $R_0 > 1$.

**Theorem 2**. *The awareness free equilibrium $E_{afe}$ always exists in the system and is locally asymptot- ically stable if $R_0 < 1$, which becomes unstable if $R_0 > 1$ and interior equilibrium $E_{ie}$ appears which is asymptotically stable.*

***Remark 1.*** *At $R_0 = 1$, the Jacobian matrix $J_{E_{afe}}$ has simple zero eigenvalue and rest two eigenvalues have negative real parts, so the system undergoes transcritical bifurcation in the forward direction at$R_0 = 1$.*

## NUMERICAL SIMULATION

To justify the analytical findings, the numerical simulations of the system (1) are performed using MATLAB 2018. The description of the parameters and their values for the purpose of numerical simulation is given in the Table (1). The set of values in the Table (1) is used throughout the simulations unless otherwise stated. For this set of parameters value the value of $R_0$ is more than one and also theeigenvalues of the Jacobian matrix $J_{E_{ie}}$ are all negative, ensuring that the interior equilibrium exists and is asymptotically stable. Figure (2) shows the variation plots of the state variables in the system
(1) for different values of the transmission rate of the unaware people to aware class due to awareness disseminated through word of mouth. It is seen that the number of unaware individuals as well as the number of individuals suffering through CVD decrease as the rate of awareness increases whereas, the number of aware individuals increases due to increase in the value of $\beta$. This suggests that the number of

**Table 1:** Parameters description with their values used for numerical simulations.

| Parameters | Description | Values |
|---|---|---|
| $\lambda$ | Recruitment rate of human population | 10 persons$day^{-1}$ |
| $\beta$ | Rate of transfer of unaware individuals to aware class due to awareness through word of mouth | 0.00009 $person^{-1}day^{-1}$ |
| $\gamma$ | Rate at which unaware individuals suffer through CVD | 0.005 $day^{-1}$ |
| $\gamma_0$ | Fraction representing the reduced chance of aware individual to suffer through CVD | 0.1 |
| $\lambda_0$ | Rate of transfer of aware individuals to unaware class | 0.03 $day^{-1}$ |
| $d_c$ | Disease induced mortality | 0.02 $day^{-1}$ |
| $d_n$ | Natural death of human population | 0.01 $day^{-1}$ |

Cases of CVD in the communities can be significantly controlled by spreading awareness through word of mouth. From the Figure (3), it is seen that for different initial starts, the solution trajectories approach to the unique interior equilibrium. That is Eie is globally asymptotically stable. In figure (4), the contour plot is plotted to show the variation in the awareness generation number $R_0$ due to simultaneous change in the value of transmission rate from unaware to the aware class (β) and the efficacy of the transmission rate (γ0). It is seen from the figure that for the higher values of β and lower values of $\gamma_0$, the value of $R_0$ is greater than one whereas less than one for lower value of β and higher value of $\gamma_0$. Thus, size of the Ch class can be reduced by increasing the value of β and by lowering the value of $\gamma_0$.

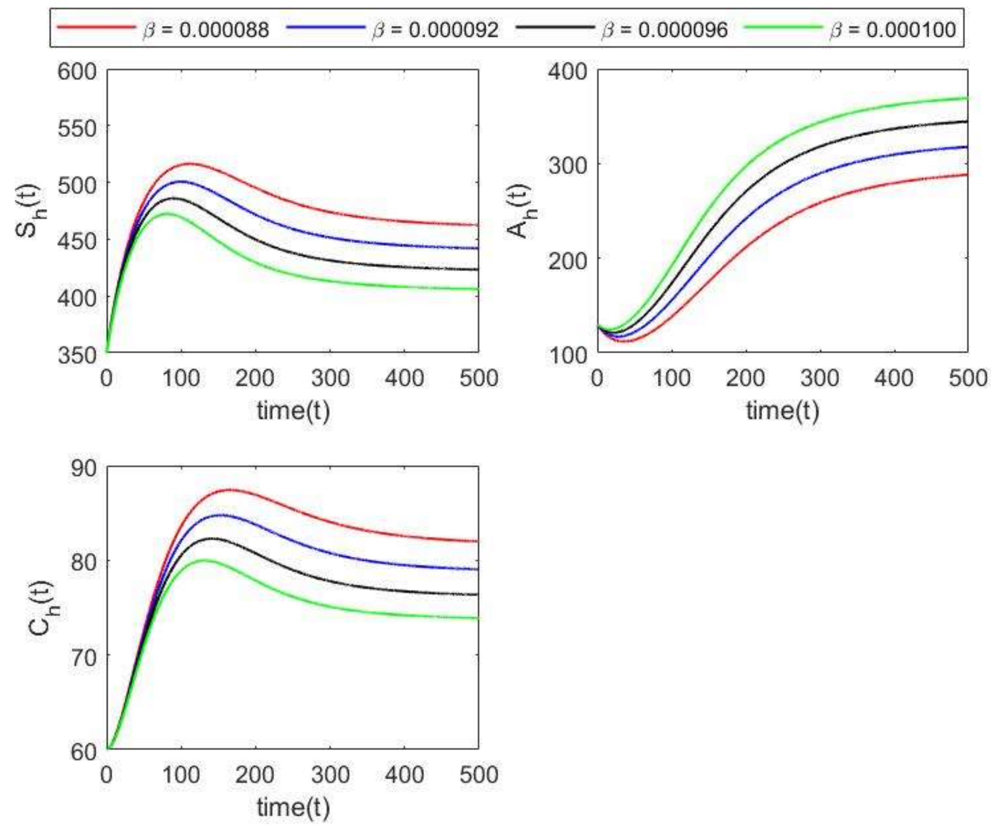


**Figure 2:** Variation plots of *Sh*, *Ah* and *Ch* for the system (1) for different values of *β*.

## CONCLUSION

Cardiovascular disease is the group of disorder of the heart and blood vessels. It is caused due to reduced blood flow to the heart, infection or high blood pressure. The treatment may include change in lifestyle such as diet modification and exercise. In this article a non-linear mathematical model is proposed and analyzed with the assumption that people become aware of the Cardiovascular diseases through the word of mouth from the community people. They follow preventive measures and change their lifestyle to avoid the risk of CVD. The awareness free reproduction number $R_0$ is calculated. It is found for $R_0 < 1$, the number of people with CVD is maximum and awareness free equilibrium is stable but for R0 > 1, the awareness free equilibrium loses it's stability and stable endemic equilibrium, at which the number of people with CVD is comparatively less, becomes feasible. Thus, to reduce the density of people with CVD in the community anyhow R0 is brought above unity and this is achieved through

Increasing the transmission rate of unaware people to aware class by the dissemination of awareness through word of mouth and lowering the probability of transmission of people to the CVD class.

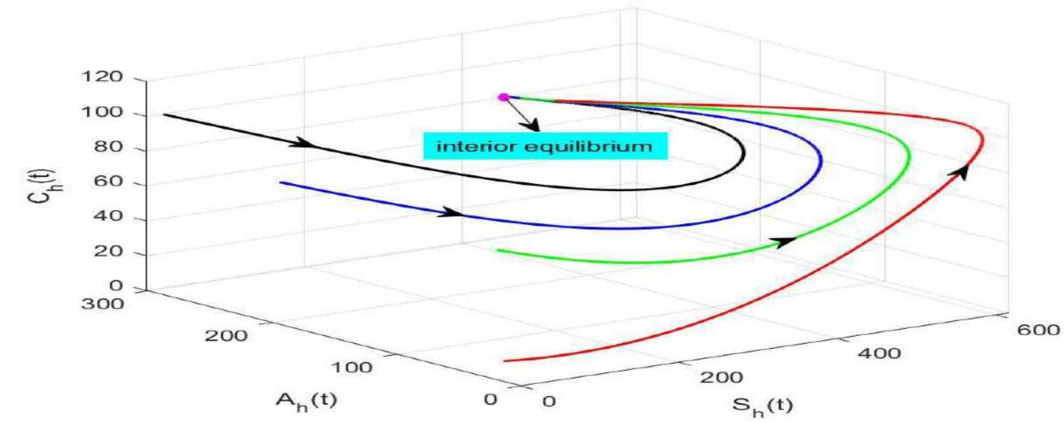


**Figure 3:** Global stability behavior of the equilibrium *Eie* for the system (1) in *Sh*, *Ah* and *Ch* plane. All the solution trajectories tend to *Eie* for different initial values.

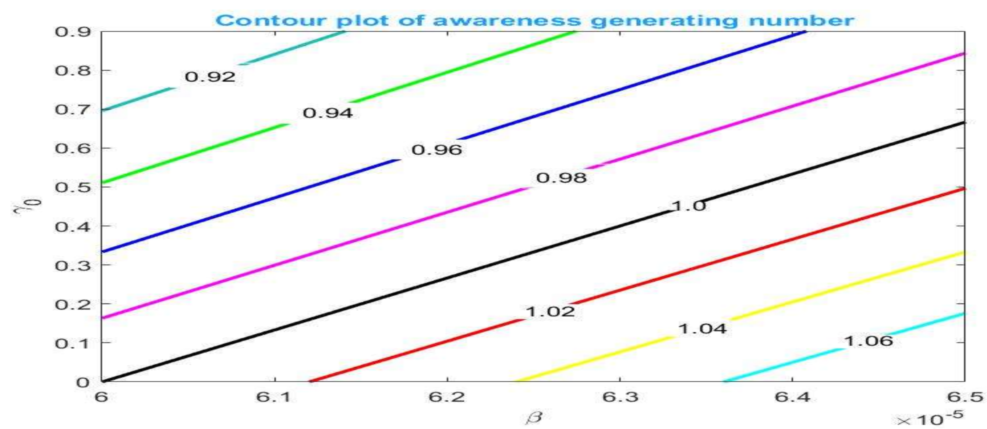


**Figure 4:** Contour plot of *R*0 for the system (1)with respect to *β* and *γ*0.

## REFERENCES


NHLBI morbidity and mortality chartbook, 2002. Bethesda, Md.: National Heart, Lung, and Blood Institute, May 2002. Accessed June 10, 2003, at http://www.nhlbi.nih.gov/resources/docs/cht-book.htm.

Mendis, S., Puska, P., Norrving, B. E., & World Health Organization. (2011). Global atlas on cardiovas- cular disease prevention and control. World Health Organization.

W. B. (2008). General cardiovascular risk profile for use in primary care: The Framingham Heart Study. *Circulation, 117*(6), 743-753.

Hippisley-Cox, J., Coupland, C., Vinogradova, Y., Robson, J., Minhas, R., Sheikh, A., & Brindle, P. (2008). Predicting cardiovascular risk in England and Wales: Prospective derivation and validation ofQRISK2. *Bmj, 336*(7659), 1475-1482.

Eilat-Adar, S., Sinai, T., Yosefy, C., & Henkin, Y. (2013). Nutritional recommendations for cardiovasculardisease prevention. *Nutrients, 5*(9), 3646-3683.

Stuart-Shor, E. M., Berra, K. A., Kamau, M. W., & Kumanyika, S. K. (2012). Behavioral strategiesfor cardiovascular risk reduction in diverse and underserved racial/ethnic groups. *Circulation, 125*(1), 171-184.

D. (2006). Prediction of lifetime risk for cardiovascular disease by risk factor burden at 50 years of age. *Circulation, 113*(6), 791-798.

Strasser, T., (1978). Reflections on Cardiovascular Diseases. *Interdisciplinary Science Reviews, 3*, 225-230.

Kavey, R. E. W., Daniels, S. R., Lauer, R. M., Atkins, D. L., Hayman, L. L., & Taubert, K. (2003). American Heart Association guidelines for primary prevention of atherosclerotic cardiovascular disease beginning in childhood. *Circulation, 107*(11), 1562-1566.

Claude, L., (1996). Task Force on Research in Epidemology and Prevention of Cardiovascular Diseases. *Circulation, 93*, 16051607. https://doi.org/10.1161/01.CIR.93.9.1605

Dubey, B., Dubey, P., & Dubey, U. S. (2016). Role of media and treatment on an SIR model. Nonlinear Analysis: Modelling and Control, 21(2), 185-200.

Diekmann, O., Heesterbeek, J. A. P., & Roberts, M. G. (2010). The construction of next-generation matrices for compartmental epidemic models. *Journal of the Royal Society Interface, 7*(47), 873-885.

Hale, JK., (1969). *Ordinary Differential Equations*. Wiley-Interscience, New York.