

Modified SEIR Model

Keeping in mind India's containment strategy for the novel coronavirus (subsequently named SARS-CoV-2) causing the disease Covid-19, a Detected & Isolated(I_D) stage has been added in the conventional SEIR Model. So, as soon as an infected patient is identified and is tested positive, he/she moves to Detected & Isolated(I_D) stage. At this stage, the patient doesn't infect anyone anymore as he/she is completely isolated. In short, I_D is the govt data for active cases given out every day. To read about conventional SEIR Model, [click here](#).



S: Susceptible population

E: Exposed population (exposed to the virus but not infectious yet)

I: Infectious population (asymptomatic or symptomatic patients who are infectious but not detected yet)

I_D : Detected & Isolated population (detected patients who have been isolated. Even though this population is still infectious, it doesn't infect anyone anymore as patients at this stage are completely isolated. It is the govt data for active cases)

R: Recovered or Dead population

β: rate of transmission (transmissions per S-I contact per time)

σ: rate of progression (inverse of incubation period)

γ: rate of detection for infectious individuals (inverse of disease onset to diagnosis time)

δ: rate of recovery (inverse of recovery period)

Equations:

- $\frac{dS}{dt} = -\frac{\beta SI}{N}$
- $\frac{dE}{dt} = \frac{\beta SI}{N} - \sigma E$
- $\frac{dI}{dt} = \sigma E - \gamma I$
- $\frac{dI_D}{dt} = \gamma I - \delta I_D$
- $\frac{dR}{dt} = \delta I_D$
- $R(\text{reproduction number}) = \frac{\beta}{\gamma}$
- $N = S + E + I + I_D + R$

Values used as input of the modified SEIR Model:

R_0 or R naught(reproduction number)^[1]: 1.5 to 4 ^[2]

Disease onset to diagnosis time: 5-7 days in India (As told by government doctors involved in Covid-19 detection). Average of 5 days calculated in a Wuhan study.^{[3][4]}

Average hospitalization period: 12.39 ± 4.77 days^{[3][4]}

Infection period: $12.39 + 5$ i.e. 18 days

Average time before a patient is declared recovered or dead(Recovery period): 15 days

Incubation period: 5.2 days^[5]

Infection mortality rate: 2%^[6]

Distribution of Infection, Incubation and Recovery periods: Lognormal Distribution^[7]

So, values of different rates in the equations of modified SEIR are set as;

$$\begin{array}{ll} \beta: \text{varying with } R & \sigma: \frac{1}{5.2} \\ \gamma: \frac{1}{6} & \delta: \frac{1}{21} \end{array}$$

These rates are the same for the whole country.

Note 1: Change in infection spread due to any decision, i.e. partial lockdown, total lockdown and sealing off areas/districts will be seen in I_D in around 10-12 days after the decision.

Note 2: Since Incubation period is a lognormal distribution^[7] with average 5.2 days, minimum 3 and maximum 12 days with 97.5% Confidence Level^[4], initial exposed(E_0) population was calculated using such a distribution on the new cases of next 12 days.

Infectious(I_0) population was also calculated in the same manner with an average detection time 6 days and maximum detection time 9 days (forming a lognormal distribution).

Covid-19 patient data in the next part is extracted from APIs exposed by <https://www.covid19india.org/>^{[8][9]} and model has been coded on Python 3.8.

1. Delhi:

Initial Susceptible Population (S_0): 19 million (total population)^[10]

Average Number of contacts per person in Delhi: 33.4^[11]

Partial Lockdown:

- Implemented on 13th March. (Schools, colleges, cinemas got closed from 13th March)^[12]
- The effect will be seen 24th March onwards.
- So, input values taken in the modified SEIR model:
 - Exposed (E_0): 320.45
 - Infectious (I_0): 70
 - Isolated/Detected (I_{D0}): 23
 - Recovered (R_0): 6
 - Fatalities (F_0): 1

Total Lockdown:

- Implemented on 22nd March.^[13]
- Effects will be seen 3rd April onwards.
- Input values taken in the modified SEIR model:
 - Exposed (E_0): 733.76
 - Infectious (I_0): 378.59
 - Isolated/Detected (I_{D0}): 372
 - Recovered (R_0): 8
 - Fatalities (F_0): 6

Observation:

Partial Lockdown/Social Distancing:

- R(reproduction number for partial lockdown) in Delhi was hovering around **2.25 - 2.5** during the end of partial lockdown (graph was showing upwards trend from 27th March)
- At this rate, total cases in Delhi by 3rd May would have reached 6,497 – 9,699. By 10th May it would have been between 20,127 & 32,774. *Figure 1* shows the predicted increase in total cases till 25th April at different values of R.
- If R_0 (reproduction number under normal conditions without any measure to reduce contact ratio) for Delhi is assumed 3, then partial lockdown reduced the contact ratio in Delhi by 16.66% - 25%

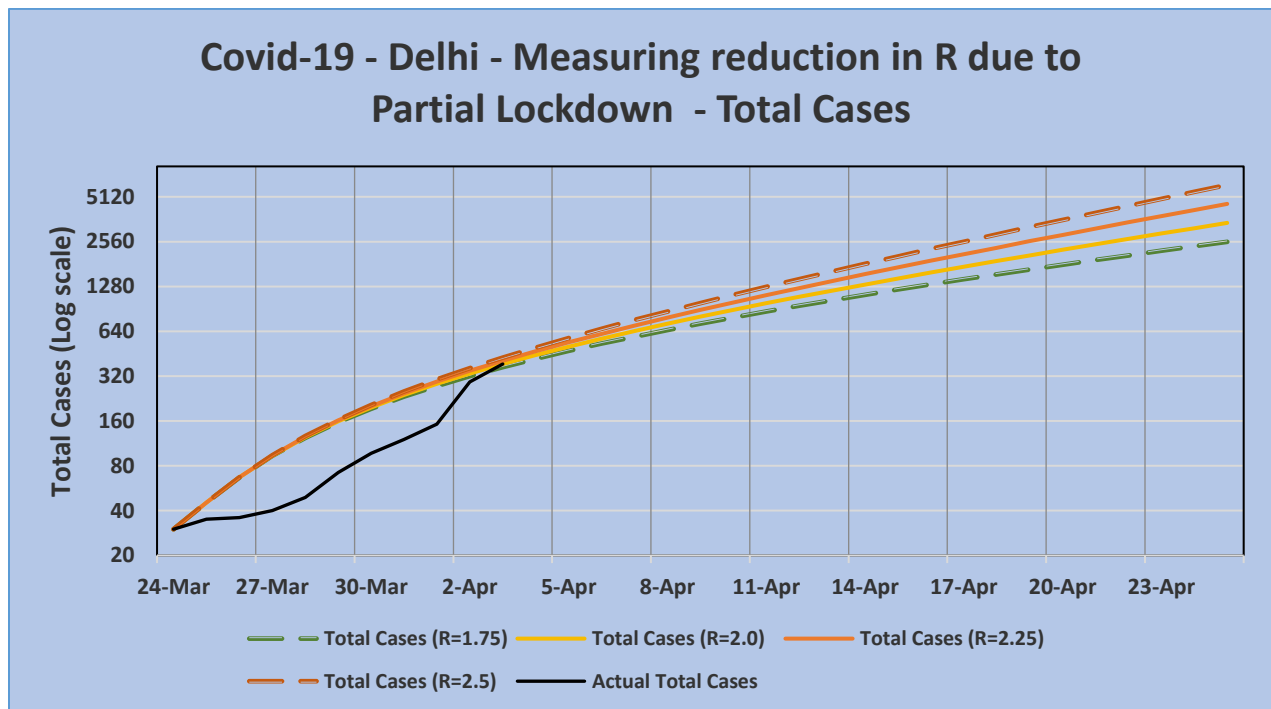


Figure 1

Complete Lockdown:

Observation on 3rd May:

- Total cases in the state on 3rd May – 4,549
- R(reproduction number for complete lockdown) in Delhi is steady was steady at **1.25** from a week. But from last 2 days, there has been a gradual increase towards 1.5. (major decline is seen from 13th April, probably because of shutting off hotspot areas. Before 13th, R was around 1.5)

For 10th May:

- At this rate, **total cases** by 10th May would be between **5,467 & 7,693** as shown in *Figure 2*.
- Also, by 10th May total active cases would be between **2,224 & 3,539** as shown in *Figure 3*.

For 17th May:

- **Total cases** in Delhi by 10th May would be between **6,980 & 10,777**.

If R_0 (reproduction number under normal conditions without any measure to reduce contact ratio) for Delhi is assumed 3, then total lockdown reduced the contact ratio in Delhi by 58.33% - 50%.

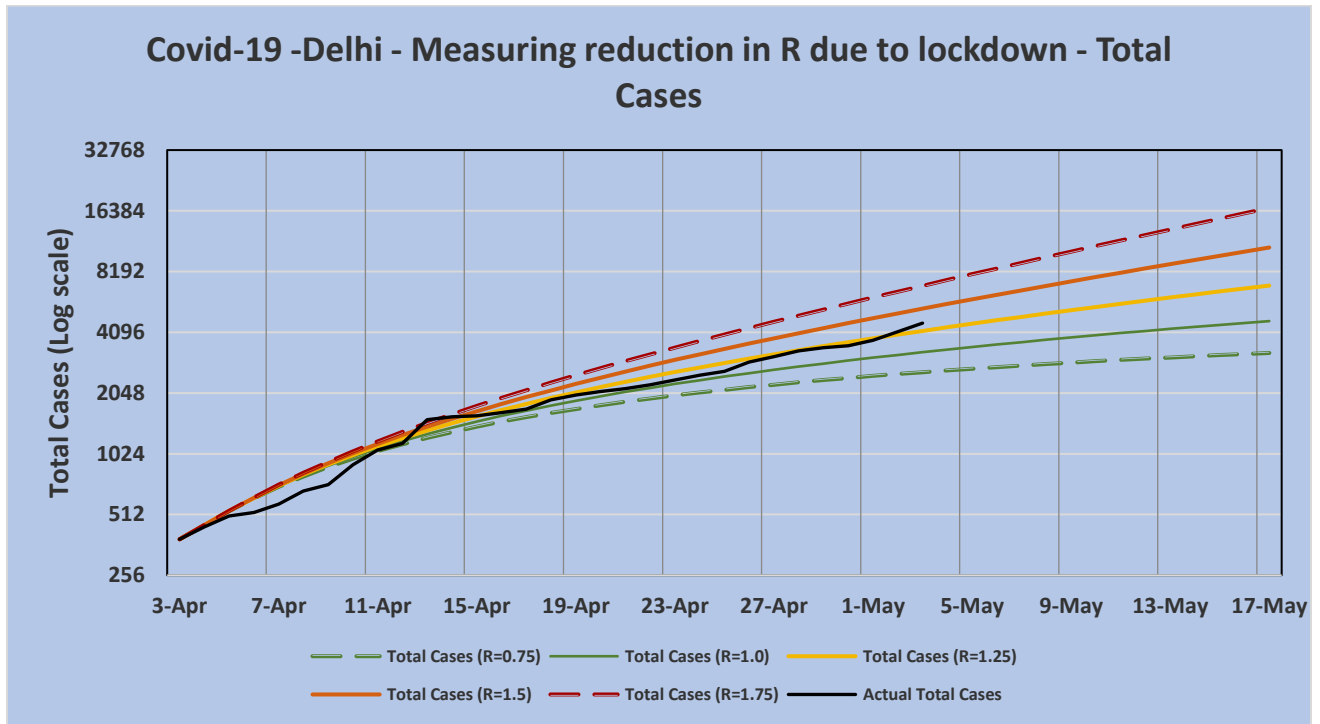


Figure 2

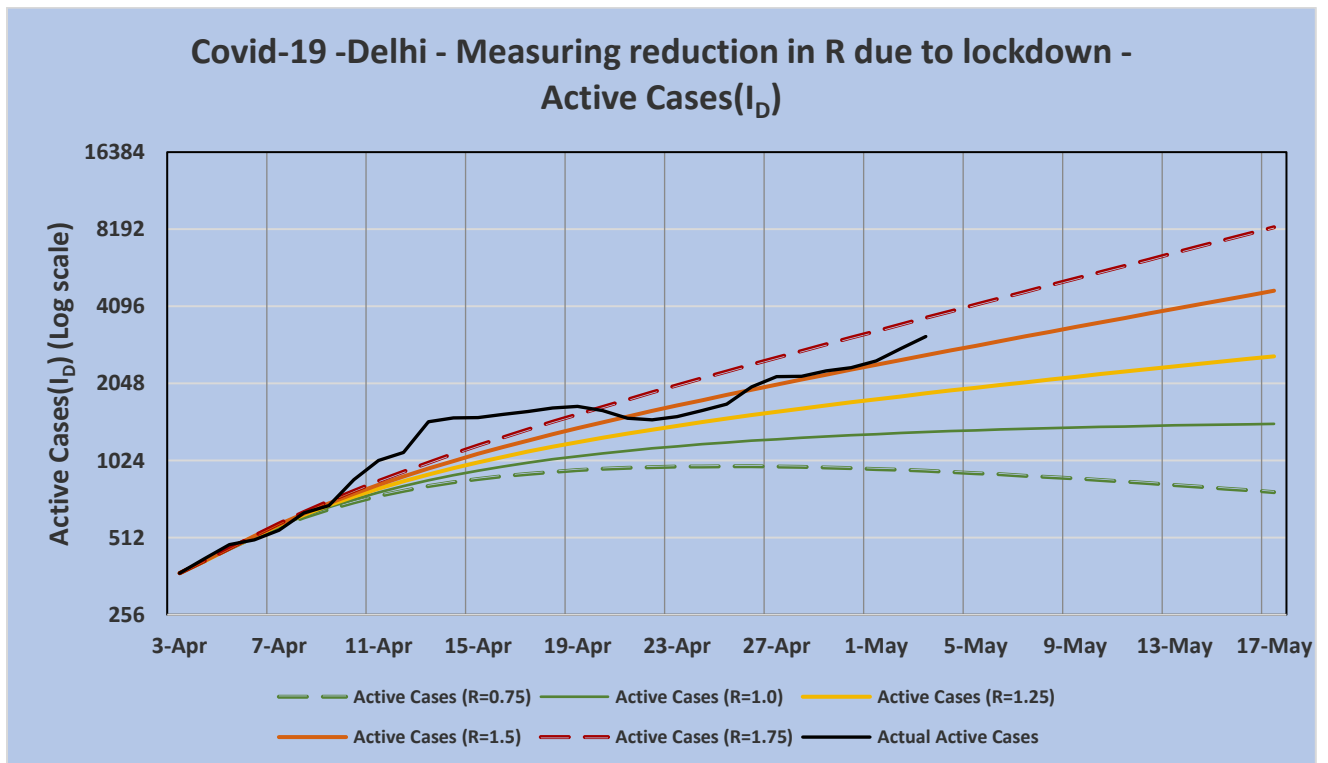


Figure 3

2. Maharashtra:

Initial Susceptible Population (S_0): 124.9 million (total population)^[14]

Partial Lockdown:

- Implemented from 13th - 15th March. (Schools, colleges, cinemas got closed from 15th March^[15])
- The effect will be seen 22nd March onwards.
- So, input values taken in the modified SEIR model:
 - Exposed (E_0): 320.45
 - Infectious (I_0): 513.31
 - Isolated/Detected (I_{D0}): 121
 - Recovered (R_0): 3
 - Fatalities (F_0): 1

Total Lockdown:

- Implemented around 22nd - 23rd March.^{[13][16]}
- Effects will be seen 3rd April onwards.
- Input values taken in the modified SEIR model:
 - Exposed (E_0): 1,242.55
 - Infectious (I_0): 851
 - Isolated/Detected (I_{D0}): 411
 - Recovered (R_0): 50
 - Fatalities (F_0): 26

Partial Lockdown/Social Distancing:

- R(reproduction number for partial lockdown) in Maharashtra was rising sharply towards 2.5 – 2.75 (graph was showing upwards trend from 30th March)
- At this rate, total cases in Maharashtra by 3rd May would have been between 18,730 – 25,512. *Figure 4* shows the predicted increase in total cases till 25th April at different values of R.
- Partial lockdown reduced the contact ratio very marginally in Maharashtra. (16.66% - 8.33%)

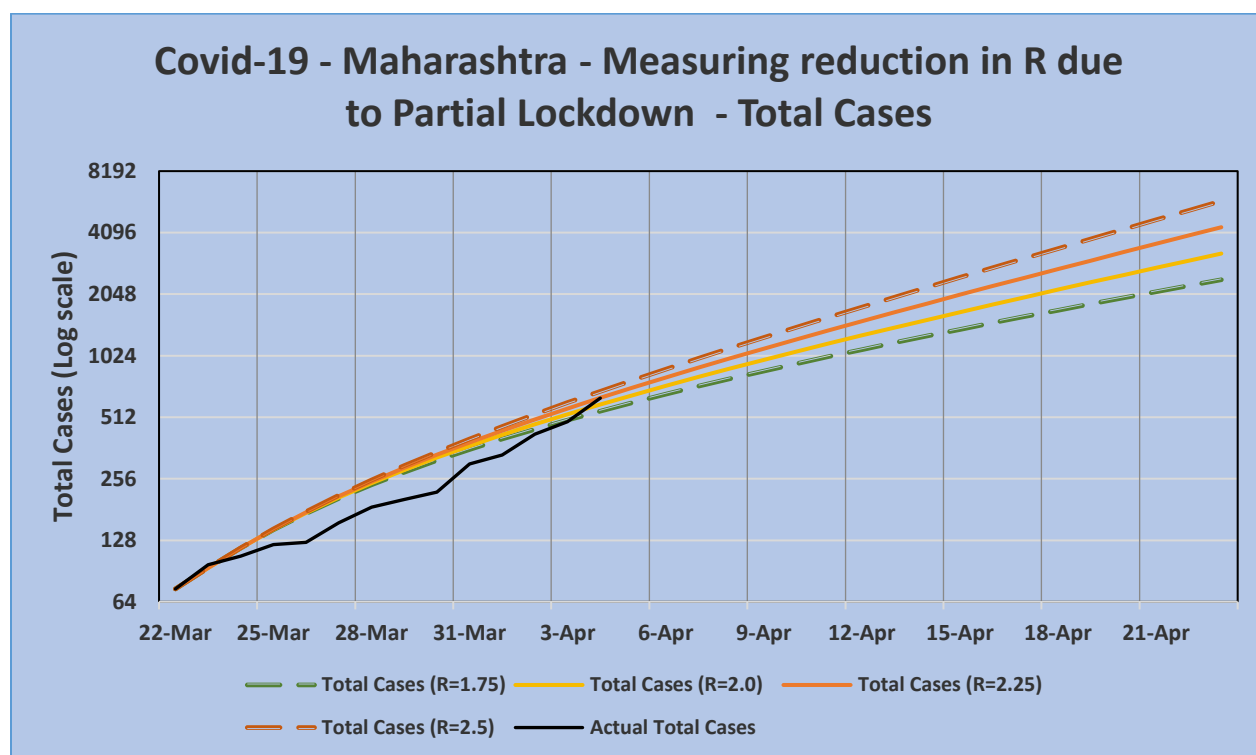


Figure 4

Complete Lockdown:

Observation on 3rd May:

- Total cases in the state on 3rd May – 12,974
- R(reproduction number for complete lockdown) in Maharashtra is holding steady at **1.75** from last 10 days(Maharashtra is still not showing any significant decline in R value even after more than 30 days of lockdown)

For 10th May:

- At this rate, total cases in Maharashtra by 10th May would be around **20,804**, as shown in *Figure 5*. If Maharashtra is able to reduce its R to 1.5 in the next week, then the cases might reduce to **17,640**.
- Also, by 10th May total active cases would be around **10,653** as shown in *Figure 6*

For 17th May:

- **Total cases** in Maharashtra by 17th May would be between **20,360 & 32,258**.

R_0 (reproduction number under normal conditions without any measure to reduce contact ratio) for Maharashtra is assumed 3, then total lockdown reduced the contact ratio in Maharashtra by 41.66% - 50%.

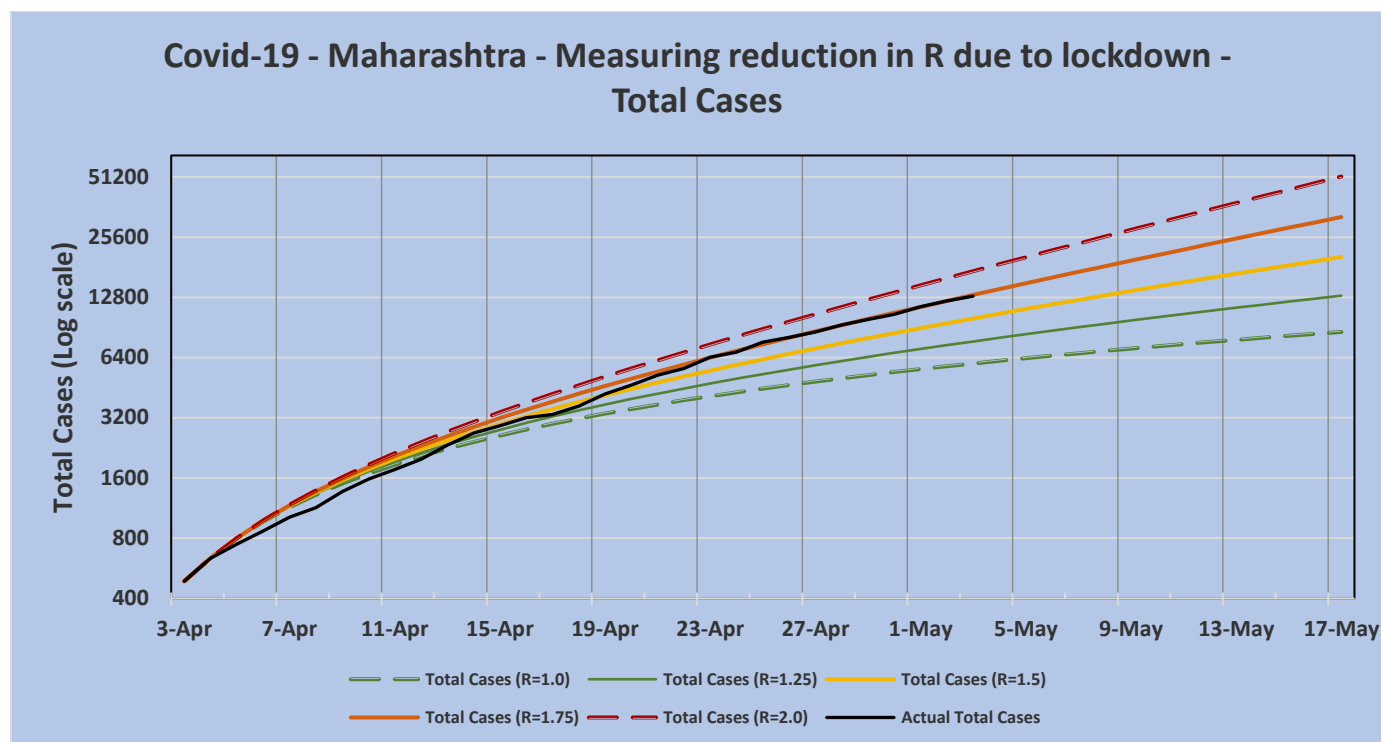


Figure 5

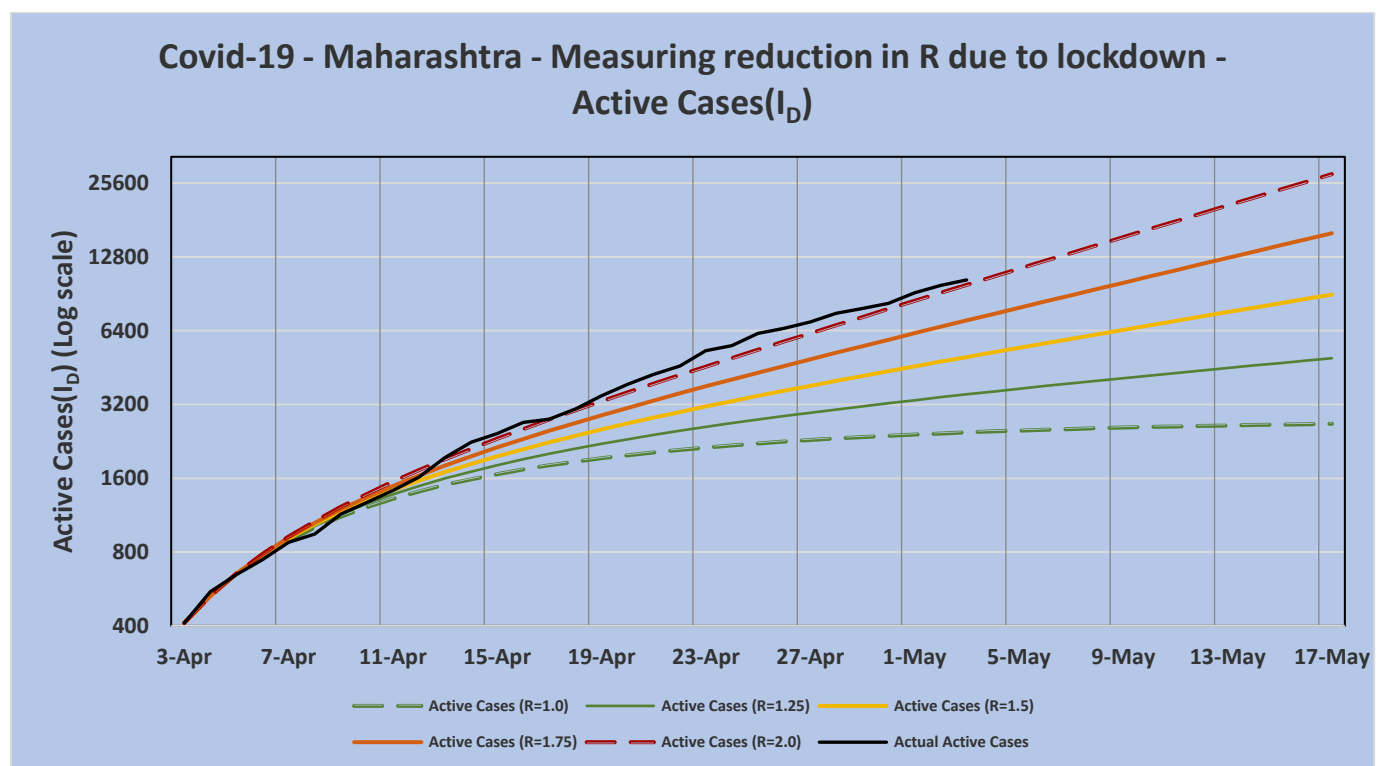


Figure 6

3. Gujarat:

Initial Susceptible Population (S_0): 64.8 million (total population)^[17]

Complete Lockdown:

- Implemented around 22nd – 23rd March. (Almost all hotspots sealed after Junta Curfew)^[18]
- Effects will be seen 3rd April onwards.
- Input values taken in the modified SEIR model:
 - Exposed (E_0): 396.57
 - Infectious (I_0): 180.4
 - Isolated/Detected (I_{D0}): 76
 - Recovered (R_0): 10
 - Fatalities (F_0): 9

Observation on 3rd May:

- Total cases in the state on 3rd May – 5,428
- R(reproduction number for complete lockdown) in Gujarat is falling gradually from last 10 days. If the trend continues, R will reach **2** in the mid of the next week.
- At this rate, total cases will be around **7,970** by 10th May. The actual number of cases and the future trend of total cases in the state can be seen in *Figure 7*.
- By 17th May, this figure will be between 8,613 & 13,689.

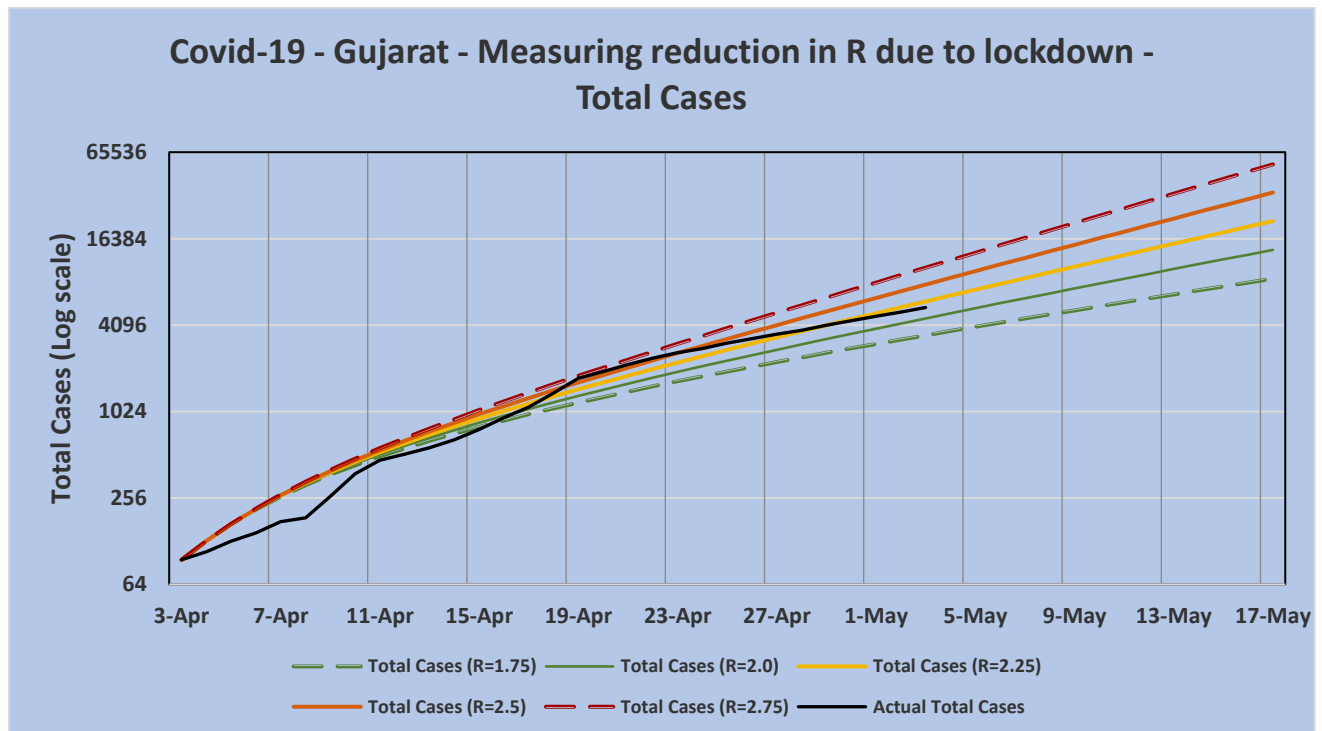


Figure 7

4. Kerala:

Initial Susceptible Population (S_0): 37.96 million (total population)^[19]

Complete Lockdown:

- Implemented around 22nd - 23rd March.^[20]
- Effects will be seen 3rd April onwards.
- Input values taken in the modified SEIR model:
 - Exposed (E_0): 30
 - Infectious (I_0): 57
 - Isolated/Detected (I_{D0}): 251
 - Recovered (R_0): 42
 - Fatalities (F_0): 2

Observation on 3rd May:

- Total cases in the state on 3rd May - 500
- R(reproduction number for complete lockdown) in Kerala has reduced to somewhere around **0.75 to 1** in last 35 days.
- As R has reduced below 1, there has been a gradual decline in the number of new cases. And the number of new cases will keep on declining in the next week as well.
- At this rate, total cases will be between **504 - 591** by 10th May. The actual number of cases and future trend of total cases in the state can be seen in *Figure 8* (last 2 green lines).

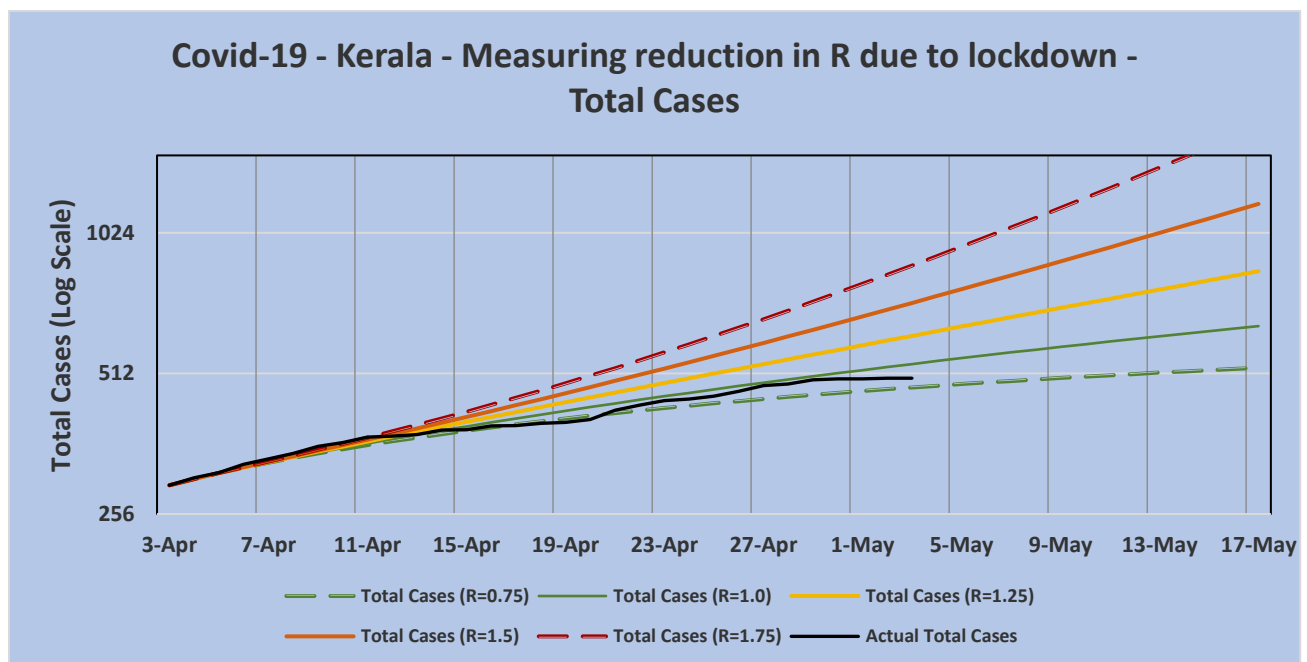


Figure 8

5. Uttar Pradesh:

Initial Susceptible Population (S_0): 233.37 million (total population)^[21]

Complete Lockdown:

- Implemented around 22nd - 23rd March.^[22]
- Effects will be seen 3rd April onwards.
- Input values taken in the modified SEIR model:
 - Exposed (E_0): 243.02
 - Infectious (I_0): 219.55
 - Isolated/Detected (I_{D0}): 155
 - Recovered (R_0): 17
 - Fatalities (F_0): 2

Observation on 3rd May:

- Total cases in the state on 3rd May – 2,645
- R(reproduction number for complete lockdown) in Uttar Pradesh is declining from **1.75** to **1.5** (from 27th onwards).
- At this rate, total cases by 10th May will be around **3,318 – 4,757** (most likely on the **lower side** of the range if the decline continues). The actual number of cases and future trend of total cases can be seen in *Figure 9*.

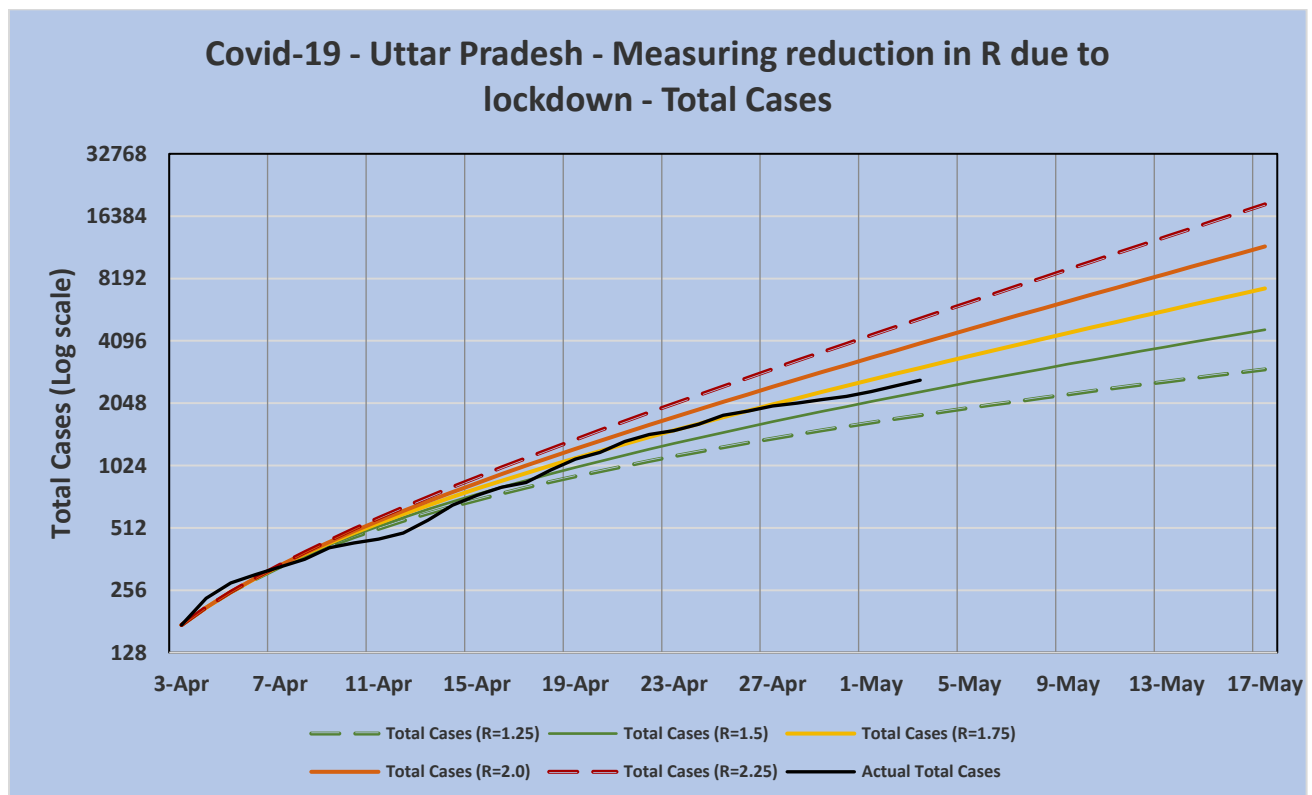


Figure 9

6. Karnataka:

Initial Susceptible Population (S_0): 67 million (total population)^[23]

Complete Lockdown:

- Implemented around 22nd - 23rd March.^[20]
- Effects will be seen 3rd April onwards.
- Input values taken in the modified SEIR model:
 - Exposed (E_0): 71
 - Infectious (I_0): 65.35
 - Isolated/Detected (I_{D0}): 113
 - Recovered (R_0): 11
 - Fatalities (F_0): 4

Observation on 3rd May:

- Total cases in the state on 3rd May - 614
- R(reproduction number for complete lockdown) in Karnataka is declining rapidly. It has reached 1.25 this week.
- At this rate, total cases will be between **768 – 1,056** by 10th May. The actual number of cases and future trend of total cases in the state can be seen in *Figure 10*.

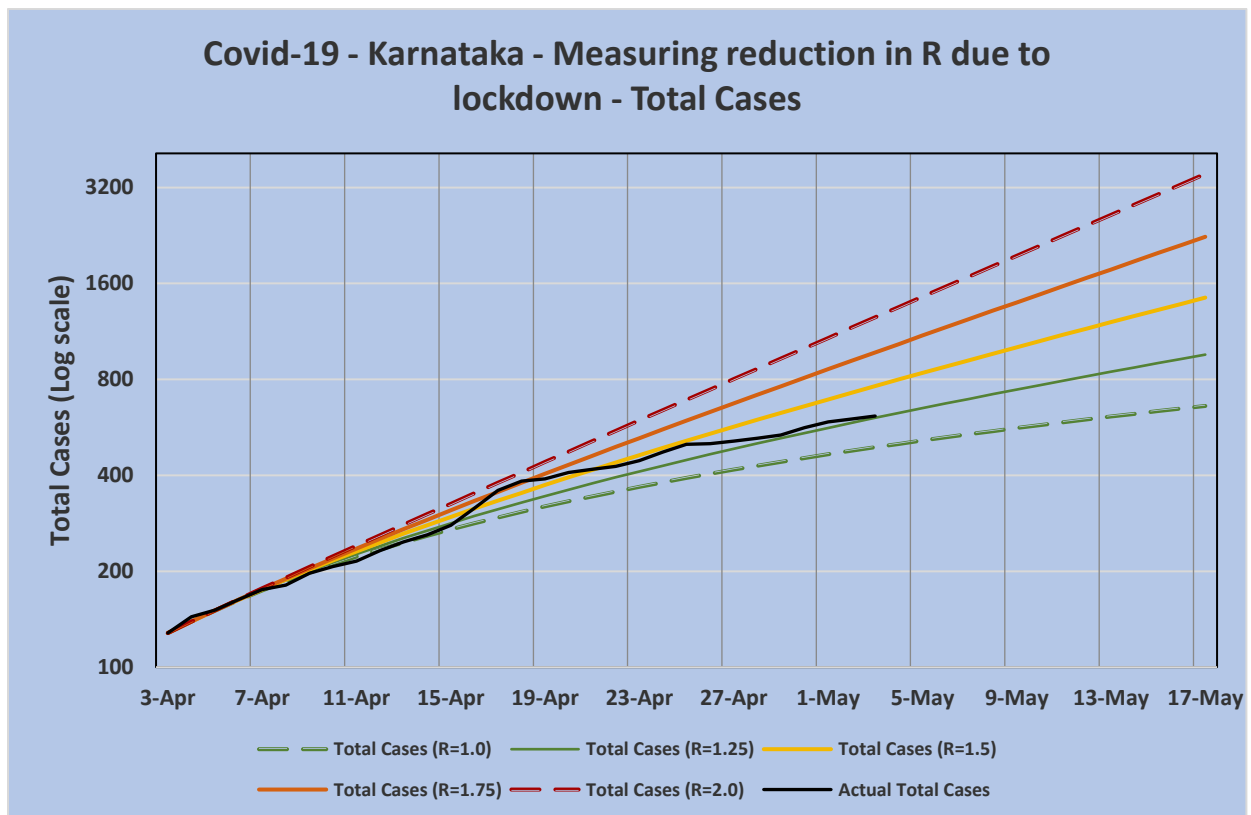


Figure 10

Limitations:

1. The current model works for Stage-2 of the pandemic. But at Stage-3, we need to account for those patients who were not tested and hence not detected. Those patients would spread the virus during the total duration of their infection.
2. Further reduction of R (reproduction number) due to containment measures and sealing off areas is not taken into account.

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