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The Prediction of Number of Deaths by COVID-19 in Gujarat, India**Digish K. Patel^{1*}, Sagar K. Ambavale² and Pimi Suthar¹****Affiliation:** 1- Faculty of Science, Ganpat University, Mehsana– 384012, Gujarat, India. 2-Vishwakarma Govt. Engg. College, Chandkheda, Ahmedabad, Gujarat, India.***Author for correspondence:** Dr. Digish K. Patel, Assistant Professor, Faculty of Science, Ganpat University, Mehsana - 384012, Gujarat, India. Email: dkp01@ganpatuniversity.ac.in

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ABSTRACT

We have used analytical model to describe the fast increase of deaths occurred due to the corona virus (COVID-19) infection in Gujarat, the western state of India which is among top 3 states with most number of total deaths as well as highest mortality rate due to COVID-19. The model used here comes from a simplified version of the SIR (susceptible-infected-recovered) model known as SI model. It assumes that, there is no recovery assuming that all recovered are again susceptible to infection. In that case the dynamical equations can be solved analytically and the result is extended to describe the function that depends on three parameters that we can fit to the data. This allows us to make predictions for the development of the disease and number of deaths under different conditions of lockdown in Gujarat.

Key word: COVID-19, SIR model, Gujarat**INTRODUCTION**

Since the beginning of recorded history there have been epidemics that have invaded populations, often causing many deaths before disappearing, possibly recurring years later, possibly diminishing in severity as populations develop some immunity. [1] Mathematical models can project how infectious diseases progress to show the likely outcome of an epidemic and help inform public health interventions. Models use basic assumptions or collected statistics along with mathematics to find parameters for various infectious diseases to obtain short and long-term predictions, which in turn may enable decision makers optimize possible control strategies, such as containment measures, lockdowns and mass vaccination campaigns. The modelling can predict future growth patterns and can help decide which intervention/s to avoid and which to trial, etc. [2] The basic compartmental models to describe the transmission of communicable diseases are contained in a sequence of papers by W.O. Kermack and A.G. McKendrick.[3]

The SIR model is one of the simplest compartmental models, and many models are derivatives of this basic form. The model consists of three compartments: S for the number of susceptible, I for the number of infectious, and R for the number of recovered or deceased (or immune) individuals. These variables (S , I , and R) represent the number of people in each compartment at a particular time. The name SIR indicates that the passage

of individuals is from the susceptible class 'S' to the infective class 'I' to the removed class 'R'. To represent that the number of susceptible, infected and recovered individuals may vary over time (even if the total population size remains constant), we make the precise numbers a function of t (time): $S(t)$, $I(t)$ and $R(t)$. [2] The SIR model assumes that the person once recovered from a disease becomes immune against re-infection. Usually, diseases caused by a virus are of SIR type.

The dynamics of the system can be explained by three coupled non-linear ordinary differential equations;

$$\frac{dS(t)}{dt} = -\beta S(t)I(t) \quad (1)$$

$$\frac{dI(t)}{dt} = \beta S(t)I(t) - \gamma I(t) \quad (2)$$

$$\frac{dR(t)}{dt} = \gamma I(t) \quad (3)$$

$$S(t) + I(t) + R(t) = N. \quad (4)$$

Where, $\beta > 0$ is the corona virus transmission rate, $\gamma > 0$ is the recovery rate, and N is the total population size.

The system is reduced to two coupled differential equations, which does not possess an explicit analytical formula for the solution, but can be solved numerically. The SIR model is usually parameterized using actual infection data and the solution of the $I(t)$ function can be compared with actual infection data, to predict the evolution of the disease.

In this paper we have predicted the deaths due to COVID-19 over the time period of 90 days in Gujarat state taking in to consideration data from two different time durations i.e. from 1st April to 4th May and from 15th April to 4th May, 2020 using the analytical formula derived from the several assumptions. This analytical formula can be useful as a fast method to forecast the global behaviour as a first approach before applying more sophisticated methods. We have assumed $R(t)$, the no. of recovered individuals as zero. The reason behind this crude assumption is nearly zero recovery rate in the early phase of the contagion. And at the later stage when there is considerable number of recovered cases, they are considered as susceptible. Because, in case of COVID-19, the idea that one-time infection can lead to immunity remains unproven as there is 'No Evidence' yet that Recovered COVID-19 Patients are immune to second round of infection. [4, 5] Since February, it was estimated that about 14% of discharged patients in Guangdong province and elsewhere were testing positive after their release from the hospital and had to return to the hospital for observation. [6, 7, 8]

METHODOLOGY

The first basic assumption of the model is that there is no recovery from COVID-19 virus, at least during the pandemic time interval. Thus, infected cases either get susceptible again or get deceased. This drastic assumption could be reasonable if the spreading time of the pandemic is much faster than the recovery time i.e. $\gamma \ll \beta$ and recovered cases are assumed to be susceptible against infection.[9]

Under this simple assumption $R(t) = 0$, and the SIR equations reduce to the single equation of the well-known SI model

$$\frac{dI}{dt} = \beta(N - I(t))I(t) \quad (5)$$

where, total population size depends on susceptible and infectious individuals, i.e. $N = S(t) + I(t)$.

Therefore, the infection rate is proportional to the infected, I and to the non-infected $N - I$ or susceptible individuals S . This equation is easily solved in the following way. Dividing by $(N - I)I$ and multiplying by dt ,

$$\frac{dI}{(N-I)I} = \beta dt \quad (6)$$

Integrating over initial time $t = t_0$ to later time t we obtain

$$I(t) = \frac{I_0 e^{(t-t_0)/b}}{1 - C + C e^{(t-t_0)/b}} \quad (7)$$

Where we have defined the constants

$b = \beta^{-1}$, $C = \frac{I_0}{N}$ where I_0 is the initial infected at initial time $t = t_0$.

The parameter b is the characteristic evolution time of the initial exponential increase of the pandemic. The infection rate β is calculated from the following discrete-time version of the Kermack-McKendrick equation. [10,11]

$$\beta = \frac{(I(t+1) - I(t)) N}{I(t)(N - I(t))} \quad (8)$$

The constant C is the initial infection rate (with respect to the total population). Assuming that initially $C \ll 1$, this constant can be neglected in the denominator, obtaining

$$I(t) = \frac{I_0 e^{(t-t_0)/b}}{1 + C e^{(t-t_0)/b}} \quad (9)$$

Now to predict the number of deaths in this model we assume that the number of deaths at some time t is proportional to the infection at some former time τ , that is,

$$D(t) = mI(t - \tau) \quad (10)$$

Where m is the mortality or death rate, and τ is the mortality time. With this assumption we can finally write the equation as

$$D(t) = \frac{ae^{(t-t_0)/b}}{1 + ce^{(t-t_0)/b}}$$

included inside the fitted parameters a, b, c .

RESULTS

We have approximated the infection rate, $\beta = 0.1356/\text{day}$ (i.e. $b = 7.37$ days) using eq. (8) from supplementary data for Gujarat state available on COVID-19 Tracker [12] for 34 days (i.e. 1st April-2020 to 4th May-2020). In fig. 1 (a), the data of total deaths till date are plotted against number of days since the first reporting day. Which is used for the curve fitting and we get, value of parameters $a = 5.38$ and $c = 0.005$. These values of a, b , and c parameters are used for prediction of future number of deaths for duration of 1st April-2020 to 29th – June 2020 which is shown in fig. 1 (b). Depending on the ground situation, there may be variation in infection/transmission rates and therefore, we have also included predictions with $\pm 10\%$ variation in value of parameter b . Fig. 1(c) denotes the number of deaths per day.

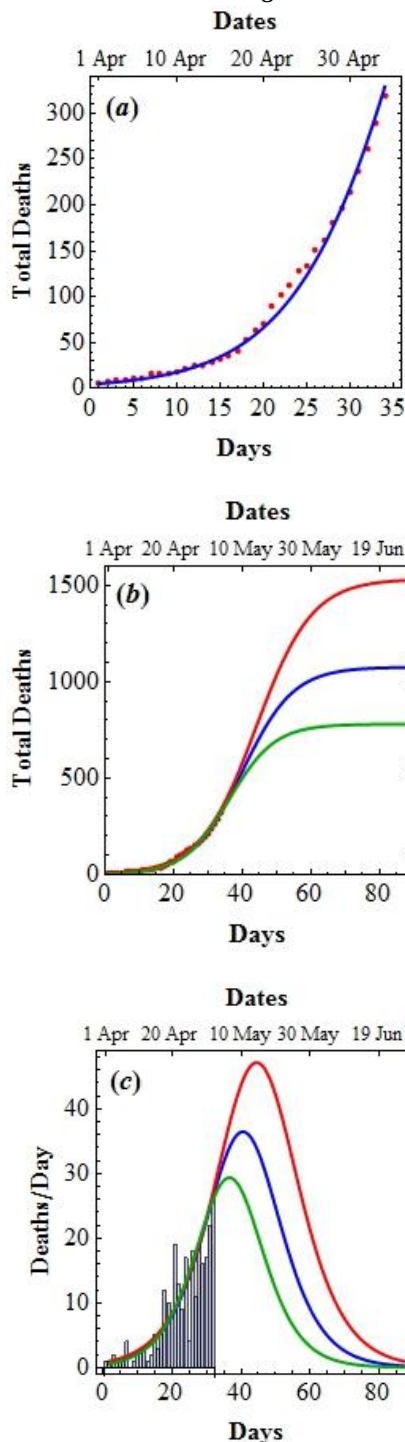


Figure 1: (a) Total Deaths in COVID-19 for Gujarat from 1st April to 4nd May, 2020 (34 Days). Red circles show the confirmed deaths and solid blue line shows the model fitting curve. (b) Predicted total Deaths in Gujarat due to COVID-19 for 90 days i.e. from 1st April to 29th June, 2020 for three different values of characteristic evolution time $b = 7.37$ (blue line), 7.86 (red line) and 6.3 (green line).

(c) Predicted number of Deaths per day in Gujarat due to COVID-19 for 90 days i.e. from 1st April to 29th June, 2020 for three different values of characteristic evolution time $b = 7.37$ (blue line), 7.86 (red line) and 6.3 (green line).

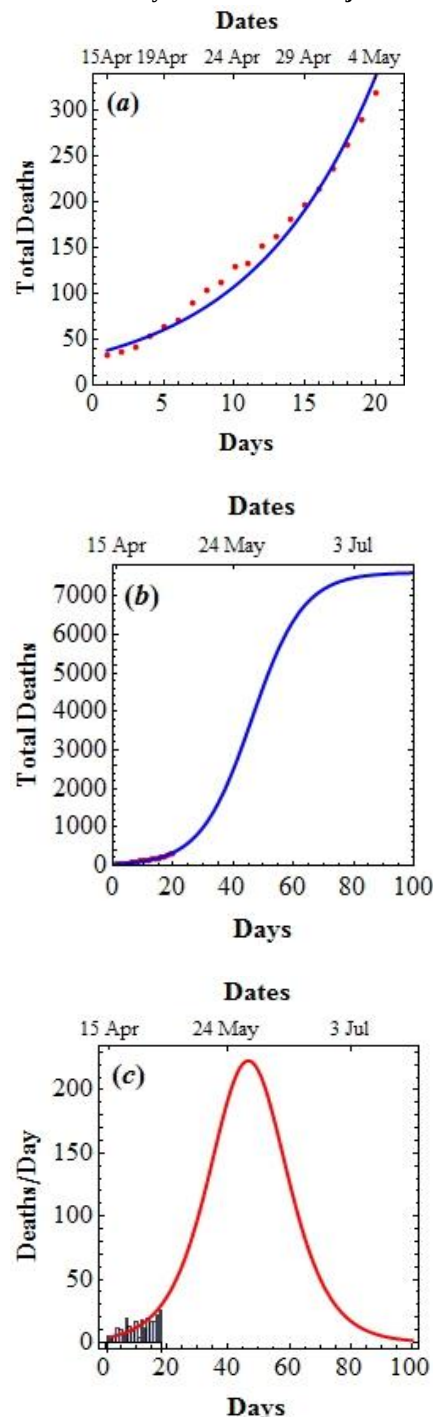


Figure 2: (a) Total Deaths in COVID-19 for Gujarat state in second phase of lockdown from 15th April to 4nd May, 2020 (20 Days). Red circles show the confirmed deaths and solid blue line shows the model fitting curve. (b) Predicted total Deaths in Gujarat due to COVID-19 for period of 100 days from 15th April. (c) Predicted Deaths per day in Gujarat state due to COVID-19 for 100 days for the period from 15th April.

In fig. 2, we have taken data of 20 days only (i.e. from 15th April to 4th May) for calculations as from 15th April onwards second phase of lockdown was imposed and as during this period several conditions of lockdowns were changed and restrictions were eased down for keeping certain economic activities running.

DISCUSSION

We have predicted number of deaths in Gujarat due to COVID-19 pandemic using some modification in SIR model. These predictions are based on the calculations of number of different parameters using actual data of infected and deceased cases provided by government of Gujarat. As shown in fig. 1 (c) we have predicted the number of deaths per day to reach the maximum i.e. nearly 40 around 10th May, 2020 and flattening of the cumulative death curve around 30th May, 2020. However, considering the changes in prevailing lockdown conditions in the state because of government interventions in form of changes in the relaxation granted to various areas and businesses, the nature of curve and ultimately the parameters a, b and c get changed. These changes in parameters lead to higher number of mortals per day. To incorporate these changes conditions and resulting change in input numbers, we have taken different starting dates for calculation of parameters, and as shown in fig.2 we get considerable change in predicted number of infected and deceased cases. As shown in fig. 2 (c), number of maximum deaths increases to more than 200 deaths per day around last week of month of May. Particularly at the end of the second phase of lockdown, the rate of infection, mortality rate and ultimately the number of deceased are changed. With increase in social interaction in view of festivals and migration of labours to home state may cause another jump transmission rate across the nation and eventually further increase in number of deaths cannot be denied. We also state that further with the change in testing and contact tracing strategies, social-distancing policies, reopening of community strategies or stay-at-home policies change significantly in the coming days and weeks, the predicted death toll will also change and accordingly we have to retrace the basic parameters of our calculations and prediction can change accordingly. We also foresee effect of seasonal influenza may affect the transmission rate, infection numbers and thus eventually the total number of deaths. Currently the spread of COVID-19 is in a very dynamic state, based on the change in growth parameter final outcome will also differ. As spread of COVID-19 pandemic is still very dynamic and mysterious due to various known/unknown parameters, prediction of its growth trajectory is very difficult. Hopefully, discovery of effective medicines and vaccine together with proper implementation of containment strategies will bring mortality and transmission rate lower and put break over spread of the disease further.

Academic Interest: Here mathematical model is used for academic purpose for predicting number of deaths due to a new disease for planning and preparedness activities.

Disclaimer: The views expressed in the article are the authors' own and do not represent that of their respective organizations. All mathematical models of infectious diseases epidemiology are based on some strict assumptions. Please interpret the findings carefully. Currently the spread of COVID-19 is in a very dynamic state, based on the change in growth parameter final outcome will also differ.

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