A Modified SIRD Model for the COVID-19 Contagion in Kerala, India

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Abstract

The purpose of this work is to give a contribution to understanding the COVID-19 contagion in Kerala, India. We developed a modified Susceptible-Infectious-Recovery-Death(SIRD) and an improved one, Susceptible-Infectious-Recovery-Death-Vaccination(SIRDV), using the official data of the pandemic from April 30th, 2021 to May 30th,2021. In addition, following the basic assumption of SIR model, we assumed that population, death rate, vaccination rate and vaccination effectiveness rate, and other parameters are constant and fixed. Moreover, we supposed people who are infected by COVID-19 will not be infected again and people who are recovered from the virus do not need to be vaccinated. Finally, we altered the parameters and succeeded to control the increment of Infectious. Moreover, the figures and results we got are closer to the reality than before the modification.

1. Introduction

COVID-19 has become a serious health problem threatening the world due to its rapid spread. We chose Kerala, one of the city of India, as our preference, since the data is more comprehensive. Kerala has suffered from the disease attack during the whole year.The total population(N) of Kerala is 35336581. The total population(N) is equal to the sum of the Susceptible(S), the Infectious(I), the Recovery(S) and the Death(D), which is immutable. In symbol words, N=S+I+R+D. From April 30th, 2021 to May 30th, 2021, there are 22818513 people infected and 8641 dead by virus. Mathematical model is a tool to provide a clear figures and tendencies for researchers to make a significant reduction of infected people and the death. We defined β as transmission rate of COVID-19, γ as recovery rate, μ as death rate, η as vaccine effectiveness, α as vaccine rate (see Table 2). According to the research "A Modified SIR Model for the COVID-19 Contagion in Italy", our group attempted to make a SIRD model to make a decline of Infectious factor by these parameters.

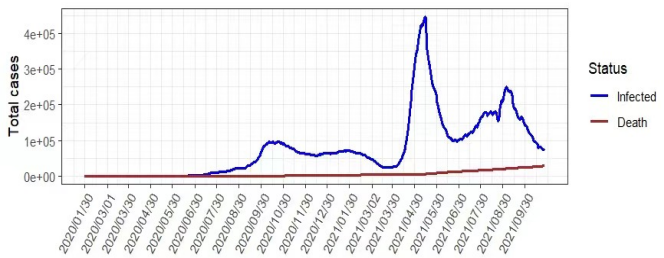

Figure 1: The Infected and Death Amount of Kerala State

variables	Description
$S(t)$	the population of individuals susceptible of contracting the infection at time t
$I(t)$	the population of infected individuals that are active at time t
$R(t)$	the cumulative population of individuals that recovered from the disease up to time t
$D(t)$	the cumulative population of individuals that deceased due to the disease, up to time t
$V(t)$	the population of vaccinated individuals at time t
D	the duration of infection

Table 1: Involved variables

parameters	Description
β	Transmission rate of COVID19 – It depends on basic reproduction number of COVID19 and *gamma*
γ	Recovery rate – inverse of the COVID infectious period
μ	Death rate – depends on COVID19
α	The vaccination rate
η	The vaccine effectiveness

Table 2: Parameters of the mathematical model

2. An Approach Using the Regular SIRD Model

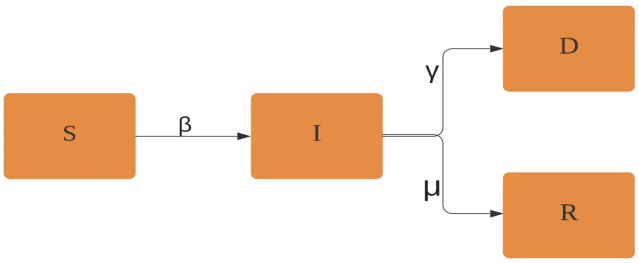

Figure 2: Flow Chart of SIRD model

After applying the regular SIRD model to analyze the infected proportion of the population, the result is shown below:

Figure 3: Prediction and Real Value of I after Applying Regular SIRD Model

The equations we used are listed below:

$$\frac{dS}{dt} = -\beta SI$$
$$\frac{dI}{dt} = \beta SI - \gamma I - \mu I$$
$$\frac{dR}{dt} = \gamma I$$
$$\frac{dD}{dt} = \mu I$$

Where β is the transmission rate, γ is the recovery rate, μ is the death rate. The parameter $\beta > 0$ and $\gamma > 0$. For the recovery rate γ, $\gamma = 1/D$, where D is the duration of infection. Let the Basic reproduction number(the average number of people that an infected individual would infect) to be R0, notice $R_0 = \frac{\beta}{\gamma}$ and we need to get a overall data of the COVID-19 to get R_0. At the early stage of the spread of the pandemic, the susceptible population is approximate to the total number of people, that is, N≈S then we can simplify the relationship between the number of infections and time:

$\frac{dI}{dt} = \beta SI - \gamma I - \mu I \approx (\beta - \gamma - \mu)I$

The approximate number of infected people is:

$I(t) = exp(\beta - \gamma - \mu)t$

After the value of the death rate μ and the recovery rate γ were plugged in, the transmission rate β could be calculated. Obviously, after applying the regular SIRD model to predict the total infection proportion, the result was far from real values, thus other variables were contributing to the change of total infected proportion. As we were checking the news of that time, we found out that India dramatically increased the vaccination proportion during the time we investigated. Thus it was necessary to add the effect of vaccination to the model to better mimic the tendency of infected proportion and better decide what variables need to be controlled to make the infected proportion grow slower.

3. An Approach Using a Modified SIRDV Model

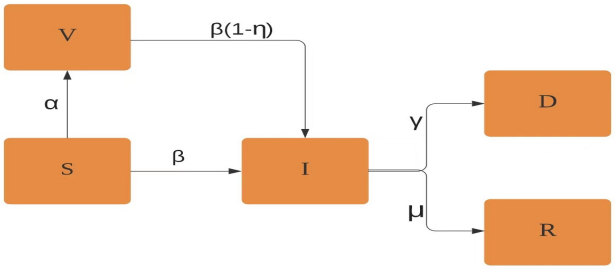

Figure 4: Flow Chart of SIRDV model

To make the model more practical, the effect of vaccination needs to be considered. However, due to the lack of vaccines and the low rate of complete vaccination, we considered the population who get one shot as vaccinated one in India. By the characteristic of vaccination, we assumed that η is the proportion of efficient vaccinations, and the population that is vaccinated, denoted by V, comes from S and reduces the infection proportion according to its efficiency. Thus our modified model should be based on the equations:

$V(t)$: the population of vaccinated individuals at time t;

$$\frac{dS}{dt} = -\beta SI - \alpha$$
$$\frac{dI}{dt} = \beta SI + \beta(1-\eta)VI - \gamma I - \mu I$$
$$\frac{dV}{dt} = -\beta(1-\eta)VI + \alpha$$
$$\frac{dR}{dt} = \gamma I$$
$$\frac{dD}{dt} = \mu I$$

Where β is the transmission rate, γ is the recovery rate, μ is the death rate, α is the vaccination rate, η is the vaccine effectiveness. For $\frac{dV}{dt} = -\beta(1-\eta)VI + \alpha$, $(1-\eta)V$ represents for the population that who is vaccinated but fails to immunization, thus they are people in V population but response to virus same as S population. α represents for the vaccination rate.

Figure 5: Prediction and Real Value of I after Applying Regular SIRD Model

The tendency of the infected proportion significantly decreases, which is closer to the real situation. Thus this modified model can better describe the infected proportion, and we can change the parameters of the model to see which of them should be controlled to flatten the infection curve.

4. Sensitivity Analysis

After successfully building the model, we needed to find what parameters of the model could be changed to make the infection curve flatter, so that hospitals will not be running at full capacity and more patients can be cured.

To start with, we analyzed the infection graph after changing the vaccination rate α. The result is shown below:

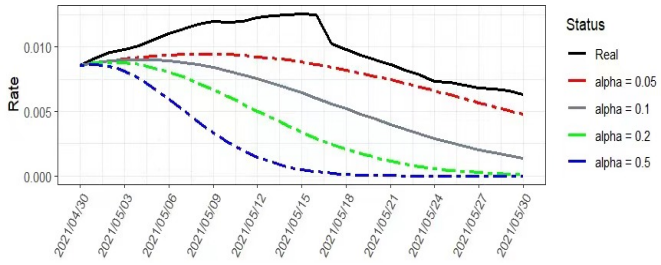

Figure 6: Infection rates after Changing α

Clearly, as α increases, the infection proportion curve goes flatter, meaning that the spreading of virus has been slowed down, thus getting more people to be vaccinated can flatten the infection curve.

Then we changed β, the transmission rate of the virus. The result is shown below:

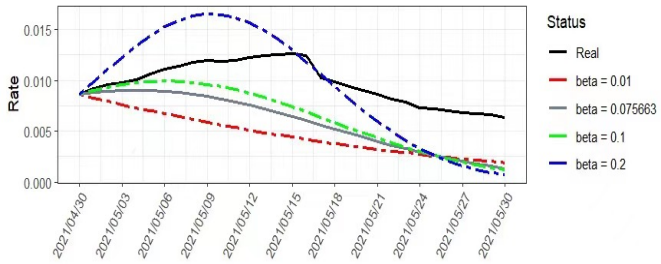

Figure 7: Infection rates after Changing β

As β increases, infection proportion also increases. Thus to decrease the infection proportion, policies need to be established to decrease the transmission rate or transmission rate of the virus, including quarantine and encouraging people to wear masks.

5. Conclusion

Firstly, we fitted a SIRD model to our Kerala data following the setup in "A Modified SIR Model for the COVID-19 Contagion in Italy". The model was not satisfactory. The total infection rate kept increasing while the real data encountered a turning point on May 15th, 2021. Since India dramatically increased the vaccination rate during the time we investigated, it is necessary to add the effect of vaccination to the model to better mimic the tendency of the infected rate. Therefore we had modified the model by adding the effect of vaccination. Under a vaccination rate of 10% and a vaccine effective rate of 75%, the total infection rate predicted by our modified SIRDV model followed the same pattern with the real data. A turning point had occurred and the infection rate kept decreasing after May 5th, 2021. We have successfully modified the original model in the paper to better fit the real data.

To better evaluate which parameter is significant in lowering the infection rate, we chose to investigate α, the vaccination rate, and β, the transmission rate of COVID-19. Since other parameters should be fixed and based on our research data, we think it would be practical to find out how changes in those two parameters affect our SIRDV model. After adjusting parameters and numerical simulation with Kerala data, we have concluded that: As the vaccination rate increases, and the transmission rate decreases, the infection proportion would be significantly lowered based on our SIRDV model.

The results allow new insights into future COVID-19 trends and the sensitivity of pandemic dynamics to various behavioral and other model parameters. As more exact information becomes available, new data can be directly incorporated into our model to produce more accurate results. The numerical values and ranges for the model parameters found in this study could be used as estimates to predict potential infection outcomes for scenarios where limited data is available (e.g., future pandemics). As model-based predictions get increasingly accurate, we expect that they will help guide informed policy decisions for the general public.

6. Limitation

Although the current model better simulates the real situation than the regular SIRD model, it has some obvious limitations. The turning point of predicted infection proportion is around one week before the real situation's turning point. The inaccuracy of this might be caused by our assumption that the vaccine works after just the first shot that overestimated the efficiency of vaccination. Also, although the testing rate of Kerala is one of the highest in India, it is not high enough to get an accurate value. We couldn't assume the total number of infected people by simply dividing the tested positive number by test rate since most people would test for COVID-19 if they do not feel well, but we do not know the exact rate, thus throughout the whole progress, the infection rate remains highly inaccurate. Moreover, in the real situation, all parameters like α, β, and so on are dynamic, but for easier implementation, we simplified them to be fixed.

Another inconsistency with the real world data was the Basic reproduction number(the average number of people that an infected individual would infect) calculated with our optimal β and chosen γ. Based on the formula, our $R_0 = \frac{\beta}{\gamma} = \frac{0.075663}{\frac{1}{22}} = 1.6646$. However, in the real world the basic reproduction number in Kerala, India was 5.7, which indicates the expected number of cases directly generated by one case was 5.7 in Kerala where all individuals are susceptible to infection. Our number was much lower than 5.7, and it seems impossible that the expected number of cases directly generated by one case was 1.7 in Kerala due to the large population and low quarantine rate. This inconsistency might be because Kerala has a relatively low test rate of COVID-19, which means the data we got might not represent what really happened in the spreading of COVID-19 in that area. If the testing rate in Kerala increases, we might end up with a better model using more accurate data.

7. Data availability

COVID data was obtained from the Government of Kerala COVID-19 Data.
The data contains the confirmed, recovered and deceased cases of Covid-19 cases in Kerala, India from January 31, 2020 to October 27, 2021 . This dataset can be used for EDA and time series analysis. All our plots and model simulations were done using RStudio.
https://dashboard.kerala.gov.in/index.php

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