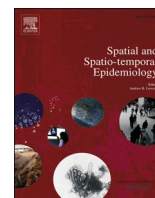




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Epidemiological findings for the first and second waves of COVID-19 pandemic in Maharashtra, India

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ARTICLE INFO

Keywords:

COVID-19
India
Maharashtra
Reproduction number
Attack rate
Epidemiology mathematical modeling

ABSTRACT

India is one of the worst affected countries during the COVID-19 pandemic. We carried out comparative analyses of the COVID-19 situation in the Maharashtra state, India for the first and second waves. Epidemiological and demographics data were obtained from open sources and the Government of Maharashtra. Mathematical modeling and analyses were conducted to estimate the epidemiological parameters like basic reproduction number (R0) for the first wave at different times. The districts with a higher percentage of the urban population recorded a higher attack rate during the first wave. However, during the second wave, the rural population was more affected. The effective reproduction number (Re) was estimated for the second wave at different times. The second wave affected more individuals than the first wave due to various factors such as strictness of restrictions or the lack of it and the emergence of new strains.

1. Introduction

Since its emergence in Wuhan, China in December 2019, the SARS-CoV-2 virus has generated the worst pandemic of human history (Li et al., 2020; Nicola et al., 2020; Pak et al., 2020). Till April 2021, COVID-19 affected all the countries of the world infecting and killing millions. In India, the virus was introduced first (Andrews et al., 2020) by travelers returning home from various countries followed by local transmission (Shukla, 2020).

Local clusters of cases (Sengupta et al., 2021) were detected in March 2020 in various parts of the country seeded by the travelers and also due to religious gatherings and internal migration (coming home) of the migrant labor force (Mukhra et al., 2020; Outlook Staff, 2020; Prasad, 2020). The first wave started in Maharashtra from Pune on 9th March 2020 and reached its peak in September 2020. By mid-February 2021, the daily cases dropped to a minimum of 656 cases. However, the cases started increasing towards the end of February 2021.

At the beginning of March 2021, there was a surge in daily cases marking the onset of the second wave (Ranjan et al., 2021; Bhardwaj and Agrawal, 2021). In the first wave, there had been more than 15 million infections in India. COVID-19 covered all the districts of India by August 2020 (Shil et al., 2021). As per the WHO situation report (<https://covid19.who.int/region/searo/country/in>), in India from 3rd January 2020 up to, 31st May 2021, there have been 2,88,09,339 confirmed

cases of COVID-19 with 3,46,759 deaths. After the US, India is the most affected country due to the COVID-19 (<https://covid19.who.int/region/amro/country/us>).

The state of Maharashtra is worst affected with a 20.3% share of all India cases as of 31st May 2021. The state recorded 28.6% of the countrywide fatalities due to COVID-19. Over 95% of the infections in Maharashtra recorded successful recovery. It should be noted that Maharashtra state is home to 11% of the total Indian population (Census of India 2011). In the present article, we describe the COVID-19 situation in the state of Maharashtra.

2. Methodology

2.1. Study area

The Maharashtra state is located in western India and is divided into 36 administrative districts. The State is bound by the Arabian Sea to the west and has shared borders with Gujarat and Madhya Pradesh states to the north, Chhattisgarh, and Telangana to the east, and Karnataka and Goa states to the south. There is a narrow coastal plain to the east of which is located the Western Ghats mountain range and the rest of the state from west to east is covered by the Deccan plateau. Mumbai is the largest metropolitan city of India and serves as the capital of the Maharashtra state. Pune, India's fastest-growing metropolis is located in

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<https://doi.org/10.1016/j.sste.2022.100507>

Received 18 August 2021; Received in revised form 4 February 2022; Accepted 21 March 2022

Available online 26 March 2022

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Maharashtra around 200 km to the southeast of Mumbai. As per the Census of India 2011, around 45.2% of the total population of the state lives in the urban centers (https://mahades.maharashtra.gov.in/docs/pdf/ENG_B.pdf). While Mumbai, Pune, and Thane are most urbanized, Gadchiroli, Sindhudurg, and Hingoli are the least urbanized districts (<https://www.dnaindia.com/mumbai/report-maharashtra-third-most-urbanised-state-1567143>).

2.2. Data

Epidemiological data for all the districts of Maharashtra were obtained from <https://howindialives.com/gram/coronadistricts/> and <https://www.covid19india.org/> and Public Health Department, Government of Maharashtra. We set up our updated dataset and cured the same for mathematical analyses and GIS applications. Population demographics data were obtained from the Census of India website (<https://censusindia.gov.in/2011-common/censusdata2011.html>) and the Government of Maharashtra (https://mahades.maharashtra.gov.in/files/publication/unicef_rpt/chap1.pdf). Considering the 16% decadal growth rate (Census of India 2011), the populations of all districts were estimated (adjusted) for the year 2020–21 based on the 2011 census.

2.3. Mathematical epidemiology

We estimated various epidemiological parameters based on the principles of mathematical epidemiology (Anderson and May, 1992). District-wise attack rate and Case fatality Ratio (CFR) were estimated using the following formulae:

$$\text{Attack Rate (\%)} = \frac{\text{Number of confirmed cases}}{\text{Total population}} \times 100 \quad (1)$$

and

$$\text{CFR} = \frac{\text{Number of deaths}}{\text{Total number of Confirmed cases}} \times 100 \% \quad (2)$$

For each district, the percentages of the population living in the urban area (percentage urban population) were calculated:

$$\text{UR\%} = \frac{\text{Number of people living in Urban Areas}}{\text{Total population of the district}} \times 100 \quad (3)$$

The epidemic growth rate (ρ) was calculated by fitting the number of cumulative confirmed cases (y), to an exponential growth model using the formula:

$$y = y_0 e^{\rho t} \quad (4)$$

where y_0 is the initial number of cases (at $t = 0$) and t is the time duration.

The Basic reproduction number, R_0 for the first wave was estimated by using the formula:

$$R_0 = \left(1 + \frac{\rho}{k}\right) \left(1 + \frac{\rho}{\theta}\right) \quad (5)$$

where ρ is an exponential growth rate of the epidemic, $1/k$ is the mean latent (incubation) period and $1/\theta$ is the mean "onset to hospitalization" period during which the individual displays symptoms and can infect others (Kumar et al., 2018; Shil et al., 2021).

For the second wave, we determined the effective reproduction number (R_e) by modifying the Eq. (5). as

$$R_e = \left(1 + \frac{\rho}{k}\right) \left(1 + \frac{\rho}{\theta}\right) \eta \quad (6)$$

where η is the proportion of population susceptible (Gurav et al., 2017).

The doubling time for the outbreaks was estimated using the formula:

$$\tau = \frac{\ln(2)}{\rho} \quad (7)$$

where ρ is the epidemic growth rate (Eq. (4)) (Shil et al., 2021; Kumar et al., 2018).

Spatio-temporal analyses:

Spatial analyses were carried out using Q-GIS v3.14, wherein the ranking of the districts was done based on a total number of cases from 1st March 2020 till 31st May 2021. Statistical analyses were performed in R. Graph plotting and analyses were performed in MS Excel Eqs. (1)–(3), (7).

3. Results

We have integrated the COVID-19 data for the state of Maharashtra, from 1st March 2020 till 31st May 2021. Fig. 1 describes the daily cases in the state. The first wave extended from March 2020 to mid-February 2021 when the least number of daily cases (656) was recorded on 12th February 2021 (Ranjan et al., 2021). Subsequently, cases started increasing and in the last week of February 2021, there was a sudden surge in daily cases indicating the onset of the second wave.

District-wise distribution of COVID-19 cases in Maharashtra State is depicted in Fig. 2. From March 2020 to 31st May 2021 Pune district was worst affected with 10,17,154 cases and 12,507 fatalities. Mumbai is the second most affected region with 7,05,288 cases and 14,826 fatalities. We have considered the entire metropolis of Mumbai as one unit (Mumbai Urban and Mumbai Suburban districts). Thane district adjoining Mumbai recorded 5,63,098 cases and 8225 fatalities. The city of Nagpur located in eastern Maharashtra recorded 4,89,819 cases and 6602 fatalities followed by, Nasik with 3,87,572 cases 4677 fatalities. These were the five most affected districts in the state. Hingoli district recorded the least number of cases (17,788) and 336 fatalities.

A ranking of districts by a total number of cases was carried out for both the first wave (9th March 2020 to 11th Feb 2021) and the second wave starting from 12th February 2021 onwards (as on 31st May 2021) (Fig. 3). For the first wave, the five worst-affected districts were Pune, Mumbai, Thane, Nagpur, and Nasik (> 1,00,000 cases). The least affected districts (< 5000 cases) were Hingoli, Washim, Parbhani, Sindhudurg, and Gadchiroli. In the second wave, the following districts recorded more than 1,00,000 cases each since 12th February 2021: Mumbai, Pune, Thane, Nagpur, Nasik, Ahmednagar, Aurangabad, Jalgaon, and Raigarh (Fig. 3B). The overall CFR for the state of Maharashtra for the first wave was 2.48%, whereas CFR for the second wave starting from 12th Feb 2021 till 31st May 2021 was estimated as 0.65% spanning 109 days. The overall attack rate for the State for the first wave was 1.54% and for the second wave was estimated as 2.8%, which is almost 1.8 times more than the first wave.

Fig. 4 represents the daily confirmed cases time-series for the first wave with basic reproduction numbers calculated at different durations for the state of Maharashtra. The R_0 was estimated using Eq. (5) by considering the mean incubation period for COVID-19 to be 4 days and the average "onset to hospitalization/isolation" period being 5 days (Li et al., 2020; Shil et al., 2021). Epidemic growth rates were estimated at different time periods (time-frames 20 days each) by best-fit to exponential model (Eq. (4)). For the first 20 days there were no restrictions on human social behavior and the R_0 was estimated as 5.2. For the next 20 days (30th March to 18th April 2020) Maharashtra state came under nation-wide total lockdown and the estimated R_0 was 2.9. Between 19th April and 8th May 2020, R_0 was 1.9 and between 9th May and 28th May 2020, the value of R_0 was 1.6. Beyond 29th May 2020, the value of R_0 remained as 1.5.

Considering a COVID-19 seroprevalence of ~30% (Marpakwar, 2021), we assumed that 70% of the population to be susceptible during the onset of the second wave in Maharashtra. Thus, the effective reproduction number R_e was estimated for the second wave at different time

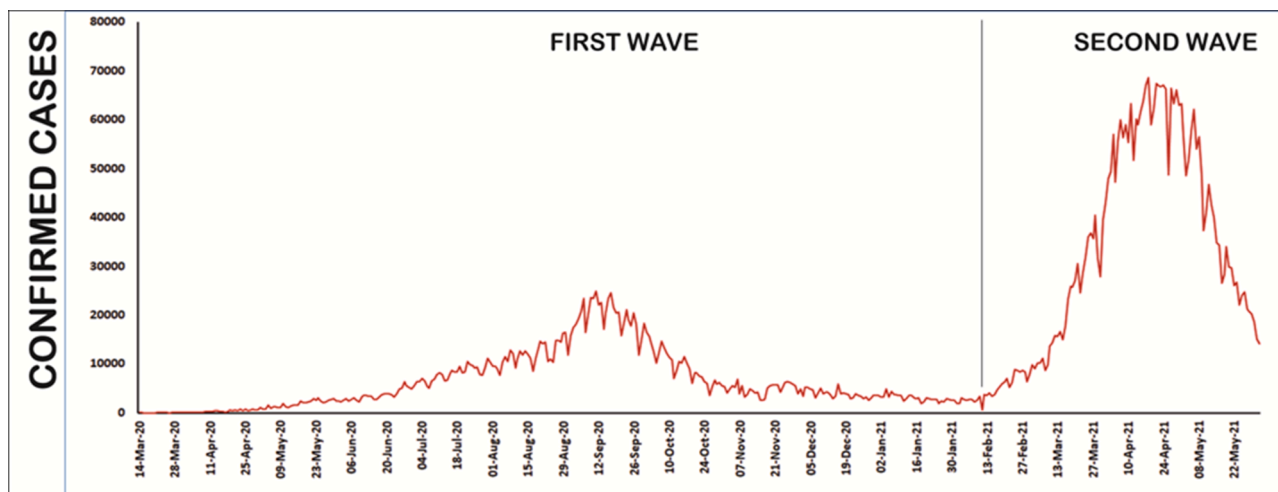


Fig. 1. COVID-19 scenario in Maharashtra India, confirmed daily incidences from 1st March 2020 to 31st May 2021.

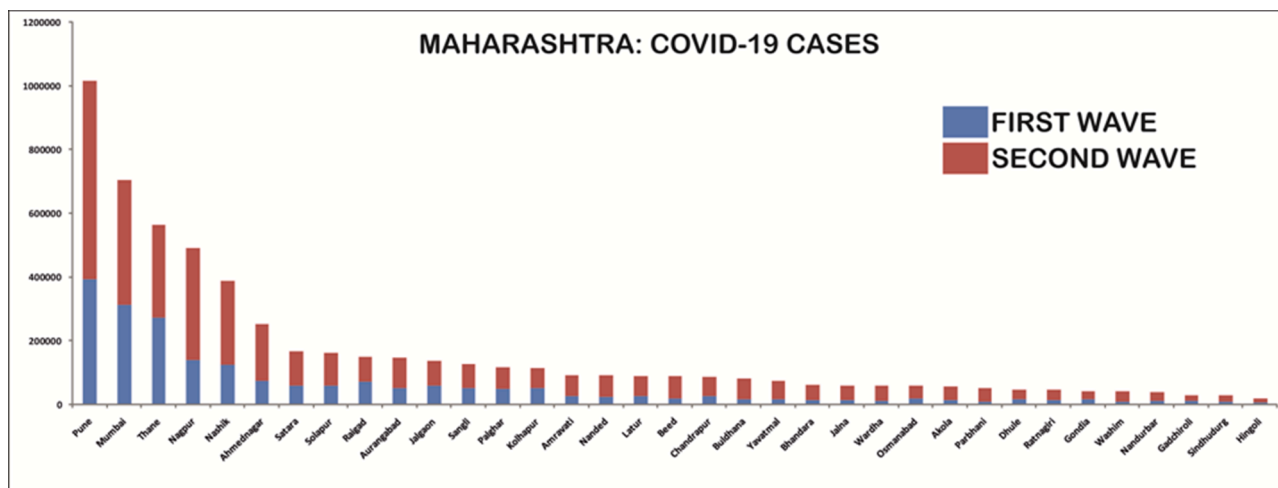


Fig. 2. COVID-19 cases for the districts of Maharashtra state (1st March 2020 till 31st May 2021).

periods based on the epidemic growth rate (Fig. 5). Epidemic growth rates were estimated at different time periods by best-fit to the exponential model (Eq. (4)). The estimated values for effective reproduction number are as follows:

- $R_e = 3.0$ between 12th and 25th February 2021 (76916 cases),
- $R_e = 3.4$ between 26th February and 7th March 2021 (89906 cases),
- $R_e = 5.2$ between 8th and 14th March 2021 (94686 cases),
- $R_e = 4.5$ between 15th and 20th March 2021 (134734 cases),
- $R_e = 4.1$ between 21st and 27th March 2021 (224314 cases) and
- $R_e = 3.8$ beyond 28th March 2021.

Fig. 6 presents the comparison of R_0 and R_e at different time points (in days since beginning of the COVID-19 waves). A comparative analysis of the epidemiological parameters for both the first and the second waves is summarized in Table 1.

To understand the effect of urbanization on the spread of COVID-19, we made a comparison of the total number of COVID-19 cases with the percentage of urban population for all the districts for the first and second waves (Fig. 7). During the first wave, the districts with a high percentage of the population living in urban areas recorded higher attack rates for COVID-19. A strong positive association has been established between the percentage of urban population (UR%) and attack rate for COVID-19 with Pearson’s correlation coefficient, $r = 0.70$ (Supplementary Table 1). However, no significant correlation could be established between the percentage of urban population (UR%) and CFR

(Pearson’s correlation coefficient $r = 0.09$). During the first wave Hin-goli, Parbhani, and Yavatmal districts had the lowest attack rates. However, during the second wave, a weak positive association was observed between the percentage of the urban population and attack rate (Pearson’s correlation coefficient, $r = 0.44$) (Supplementary Table 2). It was observed that many districts with lower urbanization also had very high attack rates like Bhandara, Ahmednagar, Satara, and Wardha (Fig. 7b). As per the reports, rural populations were affected in the second wave in contrast to the first wave when mostly the urban centers were affected (Gilai, 2021). No significant association was observed between the percentage of urban population and CFR.

Fig. 8 compares the district-wise population density with the total number of cases for the first and second waves of COVID-19 in Maharashtra state. A statistical comparison of the total number of cases with population densities of districts revealed moderate association (Pearson’s correlation coefficient, $r = 0.51$ during the first wave and $r = 0.45$ for the second wave).

4. Discussion

World Health Organization (WHO) declared COVID-19 as pandemic on 11th March 2020. Since then, for more than a year deadly COVID-19 (SARS-CoV2 virus) has continued to disrupt public life and impacted human health hugely across the world. India is no exception. The

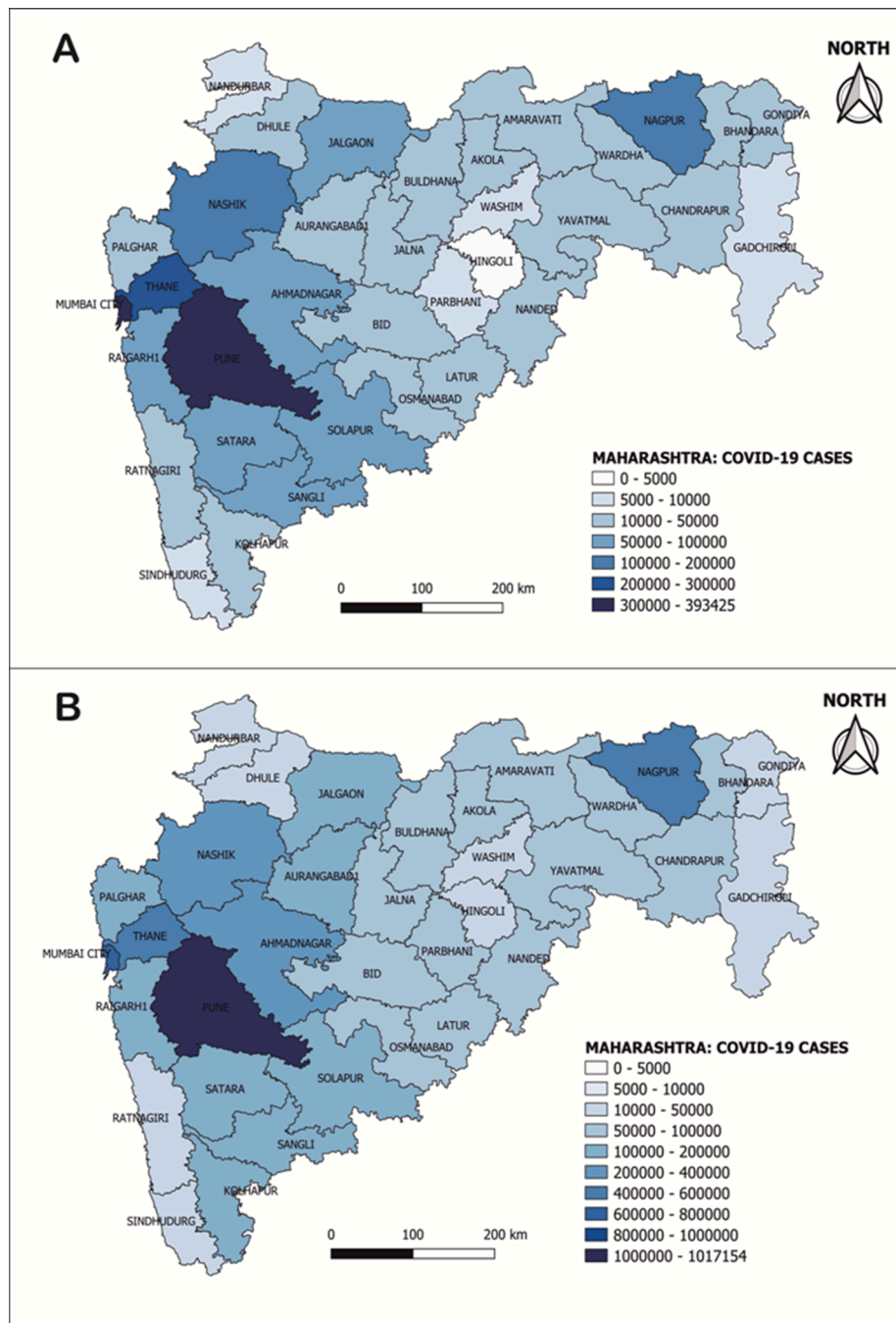


Fig. 3. Ranking of the districts of Maharashtra state by number of COVID-19 cases: (A) first wave (9th March 2020 to 12th Feb 2021), (B) second wave (12th February 2021 to 31st May 2021)

country has seen 28,173,655 cases till 31st May 2021, the second wave is more severe than the first wave for COVID-19 cases (source: www.worldometers.info/coronavirus/country/india/).

In an earlier study, authors have described the spread of COVID-19 across India and determined the Basic reproduction number, R_0 for all the 716 districts (Shil et al., 2021) in the initial phase in 2020. After the first cluster was reported in Pune, in March 2020, local clusters got generated in the different districts due to people returning home from abroad or from affected areas within in India. It was observed that the internal migrant labor had also contributed in spreading COVID-19 as they returned to their home states. It was also reported that variation in R_0 values across districts depended on various factors including local social traditions, local living conditions, super-spreading events and

state-wise variation in the implementation of COVID-19 restrictions (Shil et al., 2021; Vaidyanathan, 2021). In this paper, we have analyzed the COVID-19 scenario in the state of Maharashtra with a view to understand the similarities and differences between the first and second waves.

In Maharashtra, the first wave of COVID-19 started on 9th March 2020 with the first case reported in Pune. The steady rise in the daily cases reached its peak on 11th September 2020 (24,886 cases per day) and then decreased gradually till 11th February 2021 (652 cases per day). This was in sync with the all-India trend (<https://www.covid19india.org/>).

From 12th Feb 2021, the daily cases started increasing resulting in a surge by the first week of March 2021. On 18th March 2021, the daily

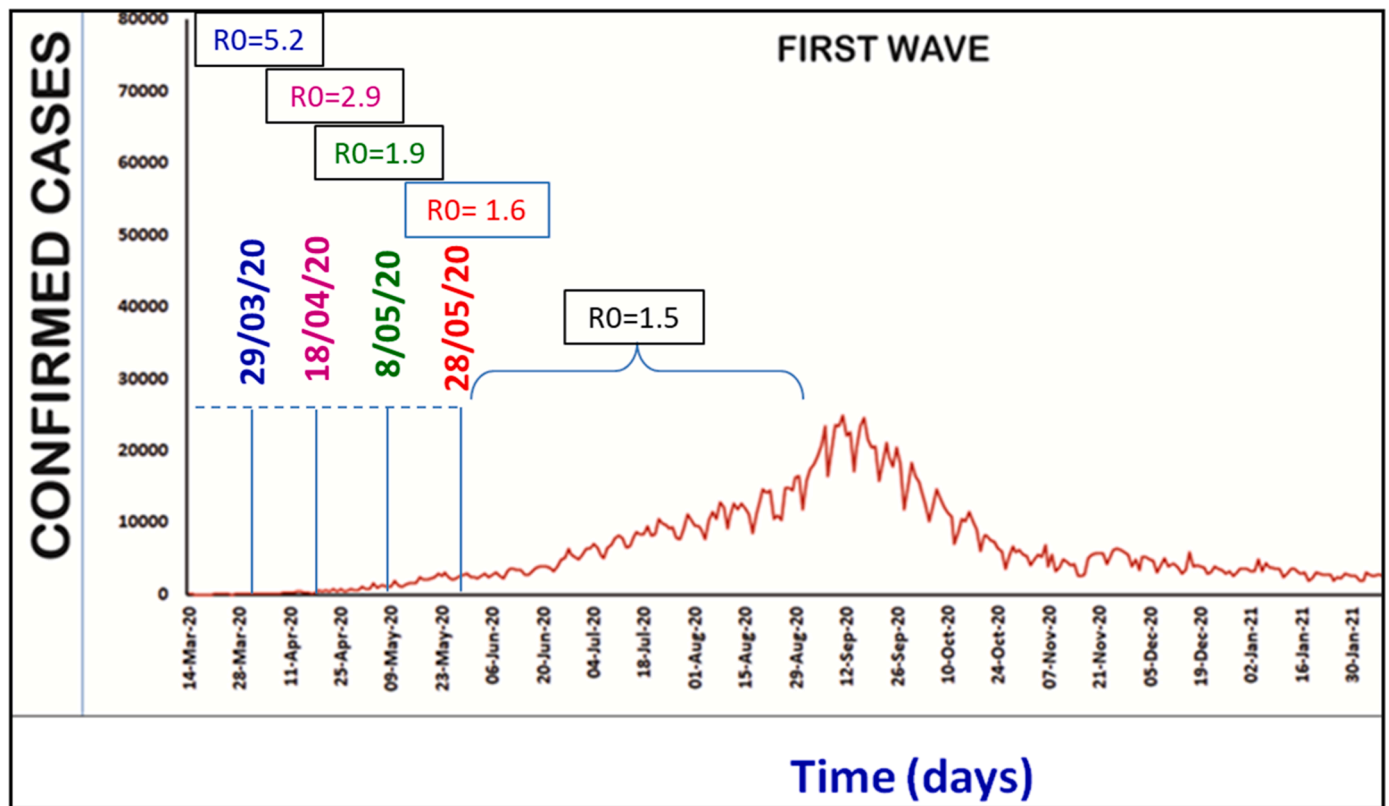


Fig. 4. Time-series of COVID-19 cases in Maharashtra state during the first wave. Basic reproduction number determined at different points in time.

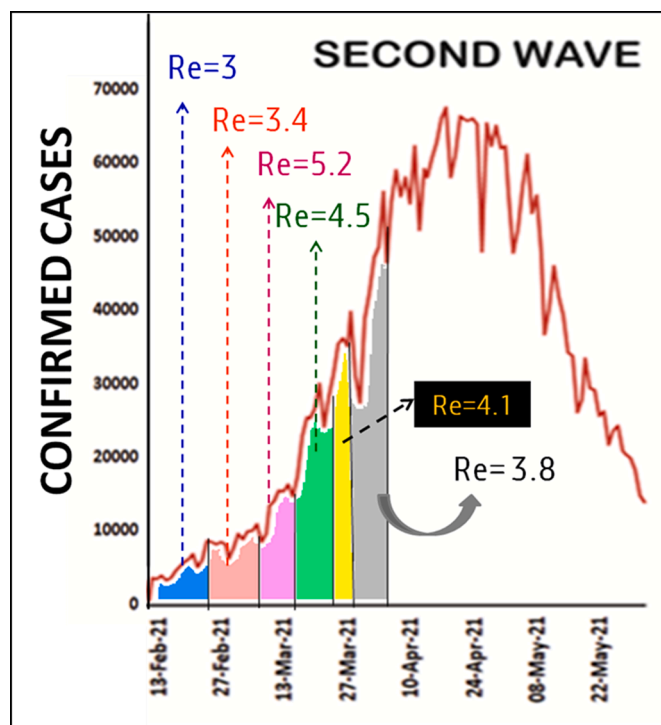


Fig. 5. Time-series of COVID-19 cases in Maharashtra state during the second wave. Effective reproduction number determined at different points in time.

confirmed cases were 25,833, which was greater than the peak of the first wave reached on 11th September 2020 (24,886 cases). The daily cases continued to grow rapidly and by 18th April 2021 reached 68,631

cases per day. This rapid increase in the daily cases was noted as the second wave of COVID-19. The daily confirmed cases continued to be above 60,000 till 30th April 2021.

For the first wave, we have estimated the Basic reproduction number as per Eq. (5) assuming that the total native population to be susceptible. The value of $R_0= 5.2$ was comparable to that of China (Li et al., 2020) and Italy (Tuite et al., 2020) in the initial 20 days of the outbreak, when there were no social restrictions on the population (that is, no COVID-19 restrictions). Maharashtra came under national lockdown in the last week of March 2020, following which the R_0 decreased to 2.9. Between 18th April and 8th May 2020 the $R_0 = 1.9$ was estimated as new cases and clusters were reported due to return of cross-country travelers and migrant workers to their respective towns and villages (Shil et al., 2021). The peak of the first wave occurred in September 2020 and subsequently decreased with cases continuing till early February 2021.

Lowest number of cases were recorded on 12th February 2021, following which the daily cases started increasing rapidly. This is mostly due the fact that by end of January 2021, lock down was eased and many restrictions withdrawn, though educational institutes remained closed. Meanwhile, sero-surveys revealed the gradual increase in sero-prevalence of COVID-19 in the population (Murhekar et al., 2021). Hence, for the second wave, we estimated the effective reproduction number, R_e (as in Eq. (6)) instead of R_0 .

The estimated value of $R_e= 3.0$ (12th–25th February 2021) is comparable to European countries that had experienced second waves (Ke et al., 2021). It should also be noted that the total number of cases is higher in the second wave compared to the first due to various factors. Of these, the following may be the most important: (i) easing of restrictions with the opening of eateries and road-side vendors, the opening of places of worship, religious gatherings and marriages, etc, (ii) complacency in the population and reluctance to maintain personal protection; and (iii) emergence of new mutant strains which are more virulent (Bureau, 2021). The US, UK, and other major countries also witnessed second and third waves affecting millions (Times of India,

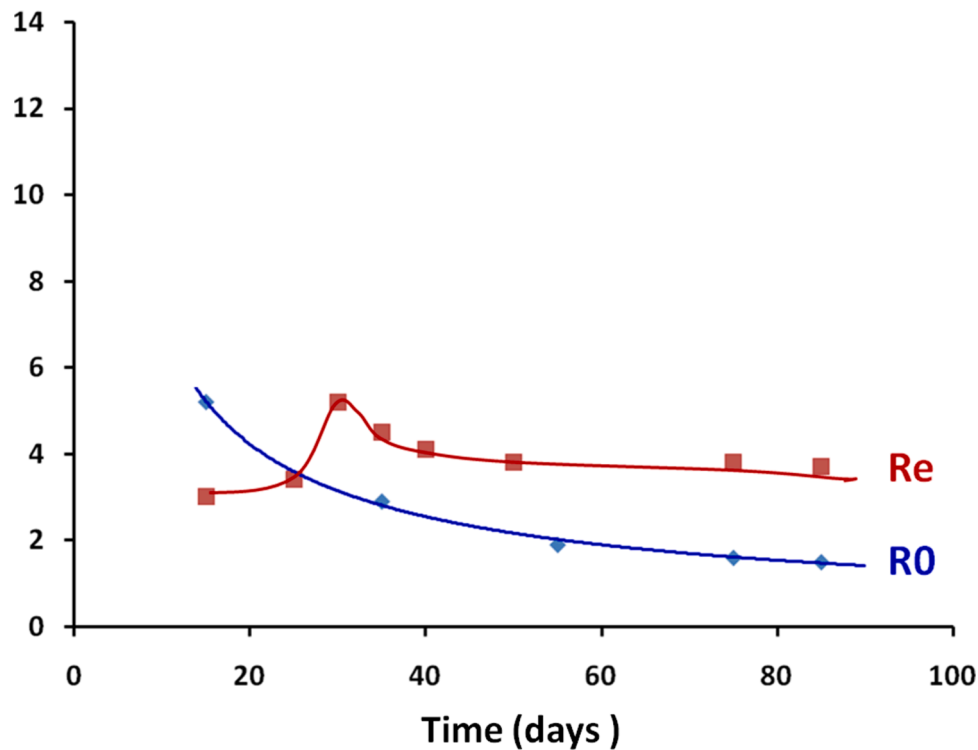


Fig. 6. Basic reproduction number and Effective reproduction number at different times (days since beginning of the COVID-19 waves/outbreaks).

Table 1
Epidemiological parameters for COVID-19 in Maharashtra state, India.

Parameter	First Wave	Second Wave
Cumulative confirmed cases	20,56,429	36,90,317
Case Fatality Ratio (CFR)	2.48%	0.65%
Overall Attack rate	1.54%	2.8%
Epidemic doubling time	2.5 days	2.8 days

2021). Also, it should be noted that during the first wave mostly the urban centers were affected whereas during the second wave rural population (Gilai, 2021) were also affected as revealed by Fig. 7.

The total number of cases showed moderate positive association with population density (Fig. 8). However, Pune having much lower population density compared to Mumbai, had the largest number of cases during both the waves.

It is necessary also to consider the stringency of implementation of restrictions for COVID-19 in the state of Maharashtra. The first wave was started in March 2020 by tourists or students returning home from abroad (Parashar, 2020). Some infective individuals were isolated, wherever many other led to the generation of local clusters (family members, neighbors, etc.). In March 2020, there was no restriction in public life and scheduled religious events have contributed to local transmissions. Maharashtra along with the whole of India came under total lockdown and curfew starting from 24th March 2020.

For the first sixty days of the first wave, restrictions (lockdown) were imposed after 2 weeks and continued thereof. Shops opened once in 15 days, and social distancing was followed. Restrictions were slowly eased in phases starting from June 2020, when containment zone-based restrictions were planned. Removals of restrictions were conducted in a phased manner starting from August 2020. After the reduction in daily cases in January 2021, more restrictions were eased including the opening of restaurants and street food kiosks, and places of worship.

During the first sixty days of the second wave, there existed very few restrictions (COVID-19 appropriate restrictions) as the nation was unlocked in January 2021. This may have resulted in intense

transmission and a large number of cases for the second wave. In between 12th February 2021 and 14th April 2021, all educational institutes were closed, but companies and factories operated with varying strengths, shops/malls and religious places, mostly remained open, and inter-district, as well as inter-state travel, were possible. Restaurants and roadside eateries were frequented by people. Also, some people turned a more relaxed approach towards social distancing and masking protocols. There are reports of mutant strains contributing to cases as well (Vaidyanathan, 2021). It was reported that new mutant variants of COVID-19 - Kappa and Delta, were circulating in Maharashtra in February 2021 onwards (Cherian et al., 2021; Asrani et al., 2021). This may have also contributed to the surge of the second wave. However, imposition of COVID-19 appropriate restrictions from the 3rd week of April 2021 may have resulted in bringing down the number of new cases per day from the first week of May 2021.

It should be noted that India has launched its vaccination drive on 16 Jan 2021, in starting with the healthcare workers, followed by the elderly (Akhter and Kamraju, 2021). But only the fraction of population was vaccinated till end of February 2021. The vaccination drive was on while the second wave arrived.

Seasonality of any disease at any particular geographical location can be estimated from the time-series data for 3–5 years (Shil et al., 2020). In case of COVID-19 in India and elsewhere, such data is not yet available. Hence, the seasonality of the disease could not be analyzed. Also, the virus is thermally stable by structure and function in the temperature range 4–60 °C (Chin et al., 2020) and spreads fast in Siberia as well as in Arabian deserts or in tropical regions of India and other countries (Riddell et al., 2020). Hence, it is premature to determine the seasonality of COVID-19 or effects of climate on its spread. This can be a limitation of the study.

In summary, the second wave followed after high number of natural infections in the first wave along with vaccination drive for the high risk groups like health care workers, the elderly and adults with comorbidities. Also new variants emerged during the second wave which propelled higher transmission in unaffected areas along with surge in the urban areas affected earlier. Our observation indicate the need of

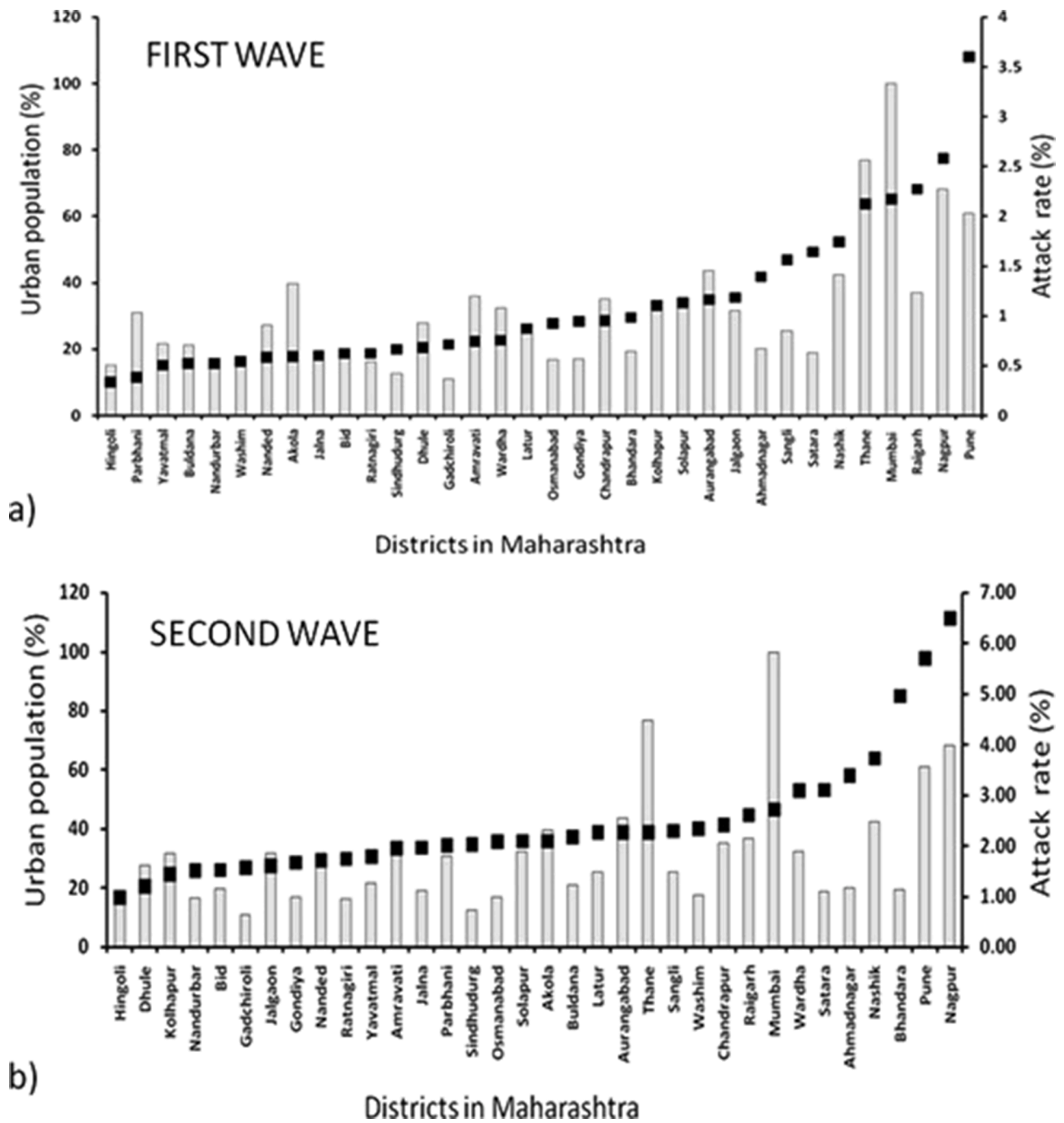


Fig. 7. District-wise comparison of the percentage of urban population (grey bars) with attack rate (shown as black dots) for the Maharashtra state, India: (a) First wave (9th March 2020 to 11th February 2021) and (b) Second wave (12th February 2021 to 31st May 2021).

continued vaccination for the at-risk population, enforcement of COVID-19 appropriate behavior and surveillance of new genetic variants of COVID-19 for effective control of future waves.

5. Conclusion

We conclude that the districts with a high percentage of the urban population and high population density had higher attack rates compared to less urbanized districts during the first wave, but during the second wave, the rural population was also affected across the state. A plethora of factors have contributed to the emergence of second wave in Maharashtra, India. We hope that the present analyses will help the public health authorities and researchers in epidemiology for estimating

the impact of preventive and control measures. Additionally, such exercises, if considered during the different phases of pandemic, then public health authorities can explore the use in real time to prioritize the surveillance, testing and control aspects.

CRedit authorship contribution statement

Pratip Shil: Visualization, Data curation, Formal analysis, Writing – original draft. **Nitin M Atre:** Data curation, Formal analysis. **Babasaheb V Tandale:** Visualization, Writing – original draft, Writing – review & editing.

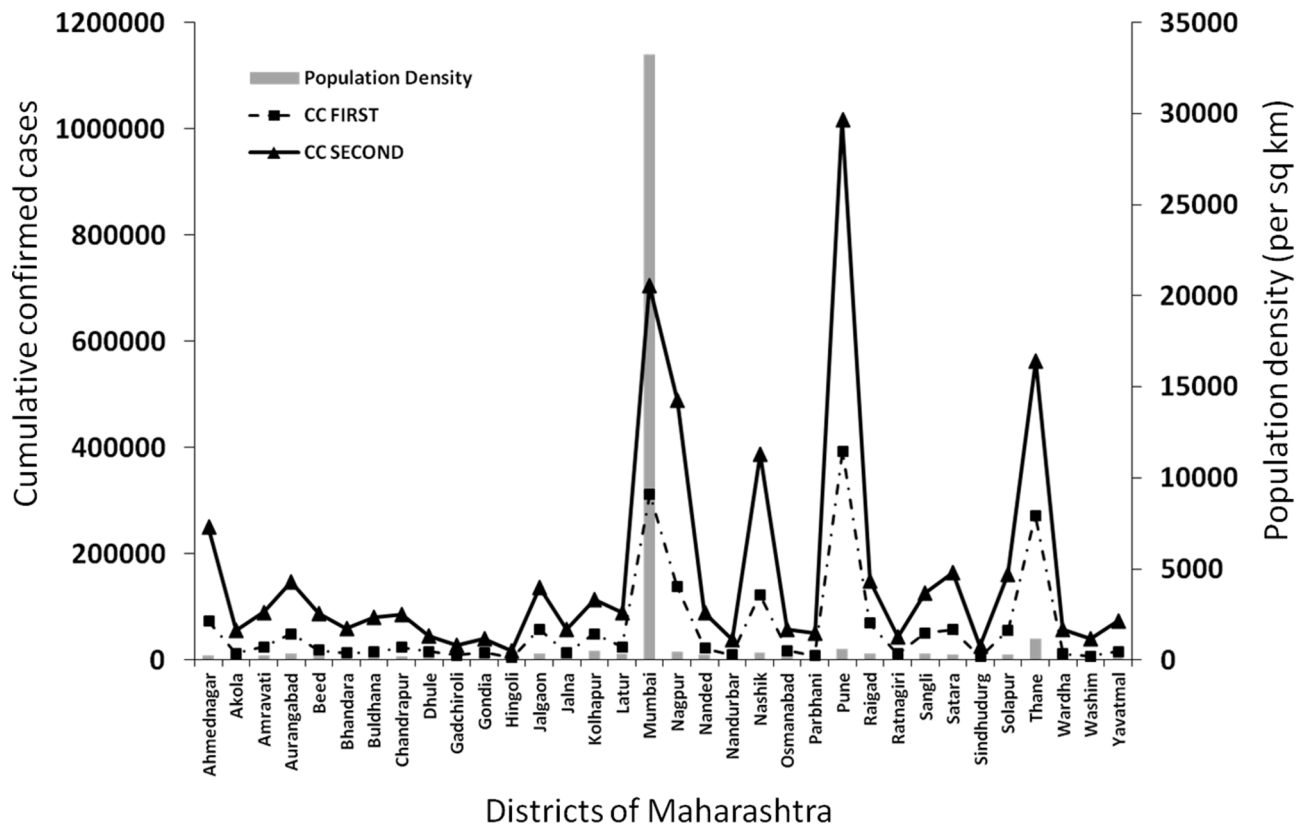


Fig. 8. Comparison of population density with total number of cases (Cumulative confirmed cases) for the first and second waves.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.sste.2022.100507](https://doi.org/10.1016/j.sste.2022.100507).

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