Pattern and Future Magnitude of COVID 19 Cases in Selected Red Zone Areas of India

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Research Highlights

1. **Confirmed positive COVID – 19 cases have been rising, and at a varying pace in the selected red zone areas.**
2. **While 4 – parameter Logistic growth models fit best for Mumbai, New Delhi, Hyderabad, Thane, Guntur, and Coimbatore, 4 – parameter Gompertz model fits best for Chennai, Bengaluru, Ahmedabad, Pune and Kurnool. Exponential model grossly overestimated the cases.**
3. **The rising trend is expected to continue in the coming days, more importantly in Ahmedabad followed by Mumbai, Pune, New Delhi and Hyderabad.**
4. **The inflection date for reported positive cases in Mumbai, New Delhi, Chennai, Bengaluru, and Thane has already occurred. Hyderabad is expected to experience the same after July 12, 2020.**
5. **Chennai and Coimbatore may witness 'zero new cases' of the COVID – 19 by May 4th/5th, 2020. While Hyderabad may have to wait until mid–July or so. Others may have to wait about 4 to 6 weeks more to experience 'zero new cases' scenario if the current patterns continue.**
6. **Doubling time is estimated to go up to 21 days for Mumbai and Thane and 8–9 days for Hyderabad and Pune during the lockdown 2.0.**
7. **The cases are unlikely to double before June 9 in New Delhi, June 14 in Chennai, May 9 in Bengaluru, April 30 in Kurnool, July 3 in Guntur and June 29 in Coimbatore this year.**

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Introduction:

As of April 20, 2020, the total number of confirmed positive COVID–19 cases in India stood at 18477 [1]. India's efforts in containing the spread of deadly diseases are being applauded globally. The WHO and other international governments and agencies abroad have recognized the effective and bold measures initiated by the Indian Government including Find, Isolate, Test, Treat and Trace measures. The WHO representative to India described India's efforts as timely, comprehensive and robust [2]. Home to one–sixth of the global population (1.4 billion), India's efforts would have the greatest impact on global scenario. This has arisen keen interest amongst global agencies who are constantly eying to understand what India is doing to address this. Along with several initiations by the state and local governments and authorities to address the issue surrounding COVID – 19 spread, the nationwide 'Janata curfew' on March 22, 2020 followed by a nationwide 21–day lockdown to further extension of the lockdown to phase two until April 14, 2020 have received positive reviews nationally and globally. Nonetheless, as a nation, India is concerned with the spread of the diseases and threats associated with it in future on health and economic well–being of its people, not to undermine the short term and long term ill–effects of over 5–week long nationwide lock down on its economic growth at micro and macro levels.

A recent study by Shamika Ravi [3] has indicated that the number of confirmed positive cases in India have been doubling every 10 days instead of every three days which was observed before the nationwide lockdown on March 24, 2020. The study also noted that the doubling curve has begun to flatten around March 23, 2020 for the country. The joint secretary, Ministry of health and family welfare, Government of India, in his statement emphasized on how the nationwide lockdown has slowed down the average doubling time of the COVID–19 cases to 7.5 days as against of the 3.4 days before the nationwide lockdown was imposed [4]. He further stated that many states have succeeded in slowing down the doubling pace of the positive cases tremendously – 72.2 days (Kerala), 39.8 days (Odisha), 24.5 days (Himachal Pradesh), 21 days (Haryana), 16.4 days (Bihar) and 14 days (Tamil Nadu). In spite of this, there is a growing concern as the positive cases are rapidly growing in the national economic capital Mumbai, political capital New Delhi and a few other fully urbanized large districts. Presently, total confirmed cases for Mumbai stands at 3090 and New Delhi at 2156. The Indian government is identifying hotspots across the country and is imposing greater restrictions of the movement of the people from these areas to outside with an intention to control the spread beyond these hotspots.

In view of this, the present study is an attempt to project COVID–19 positive cases for the ten red zone areas including state of New Delhi in India where new positive COVID – 19 cases have been rising sharply. These include – Mumbai, Thane and Pune from Maharashtra, Chennai and Coimbatore from Tamil Nadu, Bengaluru from Karnataka, Kurnool and Guntur from Andhra Pradesh, Hyderabad from Telangana and Ahmedabad from Gujarat. These eleven red zone areas together accounted for two–thirds of the national COVID–19 positive cases of 18,477 (on April 20, 2020). For each of the selected red zone area, we provide various information including estimated number of confirmed cases at the end of the lockdown 2.0 (May 3, 2020), likely date on which they are expected to attain 'zero new cases', the date of inflection (date by which growth rate for the cases starts to decline) and average doubling time during pre–lockdown 1.0, lockdown 1.0 and lockdown 2.0 till April 20, 2020 period using different mathematical growth models.

Data and methods

Due to lack of time series data at the district level from a single source, the data used in the analysis for the selected red zone areas were extracted from various sources. Majority of the data was extracted from various federal and state government websites which have been updating it regularly. Nonetheless, in cases where official statistics was inaccessible or unavailable, other sources including Wikipedia and newspaper articles, media reporting were also used to complete the time series data. We compiled the data from the day when the first case was confirmed in the areas until April 21 for New Delhi, April 19 for Mumbai, Chennai, Ahmadabad, Pune, Thane, Kurnool and Guntur and for April 18 for Bengaluru, Hyderabad and Coimbatore (For details please see Supplementary Table 1).

Mathematical models of disease transmission are helpful to understand the transmission dynamics of infectious diseases and are used for short-term and long-term epidemic forecasts crucial for public health decision-making. These models are increasingly becoming useful as rising number of emerging and re-emerging infectious disease outbreaks has increased. Following five mathematical growth models were used to model and estimate the projected cases of confirmed COVID – 19 positive cases in the selected eleven districts:

a. 2–Parameter Exponential growth model
b. 3–Parameter Logistic growth model
c. 4–Parameter Logistic growth model
d. 3–Parameter Gompertz growth model
e. 4–Parameter Gompertz growth model

The mathematical expression of the selected five models are expressed as:

a. <u>2–Parameter Exponential model:</u>

$$Y = \beta_1 \beta_2^x$$

Where,

β_1 is initial population

β_2 is growth rate

x is the time variable

b. <u>4</u>–<u>Parameter Logistic model:</u>

$$Y = \beta_0 + \beta_1 / \left(1 + e^{(-\beta_2 * (x - \beta_3))}\right)$$

c. <u>3</u>–<u>Parameter Logistic model:</u>

$$Y = \beta_1 / \left(1 + e^{(-\beta_2 * (x - \beta_3))}\right)$$

Where,

x is the time variable

β_0 is lower asymptote

β_1 is upper asymptote minus lower asymptote

β_2 is growth rate

β_3 is age at the inflection point

d. <u>4</u>–<u>Parameter Gompertz model:</u>

$$Y = \beta_0 + \beta_1 * e^{\left(-e^{(-\beta_2 * (x - \beta_3))}\right)}$$

e. <u>3</u>–<u>Parameter Gompertz model:</u>

$$Y = \beta_1 * e^{\left(-e^{(-\beta_2 * (x - \beta_3))}\right)}$$

Where,

x is the time variable

β_0 is lower asymptote

β_1 is upper asymptote

β_2 is growth rate

β_3 is age at the inflection point

When population growth is unaffected by resource limits, the curve follows exponential resulting in a *J–shaped* curve. As a consequence, the population never attains stabilization. In reality, the available resources influence populations growth. Verhulst [5,6] considered the saturation level characteristics (carrying capacity) of a stable population for growth based modelling and forced a numerical upper bound on the growth. To incorporate this, he extended the exponential growth model and introduced S–shaped Logistic growth curves in which population may grow exponentially until it reaches the carrying capacity and slows down or stops thereafter. In its standard form, the Logistic growth curve considers point of inflection at 50% of the asymptotic size which may not hold true for all growth processes. Benjamin Gompertz [7] further extended the Logistic growth curve to estimate human mortality and derived it as a limiting case of Logistic growth curve. The point of inflection in Gompertz model is always at about 36.8 % of the asymptotic size. The 3–Parameter Logistic and Gompertz growth curves have a lower asymptote at zero, however if a non-zero asymptote is the need then the 4–parameters Logistic and Gompertz growth model are better. If a 3–parameter model is sufficient to describe the data, it is recommended over 4–parameter model since the parameters are less correlated. Moreover, in 3–parameter model, the estimates have more degree of freedom which can be important when a growth curve with small number of measured points is used. If the data points are more, then 4–parameter model may be more useful.

The unit of analysis was date–wise cumulative number of confirmed positive COVID–19 cases in selected districts and New Delhi. The analysis was conducted in two parts – Validation of the model and projection of the confirmed positive cases till 3rd May 2020 and beyond. All the confirmed positive cases till 14th of April 2020 were used for modelling and data from 15th of April to 19thof April was used for validating the models except for New Delhi for which model was fitted till 16th April and validated for 17th April 2020 to 21st April 2020 (for more details, please see the last column of Supplementary Table 1). Once the models were validated, the projected numbers of confirmed positive cases till 100th day since the start of the epidemic were estimated. However, here only the estimated confirmed positive cases as of 28th April 2020 and 3rd May 2020, the end of the second phase of complete lockdown in the nation have been presented. Apart from the confirmed positive cases, for Logistic (3 and 4 Parameters) and Gompertz model (3 and 4 Parameters). We further provide the date at which the districts are expected to observe 'zero new cases' of COVID – 19 was also estimated along with the date of point of inflection (expected date by which the number of new cases would start declining, the growth rate starts declining). These estimated are provided for each of the districts and New Delhi. We also provide estimated average doubling time of the positive cases for the period pre–lockdown 1.0, during lockdown 1.0 and during lockdown 2.0 for each district plus New Delhi. The analysis is conducted in STATA 16.

Sensitivity analysis: Beside analyzing complete data (including all data points for which information was available), we conducted a sensitivity analysis. We repeated the analysis using a subset data of confirmed positive cases restricting for the last 30 days' data for selected red zone areas. The results of the subset analysis were broadly similar to that of models with complete data till date. Hence, we have presented the results of the analysis with complete data only.

Profile of the study populations

According to the 2011 census, New Delhi recorded the highest population of 16.8 million followed by Thane (11.1 million) and Bengaluru and Pune (around 10 million) (Table 1). The population in other districts ranged between 3.1 – 7.2 million. While Mumbai and Coimbatore recorded a negative population growth rate between 2001 and 2011 censuses, Bengaluru and Thane grew at an annual rate of over 3%. Chennai recoded very high population density (26,553 persons per square kilometer) followed by Mumbai (19,652), Hyderabad (18172) and New Delhi (11,320). Contrary to this, the population density ranged between 230 in Kurnool to Bengaluru (4,381). Mumbai, Chennai, and Hyderabad were fully urbanized districts whereas nearly 98% of the New Delhi population and 91% in Bengaluru in 2011 lived in the urban areas. Share of urban population varied between 28% in Kurnool to 84% in the remaining districts. The work participation rate varied between 33% in New Delhi to 50% in Kurnool. Seventy–three to 90% of the people residing in the districts were literate. Forty–two percent of the Mumbai people lived in slums. The corresponding figure for Hyderabad was 33% and 29% for Chennai. In Guntur, Kurnool, Pune, Thane, Coimbatore and New Delhi, about 12% to 40% of the urban population lived in slums. However, the share of urban people resided in slums was less than 2% for Ahmedabad and 8% for Bengaluru. The mean household size varied from a low of less than 4 in Chennai, Guntur and Coimbatore to 4.7 in Ahmedabad.

A considerable proportion of the households surveyed in the National Family Health Survey – 4 (NFHS – 4) conducted in 2015–16 lacked access to improved sanitation facility (defined as flush to a piped sewer system, septic tank, pit latrine, ventilated improved pit (VIP) / biogas latrine, pit latrine with slab, twin pit/composting toilet and not shared with any other household). For example, less than 40% of the households in Mumbai had access to improved sanitation facilities. The percentage of such households varied between 53% in Kurnool to 89% in Ahmedabad. Relatively speaking, access to improved drinking water and the use of clean fuel was better, although not universal. Nearly one–quarter of the households in Thane and 36% in Kurnool used unclean fuel for cooking and about 20–25% lacked access to improved drinking water or clean fuel in Guntur. Nearly one–quarter of the surveyed households in Kurnool and 20% in Thane and Guntur and about 10–11% in Mumbai and Pune belonged to the poorest and poorer wealth quintiles. A sizeable proportion of the households in Guntur (20%), Hyderabad (16%), Bengaluru (15%), Kurnool (14%) and New Delhi (11%) had a BPL card.

The health indicators for the selected areas were not very encouraging; 43% of the children aged 6–59 months in Coimbatore and as many as 76% of them in Ahmedabad were anaemic. The share of anemic children was 66%–68% in Mumbai and New Delhi. The share of anemic adult women and men aged 15–49 years too were considerably high with a wider gender disparity; higher prevalence among adult women than men. About 49%–58% of adult women and 23%–29% of the adult men in Mumbai and New Delhi were anemic at the time NFHS – 4 was conducted. Ahmedabad too, showed higher prevalence of the anemia for both adult men and women. The percentage of adult women and men with high blood sugar levels too was alarming, however, the levels were relatively lower among adult women in Thane, Kurnool, Coimbatore and New Delhi. Nonetheless, the corresponding levels were higher in other districts (8–12%). Correspondingly, the prevalence of high blood sugar levels among adult men was low in Kurnool, Pune, Thane, and New Delhi (2–4%), whereas it was higher (8–14%) in the remaining districts. Both soap and water were available at hand washing place for the majority of the households. A significant share of households reported that one or more family members usually smoke inside the house; 17% in Pune to 41% in Coimbatore. In Coimbatore, 3.6 persons per 1000 people were suffering from TB at the time of the survey. The corresponding figure for Chennai and Pune was 3.1 per 1000 people.

Results

Supplementary Figure 1 provide a comparison of reported and modeled confirmed cases of COVID – 19 for each of the selected red zone areas. While 3–Parameter Gompertz growth modeled cases yielded much higher number of modeled cases than the reported cases for Mumbai, New Delhi, Chennai, Thane and Coimbatore, they were relatively closer for Bengaluru, Hyderabad, Kurnool, Guntur and Coimbatore. The modeled values were closer and similar to the reported cases for Bengaluru and Hyderabad from all five models included. The 2–Parameter exponential growth model and 3–Parameter Gompertz growth model yielded better fit modeled values, whereas other methods included much lower values than the observed values for Ahmedabad and Pune. The modeled values for all methods for Kurnool and Guntur were either higher or lower than the reported cases.

Before estimating the number of positive cases for future dates, we determined the goodness of fit of each of the five models used based on Mean Residual Standard Deviation. The results are presented in Table 2. The findings indicate that while 4-parameter Logistic growth model emerged to be 'best fit' for Mumbai, New Delhi, Hyderabad, Thane, Guntur, and Coimbatore, 4-parameter Gompertz model emerged as 'best fit' for Chennai, Bengaluru, Ahmedabad, Pune and Kurnool. With the exception of Chennai and Hyderabad, the 3-parameter Logistic models emerged as the 'better fit' model for the remaining red zone areas. In general, 2-parameter exponential model grossly over-estimated the cases for all red zone areas except Hyderabad where this model emerged as 'good fit'.

The estimated number of cases as of April 28, 2020 (two–weeks after the launch of the lockdown 2.0) and at the end of lockdown 2.0 are presented in Table 3 and Figure 1. At the outset, we may mention that we have included the estimated positive cases from 2–Parameter exponential growth model, we shall restrict our discussion on the estimated numbers from 3–Parameter logistic growth model, 4–Parameter logistic growth model, 3–Parameter Gompertz growth model and 4–Parameter Gompertz growth model. The estimated confirmed cases for April 28, 2020 suggest that Ahmedabad is likely to have the highest number (3473 – 5497) followed by

Mumbai (3040 – 3911), New Delhi (2242 – 2556), Pune (1079 – 1753) and Hyderabad (1070 – 1299). On the other hand, regardless of the model, expected number of confirmed cases would be 600 or fewer cases for remaining districts. The estimated cases are likely to be about 200 for Bengaluru, Kurnool, Guntur and Coimbatore, 250 – 275 for Chennai and 444 – 571 for Thane. The patterns remain similar for the period ending lockdown 2.0. While the estimated numbers on May 3rd, 2020 showed further rise in the cases for Ahmedabad (4491 – 12690) and Mumbai (3108 – 4464), they revealed a declining trend in the remaining districts. New Delhi, Hyderabad and Pune although they are likely to see a reduction in total number of cases, nonetheless, the numbers are expected to range between 1500 to 3000 cases. Thane is expected to have fewer than 700 cases on this date. The confirmed cases for Chennai, Bengaluru, Kurnool. Guntur and Coimbatore are expected to be 200 or so by May 3rd, 2020.

Table 4 gives the date of inflection by which the districts are expected to see a decline in the growth rate of the confirmed positive cases of the COVID – 19. The modeled value revealed that Mumbai, New Delhi, Chennai, Bengaluru and Thane have already experienced a reduced growth of increase in the positive cases. This validates with the date wise percentage change in the reported confirmed cases in these districts. The modeled date of inflection for Kurnool, Guntur Coimbatore largely matches with the observed pattern. The results of logistic growth models indicate that Ahmedabad and Pune too would soon experience this, whereas this may happen later in June as per the results of Gompertz growth models.

The expected date by which the districts might reach 'zero new cases' of the COVID – 19 is presented in Table 5. The results vary across models. For example, 'zero new cases' date falls earlier for Logistic growth models compared to the Gompertz growth models. This is true for all districts and New Delhi. Coimbatore is expected to attain 'zero new cases' by April 25–26, 2020 (Logistic growth models) and by May 4, 2020 (Gompertz growth models). Guntur and Kurnool too are expected to attain 'zero new cases before the end of April 2020 (Logistic growth models) or two weeks after the end of lockdown 2.0 (Gompertz growth models). Chennai too is expected to attain 'zero new cases' just around first week of May, 2020. The Logistic growth models results indicate that New Delhi may attain ‘zero new cases’ by May 13, 2020 and Mumbai a week later (May 22, 2020). The Gompertz growth models indicated that this may happen in Chennai only after June 9 and after June 22, 2020 in Mumbai. Bengaluru, Ahmedabad, Thane and Pune are expected to attain this somewhere after June 2020.

Regardless of the model, the date of inflection for Hyderabad is estimated after July 12, 2020 (Table 6). The average doubling time of the reported positive cases varied between 4 in Mumbai, Bengaluru, Pune and Thane to 5–days for New Delhi and 7 days for Chennai during the pre–lockdown 1.0 period (that is, the period between onset of the cases and March 23, 2020. Coimbatore did not experience doubling during this period. The average doubling time increased to 16 days for Bengaluru during lockdown 1.0 (between March 24 to April 14, 2020) and 5 and 6 days for Pune and Thane, respectively to 4 days for Ahmedabad. While doubling time for Mumbai remained unchanged, it declined by one day for New Delhi. The doubling time based on the modeled values for the lockdown 2.0 (April 15 to May 3, 2020) is expected to rise to 21 days for Mumbai and Thane, 9 days for Pune, 8 days for Hyderabad and 5 days for Ahmedabad. The cases are unlikely to be doubled during this period for New Delhi, Chennai, Bengaluru, Kurnool, Guntur and Coimbatore.

Discussion and Conclusion

The analysis revealed that the growth of the confirmed positive COVID – 19 cases in the selected red zone areas has been at varying pace. The areas with large population sizes have generally revealed faster growth in the confirmed cases than the districts with a small population base. The analysis further suggests that the scenario in the near future is not giving us much relief since the cases are expected to rise further and many folds, especially in Ahmadabad, New Delhi, Mumbai, Pune and Hyderabad, fully or nearly fully urbanized areas. In order to understand the dimensions of the pandemic, one must understand the settlement patterns, living conditions, and access to health services in the areas with large population sizes. It becomes even more important for India as India is a developing and resource constraint country where resources available to sudden pandemics are inadequate and so is the preparedness of the local health and other infrastructure to deal with the sudden incidents such as COVID – 19.

A substantial proportion of the population in the selected red zone areas live under very poor social and economic environment and comprise of migrant populations. Urban poverty poses several threats of housing and shelter, water, sanitation, and health. Past studies have shown that poor urban residents, particularly lack access to basic amenities [8, 9, 10] and belong to the economically deprived section of the society. Urban poor live in extremely miserable living conditions that characterize of overcrowded houses, the areas are often constructed of substandard materials, polluted and lack access to basic amenities, including health facilities [11]. The 2011 census results indicated that the homeless population in India increased by 21% in 2001 and 2011 reaching a total of nearly one million. Not only is the size of homeless people big in India, they are mainly concentrated in large cities and several live in urban shelter and are subjected to miserable living condition [12]. Further, the availability of public health services in the urban areas is poor [8, 9]. Unlike rural areas where we have an active public health delivery system in which health workers reach out to the needy population at their doorstep for service provision, in the urban areas our public health delivery system remains passive. Although, private health delivery services are better available for the urban population, many cannot afford them as they are expensive.

Rate of testing to diagnose the cases infected with the people is key to implement 'Find, Isolate, Test, Treat and Trace measures' to enable prevention of community spread of the virus. The WHO's director general in mid–March has firmly emphasized on it and said that the WHO has a single message for all countries, that is, "test, test and more test." This is clearly the most effective tool, however, for many countries including India given their financial and human resources become a major barrier. Currently, the testing rate in India is quite low when compared with other countries. As of April 22, 2020, twelve countries have attesting rate of over 10,000 per million populations, ranging between 10,004 in Netherlands to 25,993 in Switzerland [14]. On the same day, the testing rate per one million population varied from a New Delhi (1401), Tamil Nadu (765), Maharashtra (735), Andhra Pradesh (670), Gujarat (608), Karnataka (298), and Telangana (282) [14], states of the eleven districts included in the analysis. The conformed cases would rise in future, and may be at a faster rate, should India increase its testing rate. Regardless, India must accelerate its testing rate immediately to protect from wider hazards.

India so far has succeeded in keeping its COVID – 19 fatality rates low; the COVID – 19 mortality rate is about 3.3%. As of April 23, 2020, 681 lives have been lost due to COVID – 19; Maharashtra alone has contributed to about 40% of this national loss. On the brighter side, 4257 patients in India have thus far recovered from the disease and have been discharged. This is an achievement knowing how inadequate, resource deficit and overburdened our health delivery system is in the country and in several states. In terms of width of the disease spread, the available data suggests uneven distribution of the cases within an area. In fact, the government statistics is suggestive of concentration of the in selected localities/wards. For example, the majority of the confirmed cases have been recorded from a few pockets in Mumbai [15], New Delhi [16], Tamil Nadu [17], and Karnataka [18].

It is thus for India to take area specific approach in designing the strategies for containment of the spread and treatment of the patients to minimize the further damage. Additionally, different areas and localities are diverse as their settlement, socio–cultural and behavioral patterns vary considerably from one locality to another with in a district and from district to another district. For example, in a area with large concentration of cases in socio-economically deprived populations residing in slums different strategies are required. For example, isolation and quarantine strategies including full lock down may not help in overcrowded slums where even the walking space is extremely limited. Similarly, one needs to consider a completely new approach when dealing with migrant and homeless populations, single member households, etc. It would be important to commission area specific studies to find out different aspects of the disease and how it impacts people living in various environments. Such studies would not only give us insights to learn and address the on–going pandemic but also learning for future calamities/pandemics.

The present study is a very first draft of the analysis conducted by the authors and has several limitations, including standardization of data sources and application of limited modeling methods. Further, as the data is changing with every passing day and data used in the study is nearly 5 days old.

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Tables & Figures

Table 1: Selected socio-demographic and health indicators of the selected red zone areas, India

Characteristics	Mumbai	New Delhi	Chennai	Bengaluru	Hyderabad	Ahmedabad	Pune	Thane	Kurnool	Guntur	Coimbatore
Selected population indicators (source: Census of India, 2011)											
Population in million)	3.1	16.8	4.6	9.6	3.9	7.2	9.4	11.1	4.1	4.9	3.5
Annual exponential population growth rate, 2001-11	-0.79	1.92	0.67	3.87	0.29	2.15	2.65	3.08	1.38	0.90	-2.11
Population density (per sq. km.)	19652	11320	26553	4381	18172	890	603	1157	230	429	731
Urban population (%),	100.0	97.5	100.0	90.9	100.0	84.0	61.0	77.0	28.4	33.8	75.7
Work participation rate (%)	41.6	33.3	39.1	44.1	35.8	36.0	42.9	40.6	50.1	48.7	45.3
Literacy rate (%)	89.2	86.3	90.2	88.6	83.3	85.3	89.5	84.5	72.5	78.0	84.0
% share of slum population (%)	41.8	13.8	28.9	8.4	32.7	1.5	22.1	17.7	33.3	39.8	12.3
Selected socio-health indicators (Source: District factsheets, National Family Health Survey – 4, 2015-16)											
% households having improved# sanitation facility	39.2	67.7	82.3	86.2	73.2	88.5	63.5	64.7	52.9	63.2	57.6
% households having improved$ drinking water	99.6	88.5	77.4	92.0	90.5	95.0	95.3	92.0	81.7	74.9	95.7
% households using clean@ fuel	89.2	94.5	96.7	93.9	91.6	83.4	81.4	76.7	63.7	79.7	85.1
% Child anaemic (6- 59 months)	65.7	67.5	44.5	51.7	54.9	76.0	53.4	54.1	54.5	68.1	43.3
% Women anaemic (15-49 years)	49.4	57.8	53.9	39.6	54.0	62.9	50.0	48.4	54.5	57.9	54.3
% Men anaemic (15-49 years)	23.0	29.1	10.1	20.5	5.3	26.9	17.4	17.1	26.6	24.9	13.2
% Women with high blood sugar level (15-49 years)	11.8	4.8	9.7	8.3	9.0	6.0	4.6	4.1	5.2	9.3	5.5
% Men with high blood sugar level (15- 49 years)	14.0	4.2	9.3	10.9	8.3	5.4	4.0	4.5	2.4	11.1	7.8

Note: * Percentage share of slum population out of total urban population of the district.
Electricity, LPG/natural gas, biogas.
$ Piped water into dwelling/yard/plot, public tap/standpipe, tube well or borehole, protected dug well, protected spring, rainwater, community RO plant
@ Flush to piped sewer system, Flush to septic tank, Flush to pit latrine, ventilated improved pit (VIP) / biogas latrine, pit latrine with slab, twin pit/composting toilet, which is not shared with any other household

Table 1: Selected socio-demographic and health indicators of the selected red zone areas, India (contd…)

Characteristics	Mumbai	New Delhi	Chennai	Bengaluru	Hyderabad	Ahmedabad	Pune	Thane	Kurnool	Guntur	Coimbatore
Selected socio-health indicators contd..											
Mean HH size [$$]	4.4	4.6	3.8	4.0	4.5	4.7	4.3	4.3	4.5	3.8	3.9
% HH in Poorest and Poorer wealth quintiles[$$]	10.5	2.3	1.9	2.5	3.7	6.1	11.0	18.1	25.6	18.6	12.6
% HH have BPL card[$$]	1.8	11.1	2.2	15.1	16.4	4.3	5.4	7.1	14.4	19.9	2.5
% HH Soap and water were available at handwashing place[$$]	94.6	86.3	80.4	91.4	85.5	87.2	89.5	82.2	61.9	53.1	58.7
% HH reporting one or more members usually smoke inside[$$]	23.0	36.8	32.6	29.6	25.6	22.2	17.2	32.8	36.1	34.6	40.8
Population suffering from TB (per 1000) [$$]	1.6	2.1	3.1	0.5	2.4	0.5	3.1	2.7	2.4	2.2	3.6

[$$] Author calculation

Table 2: Hierarchy of models based on goodness of fit for the estimated positive COVID-19 cases for selected red zone areas, India

District Name	Best Fit	Better Fit	Good Fit	Poor Fit	Poorest Fit
Mumbai	Logistic_4P	Logistic_3P	Gompertz_4P	Gompertz_3P	Exp_2P
New Delhi	Logistic_4P	Logistic_3P	Gompertz_4P	Gompertz_3P	Exp_2P
Chennai	Gompertz_4P	Gompertz_3P	Logistic_4P	Logistic_3P	Exp_2P
Bengaluru	Gompertz_4P	Logistic_4P	Gompertz_3P	Logistic_4P	Exp_2P
Hyderabad	Logistic_4P	Gompertz_4P	Exp_2P	Logistic_3P	Gompertz_3P
Ahmedabad	Gompertz_4P	Logistic_4P	Gompertz_3P	Logistic_3P	Exp_2P
Pune	Gompertz_4P	Logistic_4P	Logistic_3P	Gompertz_3P	Exp_2P
Thane	Logistic_4P	Logistic_3P	Gompertz_4P	Gompertz_3P	Exp_2P
Kurnool	Gompertz_4P	Logistic_4P	Gompertz_3P	Logistic_3P	Exp_2P
Guntur	Logistic_4P	Logistic_3P	Gompertz_4P	Gompertz_3P	Exp_2P
Coimbatore	Logistic_4P	Logistic_3P	Gompertz_4P	Gompertz_3P	Exp_2P

Exp_2P: 2--parameter exponential growth model

Logistic_4P: 4--parameter Logistic growth model

Logistic_3P: 3--parameter Logistic growth model

Gompertz_4P: 4--parameter Logistic growth model

Gompertz_3P: 3--parameter Logistic growth model

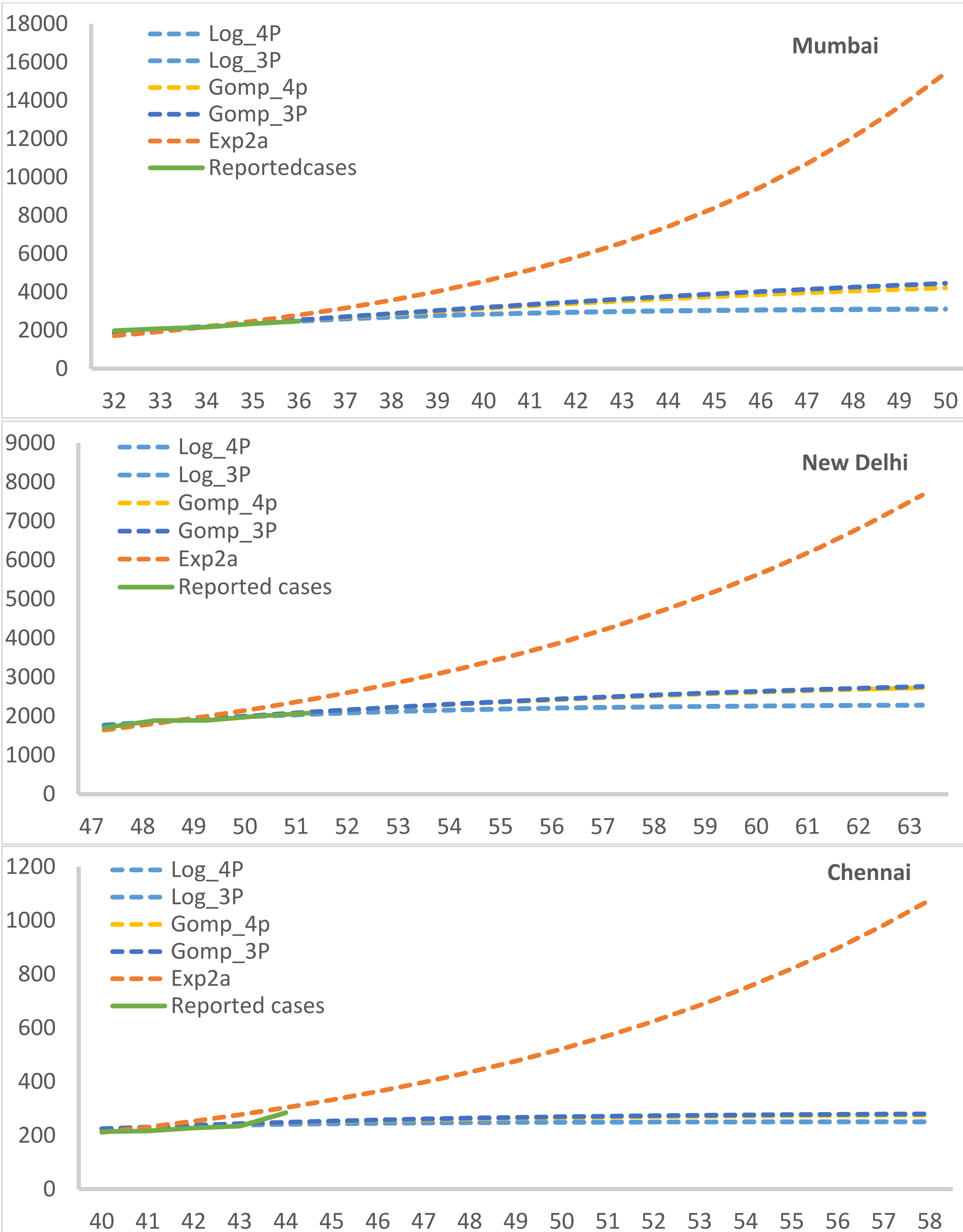
Table 3: Estimated number of confirmed cases of COVID-19 using mathematical growth models as on April 28 and May 3, 2020 for the selected red zone areas, India

District Name	Estimated number: 28th April, 2020					Estimated number: 3rd May, 2020				
	Exp_2p	Logistic_4P	Logistic_3P	Gompertz_4P	Gompertz_3P	Exp_2p	Logistic_4P	Logistic_3P	Gompertz_4P	Gompertz_3P
Mumbai	8394	3040	3058	3768	3911	15430	3108	3130	4225	4464
New Delhi	4744	2245	2242	2537	2556	7672	2285	2282	2730	2761
Chennai	685	250	250	272	275	1076	251	251	276	281
Bengaluru	192	133	107	129	117	256	150	111	144	126
Hyderabad	1140	1299	1139	1249	1070	1818	2230	1815	2054	1625
Ahmedabad	6661	3473	3810	5582	5497	18402	4491	5244	12962	12690
Pune	1938	1079	1269	1344	1753	3564	1225	1581	1866	2982
Thane	1105	444	451	531	571	1934	456	466	594	663
Kurnool	411	207	142	171	150	694	237	143	181	153
Guntur	407	149	152	176	185	695	151	154	186	200
Coimbatore	444	143	141	156	157	736	143	141	160	160
Combined	**26120**	**12461**	**12762**	**15914**	**16242**	**52278**	**14727**	**15317**	**25378**	**26105**

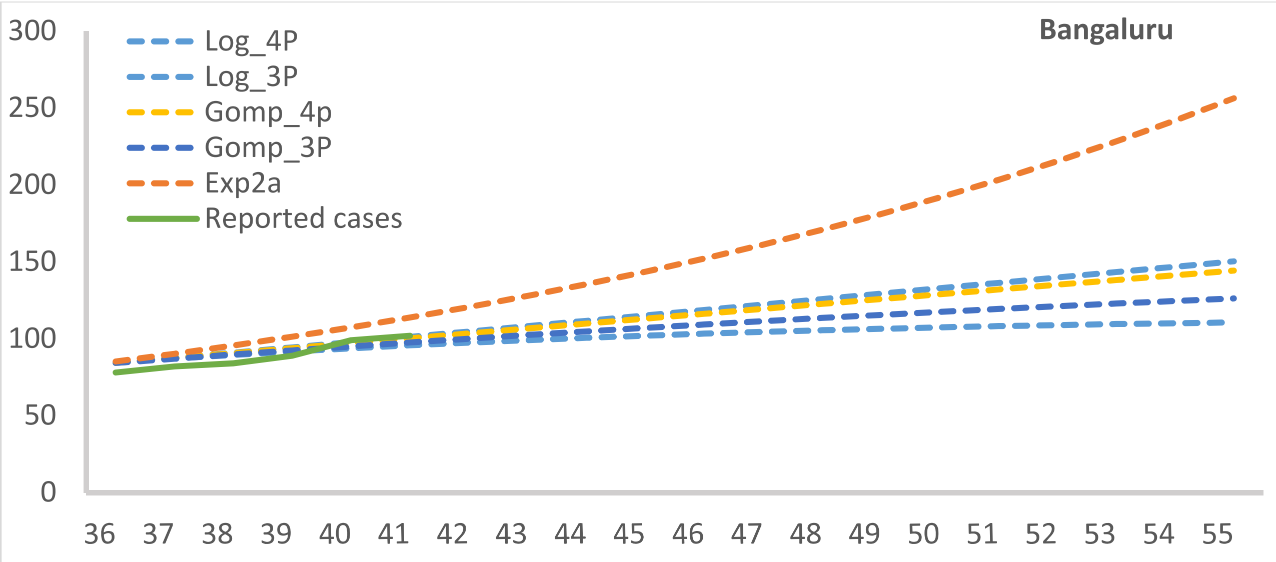
Logistic_4P: 4--parameter Logistic growth model; Logistic_3P: 3--parameter Logistic growth model

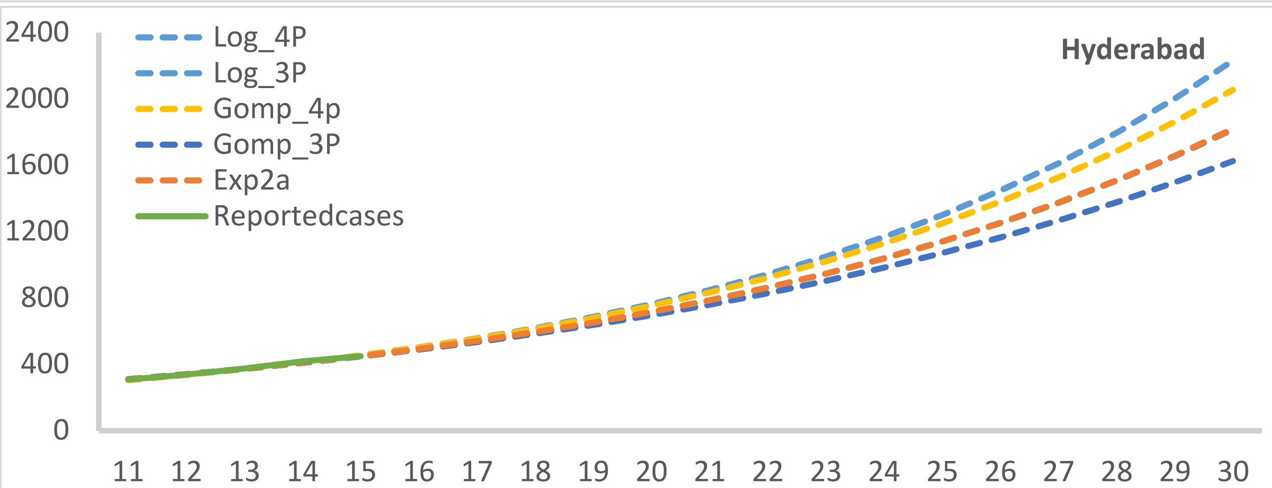
Gompertz_4P: 4--parameter Logistic growth model; Gompertz_3P: 3--parameter Logistic growth model

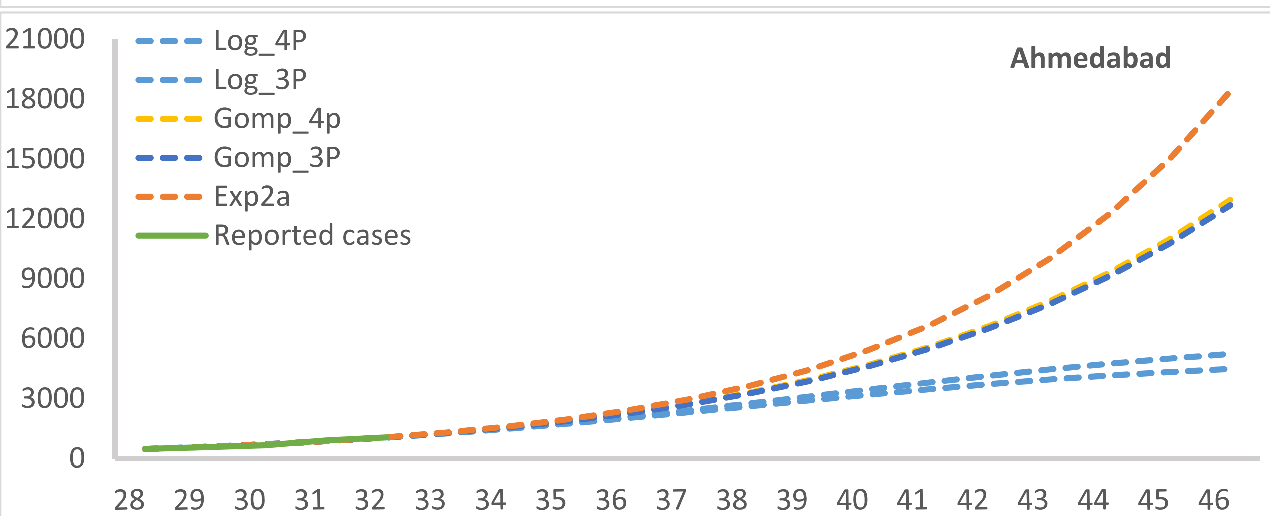
Figures 1: Estimated positive cases of COVID-19 at the end of the lockdown 2.0 (May 3, 2020) using five models for selected red zone areas, India



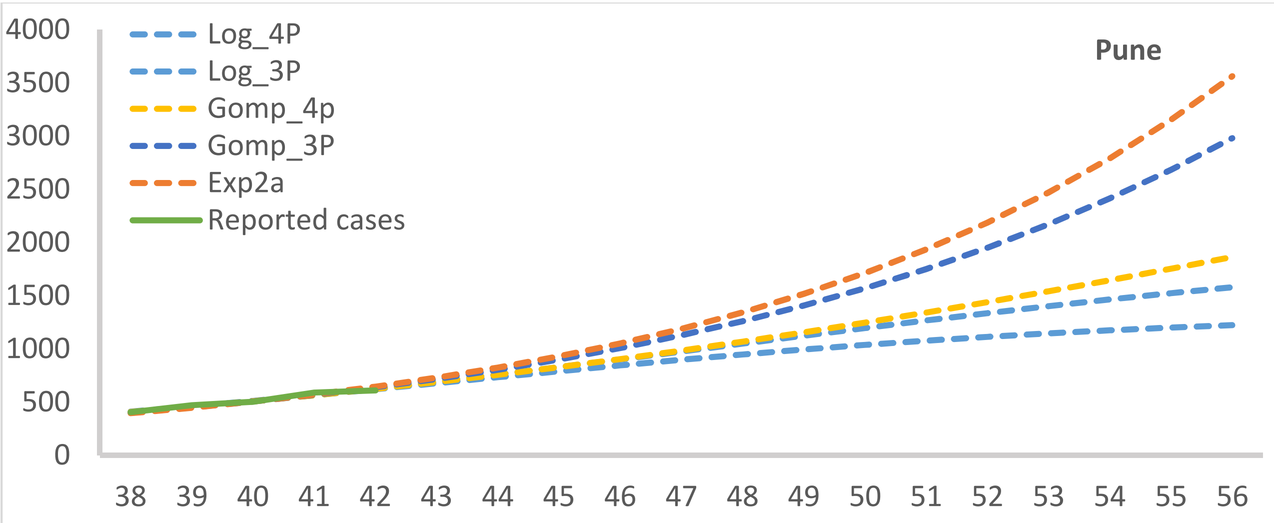
Figures 1: Estimated positive cases of COVID-19 at the end of the lockdown 2.0 (May 3, 2020) using five models for selected red zone areas, India (Contd…)

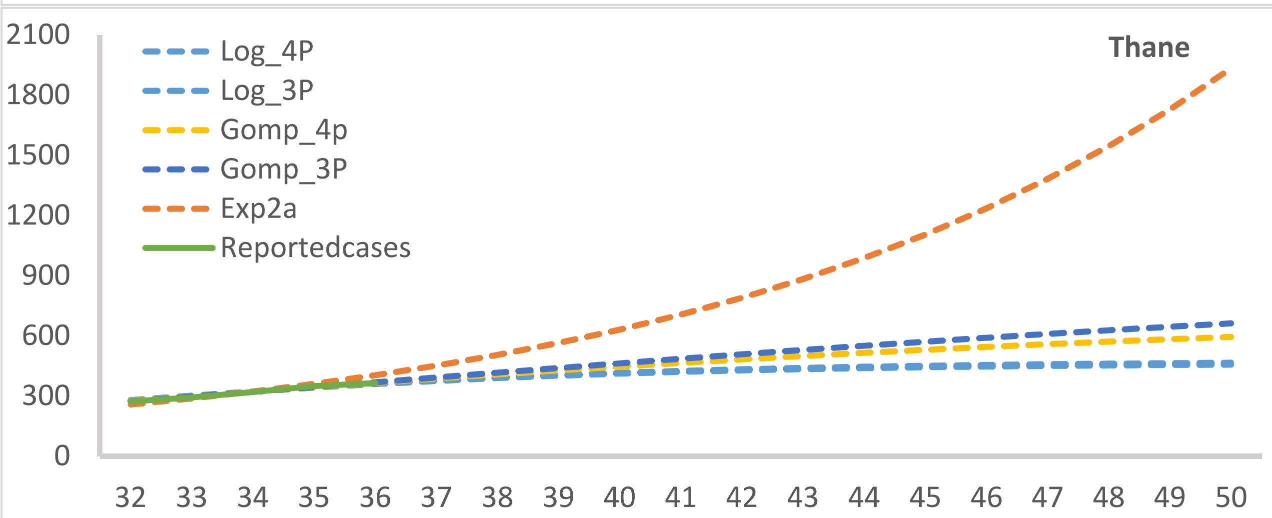


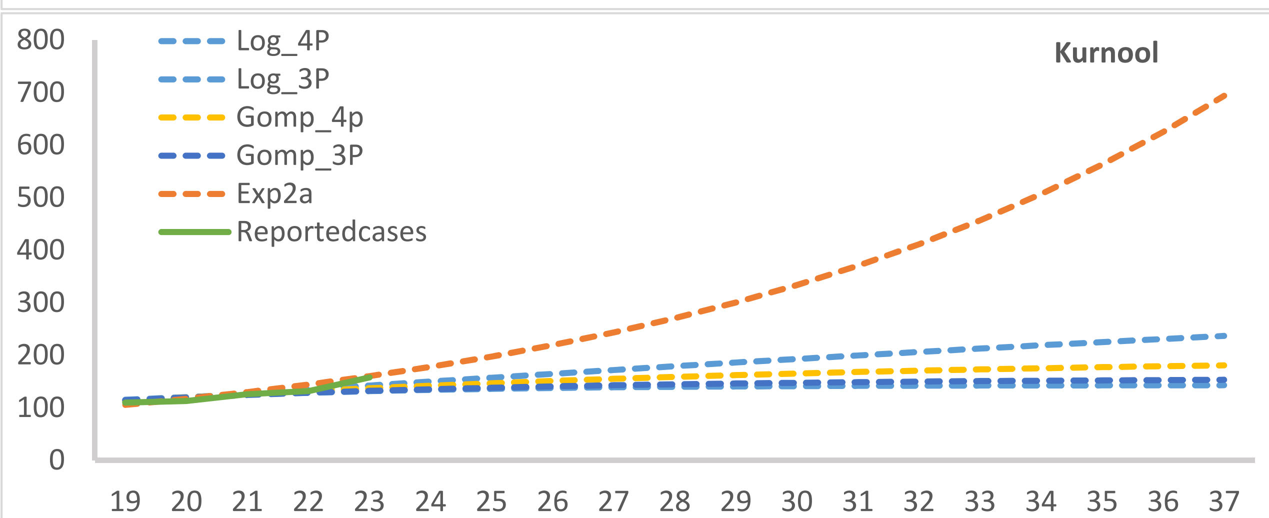




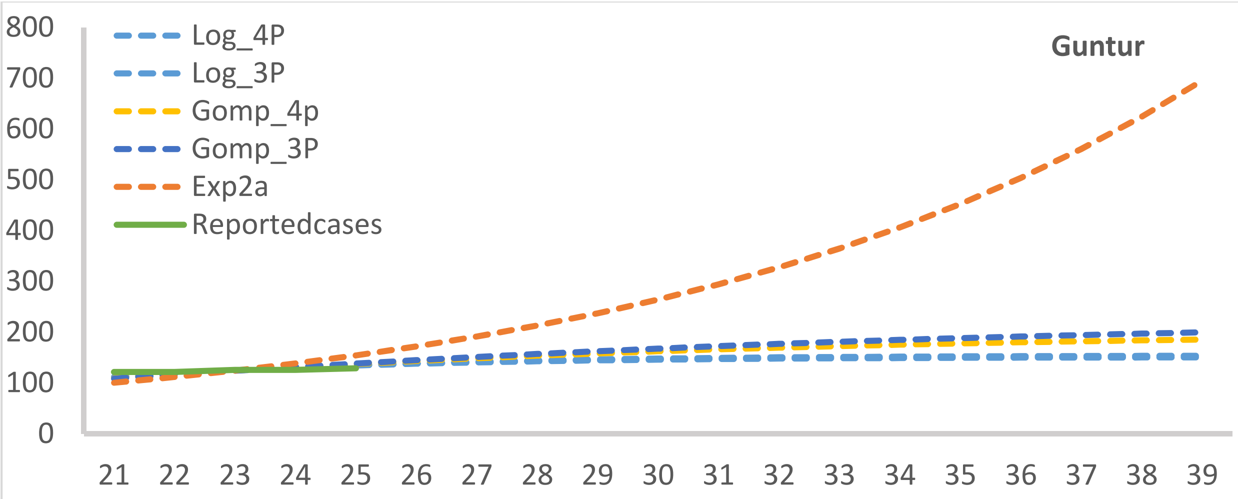
Figures 1: Estimated positive cases of COVID-19 at the end of the lockdown 2.0 (May 3, 2020) using five models for selected red zone areas, India (Contd…)

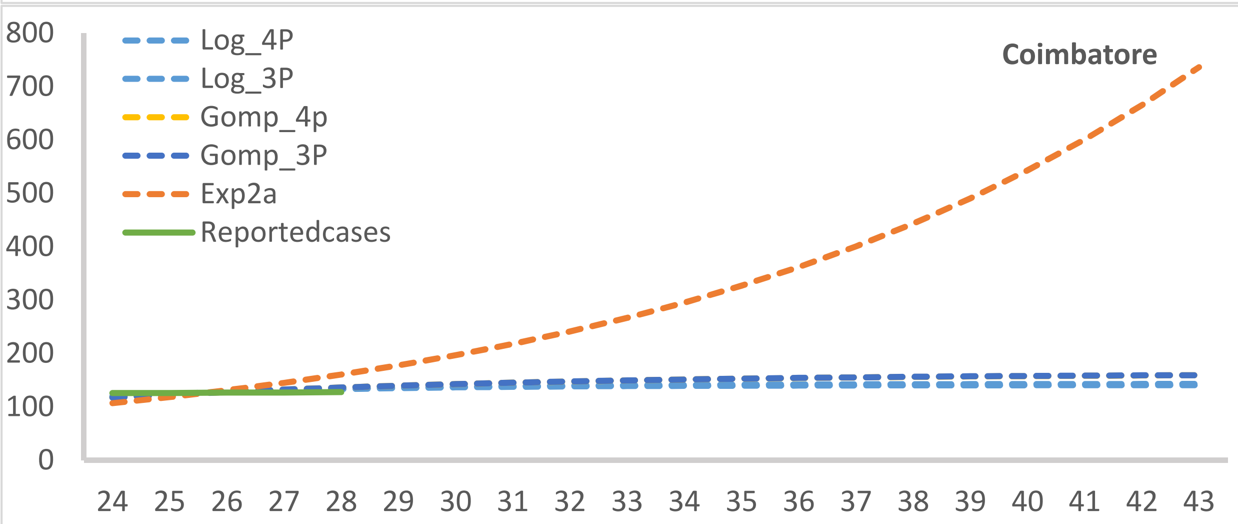






Figures 1: Estimated positive cases of COVID-19 at the end of the lockdown 2.0 (May 3, 2020) using five models for selected red zone areas, India (Contd…)





Note: X – Axis represent number of confirmed positive cases
Y – Axis represent days

Table 4: Expected date of Inflection when the red zone areas are likely to experience decline in growth rate of the COVID-19 cases: results of mathematical growth models, India

District Name	Method used			
	Logistic_4P	**Logistic_3P**	**Gompertz_4P**	**Gompertz_3P**
Mumbai	April 13, 2020	April 13, 2020	April 15, 2020	April 17, 2020
New Delhi	April 11, 2020	April 11, 2020	April 11, 2020	April 11, 2020
Chennai	April 7, 2020	April 7, 2020	April 5, 2020	April 5, 2020
Bengaluru	April 8, 2020	April 4, 2020	April 7, 2020	April 3, 2020
Hyderabad	After July 12, 2020	After July 12, 2020	After July 12, 2020	After July 12, 2020
Ahmedabad	April 25, 2020	April 26, 2020	After Jun 26, 2020	After Jun 26, 2020
Pune	April 20, 2020	April 25, 2020	May 16, 2020	After Jun 16, 2020
Thane	April 13, 2020	April 13, 2020	April 15, 2020	April 18, 2020
Kurnool	April 15, 2020	April 10, 2020	April 8, 2020	April 8, 2020
Guntur	April 11, 2020	April 11, 2020	April 11, 2020	April 12, 2020
Coimbatore	April 7, 2020	April 7, 2020	April 8, 2020	April 8, 2020

Logistic_4P: 4--parameter Logistic growth model; Logistic_3P: 3--parameter Logistic growth model
Gompertz_4P: 4--parameter Logistic growth model; Gompertz_3P: 3--parameter Logistic growth model

Table 5: Expected date when the selected red zone areas are likely to attain 'zero new cases' of COVID-19: results of mathematical growth models, India

District Name	Method used			
	Logistic_4P	**Logistic_3P**	**Gompertz_4P**	**Gompertz_3P**
Mumbai	May 22, 2020	May 21, 2020	After Jun 22, 2020	After Jun 22, 2020
New Delhi	May 13, 2020	May 13, 2020	After Jun 9, 2020	After Jun 9, 2020
Chennai	April 26, 2020	April 26, 2020	May 5, 2020	May 5, 2020
Bengaluru	After June 16, 2020	May 6, 2020	After Jun 16, 2020	May 30, 2020
Hyderabad	After July 12, 2020	After July 12, 2020	After July 12, 2020	After July 12, 2020
Ahmedabad	May 29, 2020	June 2, 2020	After Jun 26, 2020	After Jun 26, 2020
Pune	May 30, 2020	June 11, 2020	After Jun 16, 2020	After Jun 16, 2020
Thane	May 9, 2020	May 11, 2020	June 12, 2020	After Jun 22, 2020
Kurnool	June 19, 2020	April 28, 2020	May 16, 2020	May 3, 2020
Guntur	April 29, 2020	April 30, 2020	May 14, 2020	May 20, 2020
Coimbatore	April 26, 2020	April 25, 2020	May 4, 2020	May 4, 2020

Logistic_4P: 4--parameter Logistic growth model; Logistic_3P: 3--parameter Logistic growth model
Gompertz_4P: 4--parameter Logistic growth model; Gompertz_3P: 3--parameter Logistic growth model

Table 6: Observed and estimated doubling time of the confirmed positive COVID-19 cases for the pre-lockdown 1.0, during lockdown 1.0 and lockdown 2.0 period for selected red zone areas, India

District Name	Doubling time for COVID – 19 positive cases		
	Before lockdown 1.0[a]	During lockdown 1.0[b]	During lockdown 2.0[c]
Mumbai	4	4	21
New Delhi	5	4	Unlikely to double
Chennai	7	5	Unlikely to double
Bengaluru	4	16	Unlikely to double
Hyderabad	Data not available	7	8
Ahmedabad	3	4	5
Pune	4	6	9
Thane	4	5	21
Kurnool	Data not available	3	Unlikely to double *
Guntur	Data not available	3	Unlikely to double #
Coimbatore	Did not occur	3	Unlikely to double

Notes:

[a] based on reported cases till March 24, 2020

[b] based on reported cases between March 24, 2020 and April 14, 2020

[c] average of doubling time for models between April 15, 2020 to May 3, 2020

[*] doubling time for Logistic – 4P model 16 days

[#] doubling time for Gompertz – 3P model is estimated at 19 days

Pattern and Future Magnitude of COVID 19 Cases in Selected Red Zone Areas of India

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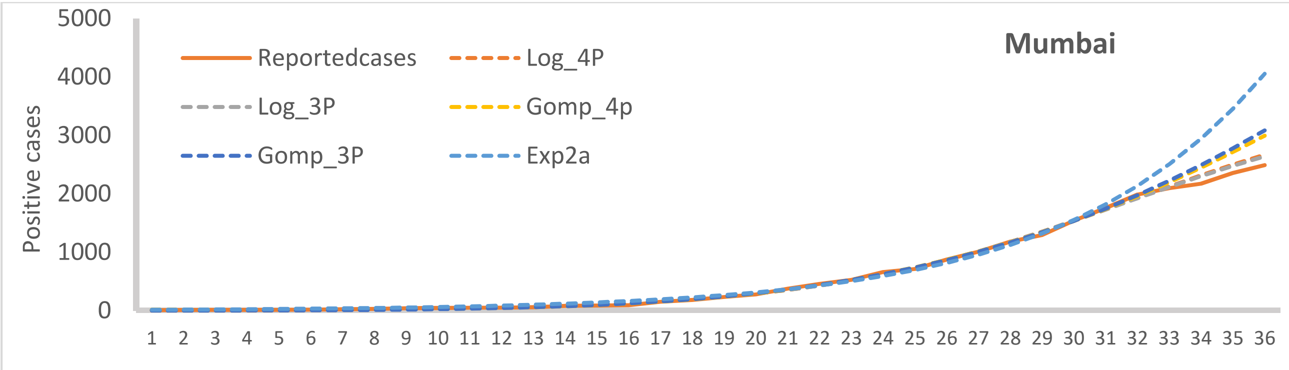
Supplementary material

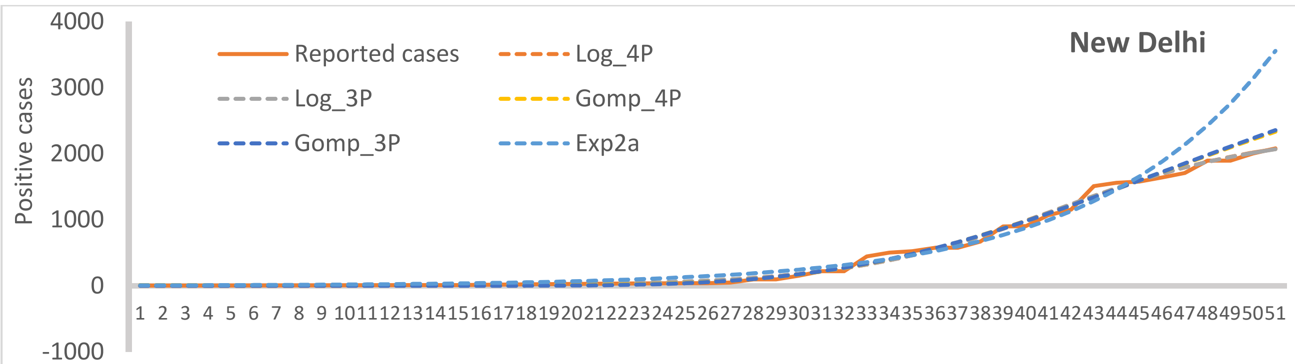
Supplementary Table 1: Description of the data used for estimation for selected red zone areas, India

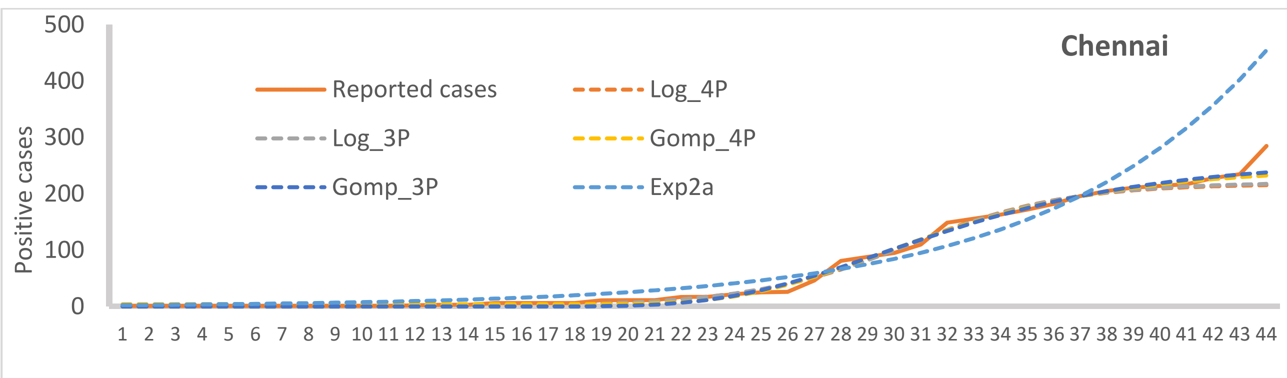
District Name	Dates for which data was used	Period for which cases were estimated to validate the method
Mumbai	15 March 2020 to 19 April 2020	15 April 2020 to 19 April 2020
Delhi	02 March 2020 to 21 April 2020	16 April 2020 to 21 April 2020
Chennai	07 March 2020 to 19 April 2020	15 April 2020 to 19 April 2020
Bengaluru	09 March 2020 to 18 April 2020	15 April 2020 to 18 April 2020
Hyderabad	04 April 2020 to 18 April 2020	15 April 2020 to 18 April 2020
Ahmedabad	19 March 2020 to 19 April 2020	15 April 2020 to 19 April 2020
Pune	09 March 2020 to 19 April 2020	15 April 2020 to 19 April 2020
Thane	15 March 2020 to 19 April 2020	15 April 2020 to 19 April 2020
Kurnool	28 March 2020 to 19 April 2020	15 April 2020 to 19 April 2020
Guntur	26 March 2020 to 19 April 2020	15 April 2020 to 19 April 2020
Coimbatore	22 March 2020 to 18 April 2020	15 April 2020 to 18 April 2020

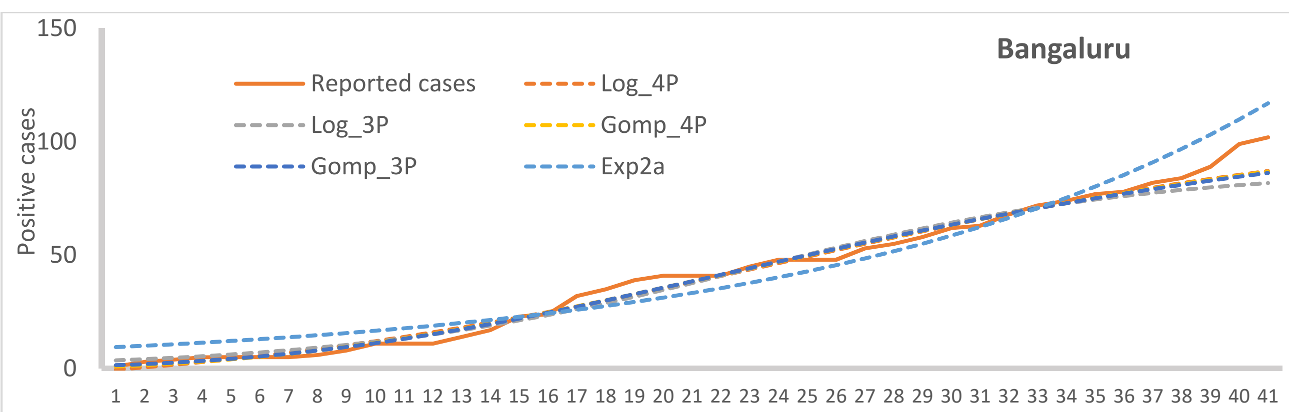
Source: Author's Compilation using various official websites of the federal and state governments

Supplementary Figures 1: Comparison of day wise reported and modeled positive cases of COVID-19 using mathematical growth models for selected red zone areas, India

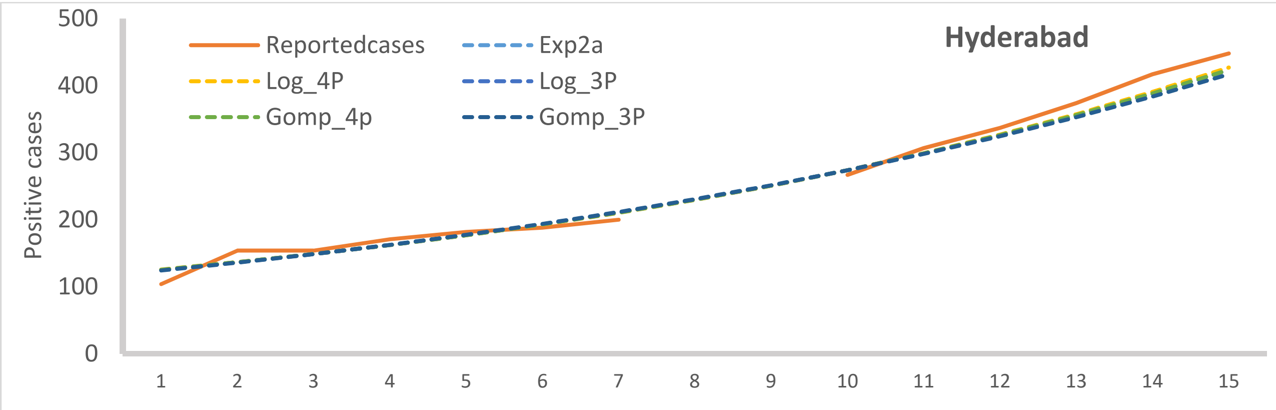


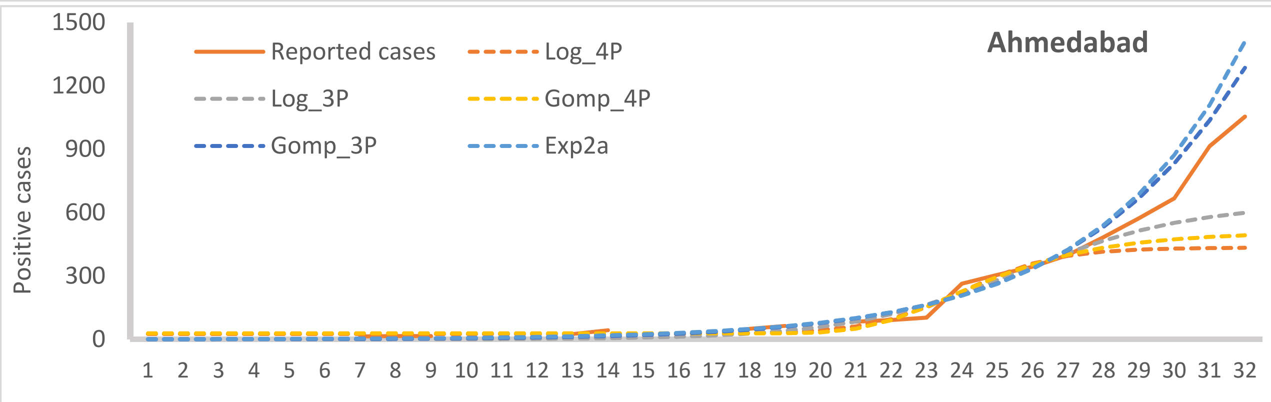


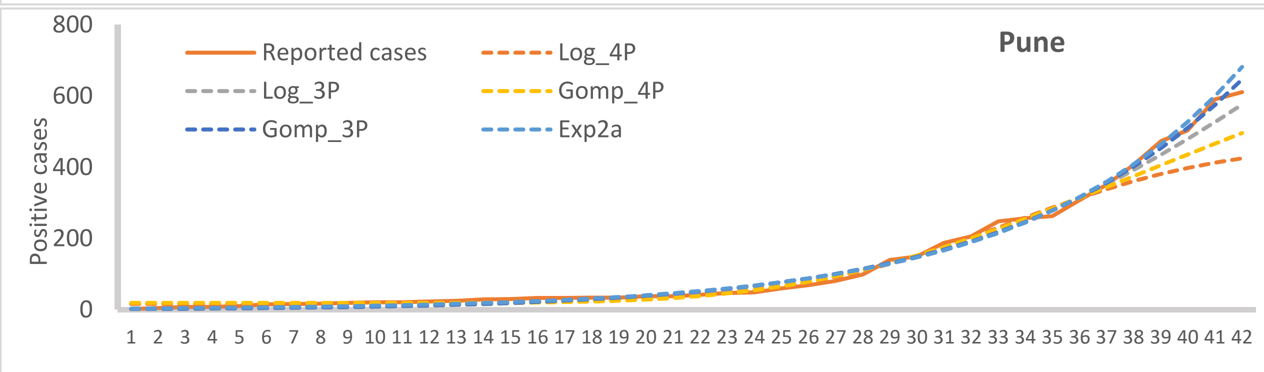


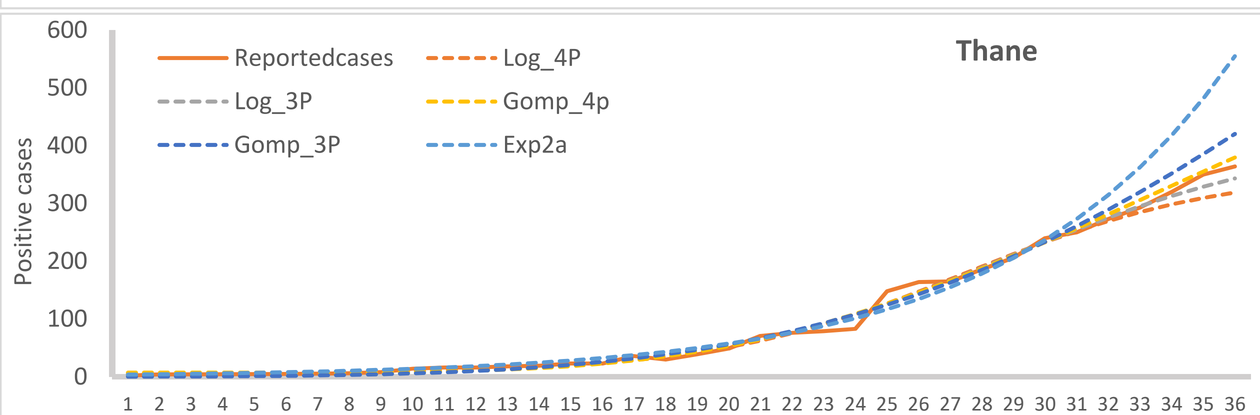


Supplementary Figures 1: Comparison of day wise reported and modeled positive cases of COVID-19 using mathematical growth models for selected red zone areas, India (cont)

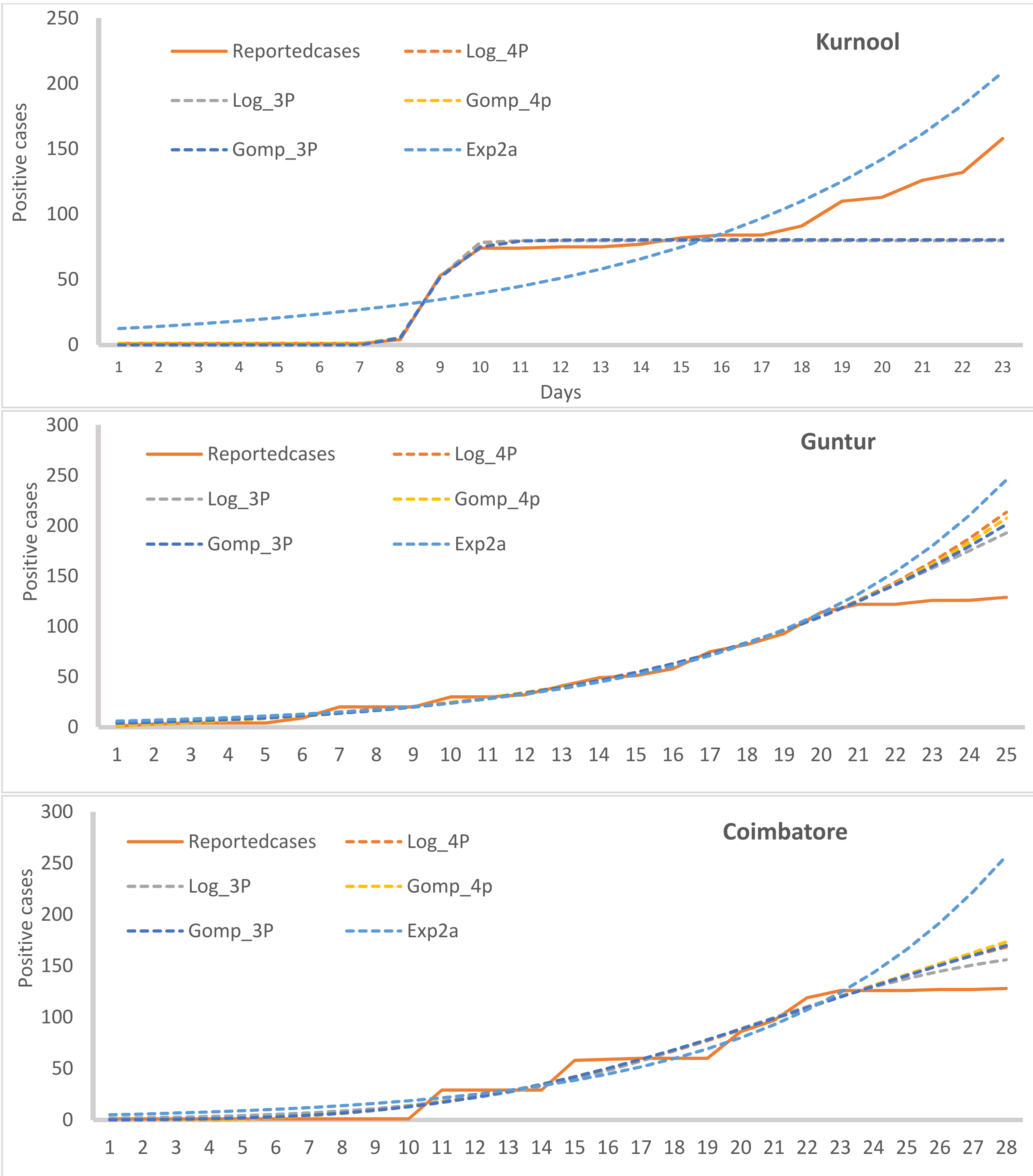








Supplementary Figures 1: Comparison of day wise reported and modeled positive cases of COVID-19 using mathematical growth models for selected red zone areas, India (cont)



Note: Y – Axis represent days.