Prediction of the Peak, Effect of Intervention and Total Infected by the Coronavirus Disease in India

Parth Vipul Shah[1]

Computer Science and Engineering Department, PES University, 100 Feet Ring Road, BSK III Stage, Bangalore, India

Abstract

We study the effect of the coronavirus disease 2019 (COVID-19) in India using the SEIR compartmental model. India, a densely populated country, is leading the fight against this disease and setting an example for the world by ensuring social distancing is protocol. After estimating the infection rate using a least square method with Poisson noise and the reproduction number to be 0.258 and 2.58 respectively, we approximate the (1) peak of the epidemic; August 11, 2020, (2) effect of intervention; a 50% drop in infection rate will push the peak by 24 days for a 1 month intervention period and (3) total individuals infected; approximately 90% of the total population.

Keywords: COVID-19, SEIR compartmental model, India, infection rate, peak prediction, intervention
2010 MSC: 00-01, 99-00

1. Introduction

In this work, on the eve of the outbreak of the pandemic coronavirus disease 2019 (COVID-19)[1], caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), we predict the possible number of infected individuals in India. This disease has demonstrated person-to-person transmission[2]. As India is a densely populated, it is necessary to understand the possible effect of this disease. January 30, 2020 marked the first identified case of COVID-19 in India.[3] The World Health Organization (WHO) declared the disease a pandemic.[4] The total number of confirmed cases in India and the daily increase in cases is depicted below in figures 1 and 2.

The growth of the number of confirmed cases can be approximated by an exponential function. The growth factor r at day t can be calculated as

$$r = \frac{\text{Cases on day t}}{\text{Cases on day t-1}} \tag{1}$$

[1]Student, parthvipulshah@pesu.pes.edu

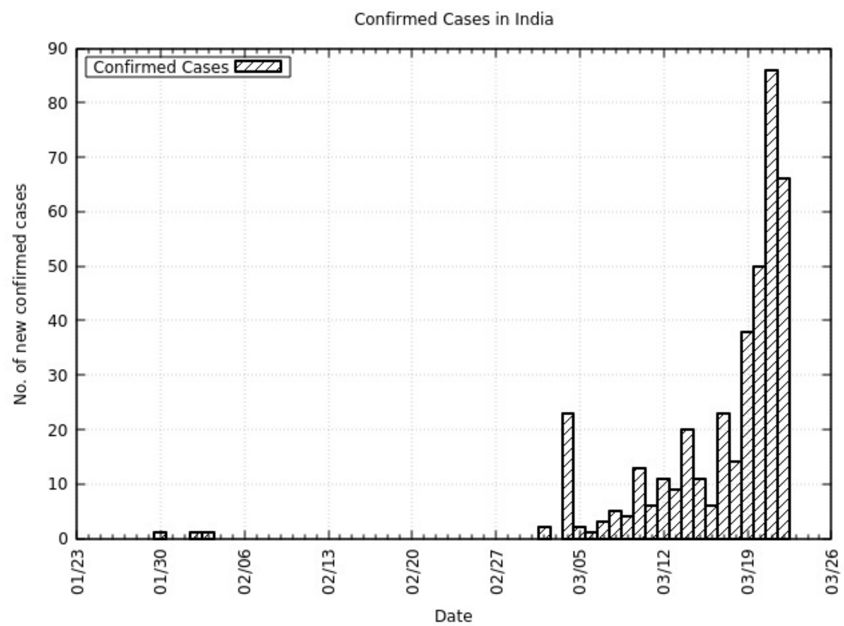

Figure 1: Daily increase in confirmed cases of COVID-19 in India. Day 0 is January 22, 2020. Data is taken from Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU)[3].

March 24, 2020, India is reporting an average growth rate of 1.230 calculated over the past 5 days. Stricter rules and measures of ensuring social distancing have begun.[5] India is leading the fight against this disease and setting an example for the world by ensuring social distancing is protocol when the number of infected individuals are low.

2. Methods

2.1. Model

A SEIR compartmental model is applied for the predictions in India based on a recent publication[6]. The methodology is adopted here. The assumption that once an individual contracts the virus and recovers, the individual is immune to this virus is assumed. Hence the SEIR model

$$\begin{aligned} S^{'}(t) &= -\beta S(t)I(t) \\ E^{'}(t) &= \beta S(t)I(t) - \epsilon E(t) \\ I^{'}(t) &= \epsilon E(t) - \gamma I(t) \\ R^{'}(t) &= \gamma I(t) \end{aligned} \tag{2}$$

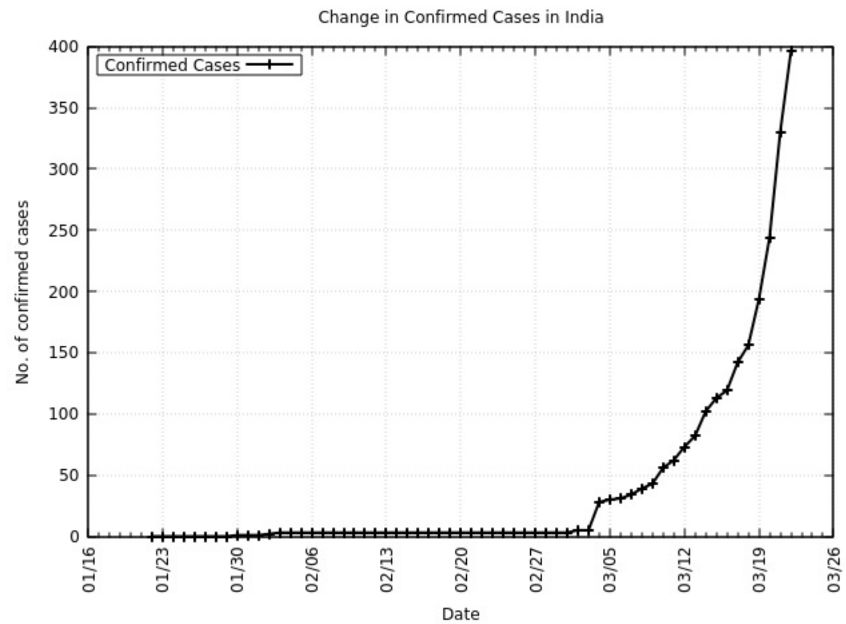

Figure 2: Cumulative confirmed cases of COVID-19 in India. Data is taken from Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU)[3].

where $S(t), E(t), I(t), R(t)$ denote the susceptible, exposed, infected and removed populations at time t, respectively. β, ϵ, γ denote the infection rate, the onset rate and the removal rate, respectively. $1/\epsilon$, $1/\gamma$ are the average incubation period and the average infectious period respectively. The unit time is 1 day. We fix $1/\epsilon$ to 5 and $1/\gamma$ to 10[7][8]. We also fix $S + E + I + R$ to 1 so that calculations are a proportion of the total. The assumption that 1 infected individual amongst a total population of $N = 1339.2 \times 10^6$ individuals is identified at $t = 0$ is adopted[9]. Therefore

$$Y(t) = pI(t) \times N \tag{3}$$

are the confirmed number of infected individuals who are identified at time t. To obtain the initial conditions of the model, we assume that there are no exposed or removed populations at $t = 0$. Therefore

$$\begin{aligned}
&E(0) = 0 \\
&I(0) = \frac{1}{p \times N} \\
&R(0) = 0 \\
&S(0) = 1 - E(0) - I(0) - R(0) = 1 - \frac{1}{p \times N}
\end{aligned} \tag{4}$$

Table 1: Parameters

Parameter	Description	Value
β	Infection rate	0.258
R_0	Reproduction number	2.58
ϵ	Onset rate	0.2
γ	Removal rate	0.1
N	Total population of India	1339.2×10^6
p	Identification rate	$0.01 - 0.1$

are the initial conditions. We fix $0.01 < p < 0.1$ based on government reports of the density of affected people in a particular regions.[10] A reproduction number, R_0 is calculated. This is the expected value of secondary cases produced by one infected individual. Based on existing methodology[11]

$$R_0 = \frac{\beta S(0)}{\gamma} = \frac{\beta}{\gamma}(1 - \frac{1}{p \times N}) \tag{5}$$

2.1.1. Estimation of the infection rate

Let $y(t), t = 0, 1, 2...60$ be the daily confirmed cases of COVID-19 in India from January 22, 2020 ($t = 0$) to March 23, 2020 ($t = 60$). Using the least square approach with Poisson noise to estimate the infection rate, the following steps are adopted. With Poisson noise, equation 3 is modified to

$$\hat{Y}(t) = Y(t) + \sqrt{Y(t)}\epsilon(t) \tag{6}$$

$\epsilon(t), t = 0, 1, 2...60$ are random variables from a standard normal distribution. The following steps are adopted to estimate β.

1. For $\beta > 0$, calculate $Y(t), t = 0, 1, 2...60$ using equation 3.
2. Calculate $\hat{Y}$ using equation 6.
3. Calculate $J(\beta) = \sum_{t=0}^{60}[y(t) - \hat{Y}(t)]^2$
4. Run step 1 to step 3 for $0.2 \le \beta \le 0.4$ and find β^* such that $J(\beta^*) = \min_{0.2\le\beta\le0.4} J(\beta)$
5. Repeat step 1 to step 4, 10000 times and obtain the distribution of β^*. Approximate the same by a normal distribution and obtain the 95% confidence interval.

We obtain a value of β equal to 0.258 and the 95% confidence interval as $0.250 - 0.266$. Also, R_0 is equal to 2.58 and the 95% confidence interval as $2.50 - 2.66$. This is represented in figure 3 with an overlap of the number of new confirmed cases. A summary of all parameters can be found in table 1.

3. Results

3.1. Peak Prediction

The epidemic peak, t^* is defined as the maximum value Y in a period of 1.5 years or $Y(t^*) = \max_{0\le t\le 550}$. As the epidemic peak and size are sensitive to

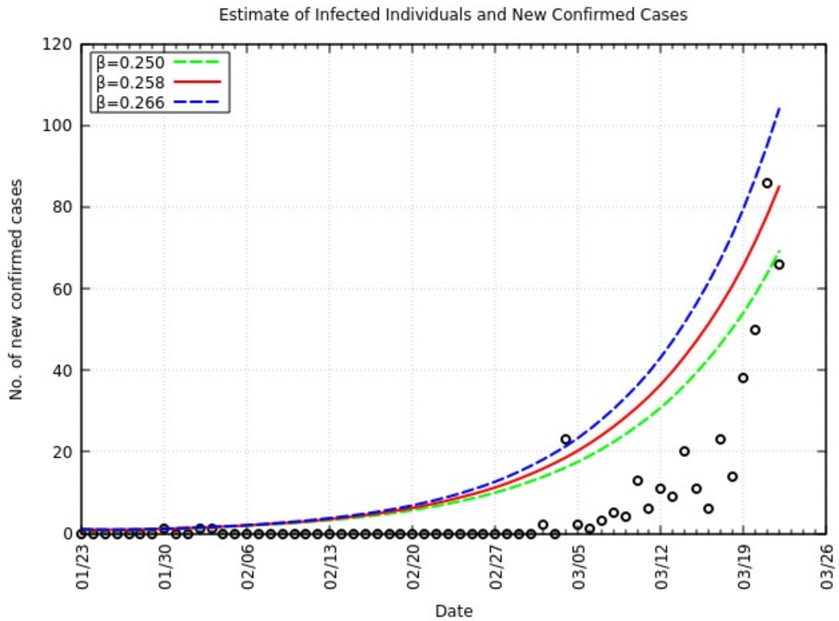

Figure 3: Comparison of daily confirmed cases and Y in India from $t = 0$ to $t = 60$

the identification rate p, we report the following.

For $p = 0.1$, the estimated peak is $t^* = 229$ with a 95% confidence interval of 221-238. That is, starting from January 22, 2020 ($t = 0$), the estimated peak is September 7, 2020 ($t = 229$) and interval ranging from August 30, 2020 to September 16, 2020. This is represented in figure 4.

For $p = 0.01$, the estimated peak is $t^* = 202$ with a 95% confidence interval of 194-210. That is, starting with January 22, 2020 ($t = 0$), the estimated peak is August 11, 2020 ($t = 202$) and interval ranging from August 3, 2020 to August 19, 2020. This is represented in figure 5.

3.2. Effect of Intervention

India has announced a 21 day complete shutdown starting March 25, 2020.[12] For our calculations, we assume that this shutdown will reduce the infection rate to 75%, 50% or 25% for a time period of 30 days or one month and 180 days or six months. The government maintains that the third stage, community transmission, has not begun[13]. Moreover, the current number of tests conducted are low[14]. Hence, the current identification rate is low. We set p to 0.01 as this closely matches available data for the next set of calculations.

For a 75% reduction in the infection rate and one month of intervention, the estimated peak is pushed from 202 to 214. A 12 day delay. Six months of intervention, the estimated peak is pushed from 202 to 270. A 68 day delay. This is represented in figure 6.

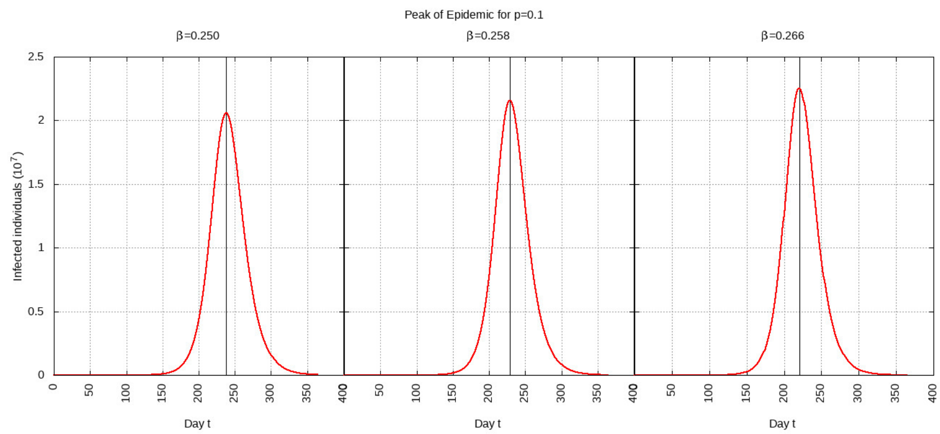

Figure 4: Infected individuals for time t, $0 \leq t \leq 550$ for $p = 0.1$

Table 2: Summary of change in estimated peak from August 11, 2020. Units are days. The 1 month and 6 months delays are the delays in the estimated peaks after respective intervention periods. The dates indicated are the revised dates of the estimated peaks.

β Drop	1 Month Delay	Date	6 Months Delay	Date
75%	12	August 23	68	October 18
50%	24	September 4	141	December 30
25%	38	September 18	234	April 2, 2021

For a 50% reduction in the infection rate and one month of intervention, the estimated peak is pushed from 202 to 226. A 24 day delay. Six months of intervention, the estimated peak is pushed from 202 to 343. A 141 day delay. This is represented in figure 7.

For a 25% reduction in the infection rate and one month of intervention, the estimated peak is pushed from 202 to 240. A 38 day delay. Six months of intervention, the estimated peak is pushed from 202 to 436. A 234 day delay. This is represented in figure 8.

A summary of all the delays in the estimated peaks can be found in table 2.

3.3. Total Individuals Infected

Upon integrating Y over time t, we obtain an approximate of the total number of infected individuals over 550 days. With no intervention, the approximate total number of infected individuals will be 1.2087×10^8 which is 9% of the total population of India. With one month of intervention and 75% reduction in the infection rate, the approximate total number of infected individuals will be the same. But with six months of intervention and 75% reduction in the infection rate, the approximate total number of infected individuals will be 1.2002×10^8 which means approximately 850,000 individuals will not be infected. The change in these numbers for a higher reduction in infection rate does not significantly

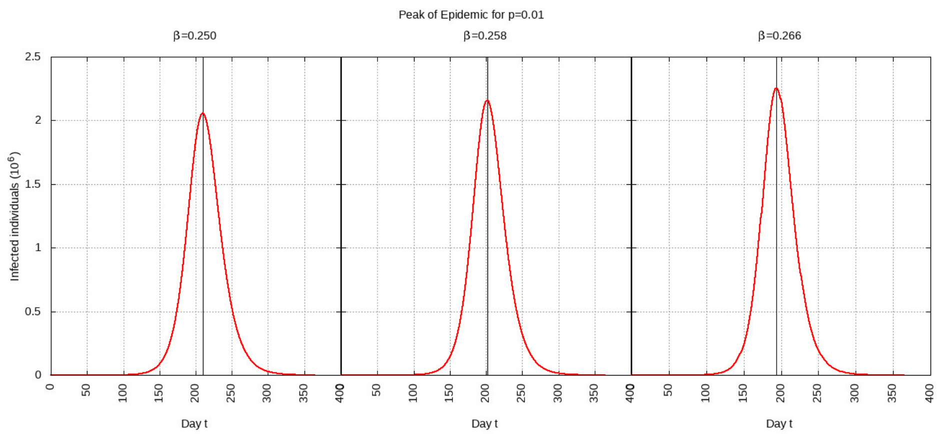

Figure 5: Infected individuals for time t, $0 \le t \le 550$ for $p = 0.01$

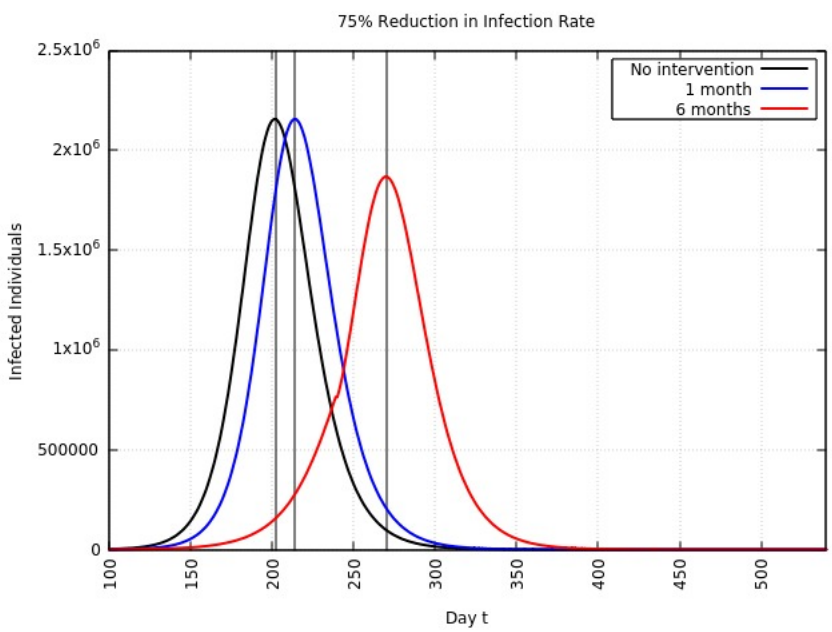

Figure 6: Variation in $Y(t)$ for time t, $0 \le t \le 550$ with no intervention, 1 month of intervention and 6 months of intervention with assumption of $\beta = 0.75 \times 0.258$

change the approximate total number of infected individuals. It only pushes the approximate epidemic peak to a later date.

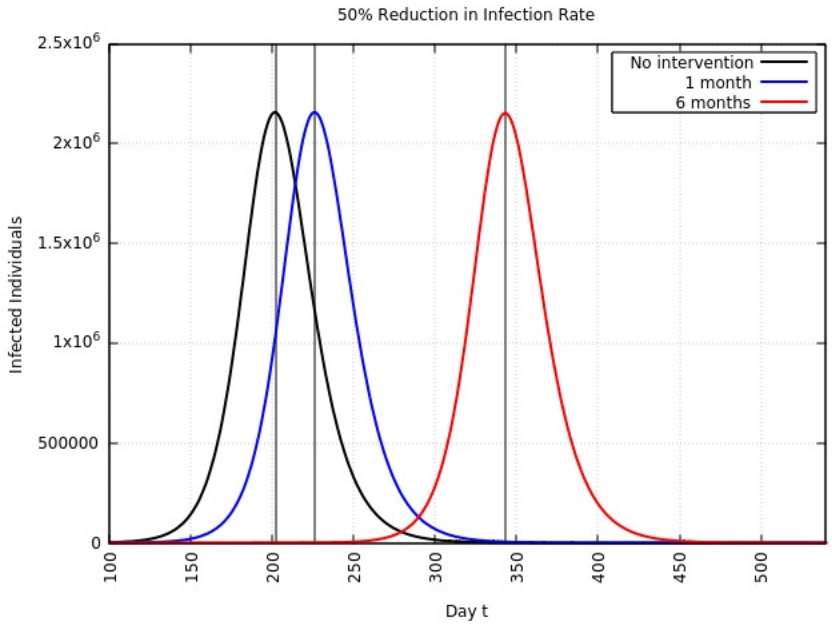

Figure 7: Variation in $Y(t)$ for time t, $0 \leq t \leq 550$ with no intervention, 1 month of intervention and 6 months of intervention with assumption of $\beta = 0.50 \times 0.258$

4. Discussion

By applying the SEIR compartmentalization model, it is clear that the epidemic peak can easily reach summer. This prediction is sensitive to changes in the behavior of not only the virus but of people and their practice of social distancing. The WHO has issued similar statements reiterating the importance of practicing social distancing to ensure that national health care systems are not strained. Moreover, India lacks a robust healthcare system, it may be ill equipped to deal with a large number of cases immediately. Delaying the peak will ensure adequate medical equipment and personnel for all her citizens.

Declarations of Interest:. None

Funding:. None

References

[1] Coronavirus disease (covid-19) pandemic, Available online: `https://www.who.int/emergencies/diseases/novel-coronavirus-2019`, accessed: 2020-03-15.

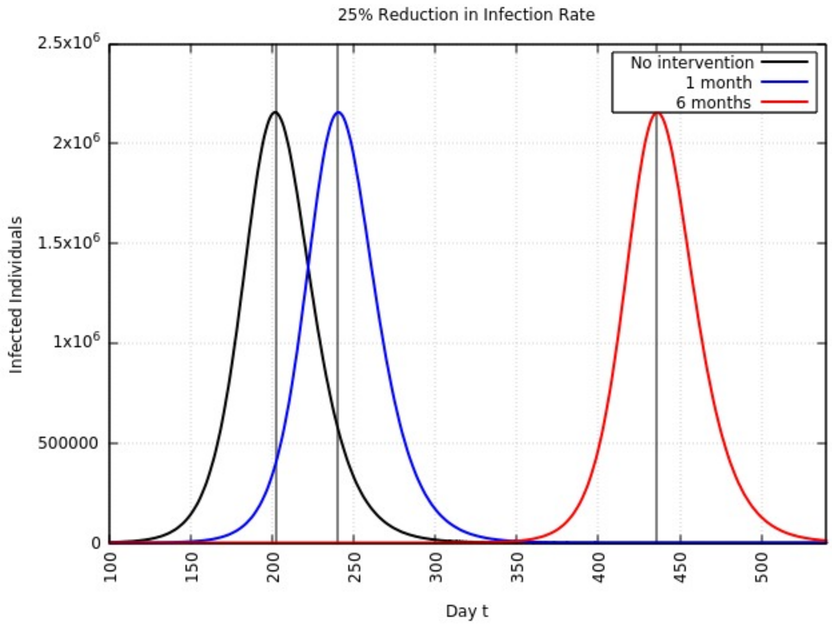

Figure 8: Variation in $Y(t)$ for time t, $0 \leq t \leq 550$ with no intervention, 1 month of intervention and 6 months of intervention with assumption of $\beta = 0.25 \times 0.258$

[2] C. I. Paules, H. D. Marston, A. S. Fauci, Coronavirus Infections—More Than Just the Common ColdarXiv:https://jamanetwork.com/journals/jama/articlepdf/2759815/jama_paules_2020_vp_200006.pdf, doi:10.1001/jama.2020.0757.
URL https://doi.org/10.1001/jama.2020.0757

[3] 2019 novel coronavirus covid-19 (2019-ncov) data repository by johns hopkins csse, Available online: https://github.com/CSSEGISandData/COVID-19, accessed: 2020-03-15.

[4] Rolling updates on coronavirus disease (covid-19), Available online: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen, accessed: 2020-03-12.

[5] Janta curfew just the beginning of a long battle against coronavirus: Pm modi, Available online: https://www.indiatoday.in/india/story/janta-curfew-just-beginning-long-battle-against-coronavirus-pm-modi-1658528-2020-03-22, accessed: 2020-03-23.

[6] T. Kuniya, Prediction of the epidemic peak of coronavirus disease in japan, 2020, Journal of Clinical Medicine 9 (3) (2020) 789. doi:10.3390/jcm9030789.

[7] N. M. Linton, T. Kobayashi, Y. Yang, K. Hayashi, A. R. Akhmetzhanov, S.-M. Jung, B. Yuan, R. Kinoshita, H. Nishiura, Incubation period and other epidemiological characteristics of 2019 novel coronavirus infections with right truncation: A statistical analysis of publicly available case data, Journal of Clinical Medicine 9 (2) (2020) 538. doi:10.3390/jcm9020538.

[8] H. Sun, Y. Qiu, H. Yan, Y. Huang, Y. Zhu, S. X. Chen, Tracking and predicting covid-19 epidemic in china mainland, medRxiv (2020). arXiv:https://www.medrxiv.org/content/early/2020/02/20/2020.02.17.20024257.full.pdf, doi:10.1101/2020.02.17.20024257.
URL https://www.medrxiv.org/content/early/2020/02/20/2020.02.17.20024257

[9] Projected population statistics, Available online: https://data.gov.in/resources/projected-population-characteristics-1st-march-2013-2001-2026-india, accessed: 2020-03-20.

[10] Ministry of health and family welfare - covid-19 statewise status, Available online: https://www.mohfw.gov.in/, accessed: 2020-03-18.

[11] P. [van den Driessche], Reproduction numbers of infectious disease models, Infectious Disease Modelling 2 (3) (2017) 288 – 303. doi:https://doi.org/10.1016/j.idm.2017.06.002.
URL http://www.sciencedirect.com/science/article/pii/S2468042717300209

[12] Coronavirus: India enters 'total lockdown' after spike in cases, Available online: https://www.bbc.com/news/world-asia-india-52024239, accessed: 2020-03-25.

[13] How rapidly can covid-19 spread in india? government did the math., Available online: https://www.ndtv.com/india-news/coronavirus-outbreak-15-lakh-delhi-covid-19-cases-in-optimistic-scenario-centres-estimate-2199464, accessed: 2020-03-25.

[14] Coronavirus: India's restrictive criteria for testing may mask toll, Available online: https://www.indiatoday.in/india/story/coronavirus-covid-19-testing-india-1656728-2020-03-18, accessed: 2020-03-18.