

Potential 3rd COVID Wave in Mumbai: Scenario Analysis (Draft Report)

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June, 2021

I. SUMMARY

The second wave of Covid-19 that started in mid-February 2021 in India is now subsiding with daily cases down from peak of 4,14,280 on May 6, 2021 to 48,768 on June 25, 2021. Similarly fatalities have also reduced from peak of 4529 on 10 May to 1183 on June 25, 2021. The second wave first arose in the state of Maharashtra, and within it, Mumbai was amongst the first cities to see the increase. Mumbai saw a peak case load of 11,163 on April 4, 2021 and peak fatalities of 90 on May 1, 2021. These numbers have come down to 648 on June 26, 2021 for the cases and 15 on June 26, 2021 for the deaths. See our analysis on the second Covid wave in Mumbai in [1].

Increasingly the focus amongst the policymakers and general public is on the potential third wave. When would it occur? Would it be as large or larger than the second wave? Would vaccines play a key role in ameliorating it? Would new, more infectious and virulent variants show up? Would they break through the immunity provided by the vaccines and by prior infection? Would reinfections increase in the coming months and contribute to this wave? Would laxity in population behaviour be the key driver for the third wave?

Many of these questions are difficult to predict through a model. How does one model the probability distribution of occurrence of the next variant, its infectiousness, and its virulence? This point was tragically illustrated in the second wave where the delta variant was the key driver, but this would have been near impossible to predict late last year. Similarly, reinfections, especially severe ones, appear rare, but based on our current understanding, it is hard to accurately predict their future pattern. Vaccines appear to be effective, but there may well be substantial breakthrough infections especially if new variants become significant.

Due to these uncertainties, instead of projecting our *best guess scenario*, which we do not have, we conduct an extensive scenario analysis and track peak fatalities in the coming

months in each of these scenarios. Peak fatalities can be compared with the past peaks and can provide a reasonable guide to the medical resources needed to successfully tackle the associated wave. Our other aim of scenario analysis is to help policy-makers become better aware of the factors that may drive the potential third wave, so that it can be caught and controlled early.

While we discuss some of the details later, our key conclusions are

- As per our model, about 80% of Mumbai population has been exposed to Covid-19 by June 1, 2021 (see Figure 2). Under the assumption that all who are exposed have immunity against further infection, it is unlikely that Mumbai would see a large third wave. It is the reinfections that may lead to a large wave (see Figure 1). Reinfections could occur because of declining antibodies amongst the infected as well as by variants that can breakthrough the immunity provided by prior infections. Mechanisms need to be in place that continuously measure emergence of reinfections and variants that can breakthrough existing immunity, including immunity provided through vaccines.
- We also consider a somewhat pessimistic scenario where
 - reinfections are significant (amongst that 80% recovered, 10% are amenable to infections, and if infected, will follow the same disease progression as the first time infected),
 - a new variant that is 50% more infectious and 50% more virulent than the delta variant (we assume that delta variant is 2.25 times more infectious than the earlier variant in Mumbai and marginally more virulent),
 - the vaccine effectiveness is only 30%.
 - the city is opened up at 60% level and the compliance is 20% in non-slums and 10% from June 2021 onwards.

The resulting peak is seen to be no larger than that under the second wave (see Figure 1, scenario VE =0.30, R=10%, dark blue bar). This may be true for other urban areas as well where a large proportion of population has already been infected. Regions that have more susceptible population may witness larger waves when faced with a similar scenario.

Interestingly, the fact that a small increase in susceptible population in presence of highly infectious variant leads to a relatively high increase in peak fatalities was illustrated through Figure 17 in [1] (where reinfections lead to a small percentage increase in susceptible population but a relatively large increase in peak fatalities). This may largely

explain why Mumbai saw a peak of around 11,000 cases a day in the second wave while Delhi saw a peak of around 28,000 and Bangalore of around 25,000. Mumbai, with a population of around 13 million, already had around 65% population exposed to the disease (as per our model) on Feb 1. Delhi with 19 million population had an estimated 55% population exposed around this time [2]. Bangalore, with a population similar to Mumbai had estimated 45% exposed around Feb. 1 (see [3]). Thus, while the Mumbai administration was well organised in tackling the second wave, the presence of high sero-positivity may have helped Mumbai avoid the tragic consequences that may have resulted from a much higher peak.

- We further observe that under the scenario where the reinfections are mild so that they affect the fatality figures negligibly, where the new variants (beyond the existing delta variant) have a mild impact, it is natural for the city to further open up over time and for the population to become more lax over time. In this scenario we observe a small wave under which the fatalities begin to increase by around mid-August. See Figure 3. Hence, since the fatalities lag reported cases by around three weeks, the cases begin to increase by mid to late July. However, if by then the vaccine coverage is extensive, and vaccines prove to be between 75% to 95% effective, this wave will be barely noticeable even till September.
- From Figure 1 it may appear that vaccines are less impactful than one may naively imagine. A key reason for that is that in a city where 80% of the population has already been exposed to the virus, only a small fraction (say, around 20%) of the vaccines are administered to the susceptible population.

Below we also plot R_t , the infection growth rate at time t , and highlight some interesting observations.

II. DETAILS

Figure 1 illustrates the key summary of our analysis. We describe it in some detail. To set the stage some estimates are in order. As mentioned earlier, we estimate that around 65% of Mumbai was infected on February 1, 2021 at the beginning of the second wave (around 80% in slums and a little over 50% in non-slums. See Figure 2. Our model assumes, as per census 2011, that 53% of Mumbai resides in slums). To best fit the fatality data from March to May 2021 where we assume that the delta variant accounted for 2.5% of the infected on February 1 and is 2.25 times more infectious than the earlier Wuhan variant in Mumbai. We further assume that the population infected by this variant, if it needs ICU treatment, it is

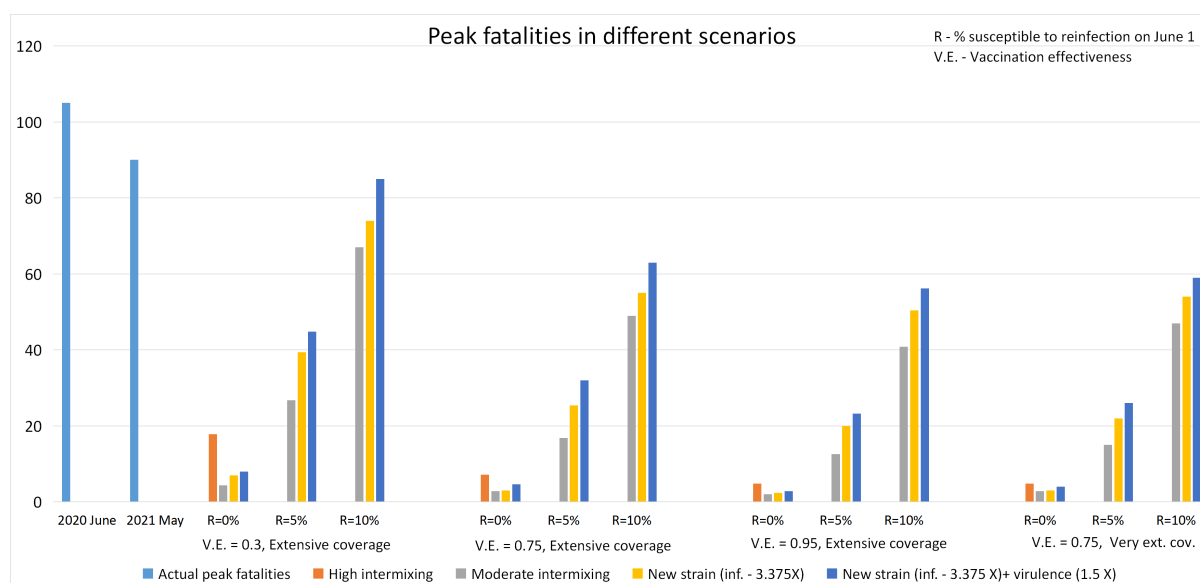


Figure 1: Peak fatality numbers under scenarios corresponding to varying reinfection rates, vaccine effectiveness and coverage, presence of infectious and virulent variant (in addition to the delta variant). Under the high intermixing orange bar scenario, we assume that that the city is opened up at 60% level in June, 80% in July and 100% thereafter. The compliance is 20% in non-slums and 10% in slums in June. This reduces to 10% and zero July onwards. In all other scenarios we assume that the city is opened up at 60% level, and the compliance is 20% in non-slums and 10% in slums June onwards.

for 18 days, an increase of 10 days over the earlier variant. This increase helps our model better fit the fatality data and is supported by our ongoing analysis of oxygen consumption data in Mumbai and Thane where we find that for the patients infected by the delta variant increasing the patient ICU stay by 8-10 days provides a better fit. Vaccines are administered in our model to roughly match the Co-win statistics for Mumbai [4]. This will be discussed in more detail in an elaborate version of this report. In our earlier reports including in [1], the symptomatic fraction of the exposed population is kept at 40%. We find that for the delta variant increasing it to 45% (this leads to 12.5% increased virulence) provides a somewhat better fit to the fatality data. Remaining parameters for the model are set as in [1].

Under this setting, we find that on June 1, 80% of Mumbai is infected, 90% in slums and 70% in non-slums. A little more than 10% of the susceptible have been vaccinated with a single dose (around 14 lakh administered a single dose and over 3 lakh administered the second dose in March and April that we conservatively assume to become effective a month later. We do not consider the vaccines administered to health care workers in our analysis).

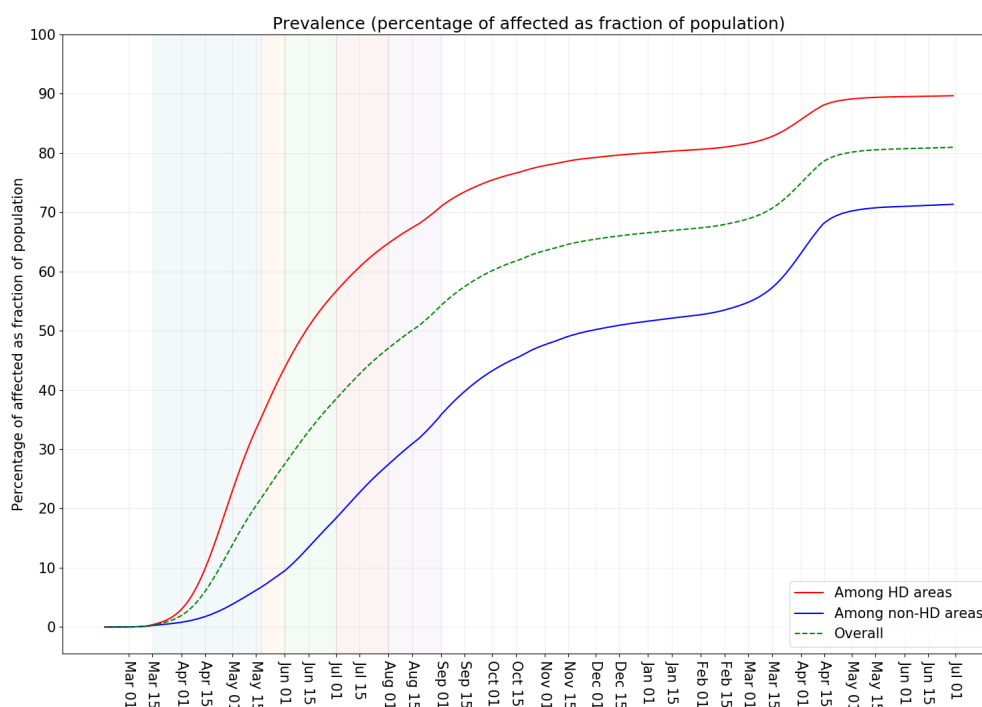


Figure 2: Prevalence (percentage of exposed as a fraction of the population). No new strain apart from the delta strain. No reinfections. City opens at 60% in June 2021, 80% in July and 100% from August. Compliance is 0.2 (non-slums), 0.1 (slums) in June and 0.1 (non-slums), 0 (slums) from July onwards.

A. Scenario analysis of peak fatalities

Given the large model uncertainty, there is an element of curve fitting through parameters in our model especially after February 1, 2021. Even then it is reasonable to believe that while the absolute numbers that we observe may have large error bars, our model output is useful in comparing scenarios. In this spirit, in Figure 1 we compare the reported fatalities peak in June 2020, and in May 2021 and compare them to 36 scenarios constructed as follows:

- Four scenarios are related to vaccine administration. These closely match the vaccines administered in Mumbai till end May. In three of these scenarios we assume that there is extensive coverage but the vaccine effectiveness takes values 0.3, 0.75 and 0.95. Under extensive coverage, monthly distribution of vaccines from March to September 2021 is 5 lakh, 12.2 lakh, 7.5 lakh, 20 lakh, 30 lakh, 30 lakh and 30 lakh doses. Again details will be provided in a later version. We make a somewhat conservative assumption that vaccines given in any month become effective a month later. Also, vaccine effectiveness of x means that every person receiving a dose is moved to the fully recovered category

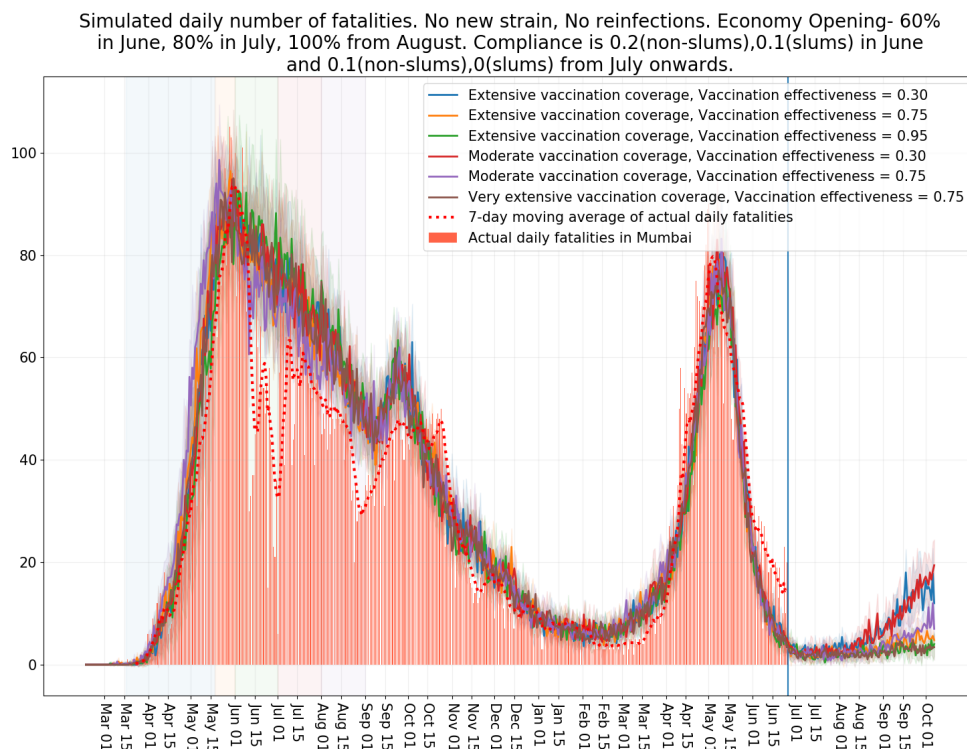


Figure 3: Simulated daily number of fatalities. No new strain apart from the delta strain. No reinfections. City opens at 60% in June 2021, 80% in July and 100% from August. Compliance is 0.2 (non-slums),0.1 (slums) in June and 0.1 (non-slums), 0 (slums) from July onwards.

with probability x . This is implemented by assuming that such a person is selected with probability x . However, it becomes recovered with probability 0.5 after the first dose. If it does not recover after first dose, and is not infected by the time the second dose is administered, then it recovers with probability 1 after the second dose. Under the fourth scenario we assume very extensive coverage (reaching 2 lac doses a day in July) and vaccine effectiveness of 0.75.

- For each of the four vaccination scenarios, we consider three reinfection scenarios. $R = 0$, $R = 5\%$ and $R = 10\%$. These increase the pool of susceptible population by assuming that fraction R of the recovered become susceptible. So with 20% susceptible population on June 1, $R = 10\%$ implies that 8% of the overall population now joins the susceptible pool increasing it to 28%. We further assume that each recovered person who joins the susceptible pool and is again infected, faces the same disease progression dynamics as a person who is infected for the first time. In practice, reinfections maybe milder than first time infections. So in essence we are only considering those reinfections that are

statistically as severe as the first time infections. Since it's not clear how reinfections will occur, as a worst case we assume that all of these occur on June 1. This would show an early and higher peak than if we had assumed that reinfections are more spread out in the coming months.

The $R > 0$ scenarios also provide insights for the case where the actual number of susceptible on June 1 are higher than the 20% suggested by our model.

- For each vaccine administration and reinfection scenario, we also consider three cases:
 - 1) There is no new strain over and above the dominant delta strain.
 - 2) There is a new strain that is present in small amount on June 1 (2.5% of the infected), whose infectivity is 50% higher than the delta strain and 3.375 times that of the strain active in Mumbai last year. Again, June 1 is chosen because this would lead to an earlier and higher peak than if the new variant were to evolve later. Virulence of this strain is assumed to be same as that of the delta strain.
 - 3) On top of the infectiousness as above in the new strain, we assume that it is 50% more deadly.

Our broad conclusions related to the scenario analysis of peak fatalities have already been discussed in the initial summary.

In Figure 3 we display the fatality projections corresponding to a plausible scenario where the reinfections are mild so that they affect the fatality figures negligibly and where the new variants (beyond the existing delta variant) have little impact. This corresponds to the first orange colored (high intermixing) bar in Figure 1. Here we assume that the city is opened up at 60% level in June, 80% in July and 100% thereafter. The compliance is 20% in non-slums and 10% in slums in June. This reduces to 10% and zero July onwards. These numbers reflect the increase in laxness that Mumbai may observe as the cases and fatalities continue their decline. In this scenario, as we mentioned earlier in the initial summary, the city may observe a small wave where the fatalities begin to increase by around mid-August. Hence, since the fatalities lag reported cases, the cases may begin to increase by mid to late July.

Fortunately, as is clear from Figure 3, if in the months of June, July and August the vaccine coverage is extensive, and vaccines prove to be between 75% to 95% effective, this wave will be barely noticeable even by September.

Model R_t : In Figure 4, we plot R_t in the above scenario as per our model. Recall that R_t is designed to measure the growth rate of the disease at time t . $R_t > 1$ signifies increasing

infection in the system and $R_t < 1$ signifies declining infection. We define R_t in two different ways. In the first method, it equals the ratio of the average number exposed between time t and $t + 1$ divided by the average number of people who stop being infective (in our model this equals the sum of the people who recover from the infectious symptomatic state and those who stop being infectious to others because they are transferred to hospitals) in this time period.

Interestingly, as can be seen in Figure 4, this number becomes roughly equal for slums and non-slums in Mumbai in August 2020, and more or less stays equal thereafter. The rationale for this may be that the interactions between the two populations in communities as well as in local trains, tends to move the two groups to equalize the differences.

Another way to define R_t is to track the average of the number of infections caused by an individual exposed at time t . These are measured at a few times and plotted as dots in Figure 4. Interestingly, this definition gives very similar numbers to the earlier one, and again these numbers are quite close for both slums and non-slums. Observe that this is true even though prevalence between slums and non-slums is substantially different.

III. SCENARIO GRAPHS AND DETAILED VACCINATION SCHEDULE

To be added

Acknowledgements to be added.

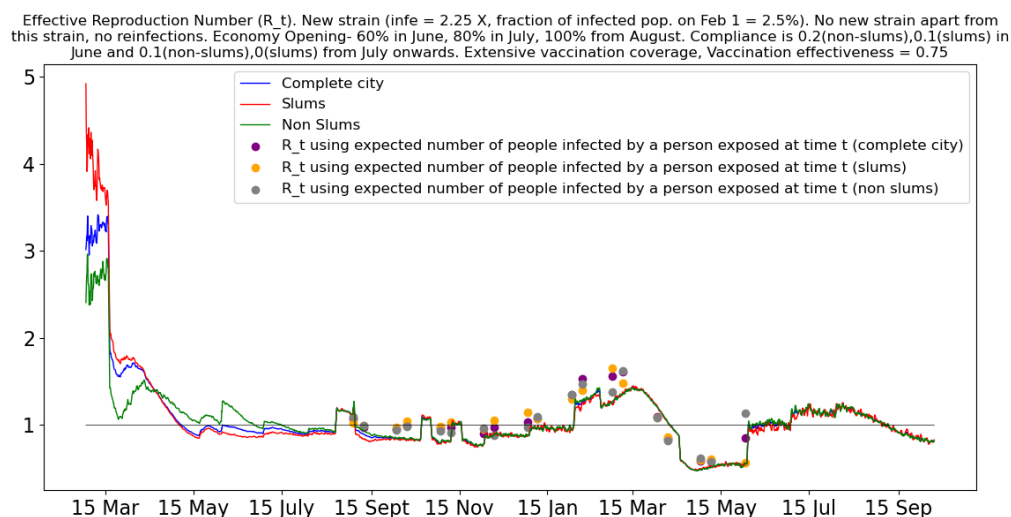


Figure 4: Effective reproduction number (R_t) for complete city as well as for slums and non-slums. Delta strain (infectiousness = 2.25 X, fraction of infected pop. on Feb 1 = 2.5%). In this scenario no new strain exists apart from the delta variant and there are no reinfections. The city opens at 60% in June, 80% in July and 100% from August. Compliance is 0.2 (non-slums) and 0.1 (slums) in June and 0.1 (non-slums) and 0 (slums) from July onwards. We consider extensive vaccination coverage scenario with vaccination effectiveness = 0.75.

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