Modified SEIR Model

Keeping India's containment strategy for the novel coronavirus (subsequently named SARS-CoV-2) causing the disease Covid-19 in mind, 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:

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

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;

β: varying with R **σ:** $\frac{1}{5.2}$
γ: $\frac{1}{6}$ **δ:** $\frac{1}{21}$

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 $\mathbf{I_D}$ 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 been between 11,883 & 15,585. *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%

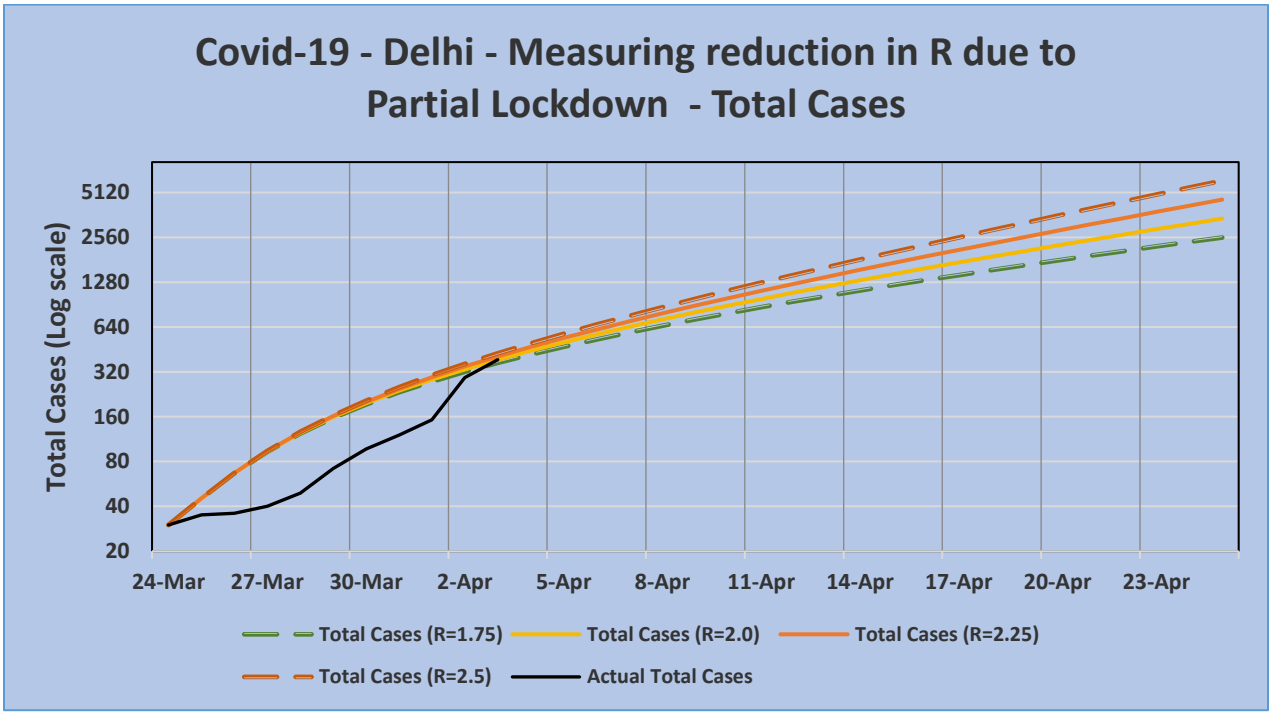

Figure 1

Complete Lockdown:

- R(reproduction number for complete lockdown) in Delhi had declined somewhere between **1** & **1.25** (major decline is seen around 13th April onwards, probably because of shutting off hotspot areas. Before 13th, R was between 1.25 to 1.50.)
- At this rate, total cases in Delhi by 3rd May would be between **3,264** & **4,161** as shown in *Figure 2*
- Also, by 3rd May total active cases would be between **1,322** & **1,872** as shown in *Figure 3*
- *Figure 4* shows the trend of the number of new cases per day. The average number of new cases per day would be between **99 & 171** on 3rd May. The figures are fluctuating, but their linear trend shows that the new cases trend lies between the R value of 1 & 1.25.

- In the worst case, R can go back to 1.5, due to which total cases by 3rd May would reach around 5,363, active cases would be around 2,637 and new cases per day would reach around 282.
- 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 66.66% - 58.33%.

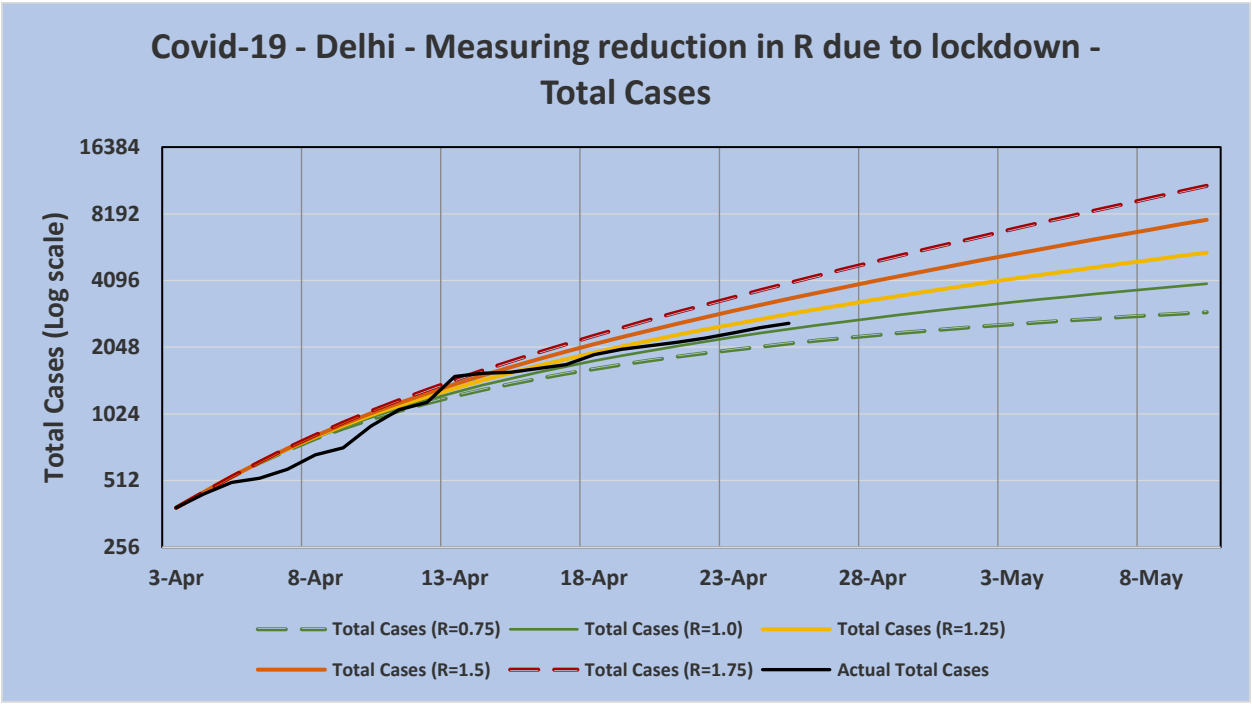

Figure 2

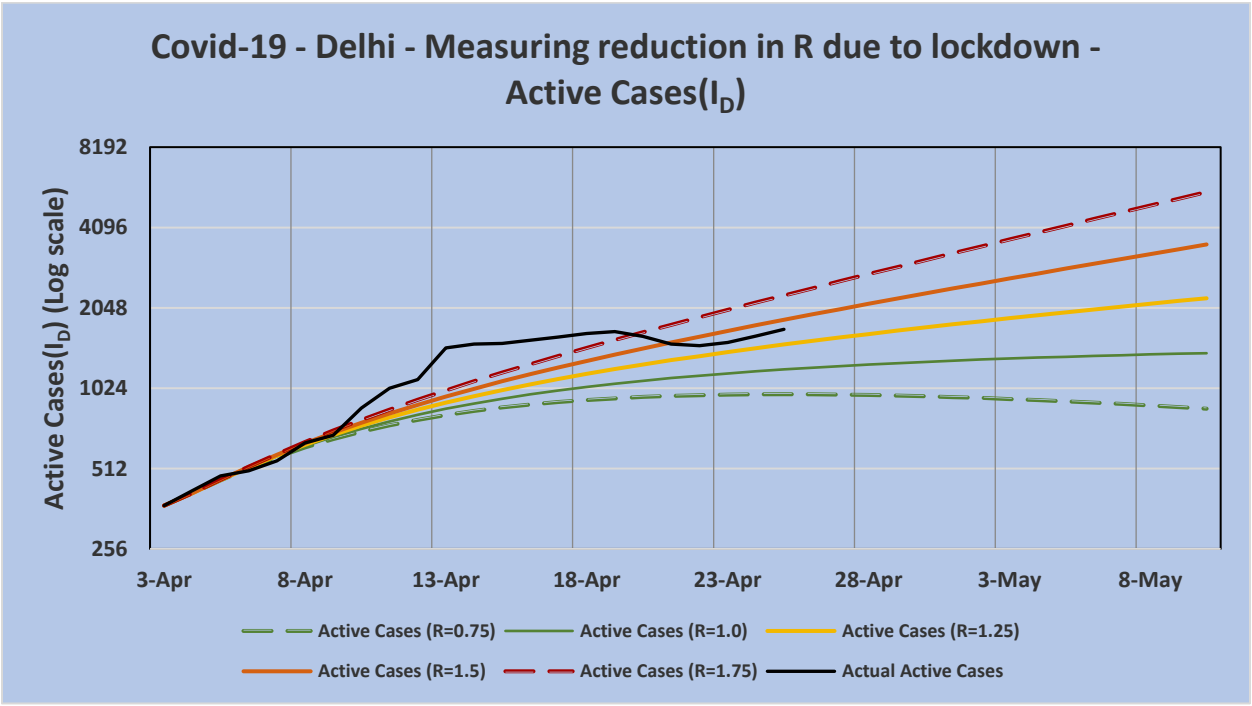

Figure 3

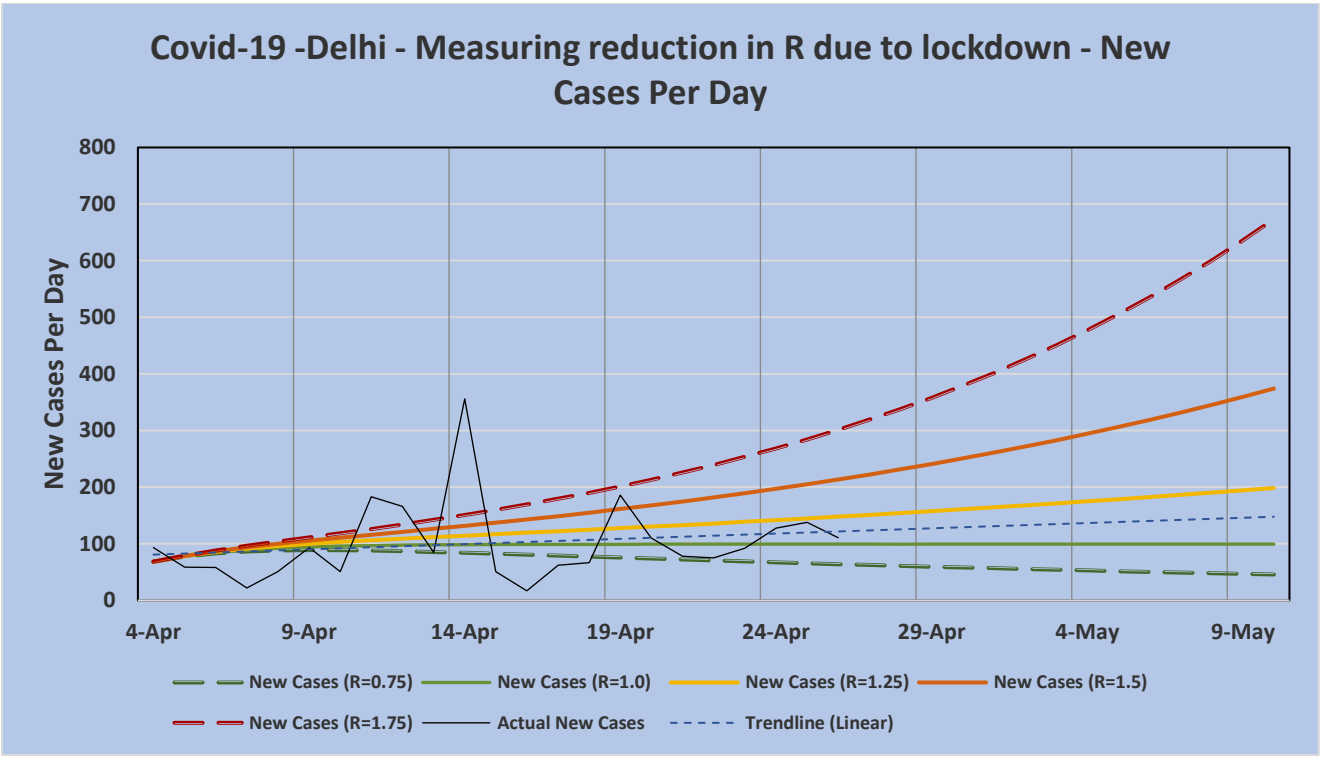

Figure 4

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): 1242.55
  - 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 hovering around **2 - 2.25** during the end of partial lockdown (graph was showing upwards trend from 31st March)
- At this rate, total cases in Maharashtra by 3rd May would have been between 11,006 & 16,067. *Figure 5* 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 Maharashtra is assumed 3, then partial lockdown reduced the contact ratio in Maharashtra by 25% - 33.33%.

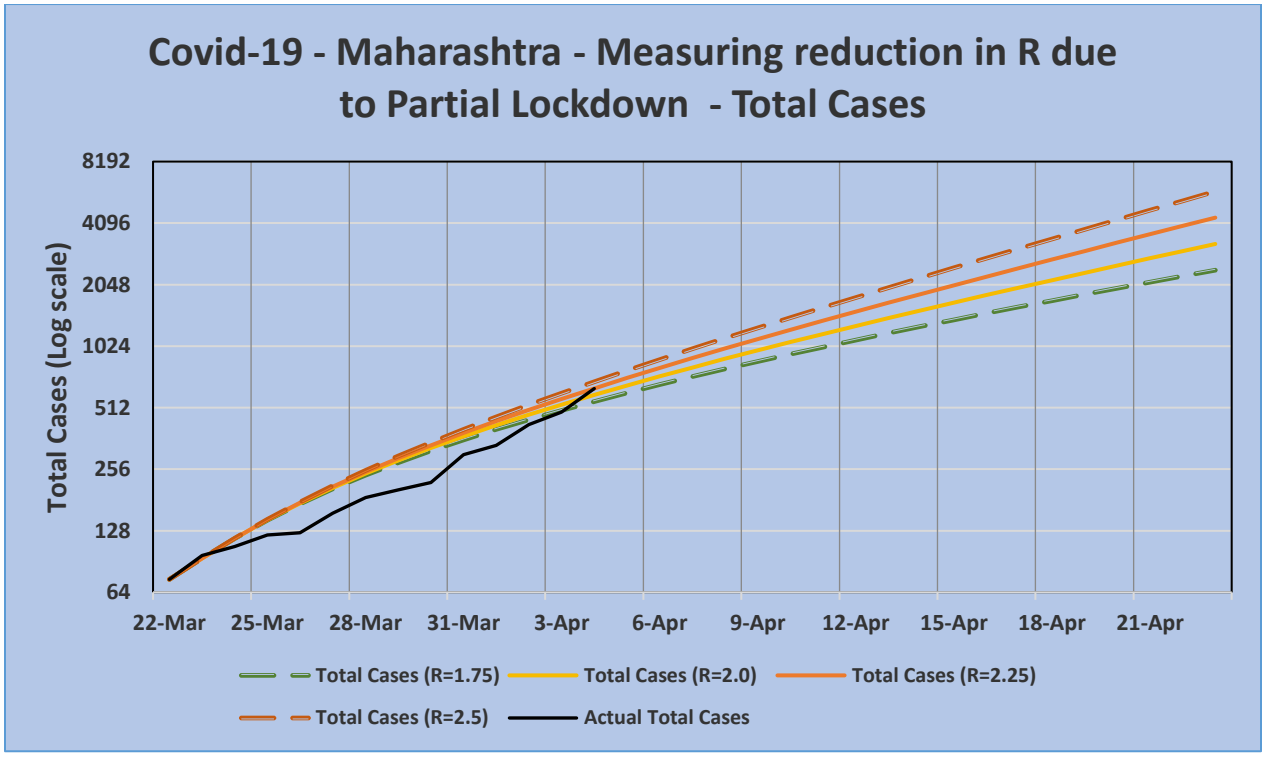

Figure 5

Complete Lockdown:

- R(reproduction number for complete lockdown) in Maharashtra has declined somewhere between **1.5** & **1.75** (Maharashtra is still not showing any significant decline in R value even after more than 30 days of lockdown)
- At this rate, total cases in Maharashtra by 3rd May would be between **10,031 & 13,145**, as shown in *Figure 6.*
- Also, by 3rd May total active cases would be between **4998 & 7044** as shown in *Figure 7*

- *Figure 8* shows the trend of the number of new cases per day. The average number of new cases per day would be between **561 & 914** on 3rd May. The figures are fluctuating, but their linear trend shows that the new cases trend lies between R value of 1.5 & 1.75.
- If 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%.

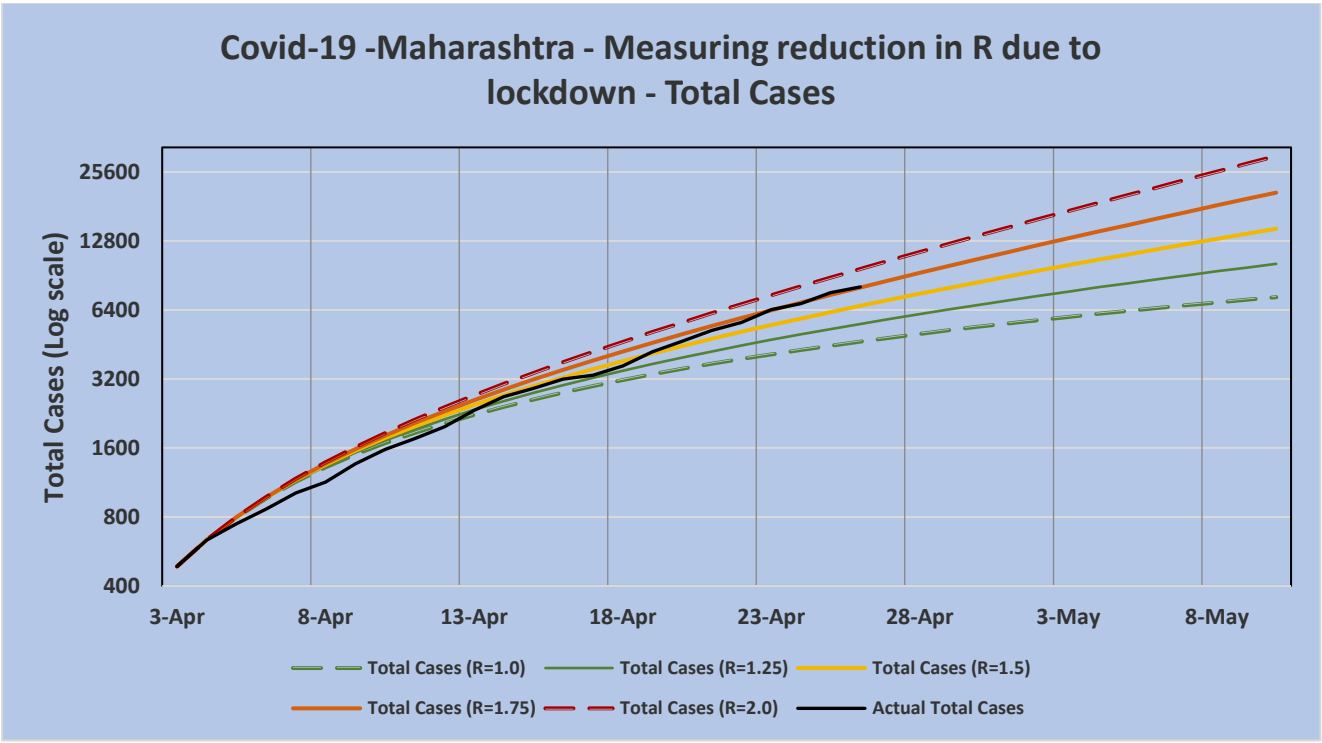

Figure 6

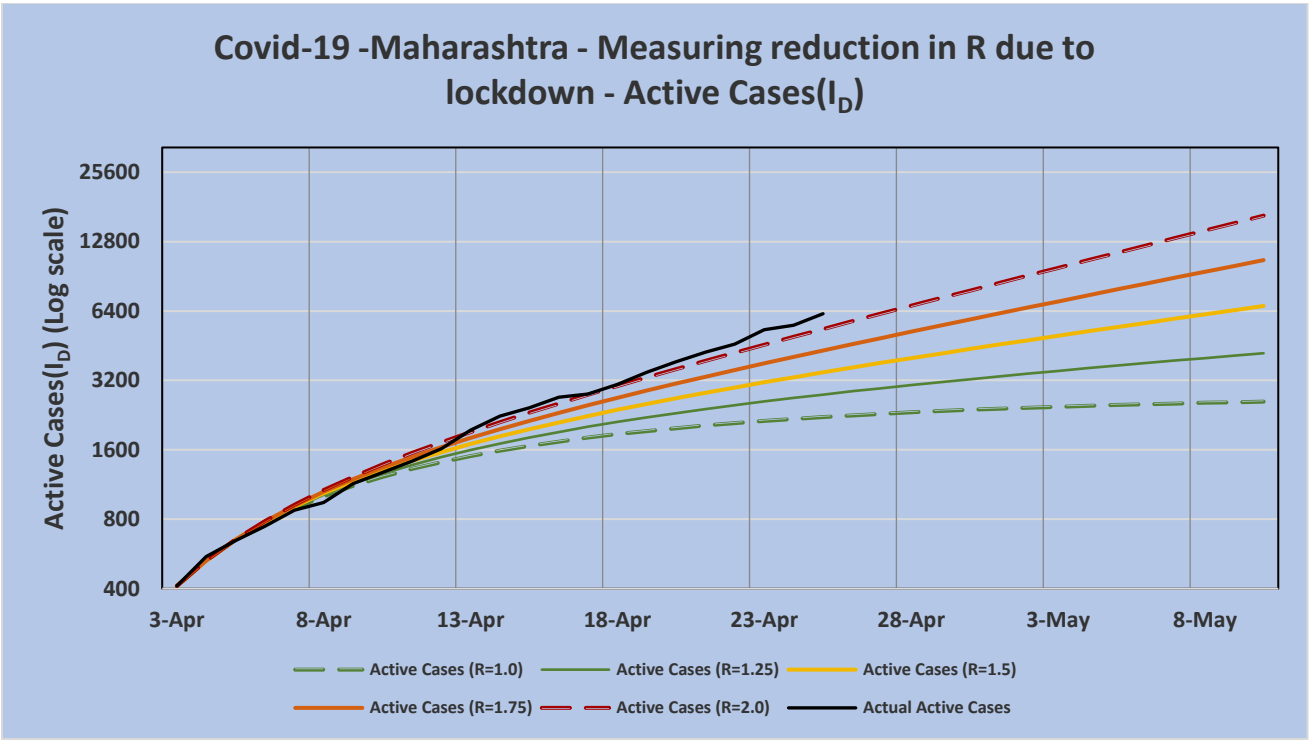

Figure 7

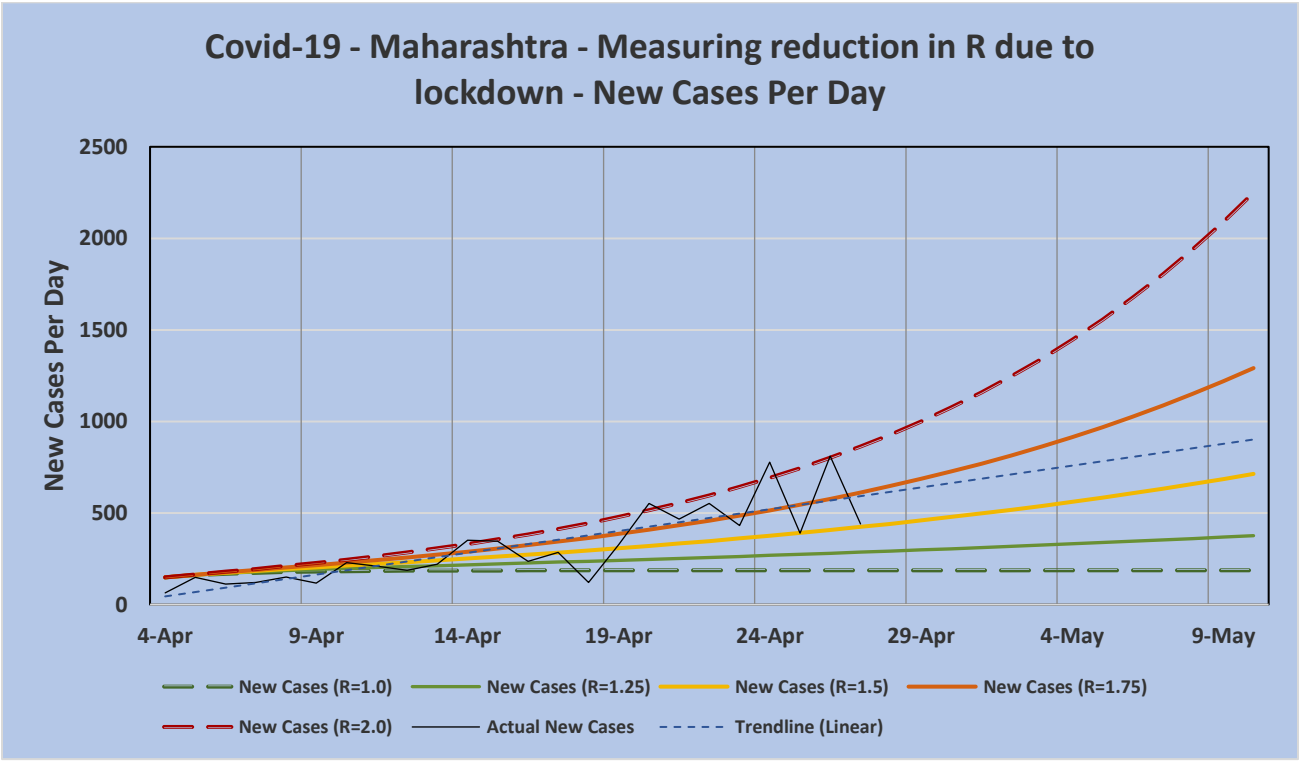

Figure 8

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:

- R(reproduction number for complete lockdown) in Gujarat is climbing up and is around **2.25 – 2.50** this week in spite of total lockdown.
- At this rate, total cases will reach around **5,990** to **7,861** by 3rd May. The actual number of cases and the future trend of total cases in the state can be seen in *Figure 9*.

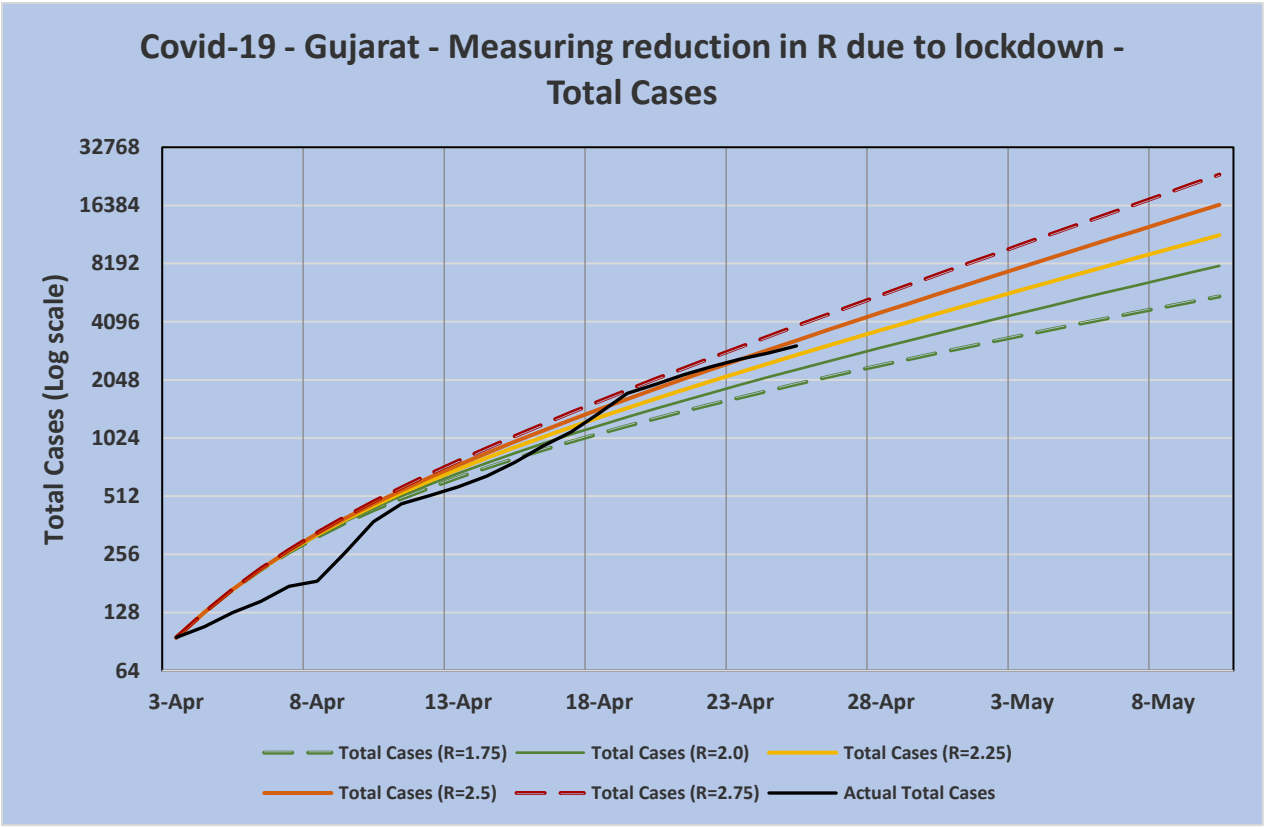

Figure 9

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:

- R(reproduction number for complete lockdown) in Kerala has reduced to somewhere around **0.75** to **1** in last 30 days.
- As R has reduced below 1, they have seen a gradual decline in the number of new cases as well. And the number of new cases will keep on declining in the next week as well.
- At this rate, total cases will be around **477 - 536** by 3rd May. The actual number of cases and future trend of total cases in the state can be seen in *Figure 10*(by last 2 green lines).

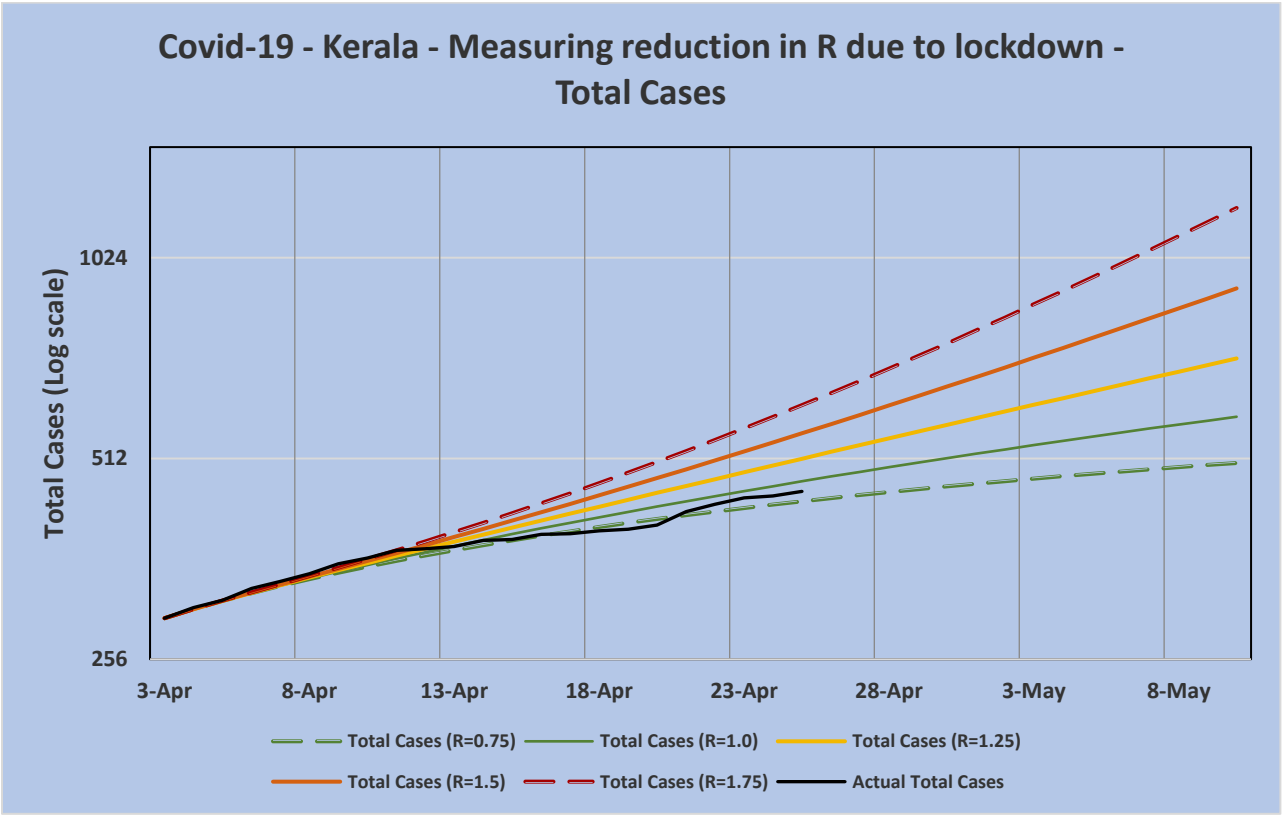

Figure 10

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:

- R(reproduction number for complete lockdown) in Uttar Pradesh has been at the lower side of the range **1.75** to **2**.
- At this rate, total cases will be around **3033 - 3980** by 3rd May. The actual number of cases and future trend of total cases in the state can be seen in *Figure 11*.

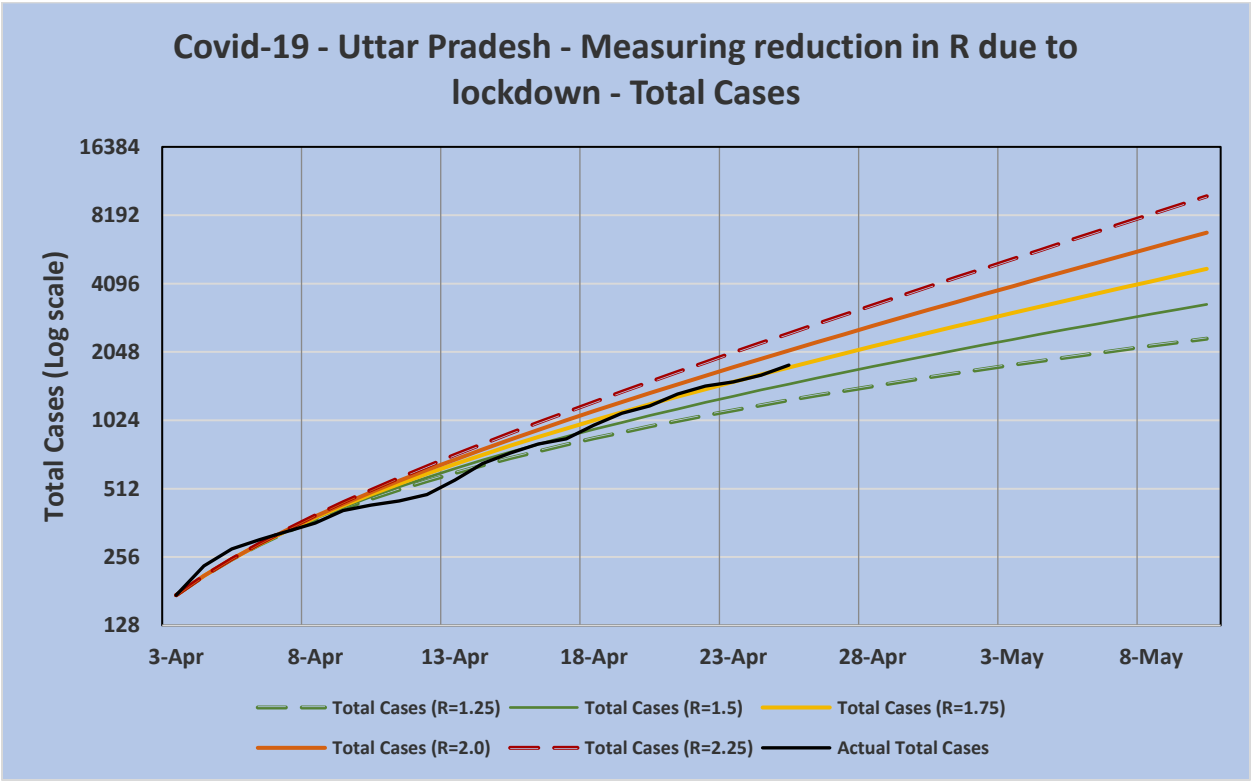

Figure 11

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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