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Transmission Dynamics of COVID-19 in Bangladesh- A Compartmental Modeling Approach

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Abstract

The coronavirus disease (COVID-19) was first identified in Bangladesh, on March 8, 2020. As of May 15, there are 20065 confirmed COVID-19 cases, including 3882 patients who have recovered and 298 related deaths. The objective of this study is to examine the transmission dynamics of COVID-19 and predict the growth of the infection in Bangladesh using the publicly available data through a mathematical model. The susceptible-exposed-infectious-recovered-dead (SEIRD) model is employed to describe the dynamics based on the kinematic parameters fitted on the data for the outbreak in Bangladesh up to May 15. The expression of basic reproduction number R_0 using the next generating matrix is derived and estimated. The kinematic parameters that describe transmission rate (0.045), recovery rate (0.03) and death rate (0.01) seems to be lower, respective of other countries. Based on the official counts for confirmed cases, the simulations suggest that the cumulative number of active infected follows an exponential trend. The mean reproduction number 2.25 (95% CI: 1.90-2.40) and transmission trends clearly indicates the outbreak of COVID-19 in Bangladesh. There is now breakneck concern regarding the capacity to respond to needs of infected patients effectively and to prevent this pandemic from further spreading in Bangladesh, one of the densest countries in the world.

Keywords: coronavirus, SEIRD, kinematic parameters, reproduction number, simulation

Introduction

COVID-19 (previously known as the novel coronavirus- *2019-nCoV*) is the third zoonotic human virus of the century in the world (1). The human being faced the similar type viruses, severe acute respiratory syndrome coronavirus (SARS-CoV) that spread to 37 countries in 2002 and Middle East respiratory syndrome coronavirus (MERS-CoV) in 2012 that spread to 27 countries. Similar to previous infections, COVID-19 exhibited symptoms of viral pneumonia, including fever, difficulty breathing, and bilateral lung infiltration in the most severe cases (2,3). Since its emergence in Wuhan of China, in December 2019, it has spread to 212 countries and territories in the world. According to the world health organization (4), the world has had 47,22,308 confirmed cases as of May 17 and 3,13,268 deaths. Cases are rising daily in Asia, the Americas, and Europe (4, 5).

Bangladesh, one of the densest country in the world, has been affected by this pandemic since the beginning of March 2020. The first case in Bangladesh was confirmed on March 8 and followed by the detection of one or two cases on average in the subsequent days. However, the number of new cases of COVID-19 infection started to increase rapidly from April 5 (Figure 1). Then it reached 100 cases on April 06 and exceeded 1000 within a week. During the month of March, only one lab had been testing COVID-19 symptoms. As of May 15, there are 20065 confirmed COVID-19 cases in Bangladesh, including 3882 patients who have recovered and 298 related deaths (6). The disease has spread to all cities. The highest attack rate (326/1M) was observed in the capital, Dhaka (IEDCR).

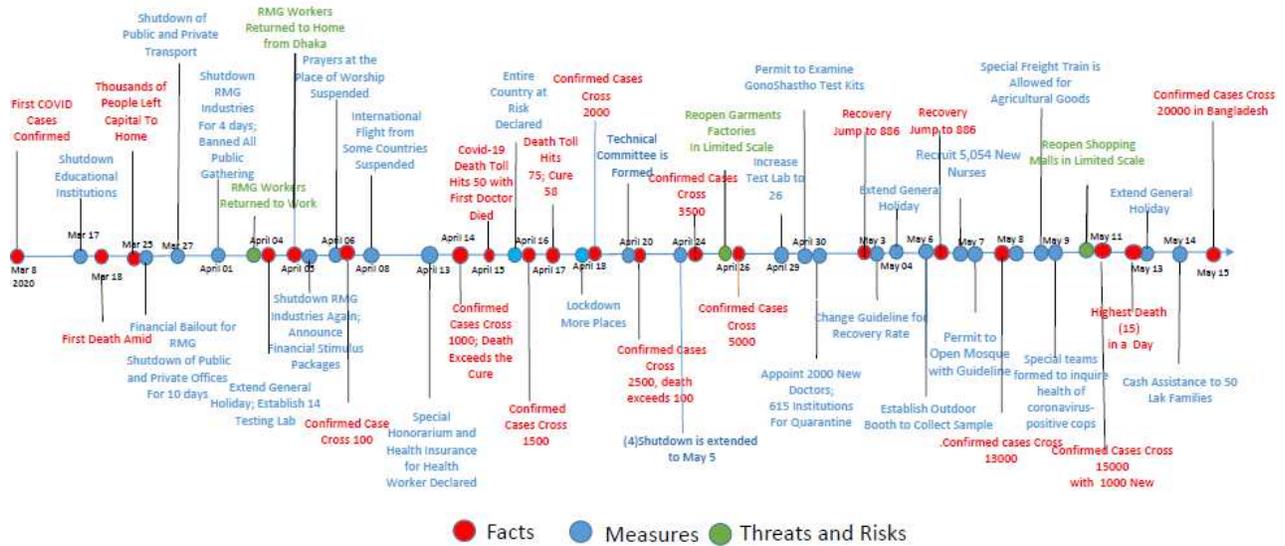


Figure 1 Timeline of Facts of COVID-19 and Control Measures Implemented in Bangladesh

The infected cases are rising rapidly as of the date, and a serious outbreak in Bangladesh is a realistic outcome. The government has been taking lots of actions to prevent this world pandemic (Figure 1). Most of the cities are in lockdown. Other controls of measures implemented in Bangladesh from March 8 to May 15 are shown in the developed timeline (Figure 1). The number of labs is gradually increasing throughout the countries and at present 37 labs are engaged to test. Rise in infected cases with rise in test indicates that the disease is already spread in the community. The cure rate is very low compared to other countries. The low cure rate is causing the rise in cumulative infected cases that might challenge the hospital facilities in the country. Lockdown has not been withdrawn but been relaxed from end of April. Garments manufacturer began to reopen factories on a limited scale within a limited number of workers from April 26 bypassing the opposition of health experts amid COVID-19 outbreak in the country. Owners have been permitted to keep shopping malls and markets open on a limited scale from May 10 though some kept their business shut due to virus transmission fears. In this situation, a transmission dynamics of coronavirus in Bangladesh has been modeled using publicly available data.

Compartmental models are the popular one to predict the transmission of a contagious disease. The models are classified in various ways with the population divided into classes and assumptions about the time rate of transfer from one class to another. The transmission rate and reproduction number need to be estimated to predict the outbreak of the disease. Toshikazu Kuniya (7) used susceptible-exposed-infectious-recovered (SEIR) model to predict the epidemic peak of COVID-19 in Japan using the data from January 15 to February 29. He found the reproduction number for that particular time is 2.6. The transfer from susceptible to expose is missing in that model. The conceptual model for the COVID-19 outbreak in Wuhan city with consideration of individual behaviors and government's actions has been proposed in (8). Another susceptible-infectious-recovered-dead (SIRD) model is used to forecast the outbreak in Wuhan city (9). Researchers estimated the transmission parameters of COVID-19 using different compartmental models in South Korea (10), in Japan (7) in Italy (11) in China (12,13). Lauer and his co-authors estimated using Wuhan's data that under conservative assumptions, COVID-19 cases will show symptoms after 14 days of active monitoring and quarantine. Junyu He. and his colleagues compared the transmission trends of China with South Korea, Italy and Iran using modified SEIR model (14,15). The expression of reproduction number using the modified SEIR model are not available in the literature. To the best of author's

knowledge, there is no published work predicting the COVID-19 outbreak in Bangladesh, one of the densest countries in the world.

Bangladesh, reports three types of data for public: daily infected, cured and dead. Since COVID-19 has long incubation and infectious period compared to others similar pandemic, we assume that SEIR model is suitable to estimate the transmission parameters through simulation using publicly available data from March 8 to May 15, 2020. The model is explained in the model development section. A new class of transmission from susceptible to expose and fatality term have been added to the conventional SEIR model. In addition to conventional SEIR model used by researchers (7), we consider that susceptible people may be infected in contact with the infected individual as well as exposed one. Hence we name our model, susceptible-expose-infectious-recovered-dead(SEIRD). The expression of basic reproduction number R_0 was derived using the next generation matrix. The reported and simulation results confirm that the growth of infection is in exponential trends. Detail comparative results are shown by Figures in the result and discussion section.

Methodology

Data Collection

Institute of Epidemiology Disease Control and Research (IEDCR), Bangladesh and World Health Organization (WHO) are the main sources of data used in this study. We collected data from those sources and used them in our model after matching with each other. The data collection period is from March 8 to May 15, 2020. Data on confirmed cases (infected), quarantine cases, cured, and death cases are collected.

Model Development

According to our model, we divide the population (N) of study region into five compartments, *susceptible* (S, vulnerable to COVID-19 infection), *exposed* (E, latent individual or asymptomatic infective) *infected* (I, symptomatic infected), *recovered* (R, immune to COVID-19), and *dead* (D, death due to COVID-19). The details of SEIRD model is described below.

$$\frac{dS}{dt} = -\frac{1}{N}(\beta_1 IS) - \frac{1}{N}(\beta_2 ES) \quad (1)$$

$$\frac{dE}{dt} = \frac{1}{N}(\beta_1 IS) + \frac{1}{N}(\beta_2 ES) - \alpha E \quad (2)$$

$$\frac{dI}{dt} = \alpha E - \gamma I - \lambda I \quad (3)$$

$$\frac{dR}{dt} = \gamma I \quad (4)$$

$$\frac{dD}{dt} = \lambda I. \quad (5)$$

The infectious rates, β_1 and β_2 , control the rate of transmission. In this model, β_1 represents the probability of infection per exposure when a susceptible individual (S) has contact with an infected patient (I) and becomes a latent exposed individual (E). While β_2 represents the potential rate per exposure when a susceptible individual (S) has mutual contact with an exposed individual (E), and transmits it to another exposed individual (E). Detail diagram is shown in Figure 2. Since the probable contact between susceptible and exposed individuals are larger than that of between susceptible and infected individuals we assume $\beta_2 = 5\beta_1$ (14). The incubation rate, α , is the rate of latent individuals becoming infectious (average duration of incubation is $1/\alpha$).

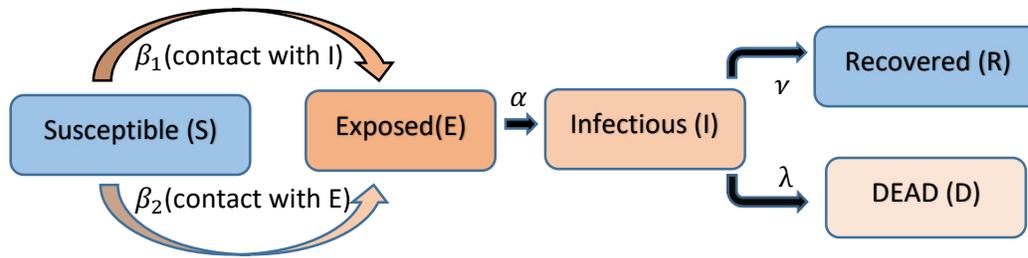


Figure 2 Digram of SEIRD model

The main features and assumptions are made in constructing the SEIRD model is as follows.

Features:

- Contact between exposed and susceptible individual is considered.
- Dead due to COVID-19 is added as a new class.
- Reproduction number is derived using two infeted parameters β_1 and β_2
- β_1 , β_2 , γ and λ are considered as dynamic.

Assumtions

- Birth and natural death (excluding death due to COVID19) during the epidemic are not considered.
- The external influence, i.e., weather, herd immunity, vaccination on the outbreak, is not considered in this paper.
- During the forecast, mobility, behavior and social distancing is considered to evolve in the same manner as it from March 08 to April 30, 2020.

Parameter Estimation

The parameter estimation is the most crucial part of SEIRD model. Optimum estimation of the parameters enables the model to describe the epidemic spread and severity accurately. To estimate the parameters, we use publicly available reported data from March 8 to April 30, 2020. The transmission rate β_1 , β_2 depends on government actions such as lockdown, shutdown, social distances, migration etc., which changes considerably during the pandemic. Considering the β_1 and β_2 as constant, thus, questions the accuracy of the model. Other parameters $\gamma(t)$ and $\lambda(t)$ are considered constant as factors they depend on such as the immunity of the population, health facilities, and management of the country.

We inserted the reported values of $I(t)$, $E(t)$, $C(t)$ and $D(t)$ into the SEIRD model and carry out regressional analysis to determine the best fitted value for $\beta_1(t)$, $\gamma(t)$, and $\lambda(t)$. Here, we use the robust linear regression method to determine the dynamic $\beta_1(t)$, and the coarse Gaussian method for estimating $\gamma(t)$ and $\lambda(t)$.

Numerical Technique

Once the transmission parameters are estimated, they are used to calculate the infection, cure, and death rate through an iteration technique explained below.

Considering $\dot{X}(t) = \frac{dX(t)}{dt}$ Equation (1-5) can be rewritten in a matrix form as follows

$$\begin{bmatrix} \dot{S} \\ \dot{E} \\ \dot{I} \\ \dot{R} \\ \dot{D} \end{bmatrix} = \begin{bmatrix} -\frac{1}{N}IS & -\frac{1}{N}ES & 0 & 0 & 0 \\ \frac{1}{N}IS & \frac{1}{N}ES & -E & 0 & 0 \\ 0 & 0 & E & -I & -I \\ 0 & 0 & 0 & I & 0 \\ 0 & 0 & 0 & 0 & I \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \alpha \\ \gamma \\ \lambda \end{bmatrix}, \quad (6)$$

which can be further written in a simple form

$$\dot{X}(t) = A(t) \times \theta(t) \quad (7)$$

where, $\dot{X} = [\dot{S} \ \dot{E} \ \dot{I} \ \dot{C} \ \dot{D}]^T$, $\theta = [\beta_1(t) \ \beta_2(t) \ \alpha \ \gamma \ \lambda]^T$.

Discretizing the time variable as $t = n \Delta t$ we derived the following form of $\dot{X}(t)$ using Euler's Forward Difference Scheme.

$$X(t+1) = \Delta t \dot{X} + X(t) \quad (8)$$

where, $X(t) = [S(t) \ E(t) \ I(t) \ C(t) \ D(t)]^T$ and Δt is the time step, and n is a natural number. Combining Equation (7) and Equation (8) we used

$$X(t+1) = \Delta t [A(t) \times \theta(t)] + X(t) \quad (9)$$

The values of infection, cure, and death rate were calculated using the equation (9) through number iterations.

Basic Reproduction Number

Basic reproduction number, R_0 defines the number of secondary cases produced by one infected individual. It is an important metric to know that either the disease is going to be an epidemic or not. We used the next-generating matrix to calculate the reproduction number which is explained below-

Consider $X_1(E, I)$ be the group of infective and infectious and $X_2(S, R, D)$ be the group of susceptible, recoverd and death.

Let $f(X_1, X_2)$ and $v(X_1, X_2)$ are the vectors of new infection parameters and other parameters respectively. Assuming $N \approx S$ then,

$$f(X, Y) = \begin{Bmatrix} \beta_1 I + \beta_2 E \\ 0 \end{Bmatrix} \text{ and } v(X, Y) = \begin{Bmatrix} \alpha E \\ -\alpha E + \gamma + \lambda \end{Bmatrix}$$

$$F = \frac{df}{dX} = \begin{bmatrix} \beta_2 & \beta_1 \\ 0 & 0 \end{bmatrix} \text{ and } V = \frac{dv}{dX} = \begin{bmatrix} \alpha & 0 \\ -\alpha & \gamma + \lambda \end{bmatrix}$$

$$FV^{-1} = \begin{bmatrix} \beta_2 & \beta_1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \frac{1}{\alpha} & 0 \\ \frac{1}{\gamma + \lambda} & \frac{1}{\gamma + \lambda} \end{bmatrix} = \begin{bmatrix} \frac{\beta_2}{\alpha} + \frac{\beta_1}{\gamma + \lambda} & \frac{\beta_1}{\gamma + \lambda} \\ 0 & 0 \end{bmatrix}$$

The maximum eigenvalue of FV^{-1} is $R_0 = \frac{\beta_2}{\alpha} + \frac{\beta_1}{\gamma + \lambda}$

Hence the expression of R_0 is $\frac{\beta_2}{\alpha} + \frac{\beta_1}{\gamma + \lambda}$.

When $R_0 < 1$, there is no chance to be an epidemic. However, when $R_0 > 1$, the disease will spread exponentially, and an epidemic occurs.

Results and Discussions

Initially, COVID-19 tests facilities were only in Dhaka. Later, many test labs have been established in other cities. The Figure 2 depicts that number of tests is increasing. From those tests average corona positive is 12% (lowest 4% and highest 15%). The health authority announces the reported data everyday and upload them in the website. Before May 03, they reported the recovery rate without following any guideline. As a result, recovered individuals on May 03 is suddenly increased (Figure 4). Recovery data are adjusted as shown in Figure 4. The adjusted data is used in the simulation.

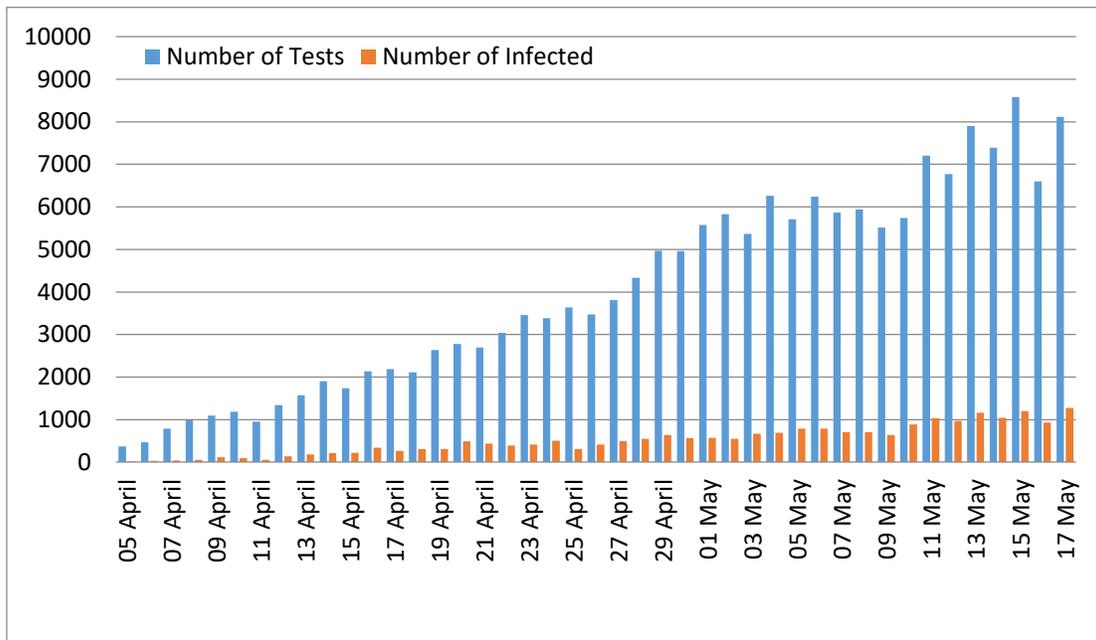


Figure 3 : Comparison of Daily Number of Tests and Infected Cases

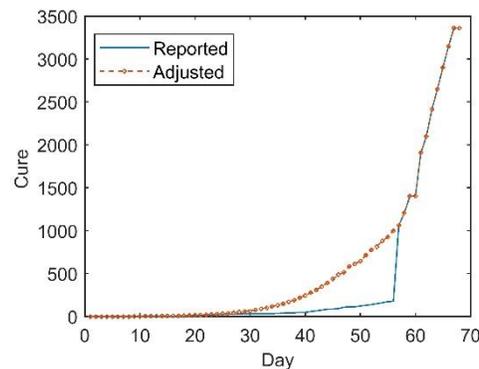


Figure 4 Adjusted Recovery Data

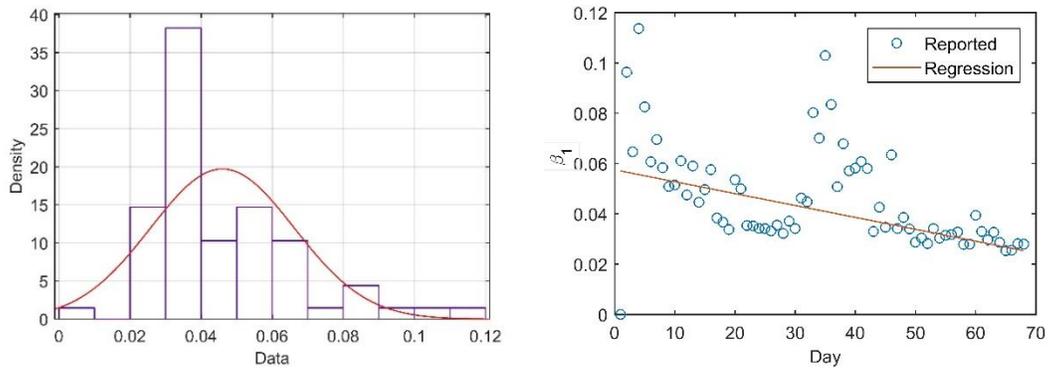


Figure 5 Distribution curve of transmission rate β_1 (left) and regression of transmission rate β_1

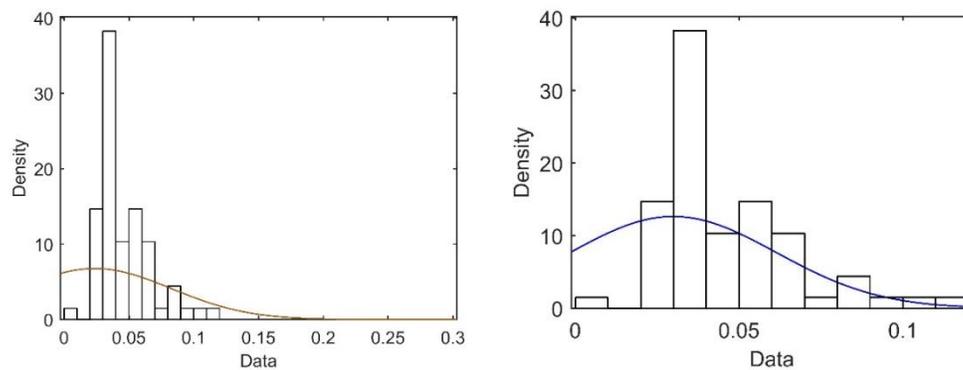


Figure 6 Distribution curve of death rate (left) and recovery rate γ (right)

Estimated Parameters

The best fitted value of parameters used in the SEIRD model are listed in Table-2. While other initial values used in the model are shown in Table 1. The pandemic started in Bangladesh with three infected, no cured, and no death individual. The initially exposed people is assumed as 10 using the information of the reported number of individual in contact with the initial infected individuals. The probability distribution of the transmission parameters are presented in Figure 5 and Figure 6. Instead of constant values, time dependent values of those parameters are used in the model to predict the growth of infection. All the parameters were estimated using the reported and the model. The recovery rate is lower than that of other countries for a particular time. For example, recovery rate China and Italy are respectively 0.035 and 0.023 (16). The lower recovery rate indicates the hospital facilities available in the country.

Growth of Infection

We found that the available data for the number of patients who are actively infected fit into an exponential trend as reported in Figure-7. Similar trend we found for the recovered and death cases as shown in Figure 8 and Figure 9.

Prediction of Transmission

Using the estimated values of the parameters β_1 , γ and λ , we again predicted the transmission potentials through simulations until 100 days from March 08. The results of the simulations with the reported data are given in Figure 7, 8 and 9. Solid lines depicted the simulation using SEIRD model, and dashed lines illustrate the corresponding lower and upper bounds as computed at the limits of the 95% confidence interval. The forecasted scenario of the outbreak shown in the same figures (right), is characterized by high

uncertainty. In particular, simulation result in an expected number of around 37,500 active infected cases but with a high variation: the lower bound is at about 15,000 infected cases while the upper bound is at 94,000 cases. Similarly, for the recovered population, the simulation results in an expected number of 20,500, while the lower and upper bounds are at 9,200 and 42,000, respectively. Finally, regarding the deaths, simulations result in an average number of 3,350, with lower and upper bounds, 1,500 and 7,400, respectively. Figure 9 illustrates the results of fitting the (numerical) solution of Equation 1 simultaneously to the data for the five populations, ie. $S(t)$, $E(t)$, $I(t)$, $R(t)$ and $D(t)$.

Table 1 The values of parameters used in the SEICD model

Parameters	Description	Value	Reference/Method
N	Total population of the country	1.6×10^8	
S(0)	Initial Susceptible	N-13	
I(0)	Initial Infected	3	IEDCR
E(0)	Initial Exposed	10	IEDCR
C(0)	Initial Cured	0	IEDCR
D(0)	Initial Death	0	IEDCR
β_1	Primary Transmission	0.045^*	Kinematic
β_2	Secondary Transmission	$5 \beta_1$	Jnnuyu et. al
α	Infection rate from exposed	1/7	Jnnuyu et. al
γ	Recovery Rate	0.03^*	Kinematic
λ	Death Rate	0.01^*	Kinematic

*average

Table 2 Statistical Values of β_1 , γ and λ

Method		β_1	γ	λ
Boxplot	Median	0.034	0.022	0.0011
	Interquartile Range	0.028-0.046	0.0075-0.073	0-0.014
	Range	0.025-0.07	0 - 0.115	0 - 0.016
Distribution Fitting	Distribution	Normal	Normal	Normal
	Mean:	0.046	0.030	0.011
	Variance:	0.00041	0.001	0.0005
	95% CI	0.036-0.051	0.01-0.04	0.0024-0.02

The Basic Reproduction Number

The reproduction number is the number of individuals infected by a single infectious patient. This parameter is a vital metric to represent the growth of the epidemic as it associated with the reproduction power of the disease. Ying Liu et.al (17) showed that the basic reproduction number of COVID-19 was 3.28 using the reported data in Wuhan City, China. Another systematic review paper (18) reported that the mean of 29 reported values of basic reproduction number from 21 studies was estimated at 3.32 (2.81-3.82), with a range of 1.9 to 6.49; all the included studies were from China. In a statement on 23 January, 2020 about the outbreak of COVID-19 the World Health Organization (WHO) gave a preliminary R_0 estimate of 1.4–2.5.

For the case of Bangladesh, initially, this value was around 4.5, which lead to an outbreak. The Figure 11 represents the change of basic reproduction number based on the kinematic parameters used in the SEIRD model. There is a clear sign of the reduction of interaction between infected or exposed individuals to the

susceptible population as a result of lockdown and other governmental actions, social awareness etc. As of May 15, it is 2.25, and we are expecting this value around 2 by May 31. If the lockdown is relaxed and people do not maintain the physical distance, the reproduction number might start to increase. As the epidemic will continue to grow exponentially unless the number goes below 1, and eventually, the disease dies out.

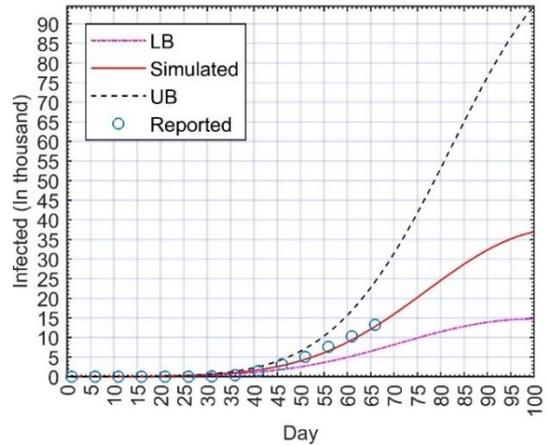
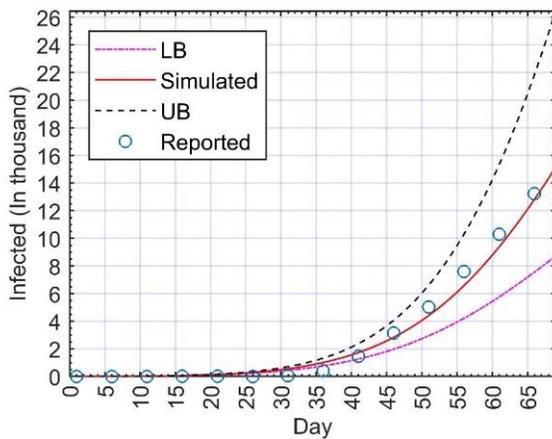


Figure 7 Cumulative active infectious until May 15 (left) and prediction (right)
(circle: reported data, solid line: simulated data using SEIRD, dotted lines: upper bounds and lower bounds)

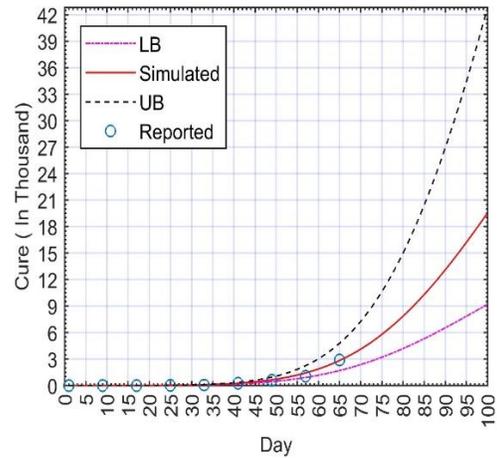
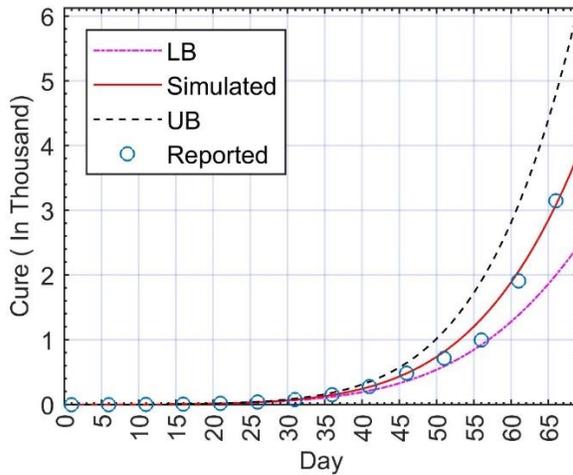


Figure 8 Cumulative number of recovered until May 15 (left) and prediction (right)
(circle: reported data, solid line: simulated data using SEIRD, dotted lines: upper bounds and lower bounds)

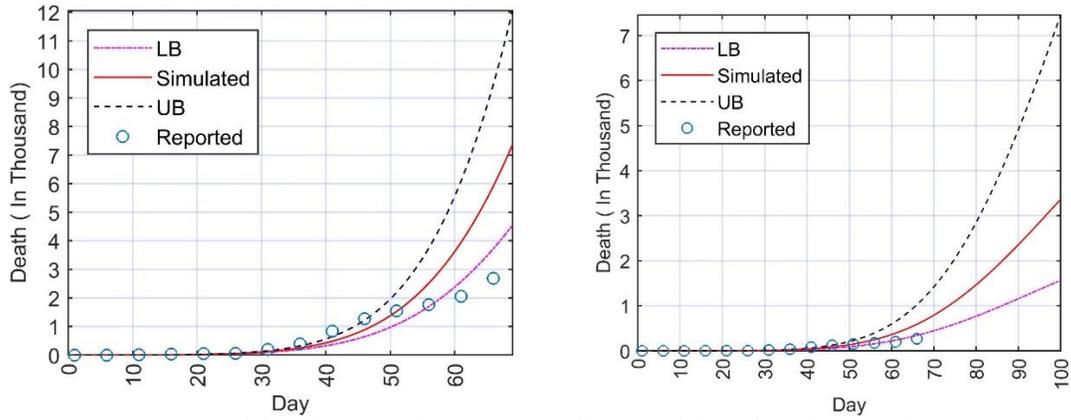


Figure 9 Cumulative number of death until May 15 (left) and prediction (right) (circle: reported data, solid line: simulated data using SEIRD, dotted lines: upper bounds and lower bounds)

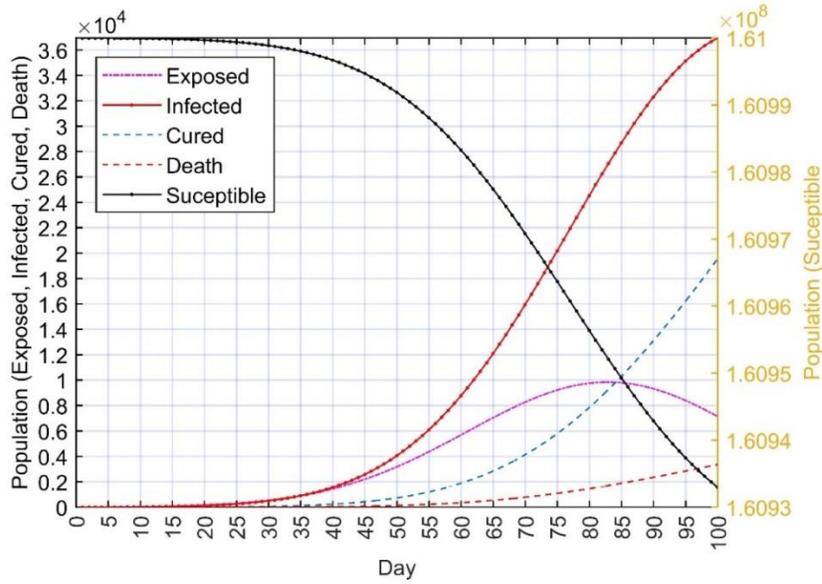


Figure 10 Prediction curve of Susceptible, exposed, infected, cured and death

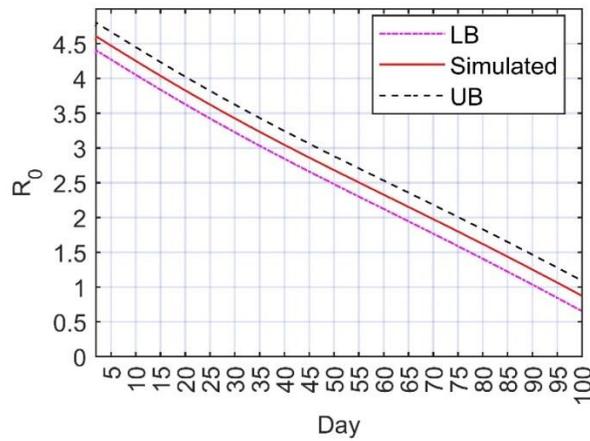


Figure 11 Reproduction number variation over days

We present the above predictions to prepare the people—those who bear the greatest responsibility for national health systems and the government, as well as local health authorities—for what is predicted to happen in the days and weeks to come. They can then implement measures regarding staff resources and hospital beds to meet the challenges of this difficult time. Official numbers of infected people during the COVID-19 virus outbreak in Bangladesh are indicative of the spread of the infection, and of the challenges that will be posed to Bangladeshi hospitals and, in particular, intensive care facilities in the rural area. The present outcome suggests that the government should take careful action to maintain social distances instead of relaxing it.

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Conflict of Interests

The authors declare no conflicts of interests.

Conclusion

In this study, we focused on the transmission potentials of COVID-19 in Bangladesh. We quantitatively described the current transmission conditions in Bangladesh through a simulation approach. Official numbers of infected people during the COVID-19 virus outbreak in Bangladesh are indicative of the spread of the infection. The outcome of this study suggests rethinking the reopening of shopping malls, industries, institutions etc. and maintain the social distances strictly a few more weeks to prevent the spread of infection further. The proposed approach has the potential to monitor disease transmission rates and predict disease case numbers in future situations. Health authorities might assimilate this analysis into their disease prevention and control decision-making process.

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Figures

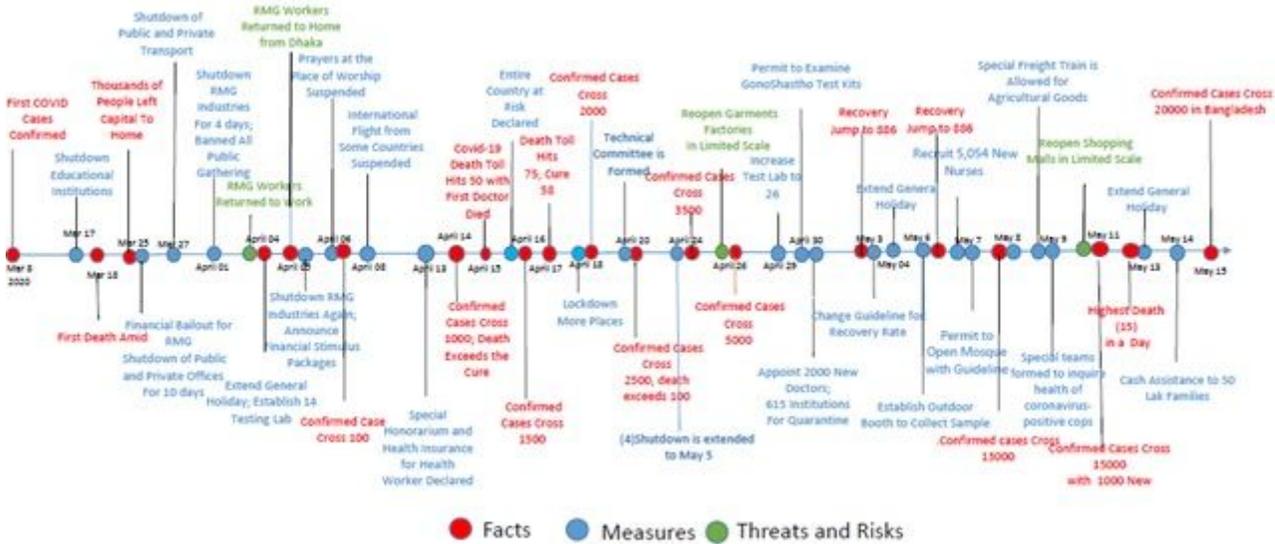


Figure 1

Timeline of Facts of COVID-19 and Control Measures Implemented in Bangladesh

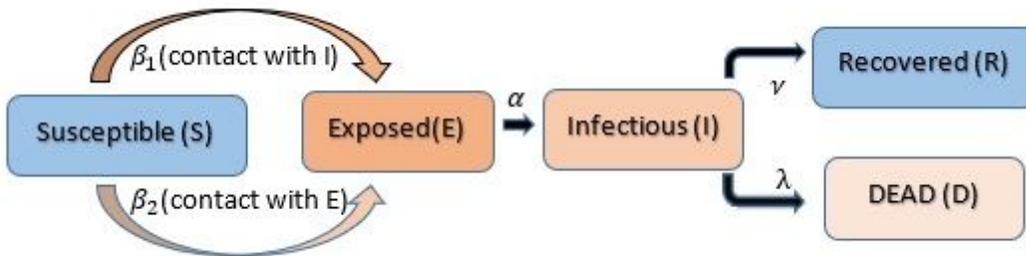


Figure 2

Diagram of SEIRD model

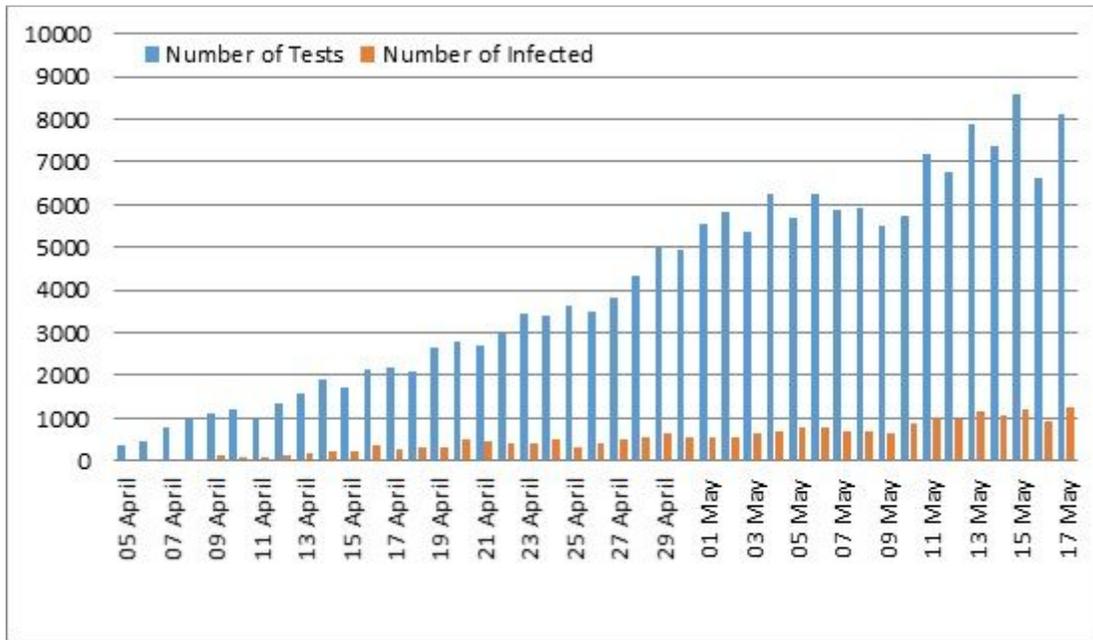


Figure 3

Comparison of Daily Number of Tests and Infected Cases

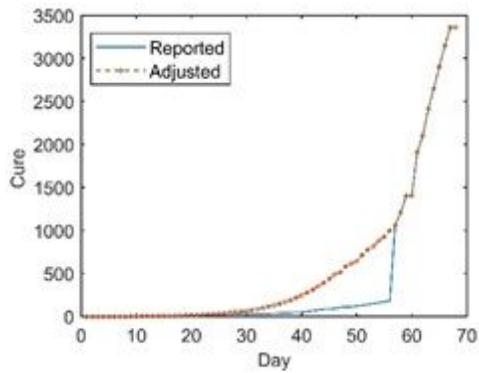


Figure 4

Adjusted Recovery Data

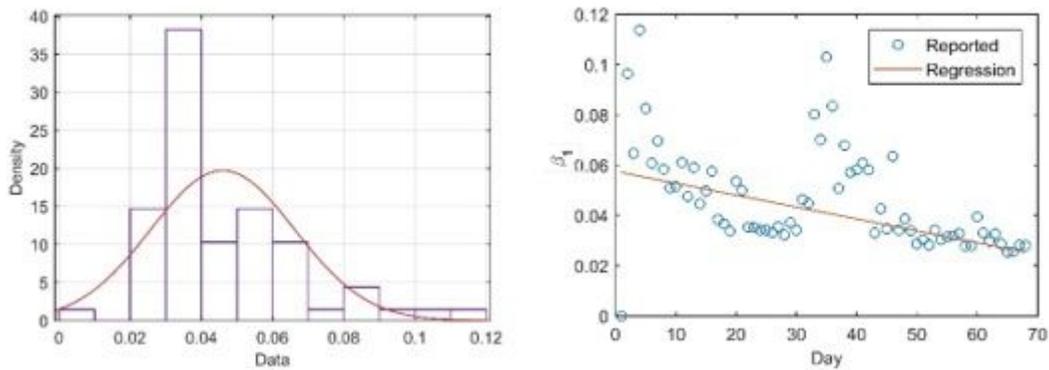


Figure 5

Distribution curve of transmission rate β_1 (left) and regression of transmission rate β_1

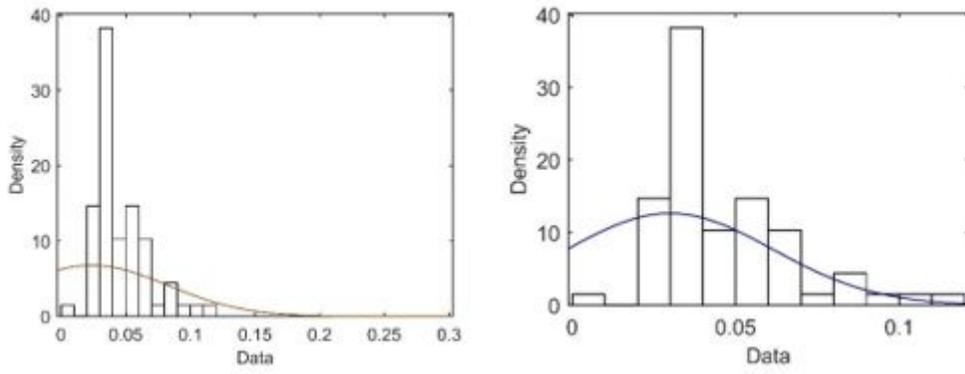


Figure 6

Distribution curve of death rate (left) and recovery rate γ (right)

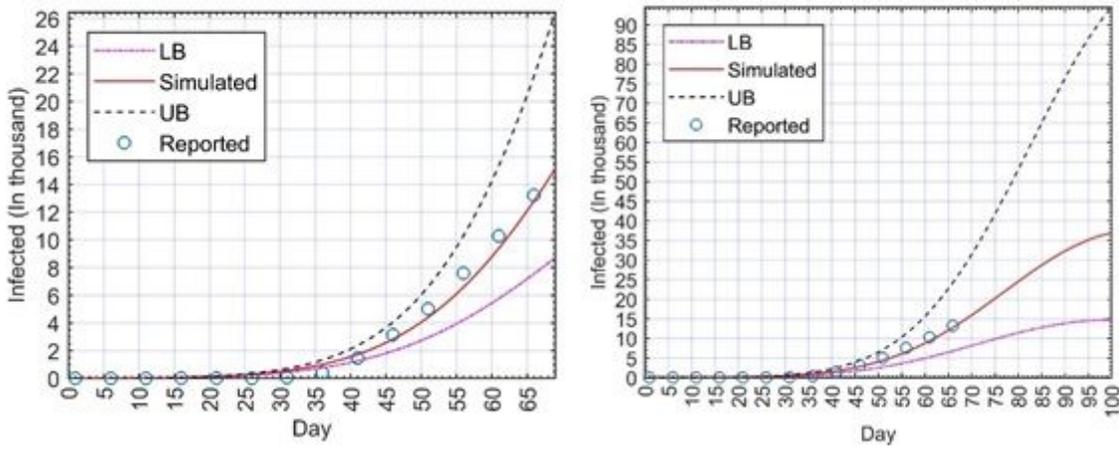


Figure 7

7 Cumulative active infectious until May 15 (left) and prediction (right) (circle: reported data, solid line: simulated data using SEIRD, dotted lines: upper bounds and lower bounds)

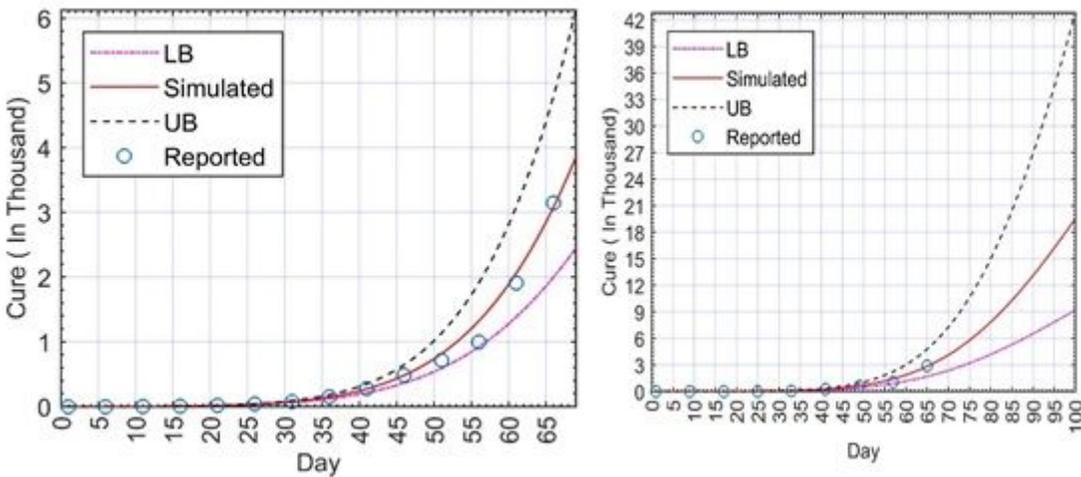


Figure 8

Cumulative number of recovered until May 15 (left) and prediction (right) (circle: reported data, solid line: simulated data using SEIRD, dotted lines: upper bounds and lower bounds)

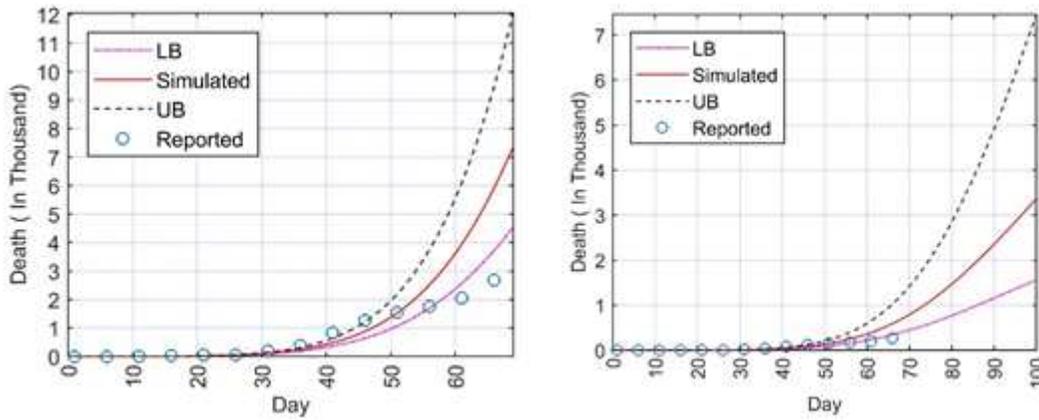


Figure 9

9 Cumulative number of death until May 15 (left) and prediction (right) (circle: reported data, solid line: simulated data using SEIRD, dotted lines: upper bounds and lower bounds)

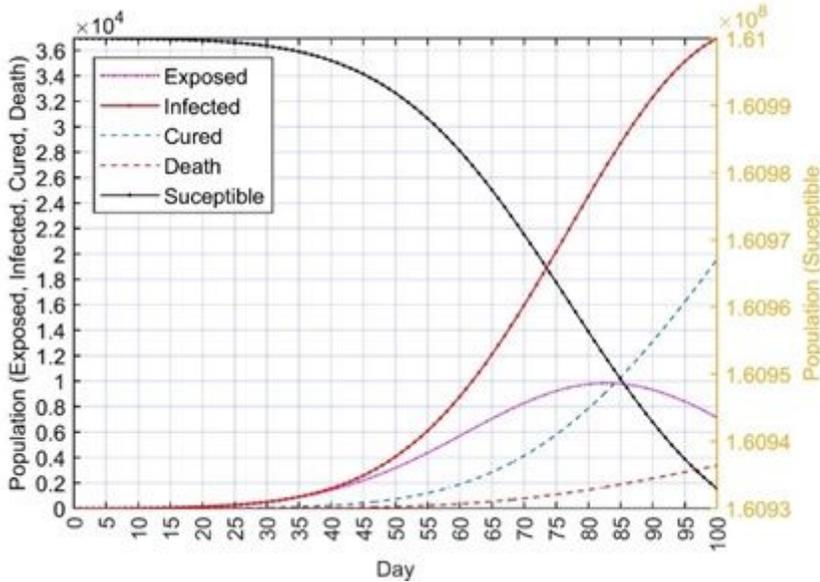


Figure 10

Prediction curve of Susceptible, exposed, infected, cured and death

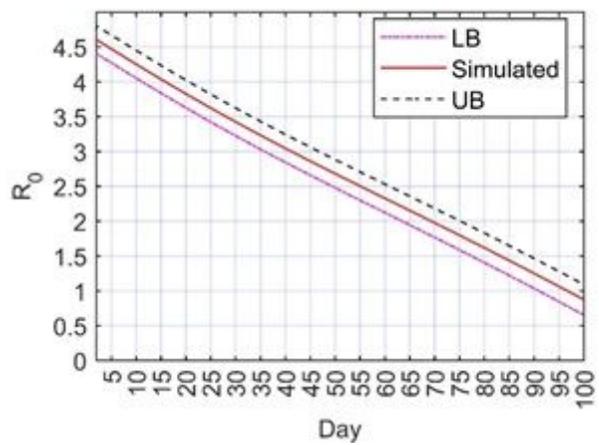


Figure 11

Reproduction number variation over days