Clinical Epidemiology and Global Health 9 (2021) 26–33

Contents lists available at ScienceDirect

Clinical Epidemiology and Global Health

journal homepage: www.elsevier.com/locate/cegh

# Forecasting COVID-19 epidemic in India and high incidence states using SIR and logistic growth models

B. Malavika [a], S. Marimuthu [a], Melvin Joy [a], Ambily Nadaraj [a], Edwin Sam Asirvatham [b], L. Jeyaseelan [c,*]

[a] Associate Research Officer, Department of Biostatistics, Christian Medical College, Vellore, Tamil Nadu, 632 002, India
[b] Technical Adviser (Health Systems and Policy), Health Systems Research India Initiative (HSRII), Trivandrum, India
[c] Professor, Department of Biostatistics, Christian Medical College, Vellore, Tamil Nadu, 632 002, India

ARTICLE INFO

*Keywords:*
COVID-19
Logistic growth model
SIR model
Time interrupted regression model
Projection

ABSTRACT

*Background:* Ever since the Coronavirus disease (COVID-19) outbreak emerged in China, there has been several attempts to predict the epidemic across the world with varying degrees of accuracy and reliability. This paper aims to carry out a short-term projection of new cases; forecast the maximum number of active cases for India and selected high-incidence states; and evaluate the impact of three weeks lock down period using different models.
*Methods:* We used Logistic growth curve model for short term prediction; SIR models to forecast the maximum number of active cases and peak time; and Time Interrupted Regression model to evaluate the impact of lockdown and other interventions.
*Results:* The predicted cumulative number of cases for India was 58,912 (95% CI: 57,960, 59,853) by May 08, 2020 and the observed number of cases was 59,695. The model predicts a cumulative number of 1,02,974 (95% CI: 1,01,987, 1,03,904) cases by May 22, 2020. As per SIR model, the maximum number of active cases is projected to be 57,449 on May 18, 2020. The time interrupted regression model indicates a decrease of about 149 daily new cases after the lock down period, which is statistically not significant.
*Conclusion:* The Logistic growth curve model predicts accurately the short-term scenario for India and high incidence states. The prediction through SIR model may be used for planning and prepare the health systems. The study also suggests that there is no evidence to conclude that there is a positive impact of lockdown in terms of reduction in new cases.

## 1. Background

Ever since a series of pneumonia cases of unknown cause emerged in Wuhan, China in December 2019 that was later confirmed and named as corona virus disease 2019 (COVID-19), it quickly spread around the planet within less than three months, infecting around 4.1 million cases and killing around 2,83,000 as of May 11, 2020.[1–3] Countries have taken extreme steps such as total lock down to partial lock down coupled with social distancing, quarantine, and isolation that prevent human movement which could reduce the transmission.[4,5] India reported its first case of COVID-19 on January 30, 2020 which rose to 100th cases on March 14, 2020 and thereafter, the reported cases have increased steadily to reach around 70,000 cases, with 22,500 recoveries and 2300 deaths reported across the country as of May 11, 2020.[6]

Since the beginning of the COVID-19 epidemic, there has been several mathematical and statistical modelling that have predicted the global and national epidemic with varying degrees of accuracy and reliability.[7,8] The accuracy of prediction and its uncertainty depend on the assumptions, availability and quality of data.[9] The results can vary significantly if there is difference in the assumptions, and values of input parameters. During a pandemic like COVID-19, the availability and quality of data keep improving as the epidemic progress, which make predictions uncertain in the early stages and expected to improve in the later stages. Moreover, an epidemic may not always behave in the same manner as pathogens are likely to behave differently over time.[10]

In terms of COVID-19, different models are used to estimate the key

* Corresponding author. Professor, Department of Biostatistics, Christian Medical College, Vellore, Tamil Nadu, 632 002, India.
*E-mail addresses:* malavikababu@gmail.com (B. Malavika), marimuthu8421@gmail.com (S. Marimuthu), melvinmj94@gmail.com (M. Joy), ambilyn90@gmail.com (A. Nadaraj), aedwinsam@yahoo.com (E.S. Asirvatham), ljey@hotmail.com, prof.ljey@gmail.com (L. Jeyaseelan).

https://doi.org/10.1016/j.cegh.2020.06.006
Received 13 May 2020; Received in revised form 2 June 2020; Accepted 22 June 2020
Available online 27 June 2020

features of the disease such as the incubation period, transmissibility, asymptomaticity, severity, and the likely impact of different public health interventions. Among the models, Susceptible, Exposed, Infection and Recover (SEIR), Susceptible, Infection and Recover (SIR) models, Agent-based models and Curve-fitting, Logistic growth models due to the exponential nature of growth of the epidemic or extrapolation models, are commonly adopted using different biological and social processes.[7,11–16] Especially, the logistic growth curve model could be relevant for short term projection while SIR models could be useful to estimate the maximum number of active cases and the peak time of attaining it. Though the SIR model is used widely in COVID-19, there is not much information about how the SIR model performed in China and other countries where the pandemic is stabilizing or indicating a declining trajectory. Therefore, it is essential to validate the SIR model using the reported data from different countries and evolve a correction factor that is in relation to the maximum number of active cases to total number of cases reported. Few researchers have used the exponential growth model to predict the number of Cumulative cases. But, these models do not have upper bound and therefore does not get stabilised, rather likely to go on increasing.[17] In this scenario, the logistic growth models are better preferred option. Choudhary (2020) has predicted the estimated cases very early till April 7, 2020, using time series models.[18] However, it was found to be a gross underestimation. In spite of the limitations, considering the unprecedented nature of the pandemic, uncertainties about the disease and the need for urgent but appropriate social, economic and public health responses; accurate forecasting of the size, severity and duration of the epidemic is critical to inform policies, programme and strategies.

This paper aims to carry out short-term projection of new cases using the logistic growth curve model; forecast the maximum number of active cases for India and selected high-burden states using the SIR model with correction factor based on China, Italy and South Korea; and evaluate the impact of lockdown and other interventions on the incidence of daily cases.

## 2. Methods

### 2.1. Modified logistic growth model

Logistic Growth is characterized by an increasing growth in the beginning, but a decreasing growth at a later stage, as it approaches the maximum. In COVID-19, the maximum limit will be the total population and the growth will necessarily come down when a greater proportion of the population is sick. The reason for using logistic growth for modelling the Coronavirus outbreak is based on the evidence that the epidemic follows an exponential growth in the early stages and expected to come down during the later stages of the epidemic. The modified logistic growth model[19,20] is presented as follows,

$$y(t) = \frac{C}{1 + a^* e^{-bt}}$$

Where.

y(t) is the number of cases at any given time t.

C is the limiting value, the maximum capacity for y. a = $(C/y_0)$–1. b is the rate of change.

- the number of cases at the beginning, also called *initial value* is: *C/(1+a)*
- the maximum growth rate is at t = *ln(a)*/b

When y is equal to C (that is, the population is at maximum size), y/C will be 1. Therefore, the (1- (y/C)) will be 0 and hence the growth will be 0. The optimum values of the parameters can be obtained by Non-linear least square method. The future prediction of covid-19 cases was done by Time series prophet model.[21]

### 2.2. Susceptible, Infected and Recovered (SIR) Model

SIR model is a compartmental model in which individuals are separated into compartments based on their infectious status and track the corresponding population sizes through time. The model divides the population into three compartments that are Susceptible (S), Infectious (I) and Recovered (R). Susceptible is the group of people who are vulnerable to exposure with infectious people. Infected are those with the disease and can transmit it to the susceptible. Recovered are those who recovered from the disease, developed immunity and not susceptible to the same illness anymore.[22,23]

β is a transmission parameter, which is the average number of individuals that one infected individual will infect per time unit. It is determined by the chance of contact and the probability of disease transmission. γ is the rate of recovery in a specific period.

D, the average time period during which an infected individual remains infectious which is derived from γ. $D = \frac{1}{\gamma}$.

The ratio $R0 = \frac{\beta}{\gamma}$, is the basic reproduction number. R is the average number of people infected by an infected individual over the disease infectivity period, in a totally susceptible population.

$$\frac{dS}{dt} = -\beta IS$$

$$\frac{dI}{dt} = \beta IS - \gamma I$$

$$\frac{dR}{dt} = \gamma I$$

In order to fit a SIR model, the parameters *β and γ* were obtained by minimizing the residual sum of squares between the observed active cases and the predicted active cases. We have fixed R0 and *D* as 2.5 and 7 days respectively.[24,25] Therefore, *γ* is 0.14 and the *β* is 0.36. The data for India was taken from the crowd sourced database available on https://www.covid19india.org and the other countries data were taken from https://www.kaggle.com/sudalairajkumar/novel-corona-virus-2019-dataset. We used R software to estimate these parameters. In order to estimate the parameters in the logistic growth model, we used Python code in Google Colaboratory (Colab) platform.

#### 2.2.1. Estimation of correction factor

Invariably, the SIR model overestimates the active number of cases. In order to compute the overestimation, the actual number of reported cases from China was obtained up to April 5, 2020 and used to estimate the maximum number of active cases in China. Subsequently, the ratio of maximum (peak) active cases projected by the model to the observed peak active cases was computed. The similar estimation was done for Italy and South Korea as well. In order to choose the best correction factor that is appropriate for India, we compared the age and gender distribution of population of these three countries with the age and gender distribution of population in India. China correction factor was applied to states such as Maharashtra, Rajasthan and Tamil Nadu. As the population size in Delhi is small which is about four to five times lower than the other states, SIR model was not done for Delhi. Data that were used in the modelling is presented in appendix.

### 2.3. Time interrupted regression analysis

Time interrupted regression analysis[26] was done to assess the impact of 3 weeks' lockdown on the incidence of new cases. Dummy variable was introduced at April 15, 2020. The hypothesis was that there will be a decline in the incidence of new cases after the lock down period, that is after April 14, 2020. That is, the regression coefficient will be significant and negative in direction. As there were only 3 cases reported from Jan 03 to March 01, 2020, we excluded these time points from the analysis.

## 3. Results

Table 1 presents the predicted cumulative number of cases with 95% CI for India and states such as Maharashtra, Tamil Nadu, Delhi and Rajasthan. The predicted cumulative number of cases in India was 58,912 (95% CI: 57,960, 59,853) by May 08, 2020 and the observed number of cases was 59,695. The predicted cumulative number of cases for Maharashtra was 18,857 and the observed number was 19,063. Similarly, the predicted cases for Tamil Nadu, Delhi and Rajasthan were 5,288, 6080 and 3634 respectively. According to the model, the expected number of cases in India by May 22, 2020 is 1,02,974 (95% CI: 1,01,987, 1,03,904). The predicted cases in Maharashtra, Tamil Nadu, Delhi and Rajasthan are 32,872, 15,258 10,332 and 4783 respectively. The diagrammatic representation of Table 1 is presented in Fig. 1a & 1b.

### 3.1. Goodness of fit statistics

Table 2 presents the goodness of fit statistics such as R,[2] AIC, BIC and MSE for India and the states that are studied. The $R^2$ statistic was 0.997 for India, suggesting that could be the best model. There is less scope for improvement as the unexplained variability is only 0.03%. The range of $R^2$ ranged from 0.958 to 0.999, implying that these are very good fit.

Based on the analysis of data from China, the ratio between the maximum number of active cases (as of April 5, 60,005) to the observed maximum number of active cases by SIR model was 5851. Similarly, the ratio between maximum numbers of active cases to the observed maximum number of active cases in Italy was 138; and for South Korea, the ratio was 1635. As the age and gender distribution of population of China are matching with Indian scenario, we choose the best possible correction factor of China.

Table 3 presents the estimates of maximum number of active cases and the time at which it could occur for India and other states from SIR model. The maximum number of active cases in India is projected to be 57,449 on May 18, 2020, while in Maharashtra, Rajasthan and Tamil Nadu, it will be 5,089, 3324 and 3221 respectively. The corresponding peak time was expected to be June 10, 2020, June 6, 2020 and June 21, 2020 respectively.

### 3.2. Impact of lockdown intervention in daily incidence cases

The diagrammatic representation of the trend is presented in Fig. 2. The results of the interrupted time regression analyses are presented in Table 4. The model indicates a decrease of about 149 daily new cases after April 14, 2020, 3 weeks after the lockdown which is not statistically significant.

## 4. Discussion

There have been several studies forecasting the incident cases of COVID-19 in various countries. However, there are a little peer reviewed articles about India. Forecasting COVID-19 through appropriate models can help us to understand the possible spread across the population so that appropriate measures can be taken to prevent further transmission and prepare the health systems for medical management of the disease. It is also essential to evaluate the effectiveness of interventions so that appropriate and timely programmatic changes can be made to mitigate the epidemic.

We forecasted the number of cumulative cases for India and four other high incidence states using logistic growth model which has projected the cumulative cases very closely to the observed cases. This model is based on the current trends of the cumulative cases in India and specific states. We have used the logistic growth model due to the exponential nature of growth of the epidemic which eventually get stabilised as against pure exponential model.[7,11–15] A study by Ranjan (2020) who used the SIR model projected 13,000 active cases by the end of May 2020. However, the total number of cases had already crossed 20,000 by April 22, 2020, which was a gross underestimation.[27]

The SIR model with correction factor predicted 57,450 cases which will be the maximum number of active cases by May 18, 2020. However, the peak time gets pushed to June in other states. When we performed the SIR model using the reported cases from China, South Korea and Italy, we found that the model predicted more number of active cases than what they observed up to a time point for which the data was analysed. In order to address the overestimation, we formulated a correction factor which is essential to predict the epidemic accurately. Besides, as suggested by Ranjan (2020), the SIR model depends heavily on the population who are susceptible. Therefore, it may overestimate the maximum cases when the epidemic is not generalized in the population. Therefore, this could be considered as a warning signal for preparing the health systems in terms of planning treatment facilities and other interventions.

In COVID-19 epidemic, assessing the effectiveness of lockdown is one

**Table 1**
Projected cumulative number of cases for India and high incidence states.

| Date | India | Maharashtra | Tamil Nadu | Delhi | Rajasthan |
|---|---|---|---|---|---|
| 01-05-2020 | 38686 (37747, 39641) | 11719 (11436, 12002) | 3118 (2721, 3466) | 4077 (3848, 4290) | 2757 (2615, 2902) |
| 02-05-2020 | 41264 (40345, 42264) | 12625 (12347, 12894) | 3246 (2894, 3617) | 4332 (4134, 4551) | 2893 (2756, 3027) |
| 03-05-2020 | 43992 (43032, 45021) | 13544 (13255, 13811) | 3512 (3137, 3874) | 4628 (4434, 4834) | 3027 (2888, 3170) |
| 04-05-2020 | 46842 (45861, 47853) | 14600 (14308, 14894) | 3814 (3416, 4194) | 4924 (4710, 5134) | 3155 (3019, 3300) |
| 05-05-2020 | 49750 (48792, 50705) | 15649 (15355, 15923) | 4141 (3768, 4510) | 5186 (4974, 5395) | 3280 (3133, 3418) |
| 06-05-2020 | 52722 (51793, 53640) | 16687 (16395, 16981) | 4502 (4162, 4899) | 5470 (5260, 5673) | 3404 (3257, 3540) |
| 07-05-2020 | 55784 (54839, 56803) | 17787 (17483, 18072) | 4878 (4521, 5226) | 5767 (5555, 5958) | 3518 (3363, 3660) |
| 08-05-2020 | 58912 (57960, 59853) | 18857 (18563, 19129) | 5288 (4930, 5693) | 6080 (5874, 6292) | 3634 (3502, 3777) |
| 09-05-2020 | 62070 (61037, 63060) | 19953 (19669, 20230) | 5589 (5206, 5927) | 6386 (6164, 6600) | 3751 (3603, 3894) |
| 10-05-2020 | 65316 (64300, 66290) | 21028 (20746, 21296) | 6041 (5692, 6445) | 6725 (6510, 6931) | 3863 (3719, 4011) |
| 11-05-2020 | 68619 (67635, 69616) | 22203 (21925, 22490) | 6542 (6172, 6916) | 7059 (6852, 7267) | 3967 (3827, 4098) |
| 12-05-2020 | 71904 (70911, 72883) | 23331 (23063, 23610) | 7086 (6728, 7469) | 7352 (7142, 7548) | 4065 (3932, 4193) |
| 13-05-2020 | 75175 (74262, 76122) | 24406 (24097, 24661) | 7679 (7323, 8071) | 7659 (7453, 7887) | 4159 (4016, 4308) |
| 14-05-2020 | 78453 (77521, 79401) | 25502 (25238, 25784) | 8306 (7911, 8674) | 7972 (7749, 8174) | 4242 (4102, 4388) |
| 15-05-2020 | 81709 (80683, 82688) | 26526 (26250, 26789) | 8987 (8614, 9320) | 8291 (8075, 8512) | 4325 (4177, 4476) |
| 16-05-2020 | 84906 (83940, 85866) | 27535 (27244, 27804) | 9579 (9186, 9951) | 8596 (8389, 8821) | 4410 (4273, 4542) |
| 17-05-2020 | 88102 (87087, 89047) | 28483 (28192, 28753) | 10344 (9976, 10729) | 8927 (8714, 9139) | 4488 (4345, 4628) |
| 18-05-2020 | 91266 (90297, 92172) | 29495 (29219, 29784) | 11184 (10845, 11564) | 9243 (9023, 9436) | 4557 (4412, 4699) |
| 19-05-2020 | 94326 (93390, 95376) | 30427 (30145, 30708) | 12091 (11710, 12444) | 9511 (9301, 9718) | 4621 (4476, 4755) |
| 20-05-2020 | 97288 (96335, 98269) | 31276 (30999, 31565) | 13076 (12716, 13466) | 9785 (9572, 9984) | 4682 (4542, 4818) |
| 21-05-2020 | 100179 (99207, 101128) | 32120 (31824, 32397) | 14124 (13759, 14494) | 10059 (9868, 10279) | 4732 (4585, 4871) |
| 22-05-2020 | 102974 (101987, 103904) | 32872 (32584, 33148) | 15258 (14881, 15653) | 10332 (10103, 10531) | 4783 (4652, 4929) |

Note: Figures in parenthesis () represent 95% Confidence Intervals for the projected number of cumulative cases.

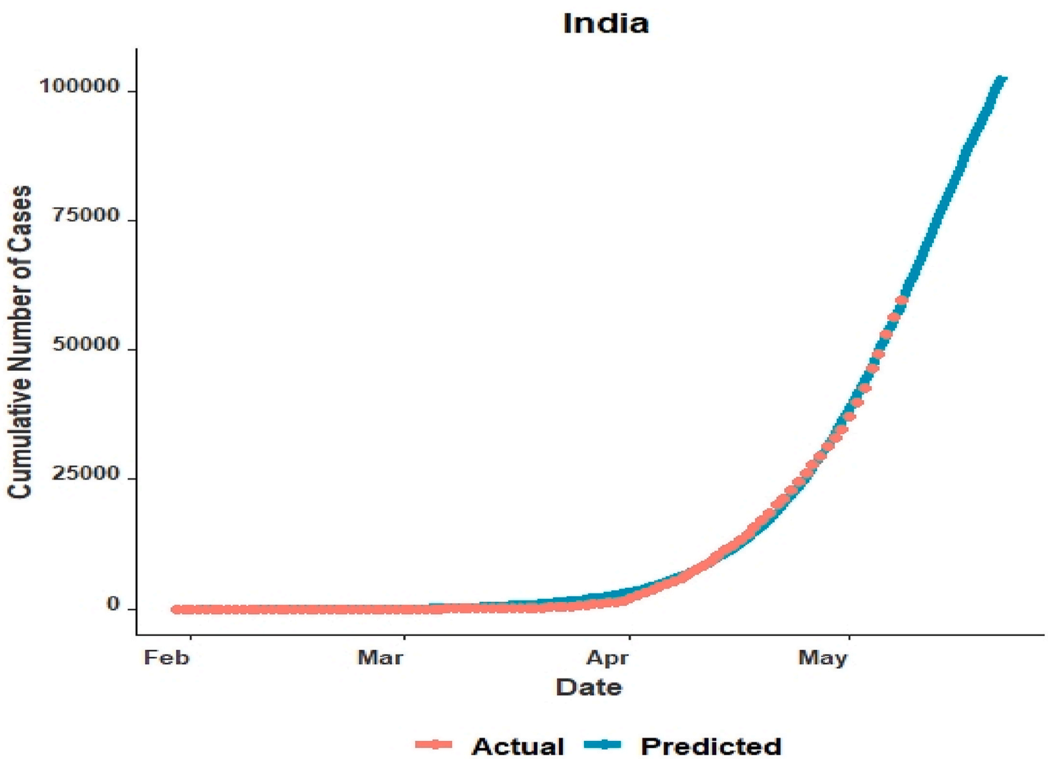


**Fig. 1a.** Cumulative number of predicted and actual COVID-19 cases for India.

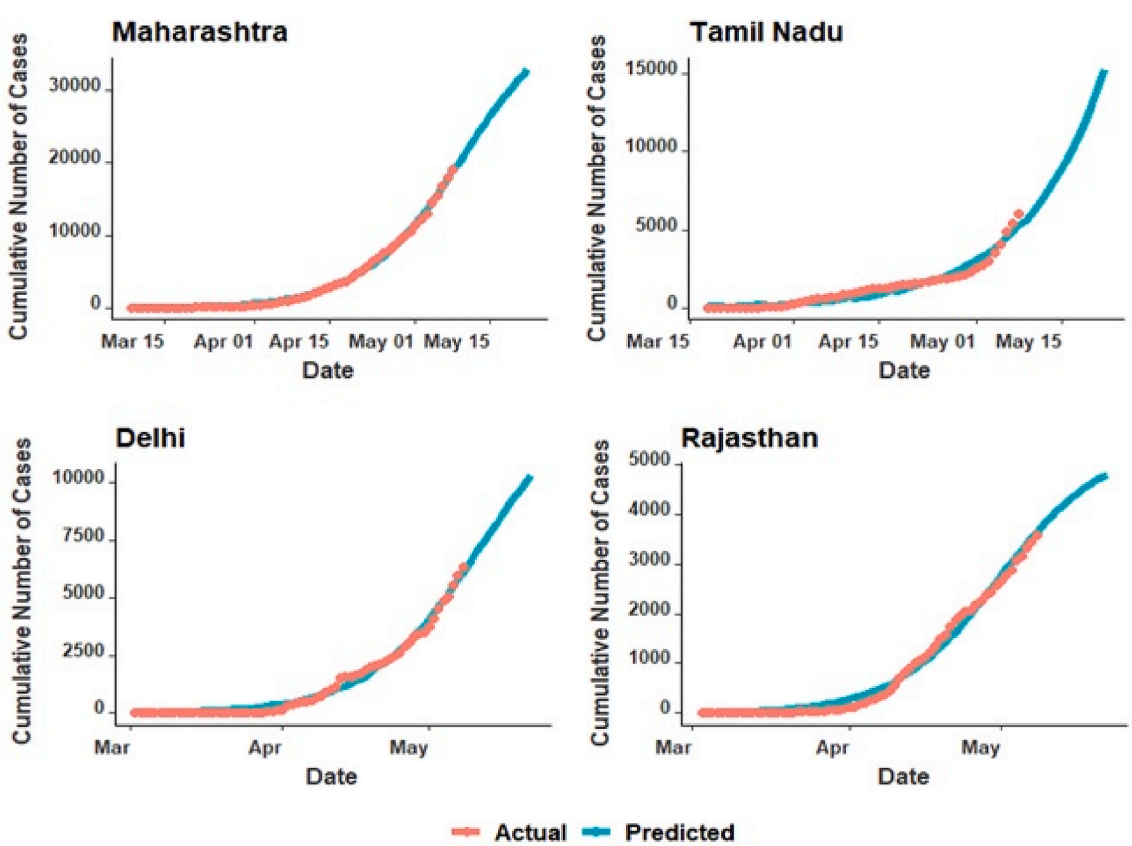


**Fig. 1b.** Cumulative number of predicted and actual COVID-19 cases for high incidence States.

**Table 2**
Goodness of fit criteria for Logistic Growth Model.

| | India | Maharashtra | Rajasthan | Delhi | Tamil Nadu |
|---|---|---|---|---|---|
| R-Squared | 0.997 | 0.998 | 0.990 | 0.991 | 0.958 |
| AIC | 1329.2 | 663.6 | 636.6 | 699.5 | 595.7 |
| BIC | 1337.1 | 669.9 | 643.2 | 706.2 | 601.5 |
| MSE | 575419.8 | 50549.3 | 12803.1 | 28110.1 | 89258.5 |

**Note: AIC -** Akaike Information Criterion; **BIC** – Bayesian Information Criterion; **MSE** - Mean Square Error.

**Table 3**
Projected No. of active cases in peak day adjusted based on 3 Countries data modelling using SIR model.

| State | Projected Population (as on 2020) | Peak Day | Projected Number of Maximum Active Cases Adjusted Based on 3 Countries | | |
|---|---|---|---|---|---|
| | | | China (CF-5851) | South Korea (CF-1635) | Italy (CF-138) |
| India | 1376566797 | 18-May-2020 | 57449 | – | – |
| Maharashtra | 121924973 | 10-Jun-2020 | 5089 | 18215 | 215804 |
| Rajasthan | 79584255 | 6-Jun-2020 | 3324 | 11895 | 140930 |
| Tamil Nadu | 77177540 | 21-Jun-2020 | 3221 | 11528 | 136577 |

Note: CF=Correction Factor.

of the key interest areas. India had a head start in imposing the lockdown relatively early, in addition to strong public health measures to mitigate the spread of the epidemic. It also raises an interesting question whether this lockdown has really impacted the incidence cases. Several studies have assessed the effectiveness of interventions with varying level of results.[28,29] We carried out interrupted time series analyses that suggested no significant decline in the number of daily cases immediately after the lock down. Ironically, there is an increase in the number of daily cases immediately after the 3 weeks of lockdown period. It indicates that the lockdown and other interventions did not have any impact on reducing the number of daily cases after a certain period. This may be due to the fact that the number of tests done over a period of time has increased significantly. However, we need to revise the model every week as and when the data gets accumulated.

**Table 4**
Regression Coefficients, 95% CI and p value of time interrupted regression analysis.

| Variables | Regression Coefficients (95% CI) | p value |
|---|---|---|
| **Days** | 22.8 (17.0, 28.6) | <0.001 |
| **Lock down effect measured** | | |
| April 15, 2020 | −148.3 (−399.9, 103.5) | 0.244 |
| Time | 88.6 (73.1, 104.1) | <0.001 |

Limitations: As in any other projection using models, the limitation is that each model would behave differently, not merely due to differences in underlying assumptions but differences in population density, existing capacity of the health systems, current level of interventions and socio-demographic and economic situation across and within the states and districts. Therefore, district level projections may be required, which would account the variations between the states and within the states. In Covid-19, there has been a higher level of uncertainly about the number of reported confirmed cases due to the issues in varying testing strategies, the proportion of asymptomatic cases and the effective transmission rate. Because of this, we may be missing a significant number of reported confirmed cases which may affect the accuracy of any models.

In conclusion, the short term projection predicts exactly well with the observed number of cases in India and in other states through the logistic growth model. The findings from SIR model may be used for planning the interventions and prepare the health systems for better clinical management of the infected in the country and respective states.

## Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Ethical approval

Not required.

## Declaration of competing interest

Prominence, professional advancement or a successful outcome. CEGH Editors strive to ensure that what is published in the Journal is as balanced, objective and evidence-based as possible. Since it can be difficult to distinguish between an actual conflict of interest and a

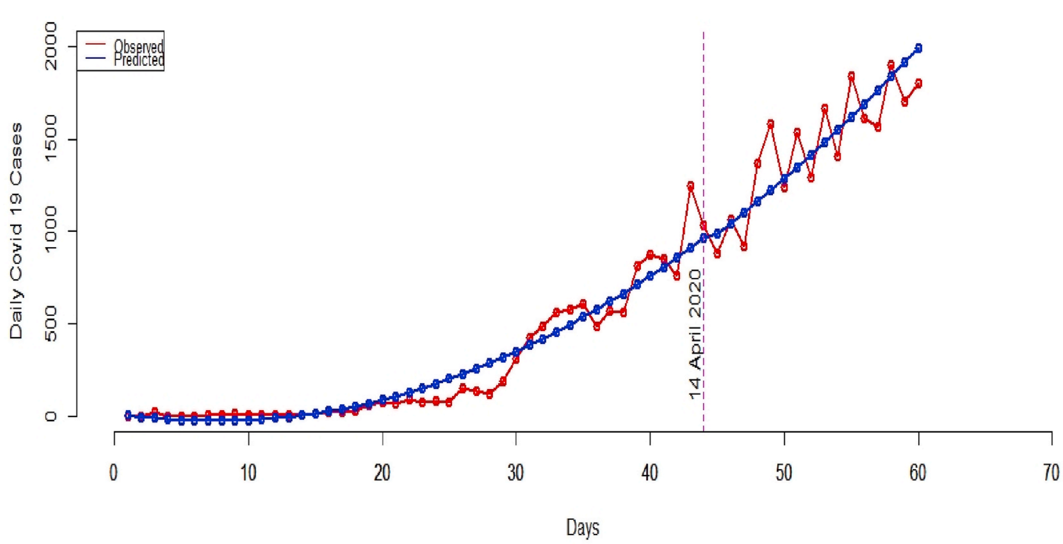


**Fig. 2.** Time interrupted regression model with lock down intervention on April 14, 2020.

perceived conflict of interest, the Journal requires authors to disclose all and any potential conflicts of interest.

Section I.

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in

Testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Section II.

The authors whose names are listed immediately below report the following details of affiliation or involvement in an organization or entity with a financial or non-financial interest in the subject matter or materials discussed in this manuscript. Please specify the nature of the conflict on a separate sheet of paper if the space below is inadequate.

## Appendix. (Data)

Table: Data used for modelling COVID-19 cases of India and high incidence States (till May 08, 2020)

| Days | Date | India | Maharashtra | Tamil Nadu | Delhi | Rajasthan |
|---|---|---|---|---|---|---|
| 1 | 30-Jan-2020 | 1 | | | | |
| 2 | 31-Jan-2020 | 1 | | | | |
| 3 | 01-Feb-2020 | 1 | | | | |
| 4 | 02-Feb-2020 | 2 | | | | |
| 5 | 03-Feb-2020 | 3 | | | | |
| 6 | 04-Feb-2020 | 3 | | | | |
| 7 | 05-Feb-2020 | 3 | | | | |
| 8 | 06-Feb-2020 | 3 | | | | |
| 9 | 07-Feb-2020 | 3 | | | | |
| 10 | 08-Feb-2020 | 3 | | | | |
| 11 | 09-Feb-2020 | 3 | | | | |
| 12 | 10-Feb-2020 | 3 | | | | |
| 13 | 11-Feb-2020 | 3 | | | | |
| 14 | 12-Feb-2020 | 3 | | | | |
| 15 | 13-Feb-2020 | 3 | | | | |
| 16 | 14-Feb-2020 | 3 | | | | |
| 17 | 15-Feb-2020 | 3 | | | | |
| 18 | 16-Feb-2020 | 3 | | | | |
| 19 | 17-Feb-2020 | 3 | | | | |
| 20 | 18-Feb-2020 | 3 | | | | |
| 21 | 19-Feb-2020 | 3 | | | | |
| 22 | 20-Feb-2020 | 3 | | | | |
| 23 | 21-Feb-2020 | 3 | | | | |
| 24 | 22-Feb-2020 | 3 | | | | |
| 25 | 23-Feb-2020 | 3 | | | | |
| 26 | 24-Feb-2020 | 3 | | | | |
| 27 | 25-Feb-2020 | 3 | | | | |
| 28 | 26-Feb-2020 | 3 | | | | |
| 29 | 27-Feb-2020 | 3 | | | | |
| 30 | 28-Feb-2020 | 3 | | | | |
| 31 | 29-Feb-2020 | 3 | | | | |
| 32 | 01-Mar-2020 | 3 | | | | |
| 33 | 02-Mar-2020 | 5 | | | 1 | |
| 34 | 03-Mar-2020 | 6 | | | 1 | 1 |
| 35 | 04-Mar-2020 | 28 | | | 1 | 2 |
| 36 | 05-Mar-2020 | 30 | | | 2 | 2 |
| 37 | 06-Mar-2020 | 31 | | | 3 | 2 |
| 38 | 07-Mar-2020 | 34 | | | 3 | 2 |
| 39 | 08-Mar-2020 | 39 | | | 3 | 2 |
| 40 | 09-Mar-2020 | 48 | 2 | | 4 | 2 |
| 41 | 10-Mar-2020 | 63 | 5 | | 4 | 3 |
| 42 | 11-Mar-2020 | 71 | 11 | | 5 | 3 |
| 43 | 12-Mar-2020 | 81 | 14 | | 6 | 3 |
| 44 | 13-Mar-2020 | 91 | 17 | | 7 | 3 |
| 45 | 14-Mar-2020 | 102 | 26 | | 7 | 4 |
| 46 | 15-Mar-2020 | 112 | 32 | | 7 | 4 |
| 47 | 16-Mar-2020 | 126 | 39 | | 7 | 4 |
| 48 | 17-Mar-2020 | 146 | 41 | | 10 | 4 |
| 49 | 18-Mar-2020 | 171 | 45 | 1 | 11 | 7 |
| 50 | 19-Mar-2020 | 198 | 48 | 2 | 14 | 9 |
| 51 | 20-Mar-2020 | 256 | 52 | 2 | 20 | 17 |
| 52 | 21-Mar-2020 | 334 | 64 | 5 | 27 | 24 |
| 53 | 22-Mar-2020 | 403 | 74 | 8 | 28 | 29 |
| 54 | 23-Mar-2020 | 497 | 89 | 11 | 30 | 32 |
| 55 | 24-Mar-2020 | 571 | 107 | 17 | 30 | 32 |
| 56 | 25-Mar-2020 | 657 | 122 | 25 | 35 | 38 |
| 57 | 26-Mar-2020 | 730 | 125 | 28 | 39 | 43 |
| 58 | 27-Mar-2020 | 883 | 153 | 37 | 40 | 50 |
| 59 | 28-Mar-2020 | 1019 | 181 | 41 | 49 | 54 |
| 60 | 29-Mar-2020 | 1139 | 203 | 49 | 72 | 59 |

(continued on next page)

(*continued*)

| Days | Date | India | Maharashtra | Tamil Nadu | Delhi | Rajasthan |
|---|---|---|---|---|---|---|
| 61 | 30-Mar-2020 | 1326 | 220 | 66 | 97 | 79 |
| 62 | 31-Mar-2020 | 1635 | 302 | 123 | 120 | 93 |
| 63 | 01-Apr-2020 | 2059 | 335 | 233 | 152 | 120 |
| 64 | 02-Apr-2020 | 2545 | 423 | 308 | 293 | 133 |
| 65 | 03-Apr-2020 | 3105 | 487 | 410 | 386 | 179 |
| 66 | 04-Apr-2020 | 3684 | 635 | 484 | 445 | 206 |
| 67 | 05-Apr-2020 | 4293 | 747 | 570 | 503 | 266 |
| 68 | 06-Apr-2020 | 4777 | 868 | 620 | 525 | 301 |
| 69 | 07-Apr-2020 | 5350 | 1018 | 689 | 576 | 343 |
| 70 | 08-Apr-2020 | 5915 | 1135 | 737 | 669 | 383 |
| 71 | 09-Apr-2020 | 6728 | 1364 | 833 | 720 | 463 |
| 72 | 10-Apr-2020 | 7599 | 1574 | 910 | 903 | 561 |
| 73 | 11-Apr-2020 | 8453 | 1761 | 968 | 1069 | 700 |
| 74 | 12-Apr-2020 | 9211 | 1982 | 1074 | 1154 | 804 |
| 75 | 13-Apr-2020 | 10454 | 2334 | 1172 | 1510 | 897 |
| 76 | 14-Apr-2020 | 11489 | 2684 | 1203 | 1561 | 1005 |
| 77 | 15-Apr-2020 | 12371 | 2916 | 1241 | 1578 | 1076 |
| 78 | 16-Apr-2020 | 13432 | 3201 | 1266 | 1640 | 1131 |
| 79 | 17-Apr-2020 | 14354 | 3321 | 1322 | 1707 | 1229 |
| 80 | 18-Apr-2020 | 15725 | 3648 | 1371 | 1893 | 1351 |
| 81 | 19-Apr-2020 | 17305 | 4200 | 1476 | 2003 | 1478 |
| 82 | 20-Apr-2020 | 18544 | 4666 | 1519 | 2081 | 1576 |
| 83 | 21-Apr-2020 | 20081 | 5218 | 1595 | 2156 | 1735 |
| 84 | 22-Apr-2020 | 21373 | 5649 | 1628 | 2248 | 1888 |
| 85 | 23-Apr-2020 | 23040 | 6427 | 1682 | 2376 | 1964 |
| 86 | 24-Apr-2020 | 24448 | 6817 | 1754 | 2514 | 2034 |
| 87 | 25-Apr-2020 | 26283 | 7628 | 1820 | 2625 | 2083 |
| 88 | 26-Apr-2020 | 27890 | 8068 | 1884 | 2918 | 2185 |
| 89 | 27-Apr-2020 | 29458 | 8590 | 1936 | 3108 | 2262 |
| 90 | 28-Apr-2020 | 31360 | 9318 | 2057 | 3314 | 2364 |
| 91 | 29-Apr-2020 | 33065 | 9915 | 2161 | 3439 | 2440 |
| 92 | 30-Apr-2020 | 34866 | 10498 | 2322 | 3515 | 2584 |
| 93 | 01-May-2020 | 37262 | 11506 | 2525 | 3738 | 2666 |
| 94 | 02-May-2020 | 39826 | 12296 | 2756 | 4122 | 2772 |
| 95 | 03-May-2020 | 42778 | 12974 | 3022 | 4549 | 2886 |
| 96 | 04-May-2020 | 46434 | 14541 | 3549 | 4898 | 3061 |
| 97 | 05-May-2020 | 49405 | 15525 | 4057 | 5104 | 3158 |
| 98 | 06-May-2020 | 53007 | 16758 | 4828 | 5532 | 3317 |
| 99 | 07-May-2020 | 56351 | 17974 | 5408 | 5980 | 3427 |
| 100 | 08-May-2020 | 59695 | 19063 | 6008 | 6318 | 3579 |

## References


1 Li Q, Guan X, Wu P, et al. Early transmission dynamics in wuhan, China, of novel coronavirus–infected pneumonia. *N Engl J Med.* 2020;382(13):1199–1207.
2 WHO. *Novel Coronavirus – China* [Internet]. Geneva: World Health Organization; 2020. Available from: https://www.who.int/csr/don/12-january-2020-novel-coronavirus-china/en/.
3 JHU-CSSE. *COVID-19 Dashboard* [Internet]. Baltimore, Maryland: Center for Systems Science and Engineering (CSSE) at Johns Hopkins University; 2020. Available from: https://www.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6.
4 Cohen J, Kupferschmidt K. Mass testing, school closings, lockdowns: countries pick tactics in 'war' against coronavirus. Science [Internet], Available from: https://www.sciencemag.org/news/2020/03/mass-testing-school-closings-lockdowns-countries-pick-tactics-war-against-coronavirus#; 2020.
5 Zhang Y, Jiang B, Yuan J, Tao Y. *The Impact of Social Distancing and Epicenter Lockdown on the COVID-19 Epidemic in Mainland China: A Data-Driven SEIQR Model Study.* 2020.
6 MoHFW. *COVID-19 Statewise Status* [Internet]. New Delhi: Ministry of Health and Family Welfare, Government of India; 2020. Available from: https://www.mohfw.gov.in/.
7 Roda W, Varughese M, Han D, Li M. Why Is It Difficult to Accurately Predict the COVID-19 Epidemic? Infect Dis Model. November 3;5.
8 Cyranoski D. When will the coronavirus outbreak peak? [Internet] *Nature*; 2020. Available from: https://www.nature.com/articles/d41586-020-00361-5.
9 Moran KR, Fairchild G, Generous N, et al. Epidemic forecasting is messier than weather forecasting: the role of human behavior and internet data streams in epidemic forecast. *J Infect Dis.* 2016;214(4):S404–S408.
10 WHO. Managing epidemics:Key facts about major deadly diseases [Internet]. Geneva, Available from: https://www.who.int/emergencies/diseases/managing-epidemics-interactive.pdf; 2018.
11 A MK. *Modeling and Predictions for COVID 19 Spread in India.* 2020.
12 Singh R, Adhikari R. Age-structured impact of social distancing on the COVID-19 epidemic in India (Updates at https://github.com/rajeshrinet/pyross; 2020.
13 Gupta R, Pandey G, Chaudhary P, Pal SK. SEIR and Regression Model based COVID-19 outbreak predictions in India. *medRxiv.* 2020, 2020.04.01.20049825.
14 Ivorra B, Ruiz Ferrández M, Vela M, Ramos AM. *Mathematical Modeling of the Spread of the Coronavirus Disease 2019 (COVID-19) Taking into Account the Undetected Infections. The Case of China.* Commun Nonlinear Sci Numer Simul Accept Press; 2020.
15 Mandal S, Bhatnagar T, Arinaminpathy N, et al. Prudent public health intervention strategies to control the coronavirus disease 2019 transmission in India: a mathematical model-based approach. *Indian J Med Res.* 2020 Mar 23, 2020/03/24.
16 Huanga Y, Yangb L, Daia H, Tiana F, Chena K. *Epidemic Situation and Forecasting of COVID-19 in and outside China* [Internet]. 16 March 2020. Bull World Health Organ; 2020. https://doi.org/10.2471/BLT.20.255158. Available from:.
17 Rai B, Shukla A, Dwivedi LK. COVID-19 in India: predictions, reproduction number and public health preparedness. *medRxiv.* 2020, 2020.04.09.20059261.
18 Choudhary I. *Forecasting COVID-19 Cases in India* [Internet]. Towards Data Science; 2020. Available from: https://towardsdatascience.com/forecasting-covid-19-cases-in-india-c1c410cfc730Towards Data Science.
19 Ji LQ. Analysis of a modified logistic model for describing the growth of durable customer goods in China. Math Comput Appl. January 4;18:30–37.
20 Korstanje J. Modeling logistic growth [Internet], Available from: https://towardsdatascience.com/modeling-logistic-growth-1367dc971de2; 2020.
21 Baranovskij A. COVID-19 Growth Modeling and Forecasting with Prophet [Internet] *Medium*; 2020 [cited 2020 May 12]. Available from: https://medium.com/katanaml/covid-19-growth-modeling-and-forecasting-with-prophet-2ff5ebd00c01.
22 Blackwood JC, Childs L M. An introduction to compartmental modeling for the budding infectious disease modeler. *Lett Biomath.* 2018 Dec 14;5(1):195–221.
23 Popovici ED, Negru DG, Olariu T, et al. Application of the susceptible-infected-recovered deterministic model in a GII.P17 emergent norovirus strain outbreak in Romania in 2015. *Infect Drug Resist.* 2019;12:2543–2551.
24 Liu Y, Gayle AA, Wilder-Smith A, Rocklov J. The reproductive number of COVID-19 is higher compared to SARS coronavirus [Internet]. 2020/02/14 *J Trav Med.* 2020 Mar 13;27(2). Available from: https://www.ncbi.nlm.nih.gov/pubmed/32052846.
25 Riou J, Althaus CL. Pattern of early human-to-human transmission of Wuhan 2019 novel coronavirus (2019-nCoV). December 2019 to January 2020 *Euro Surveill.* 2020

Jan;25(4) [Internet]. 2020/02/06., : https://www.ncbi.nlm.nih.gov/pubmed/32019669. Available from.

26 Wagner AK, Soumerai SB, Zhang F, Ross-Degnan D. Segmented regression analysis of interrupted time series studies in medication use research. *J Clin Pharm Therapeut*. 2002 Aug;27(4):299–309, 2002/08/14.

27 Ranjan R. Predictions for COVID-19 outbreak in India using Epidemiological models. *medRxiv*. 2020, 2020.04.02.20051466.

28 Ray D, Salvatore M, Bhattacharyya R, et al. Predictions, role of interventions and effects of a historic national lockdown in India's response to the COVID-19 pandemic: data science call to arms. *medRxiv*. 2020, 2020.04.15.20067256.

29 Bhatnagar M. *COVID-19: Mathematical Modelling and Predictions*. 2020.