Prediction of the Peak and Total Infected of the Coronavirus Disease in India

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Abstract: We study the effect of the coronavirus disease 2019 (COVID-19) in India using the SEIR compartmental model. India 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, (2) effect of intervention and (3) total individuals infected.
Keywords: COVID-19; SEIR compartmental model; India; infection rate; peak prediction; effect of intervention; total individuals infected

I. 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.

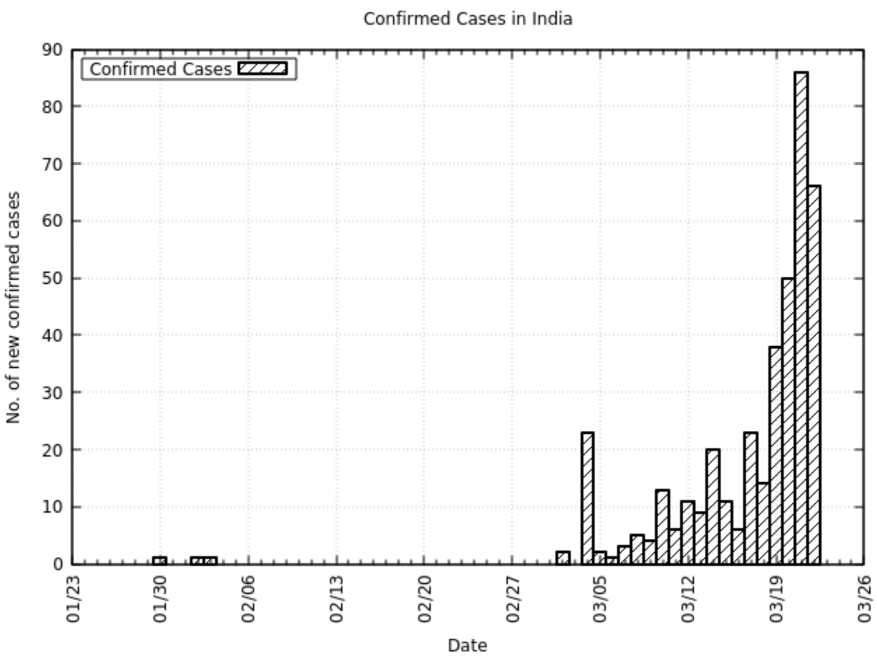

FIG. 1: Daily increase in confirmed cases of COVID-19 in India. Day 0 is January 22, 2020. Data from Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU)[3].

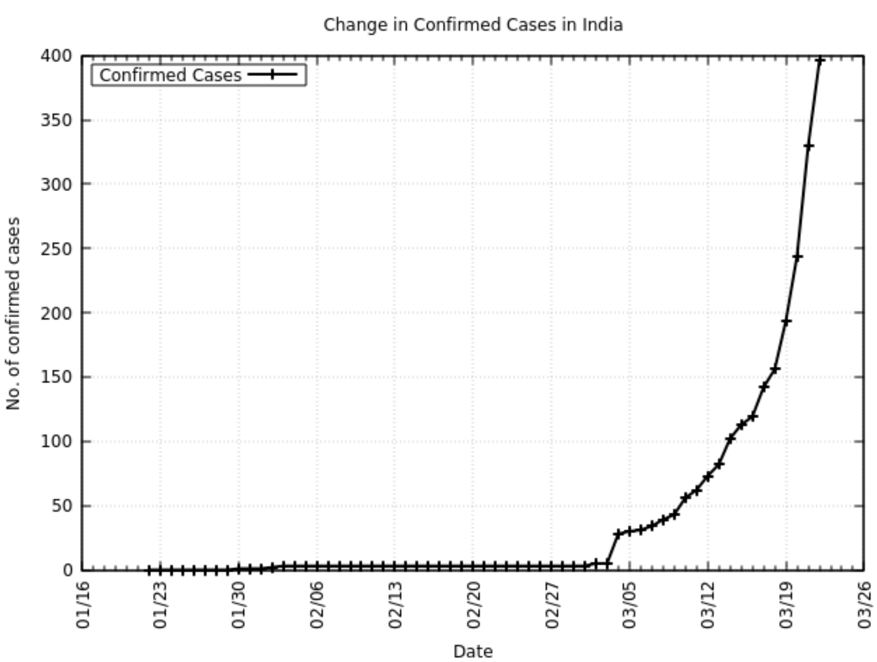

FIG. 2: Cumulative confirmed cases of COVID-19 in India. Data from Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU)[3].

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

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

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.

II. METHODS

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 adopted. Hence the SEIR model

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

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

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

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

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

a. *Estimation of the infection rate,* β

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, 202 ($t = 60$). 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.

1. For $\beta > 0$, calculate $Y(t), t = 0, 1, 2...60$ using equation 3.
2. Calculate 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 $0.2 \leq \beta \leq 0.4$ and find β^* such that $J(\beta^*) = min_{0.2 \leq \beta \leq 0.4} J(\beta)$
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 $2.50 - 2.66$.

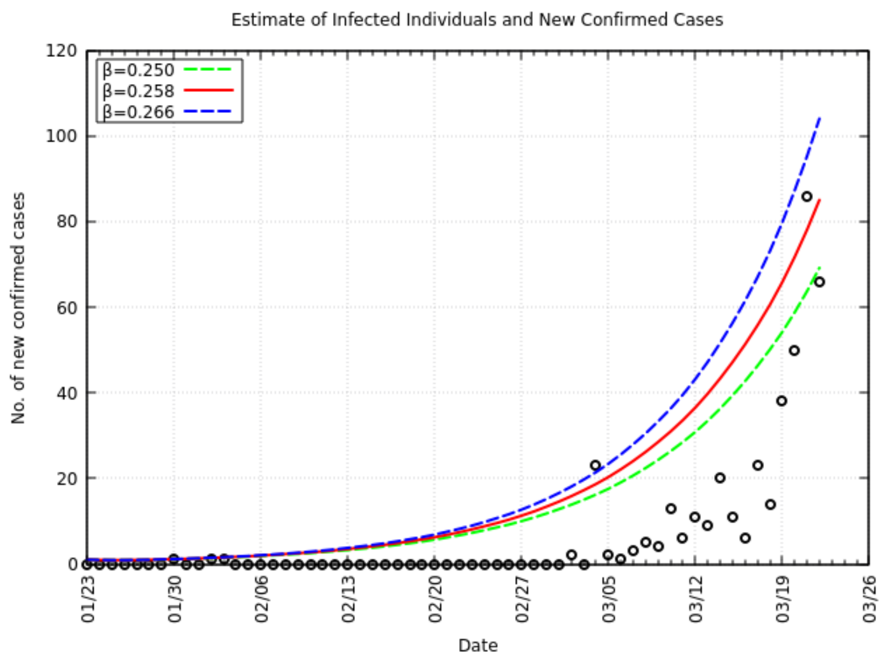

FIG. 3: Comparison of daily confirmed cases and Y in India from $t = 0$ to $t = 60$

TABLE I: 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	$0.01 - 0.1$

III. RESULTS

1. Peak Prediction

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

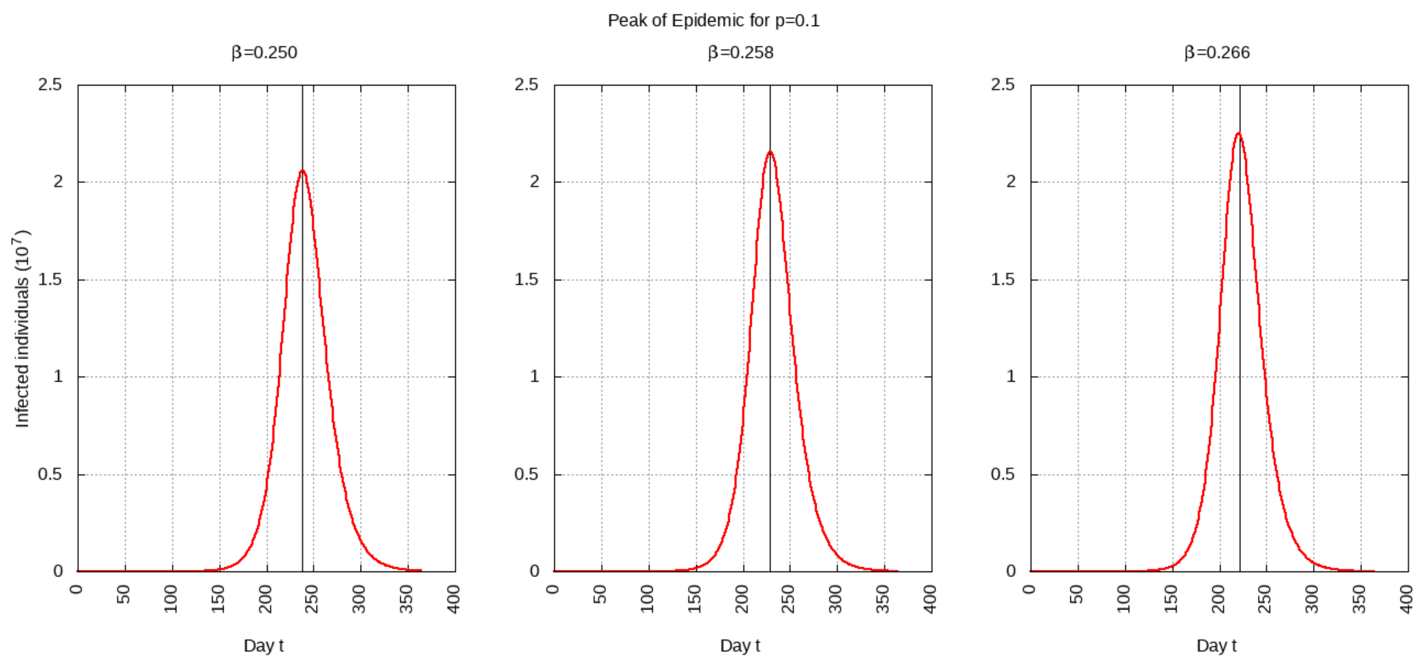

FIG. 4: Infected individuals for time t, $0 \leq t \leq 550$ for $p = 0.1$

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.

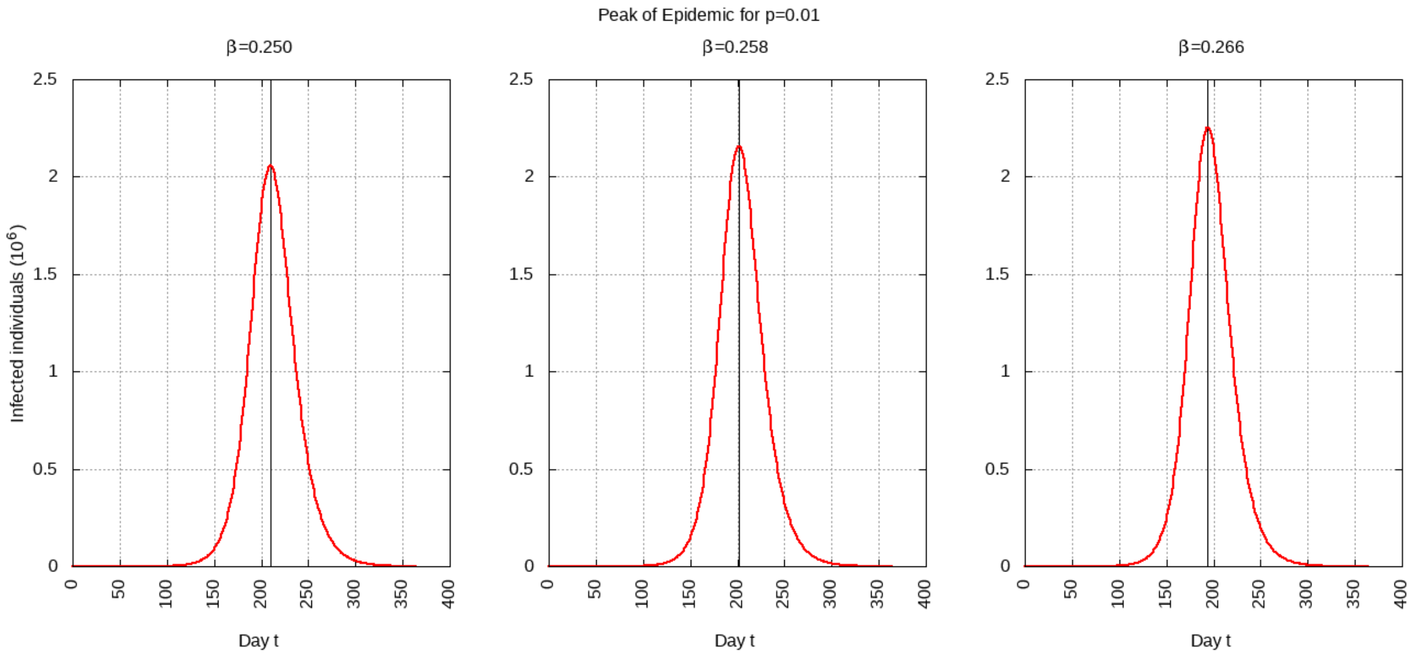

FIG. 5: Infected individuals for time t, $0 \leq t \leq 550$ for $p = 0.01$

2. Effect of Intervention

India has announced a 21 day complete shutdown starting March 25, 2020.[11] 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[12]. Moreover, the current number of tests conducted are low[13]. 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 229 to 241. A 12 day delay. Six months of intervention, the estimated peak is pushed from 229 to 295. A 66 day delay.

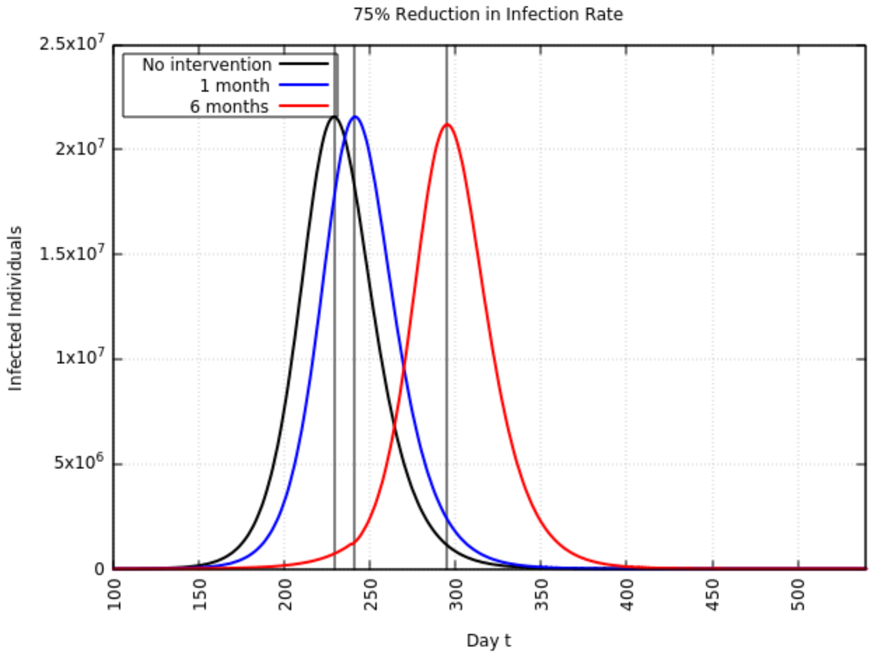

FIG. 6: Variation in $Y(t)$ for time t, $0 \leq t \leq 550$ with no intervention, 1 month of intervention and 6 months of intervention with assumption of $\beta = 0.75 \times 0.258$

For a 50% reduction in the infection rate and one month of intervention, the estimated peak is pushed from 229 to 253. A 24 day delay. Six months of intervention, the estimated peak is pushed from 229 to 370. A 141 day delay.

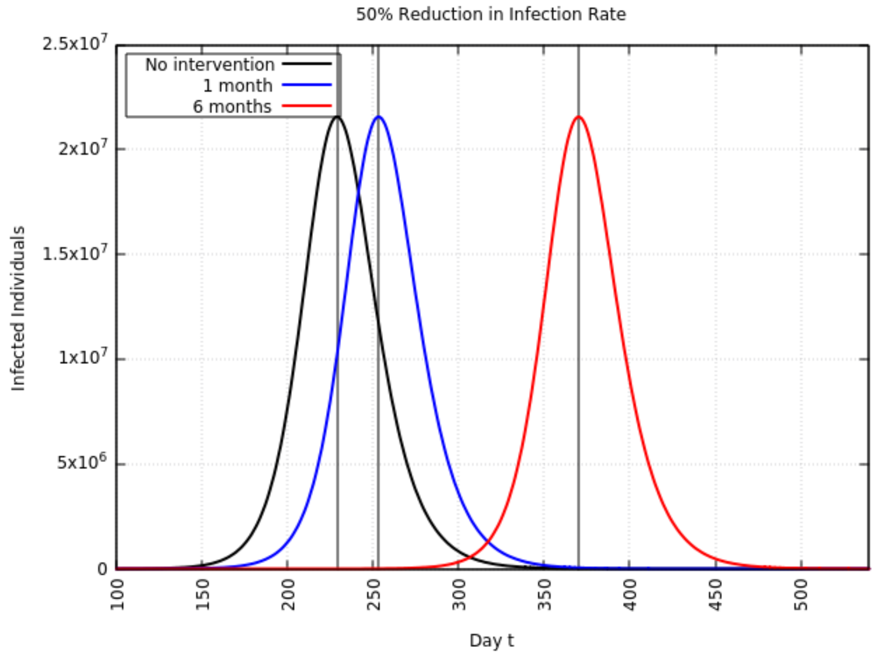

FIG. 7: Variation in $Y(t)$ for time t, $0 \leq t \leq 550$ with no intervention, 1 month of intervention and 6 months of intervention with assumption of $\beta = 0.50 \times 0.258$

For a 25% reduction in the infection rate and one month of intervention, the estimated peak is pushed from 229 to 268. A 39 day delay. Six months of intervention, the estimated peak is pushed from 229 to 461. A 232 day delay.

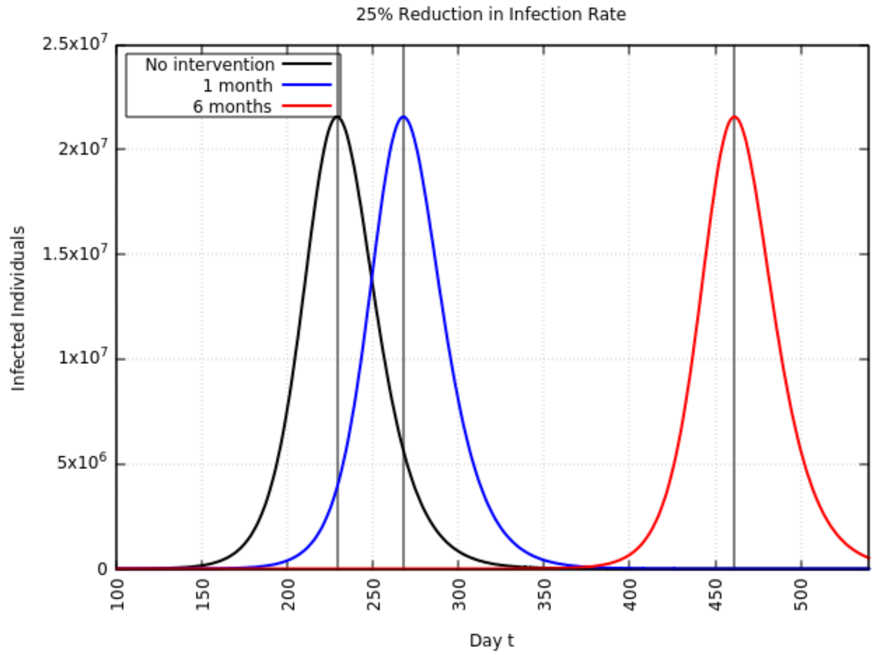

FIG. 8: Variation in $Y(t)$ for time t, $0 \leq t \leq 550$ with no intervention, 1 month of intervention and 6 months of intervention with assumption of $\beta = 0.25 \times 0.258$

TABLE II: Summary of change in estimated peak from August 12, 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, 2020	66	October 16, 2020
50%	24	September 4, 2020	141	December 30, 2020
25%	39	September 19, 2020	461	November 15, 2021

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 1.2087×10^9 which is 90% 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 75% reduction in the infection rate, the approximate total number of infected individuals will be 1.2079×10^9 which means approximately 739,260 individuals will not be infected. The change in these numbers for a higher reduction in infection rate does not significantly change the approximate total number of infected individuals (a reduction of 155 infected individuals). It only pushes the approximate epidemic peak to a later date.

IV. 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, since India lacks a robust and 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.

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