Effect of 2021 assembly election in India on COVID-19 transmission

Souvik Manik[✉] · Sabyasachi Pal[✉] ·
Manoj Mandal[✉] · Mangal Hazra[✉]

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Abstract India is one of the countries in the world which is badly affected by the COVID-19 second wave. Assembly election in four states and a union territory of India was taken place during March–May 2021 when the COVID-19 second wave was close to its peak and affected a huge number of people. We studied the impact of assembly election on the effective contact rate and the effective reproduction number of COVID-19 using different epidemiological models like SIR, SIRD, and SEIR. We also modeled the effective reproduction number for all election-bound states using different mathematical functions. We separately studied the case of all election-bound states and found all the states showed a distinct increase in the effective contact rate and the effective reproduction number during the election-bound time and just after that compared to pre-election time. States, where elections were conducted in single-phase, showed less increase in the effective contact rate and the reproduction number. The election commission imposed extra measures from the first week of April 2021 to restrict big campaign rallies,

meetings, and different political activities. The effective contact rate and the reproduction number showed a trend to decrease for few states due to the imposition of the restrictions. We also compared the effective contact rate, and the effective reproduction number of all election-bound states and the rest of India and found all the parameters related to the spread of virus for election-bound states are distinctly high compared to the rest of India.

Keywords COVID-19 · pandemic · infectious disease · virus spreading · epidemiological models · effective reproduction number · political campaign

1 Introduction

In November 2019, extremely infectious Coronavirus Disease 2019 (COVID-19) was found in the Wuhan province of China [1] Wuhan Municipal Health Commission notified the confirmation of identification of COVID-19 on December 31, 2019, [2]. The name of the Coronavirus disease announced officially as COVID-19 by the World Health Organization (WHO) and the International Committee on Taxonomy of Viruses (ICTV) also announced the name of the virus as Severe Acute Respiratory Syndrome Corona Virus 2 (SARS-CoV-2) on February 11, 2020, [3]. Presently, four mutant variants of Coronavirus are dominant, i.e. a) UK Variant [VOC 202012/01 (B.1.1.7)], b) South Africa variant [501Y.V2 (B.1.351)], c) Brazil variant [P.1

S. Manik · S. Pal (✉) · M. Mandal · M. Hazra
Midnapore City College, Kuturia, Paschim Medinipur
721129, India
e-mail: sabya.pal@gmail.com

S. Manik
e-mail: souvikmanik12@gmail.com

M. Mandal
e-mail: manojmandal@mconline.org.in

M. Hazra
e-mail: mangalkrhazra@gmail.com

(P.1)] [4], and d) Indian variant [B.1.617] [5]. WHO warned that the Indian variant, B.1.617, was spreading rapidly in India, making up more than 28% of samples from positive tests. Indian strain (B.1.617) appeared more contagious than other variants of SARS-CoV-2 [6].

Infectious diseases are caused by infectious organisms. Typically, these are bacteria, viruses, fungi, or worms/helminths. Severe Acute Respiratory Syndrome (SARS) is an example of an emerging infectious disease, where a severe variant of Coronavirus spread across continents within a short time.

India enrolled the first new positive case of Novel Coronavirus patient of Kerala in January 2020 [7]. Till May 2, 2021, 20 million total cases were reported with 0.37 million daily new cases and 0.21 million total death¹. To control the spread of the virus, few lockdowns were strictly imposed throughout India from March 24, 2020, and later, India started to reopen in phases from June 2020 [8]. COVID vaccination for people of age 50 years or above was started in India on January 16, 2021 [9], which was later opened up for the lower age group [10].

In India, the second wave of COVID-19 began around February 11, 2021. The effect of the second wave was severe with a record high daily cases of nearly three times compared to the peak of the first wave [11]. The daily deceased cases near the peak of the second wave were also nearly three times than the first wave peak, which has a great impact on society. The double mutant variant was mainly responsible in India for the second wave.

In India, assembly elections took place for four states and a union territory in multiple phases during the pandemic situation (March–May 2021) when the COVID-19 second wave was close to its peak and affected a huge number of people. The Election Commission of India (ECI) announced the tentative date of polling in different states on February 26, 2021. Polling in Assam and West Bengal was started on March 27, 2021, in three phases and eight phases, respectively. Polling in Kerala and Tamil Nadu was in a single phase on April 6, 2021. The election result was announced on May 2, 2021 [12, 13].

Election procedure with 186.8 million electors was taken place using 0.27 million polling stations in Tamil Nadu, West Bengal, Kerala, and Assam. Big campaigns

and many huge rallies took place in the election-bound regions, often with hundreds of thousands of people without following strict guidelines to restrict the spread of the Coronavirus which result in a rapid increase in infected individuals and casualties [14]. Political campaigns took place for different election candidates by supporters, party leaders, and different well-known celebrities. Political campaigns are conducted during the pre-election time to highlight a particular political party. During this campaign, huge gatherings and social interactions took place. These events have an important impact on the spread of the virus. It is well established that overcrowded gatherings increase the transmission rate of the virus drastically. Noting the impact of the election on the spread of the virus, the Madras High Court reproofed the ECI for approval of political rallies [15]. After the reprieve by Madras High Court, on April 9, 2021, ECI imposed few restrictions during the time of campaigns, election, and counting to control the spread of the Coronavirus [16]. Noting the surge of the virus, ECI announced more restrictions on political activities and the counting process of the election on April 27 and 28, 2021 [17, 18].

In this paper, we studied the variation of various driving parameters of the pandemic using different mathematical models and try to understand the effect of the pre-election activities and the impact of multiple phases of election in few states. We investigated the variation of effective contact rate (β_n) and effective reproduction number ($\mathbb{R}(t)$) of Coronavirus disease using different mathematical models for election and non-election-bound states during the assembly election of India in 2021.

We have summarized basic mathematical models for epidemics used in the article in Sect. 2. The data analysis and methodology are discussed in Sect. 3. The results of our study are given in Sect. 4. The discussion and conclusion are summarized in Sects. 5 and 6, respectively.

2 Mathematical models

We have used different mathematical models to study the effect of the election on the spread of Coronavirus. The key element of these models is to calculate the basic reproduction number ($\mathbb{R}_0$). The average number of people affected by a single infected person over a time is represented by $\mathbb{R}_0$ where $\mathbb{R}_0 > 1$ implies that the

¹ <https://www.worldometers.info/coronavirus/#countries>.

spread of the disease is increasing, $\mathbb{R}_0 = 1$ represents that the spread is stable and $\mathbb{R}_0 < 1$ means the spread is expected to stop over a time. Using different models, we investigated the evolution of the effective reproduction number $\mathbb{R}(t)$ for various election-bound states [19].

2.1 SIR model

There are several models for studying contagious disease transmission in a large population. The simplest compartmental model that can explain the evolution of an outbreak at the population level is the susceptible–infected–recovered (SIR) model [19–21]. Different compartments of the SIR model are shown in Fig. 2. When the maternal antibodies are no longer present in the body, the infant is moved as susceptible class S . When a susceptible comes into sufficient contact with an infective to allow transmission, the individual is classified as an infective class I , meaning they are infectious in the sense that they may spread the virus. When the infectious period is over, the person enters the recovered class R , which is made up of people who have infection-acquired immunity.

One of the major assumptions of the classic SIR model is that the infected (I) and susceptible (S) populations are mixed homogeneously and the total population N remains constant over the study. The susceptible population (S) in the SIR model drops monotonically toward zero. It is assumed that the time scale of the SIR model is short enough that births and deaths (other than those caused by the virus) can be ignored, and that the number of virus-related deaths is small in comparison to the total population.

This model was used to study various time-dependent parameters such as recovery rate (γ), contact rate (β), and effective reproduction number ($\mathbb{R}$). At any given time t , $S(t)$ (total population–confirmed), $I(t)$ (confirmed–recovered–deaths), and $R(t)$ (recovered + deaths) are the total number of susceptible individuals, infected individuals, and recovered individuals, respectively. N is the total population, which is assumed to be constant during our study.

These parameters can be expressed as in the form of fractions:

$$s(t) = \frac{S(t)}{N}, i(t) = \frac{I(t)}{N}, r(t) = \frac{R(t)}{N} \quad (1)$$

from the conservation law,

$$s(t) + i(t) + r(t) = 1. \quad (2)$$

SIR model can be expressed by following set of differential equations.

$$\frac{ds(t)}{dt} = -\beta(t)s(t)i(t) \quad (3)$$

$$\frac{di(t)}{dt} = \beta(t)s(t)i(t) - \gamma(t)i(t) \quad (4)$$

$$\frac{dr(t)}{dt} = \gamma(t)i(t) \quad (5)$$

We can write from Eq. 4,

$$\beta_n = \frac{1}{s_n i_n} [i_{n+1} - (1 - \gamma_n)i_n] \quad (6)$$

The effective reproduction number $\mathbb{R}(t)$ can be figured out from this equation.

$$\mathbb{R}(t) = \frac{\beta_n}{\gamma_n} \quad (7)$$

We studied the variation of recovery rate (γ_n), contact rate (β_n), and effective reproduction number ($\mathbb{R}(t)$) of Coronavirus which are dependent on time.

2.2 SIRD model

The susceptible–infectious–recovered–deceased (SIRD) [19, 21] is modified version of the SIR model (Sect. 2.1). In this model, there are separate compartments for the deceased and recovered individuals. The time-dependent functions $S(t)$, $I(t)$, $R(t)$, and $D(t)$ are the total number of susceptible individuals, the total number of infected individuals, the total number of recovered individuals, and the total number of deceased individuals, respectively, and N is the total population, which is assumed to remain constant over the study. Different compartments of the SIRD model are shown in Fig. 2. Using this model, we studied time dependence functions like the recovery rate (γ_n), contact rate (β_n), mortality rate (α_n) and effective reproduction number ($\mathbb{R}(t)$).

$s(t)$, $i(t)$, $r(t)$, and $d(t)$ can be expressed in fractional form:

$$s(t) = \frac{S(t)}{N}, i(t) = \frac{I(t)}{N}, r(t) = \frac{R(t)}{N}, d(t) = \frac{D(t)}{N} \quad (8)$$

from the conservation law,

$$s(t) + i(t) + r(t) + d(t) = 1 \quad (9)$$

SIRD model can be expressed by following set of differential equations.

$$\frac{ds(t)}{dt} = -\beta(t)s(t)i(t) \quad (10)$$

$$\frac{di(t)}{dt} = \beta(t)s(t)i(t) - [\gamma(t) + \alpha(t)]i(t) \quad (11)$$

$$\frac{dr(t)}{dt} = \gamma(t)i(t) \quad (12)$$

$$\frac{dd(t)}{dt} = \alpha(t)i(t); \quad (13)$$

from Eq. 11, we may write

$$\beta_n = \frac{1}{s_n i_n} [i_{n+1} + (\gamma_n + \alpha_n - 1)i_n]. \quad (14)$$

The effective reproduction number $\mathbb{R}(t)$ can be expressed as

$$\mathbb{R}(t) = \frac{\beta_n}{\gamma_n + \alpha_n} \quad (15)$$

2.3 SEIR Model

The most studied epidemic model is the susceptible–exposed–infectious–removed (SEIR) model [19, 22–25]. The SEIR model is a variation of the SIR model (Sect. 2.1). We used the average incubation period $1/\sigma$ ($=7$) as a constant in the SEIR model. The time-dependent functions $S(t)$, $E(t)$, $I(t)$, and $R(t)$ are the total number of susceptible individuals, the total number of exposed individuals, the total number of infected individuals, and the total number of removed individuals (recovered or deceased), respectively. We assumed the total population (N) remains constant during the study. Here, γ_n is the recovery rate, and β_n and $\mathbb{R}(t)$ are the effective contact rate and effective reproduction number of Coronavirus, respectively. The contact rate (β) is defined as the product of the average number of contacts per person per unit time by the probability of disease transmission in contact between susceptible and infectious individuals, and γ is the recovery rate. The introduction of the exposed individuals (E) in the SEIR model makes the model more efficient than the SIR model. We have shown different compartments of the SEIR model in Fig. 2. In Sect. 2.1, we have discussed how the infant propagates (S–I–R) from

one compartment to another. In the SEIR model, the exposed compartment is an addition to the SIR model. Transmission occurs when there is adequate contact of a susceptible with an infective. Then, the susceptible enters the exposed class (E) of those in the latent period, who are infected but not yet infectious. At the end of the latent period, the individual enters the class (I) and they are capable of transmitting the infection. After the end of the infectious period, the individual enters the class R .

$s(t)$, $e(t)$, $i(t)$, and $r(t)$ can be expressed in fractional form:

$$s(t) = \frac{S(t)}{N}, e(t) = \frac{E(t)}{N}, i(t) = \frac{I(t)}{N}, r(t) = \frac{R(t)}{N} \quad (16)$$

from the conservation law, we may write:

$$s(t) + e(t) + i(t) + r(t) = 1 \quad (17)$$

The SEIR model can be expressed by following set of differential equations

$$\frac{ds(t)}{dt} = -\beta(t)s(t)i(t) \quad (18)$$

$$\frac{de(t)}{dt} = \beta(t)s(t)i(t) - \sigma e(t) \quad (19)$$

$$\frac{di(t)}{dt} = \sigma e(t) - \gamma(t)i(t) \quad (20)$$

$$\frac{dr(t)}{dt} = \gamma(t)i(t) \quad (21)$$

Now, we use Eq. (19) to find β_n

$$\beta_n = \frac{e_{n+1} - e_n + \sigma e_n}{s_n i_n} \quad (22)$$

Using Eqs. 19, 20, and 22, we can write

$$\beta_n = \frac{1}{s_n i_n \sigma} [i_{n+2} + (\gamma_n + \sigma - 2)i_{n+1} + (\sigma - 1)(\gamma_n - 1)i_n] \quad (23)$$

The effective reproduction number $\mathbb{R}(t)$ can be expressed from this equation.

$$\mathbb{R}(t) = \frac{\beta_n}{\gamma_n} \quad (24)$$

2.4 Time-dependent exponential β suppression model

As the pandemic evolved, various control measures [26] were introduced, including lockdown, social distancing, and increased hygiene, causing transmission

coefficients β to become time dependent [27]. The SIR model with constant transmission coefficients is applicable only in the situation when the pandemic is let to grow without any intervention. We have introduced a time-dependent (decaying) growth rate to explain the real scenario of the spread of the virus. Apart from this, the drop in the susceptible population also decreases β [28–31]. In general, the lockdown starts on a fixed day t_l and has a duration (τ). We can incorporate these two parameters into the modeling of $\beta(t)$ in many different ways, and one of them is given below:

$$\begin{cases} \beta(t) = \beta_0, & \text{if } t \leq t_l \\ \beta(t) = \beta_0 \left[(1 - \alpha) \exp\left(-\frac{(t-t_l)}{\tau}\right) + \alpha \right], & \text{otherwise} \end{cases} \quad (25)$$

where β_0 = the initial contact rate, t_l is the time for starting lockdown, $\mu = \frac{1}{\tau}$ is the decay rate, and $\alpha = \frac{\beta_{min}}{\beta_{max}}$.

In this model, $\beta(t)$ varies from some constant β_0 to $\beta_0(1 - \alpha)$ between time $t = t_l$ and $t = \infty$. From Eq. (25), we may write

$$\mu = \frac{1}{\tau} = \frac{1}{t_l - t} \log \left[\frac{1}{1 - \alpha} \left(\frac{\beta(t)}{\beta_0} - \alpha \right) \right] \quad (26)$$

We used this model to fit the data of infected and recovered cases for election-bound states and summarized the fitting parameters in Table 2.

3 Data analysis and methodology

We used the Coronavirus data maintained by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University to track reported cases of Coronavirus in real time [32]. The time-series data of different Indian states can be accessed from these sources^{2,3}. The database comes with the counts of confirmed, recovered, and deceased individuals. At first, we have picked up the matrices (confirmed, recovered, and death) for India and then we separated them into two parts, i.e. four election-bound states (Assam, Kerala, Tamil Nadu, and West Bengal) and non-election states as the rest of India. We have used standard python packages, i.e., Numpy, Scipy, Pandas, Matplotlib for the entire work. To compare the effect of the election on the spread of Coronavirus, we used time-series data

of pre-election time and election time. We studied the impact of the election on the spread of the Coronavirus from February 2, 2021 to May 15, 2021.

We studied the variation of confirmed, recovered, and deceased individuals for all election-bound states separately and also studied the cumulative effect of all election-bound states and rest of the India. The effective contact rate ($\beta(t)$), recovery rate ($\gamma(t)$), and effective reproduction number ($\mathbb{R}(t)$) were estimated from the mathematical equations discussed in Sect. 2 for whole India and all election-bound states separately. We also studied the evolution of these parameters using timeseries data.

To minimize the effect of noise, we used a three-day rolling mean variation for our study. We have calculated the values of transmission coefficients using three basic models (for details, see Sects. 2.1, 2.2, 2.3) for four election-bound states (Assam, Kerala, Tamil Nadu, and West Bengal). For the SIR model, we have used Eqs. (6) and (7) to calculate contact rate (β_n) and effective reproduction number ($\mathbb{R}(t)$) respectively. For the SIRD model, we have used Eqs. (14) and (15) to calculate contact rate (β_n) and effective reproduction number ($\mathbb{R}(t)$), respectively. For the SEIR model, we have used Eqs. (23) and (24) to calculate contact rate (β_n) and effective reproduction number ($\mathbb{R}(t)$), respectively. We have optimized the values of all transmission coefficients by removing all negative values. To compare the effect of the election on the spread of Coronavirus, we studied separately cumulative statistics of all election-bound states and the rest of India.

We studied the variation of confirmed, recovered, and deceased individuals for all election-bound states, the cumulative effect of all election-bound states and the rest of India. The effective contact rate ($\beta(t)$), recovery rate ($\gamma(t)$), and effective reproduction number ($\mathbb{R}(t)$) were estimated from the mathematical equations discussed in Sect. 2 for whole India and all election-bound states separately. We also studied the evolution of these parameters using time series data.

The assembly election in the Union Territory of Puducherry was also held along with elections of four states. The election took place in a single phase on April 6, 2021 [12]. The population of Puducherry is ~ 1.7 million⁴, which is comparatively low than other election-

² <https://api.covid19india.org/>.

³ <https://github.com/CSSEGISandData/COVID-19>.

⁴ <https://www.census2011.co.in/census/state/puducherry.html#futurepop>.

bound states in India. So, we exclude Puducherry in our study.

4 Result

We studied the impact of the election, political activities, and a bulk amount of gatherings without maintaining COVID-19 protocols on the spread of Coronavirus. We used different basic mathematical models like SIR, SIRD, and SEIR to study the variation of different fundamental parameters related to pandemics. Figure 1 shows the variation of different driving parameters of the pandemic over entire India. The first panel of Fig. 1 shows the variation of confirmed, recovered, and deceased individuals, which indicated that the second wave of Coronavirus was effective from the second week of February 2021. The second panel of Fig. 1 Shows the variation of effective contact rate $\beta(t)$ using SIR, SIRD, and SEIR models over the same time. $\beta(t)$ showed a trend to increase from March 2021, and the value of $\beta(t)$ varied between 0.05 and 0.3 and attained a maximum of ~ 0.3 during the mid-week of March for the SEIR model. SIR and SIRD models showed a similar trend and varied between 0 and 0.17 and reached a maximum near March 19, 2021. The third panel showed the variation of recovery rate $\gamma(t)$, which was varied between ~ 0.06 to 0.12 during February–April. The variation of effective reproduction number is shown in the bottom panel of Fig. 1, which increased drastically during February–April for all the mathematical models. Using the SEIR model, the effective reproduction number ($\mathbb{R}(t)$) reached the highest value of ~ 4 during the mid-week of March 2021. For SIR and SIRD models, the value of the effective reproduction number varied between 0.75 and 2.1 and peaked near March 28, 2021. For all three models, there was a sharp rise in $\mathbb{R}(t)$ from March 27 which peaked near April 11, 2021. From Sect. 4.5, it is evident that the increase in $\mathbb{R}(t)$ is mostly contributed by four election-bound states.

4.1 Kerala

The population of the Indian state Kerala is ~ 34.8 million in the year 2021⁵. The election in Kerala was held in only one phase. The variation of different parameters

⁵ <https://www.census2011.co.in/census/state/kerala.html>.

Fig. 1 First panel: the variation of three types of COVID-19-affected populations (confirmed, recovered, and deceased individuals) with time. Second panel: using different mathematical models (SIR, SIRD, SEIR), the change in the number of contact rates ($\beta(t)$) with time. Third panel: The variation of recovery rate ($\gamma(t)$) with time using three models. Fourth panel: the variation of the effective reproduction number ($\mathbb{R}(t)$) for three models

Fig. 2 The schematic diagram showing different compartments of SIR, SIRD, and SEIR models. β is the contact rate, γ is the recovery rate, σ is the incubation period, and α is the mortality rate

Fig. 3 First panel: the standard variation of confirmed, recovered, and deceased individuals with time. Second panel: The variation of effective contact rate ($\beta(t)$) with time using SIR, SIRD, and SEIR models. Third panel: The variation of recovery rate ($\gamma(t)$) with time for three basic models. Fourth panel: The variation of the effective reproduction number ($R(t)$) using

three models. The grey dotted lines indicated the announcement date of the election, and red dashed lines pointed to the different phases of election for mentioned states. The blue solid line shows the date of warning notice of ECI to political parties. The black solid line indicates the date of counting and election result

is shown in top left of Fig. 3. The figure showed that due to single-phase elections, the spread of Coronavirus was significant but less compared to other states where the election was held in multiple phases. The number of infected, deceased individuals started to increase a week before the election when campaigns and rallies were at their peaks. The value of the effective reproduction number was below 1.05 on the date of announcement of the election and increased to nearly 3.46, 1.45, and 1.46 for the SEIR, SIR, and SIRD models, respectively, after the election (on April 6, 2021) which continue to rise drastically even after the election. During the last week of April (on April 20, 2021), the reproduction number reached ~ 13 for the SEIR model. The SIR and SIRD models also showed a rise in the value of effective reproduction number during the last week of April 2021 and reached the highest value of ~ 5 .

4.2 Tamil Nadu

The population of the Indian state Tamil Nadu is ~ 84.9 million in the year 2021⁶. The right top panel of Fig. 3 showed the variation of different parameters related to the spread rate of COVID-19 for the state Tamil Nadu. The election of this state occurred in a single phase during the first week of April 2021.

The figure implied that the effective reproduction number reached a peak during the second week of March 2021 when the election campaigns were in full swing. The effective reproduction number reached a value of 9.85 for the SEIR model during the third week of March 2021. There was another peak (~ 5.9) in the effective reproduction number just after the date of the election. The value of the effective reproduction number was ~ 1.08 on the date of announcement of the election (February 26, 2021) and increased drastically to a value of 5.9 for the SEIR model just after the election. The SIR and SIRD models also showed a trend of rising in the effective reproduction number just after the election and reached a maximum value of ~ 3 . The effective reproduction number started to decrease after the end of the election.

4.3 Assam

The population of the Indian state Assam is ~ 36.5 million in the year 2021⁷. The bottom left of Fig. 3 showed the variation of different fundamental parameters of the pandemic for the state Assam. The red dotted vertical lines indicated the phases of the election of Assam. The number of daily infected individuals showed a sharp rise from the first phase of the election in Assam. The effective contact rate and the effective reproduction number with the SEIR model reached a peak after the second phase of the election (April 3, 2021). All the models showed a very high value of the effective reproduction number during all phases of the election which started to decrease after the last phase of the election was over and reached a low value after counting of the election was over. The value of the effective reproduction number was ~ 1.62 on the date of announcement of election which increased to ~ 23.9 for the SEIR model after the second phase of election (on April 2, 2021) and increased drastically to a maximum value of ~ 25 for SEIR model after the election (on April 10, 2021). The effective reproduction number showed a trend of rising from just after the election for SIR and SIRD models and reached a maximum value of ~ 9 .

4.4 West Bengal

Indian state West Bengal is the only state where the election was held for a long duration of 33 days, with 8 phases which increased the spread rate of the virus drastically. In the bottom right panel of Fig. 3, the variation of different parameters using 3 different mathematical models for West Bengal was shown. The population of West Bengal is ~ 101.8 million in the year 2021⁸. The red dotted vertical lines showed the time of different phases of the election. The date of announcement of the election and poll counting was also added to the figure.

The figure showed that the number of individuals infected and deceased increased sharply during the election phases and reached a peak near the second phase of the election when campaigns were at their peaks for all major political parties. Before the begin-

⁶ <https://www.census2011.co.in/census/state/tamil+nadu.html>.

⁷ <https://www.census2011.co.in/census/state/assam.html>.

⁸ <https://www.census2011.co.in/census/state/west+bengal.html>.

Fig. 4 First panel: The variation of three days rolling mean of confirmed, recovered, and deceased individuals. Second panel: the variation of effective contact rate ($\beta(t)$) with time using SIR, SIRD, and SEIR models. Third panel: the variation of recovery rate ($\gamma(t)$) with time using these models. Fourth panel: evolution of the effective reproduction number ($\mathbb{R}(t)$) using three models.

Table 1 A summary of the fitting parameters for the SIR case (as visible in Figs. 5 and 6) with time-dependent exponential β suppression model used to fit infected and removed individuals. β_0 is the initial contact rate, t_l is the time for starting lockdown, $\mu = 1/\tau$ is the decay rate and $\alpha = \beta_{min}/\beta_{max}$

Model	States	$\gamma, \beta_0, \alpha, \mu, t_l$
SIR with $\beta(t)$ exp	Kerala	0.08, 0.70, 0.20, 0.20, 1.20
	Tamil Nadu	0.12, 0.47, 0.22, 0.04, 0.91
	Assam	0.09, 0.40, 0.19, 0.08, 13.97
	West Bengal	0.13, 0.61, 0.14, 0.07, 1.23
	Whole elec- tion states	0.11, 0.60, 0.20, 0.11, 0.11

ning of the election (on March 27, 2021), the daily confirmed cases were 812, which increased to 1733 after

The announcement date of the election is indicated by the grey dotted line, and the announcement date of the warning notice of ECI to political parties is shown by the blue solid line. For both plots, the pink shaded region referred to the time between starting and ending dates for the election in election-bound states. The black solid line shows the date of counting and election result

the second phase of the election (on April 2, 2021). One of the driving factors of a pandemic is the effective reproduction number, which was ~ 0.95 on the date of announcement of the election and increased to a record value of nearly 17.14 for the SEIR model after the second phase of the election (on April 2, 2021). The effective reproduction number also showed a trend to increase for both the SIR and SIRD models from the first phase of the election. Before each phase of the election, a small but significant peak was visible in the reproduction number. The effective reproduction number decreased after all election-bound activity was over with the counting of the election.

4.5 Comparison of spread rate between election and non-election states in India

To compare the effect of the election on the spread of Coronavirus between election-bound states and the

Fig. 5 Blue and orange points indicated infected and removed individuals, respectively, for all election-bound states (Kerala, Tamil Nadu, Assam, and West Bengal). The fitting with the SIR

case with time-dependent exponential β suppression model (as described in Sect. 2.4) was shown for all states with solid lines

rest of India, we studied the cumulative statistics of all election-bound states and the rest of India. Figure 4 shows the variation of infected, recovered, and deceased individuals along with the effective contact rate, and the effective reproduction number for cumulative statistics of election-bound states (left) and the rest of India (right). The number of confirmed and deceased individuals was increased drastically during the election (as shown in the shaded region of Fig. 4). The effective contact rate and effective reproduction number showed a sharp rise for the cumulative study of all election-bound states during the time of election. The

effective reproduction number was also increased drastically from early April 2021 and reached a maximum value of ~ 8 for the SEIR model. For SIR and SIRD models, the peak value of $\mathbb{R}(t)$ reached ~ 2.5 . The value of $\mathbb{R}(t)$ was ~ 1.03 on the date of announcement of the election and increased drastically to a record value of 8.3 for the SEIR model during election time (on April 11, 2021). The right side of Fig. 4 showed the variation of different parameters for non-election states of India, which indicated that the value of the effective contact rate and effective reproduction number during the same time is less compared to election-bound states. So, it

was evident that the impact of the election and political activities on the spread rate of the Coronavirus was significant for India.

4.6 Mathematical modeling of variation of reproduction number

We calculated the transmission coefficients and effective reproduction number using different mathematical models (SIR, SIRD, SEIR) for cumulative statistics of all election-bound states.

During the election time (as shown in the shaded region of Fig. 4), we fitted the effective reproduction numbers for all election-bound states with different mathematical functions, i.e. Gaussian, Lorentzian, and split Lorentzian with the least square method for different epidemiological models (SIR, SIRD, and SEIR) [33]. The values of all fitting parameters are summarized in Table 2.

Figure 5 shows the variation of infected and removed individuals for all four election-bound states separately starting from the date of the first election. The fitting with the SIR case with the time-dependent exponential β suppression model was shown for all four election-bound states (Kerala, Tamil Nadu, Assam, and West Bengal). The fitting parameters for all four states are summarized in Table 1.

In Fig. 6, we showed the cumulative variation of infected and removed individuals for all four election-bound states. The figure was similar to Fig. 5, where the fitting with the SIR model with time-dependent exponential β suppression model was shown for cumulative variation of four election-bound states.

We modeled the trend of the effective reproduction number for three epidemiological models (SIR, SIRD, and SEIR) using different mathematical functions. In Fig. 7, $\mathbb{R}(t)$ was fitted with different mathematical functions like Lorentzian, split Lorentzian, and Gaussian for SIR, SIRD, and SEIR models. We applied the least square method to fit $\mathbb{R}(t)$. The top panel of Fig. 7 showed the evolution of $\mathbb{R}(t)$ during the election period for all the election-bound Indian states. $\mathbb{R}(t)$ for the SIR model was well fitted with Lorentzian, split Lorentzian and Gaussian functions, and the value of reduced Chi-squared (χ^2) was ~ 0.05 for these functions. The middle of Fig. 7 showed the variation of $\mathbb{R}(t)$ for the SIRD model, which is fitted with the same three mathematical functions. $\mathbb{R}(t)$ for the SIRD model

Fig. 6 The same as in Fig. 5 for the summation of all election-bound states in India. Blue and orange points indicated infected and removed individuals, respectively. The fitting with the SIR case with time-dependent exponential β suppression model (as mentioned in Sect. 2.4) was shown with solid lines

was also well fitted with all the three functions, and the value of reduced Chi-squared (χ^2) was ~ 0.05 for these functions. The bottom panel of Fig. 7 represented the variation of $\mathbb{R}(t)$ for the SEIR model, which was well fitted with the Lorentzian function with reduced $\chi^2 \sim 4.79$. The variation of $\mathbb{R}(t)$ was also fitted well with a Gaussian function with a reduced χ^2 value of ~ 4.85 .

5 Discussion

The impact of the assembly election on the transmission of COVID-19 was studied for all election-bound states separately. Most of the Indian states, where the election took place with multiple phases, were affected badly by Coronavirus.

Election campaigns, political activities including political rallies, meetings, overcrowded gatherings were held regularly for different cities of the states without maintaining proper COVID-19 protocols. These political events played a crucial role in a sharp rise in the number of infected individuals as well as in the significant increment in the effective reproduction number and contact rate of the Coronavirus.

The spread of Coronavirus depended on so many factors like social distance, personal hygiene, vaccination, environmental factors, etc. During the study, we

Table 2 A summary of the fitting parameters for the models used to fit effective reproduction number during the election period (as visible in Fig. 7). For fitting of Gaussian, Lorentzian, and split Lorentzian functions, independent parameters amplitude (A),

center of Gaussian/Lorentzian/split Lorentzian (μ), and width or standard deviation (σ) are used. For fitting of split Lorentzian function, total width or standard deviation (σ) and width of right side of the split function (σ_r) are tabulated

Model	Epidemiological Models	A, μ, σ, σ_r
Gaussian	SIR	94.84, 19.03, 14.50, —
	SIRD	94.84, 19.03, 14.50, —
	SEIR	108.54, 18.53, 7.54, —
Lorentzian	SIR	148.85, 19.27, 17.91, —
	SIRD	148.85, 19.27, 17.91, —
	SEIR	150.37, 18.15, 7.90, —
Split Lorentzian	SIR	143.72, 23.29, 23.61, 10.72
	SIRD	143.72, 23.29, 23.61, 10.72

assumed that these factors remained the same for these states, and the effect of these factors on the result is marginal. The drastic change in effective reproduction number of COVID-19, effective contact rate, and daily new cases during the election period implied that the bulk gathering during the political activities played a major role to spread the virus.

We also modeled the infected and removed individuals for different election-bound states using the SIR case with the time-dependent exponential β suppression model (Fig. 5). All these four states showed that there was a rapid increase in infected individuals which matches well with the exponential β suppression model. For the states, Tamil Nadu, Assam, and West Bengal, the increase rate of infected individuals was higher than the exponential increase during the initial few days of the election. This is most probably due to the effect of frequent pre-election activities like rallies and meetings with a bulk amount of people.

The evolution of effective reproduction number for the SIR and SIRD model was well fitted with different mathematical functions (Fig. 7). The fitting statistics for SIR and SIRD model were comparatively better than the SEIR model. Most of the time, the effective reproduction number was above 1 for all three models which imply that during the election time the spread of the virus was high for all election-bound states. The peak value of the effective reproduction number for the SEIR model was comparatively higher than SIR and SIRD model.

The result showed that for West Bengal and Assam, where the election took place in multiple phases, the

new Coronavirus-infected cases were increased unusually probably due to several political movements, meetings, gatherings during the prolonged pre-election, and election period. The comparative study of the variation of different fundamental parameters of the pandemic for all election-bound states and the rest of India suggested that the effect of election played a key role to increase the spread of the virus unusually. It was evident that the states where the election was completed in single-phase were comparatively less affected than the states where the election was conducted in multiple phases.

6 Conclusion

We have summarized the result of our study on the impact of political activities and elections on the COVID-19 spread rate for different Indian states during the March–May 2021 assembly election using different mathematical models. Using epidemiological models such as SIR, SIRD, and SEIR, we investigated the effect of assembly election on the effective contact rate and effective reproduction number. We looked at each election-bound state separately and found that all of them had a significant rise in effective contact rate and effective reproduction number during the election-bound period and immediately afterward, compared to the pre-election period. The impact of pre-election activities including political rallies, movements, and over-crowded gatherings was reflected clearly in the change of effective reproduction number. States with

Fig. 7 The variation of effective reproduction number ($R(t)$) during election time is fitted with different mathematical functions using cumulative data for all election-bound states. The initial reference point represents the first date of 2021 assembly election (March 27, 2021)

single-phase elections were comparatively less affected than the states where the election was conducted in multiple phases. From the first week of April 2021, the election commission imposed additional restrictions on large campaign rallies, meetings, and other political activities which helped to slow down the effective contact rate and the effective reproduction number in all election-bound states.

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Declarations

Conflicts of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- Ma, J.: China's first confirmed COVID-19 case traced back to November 17, 13 march 2020. South China Morning Post (2020)
- Organization, W.H., et al.: Pneumonia of unknown cause—China, 5 january 2020. World Health Organization (2020)
- Organization, W.H., et al.: Naming the coronavirus disease (covid-19) and the virus that causes it. Brazil. J. Implant. Health Sci. **2**(3),(2020)
- Guidelines for international arrivals, ministry of health and family welfare, Government of India, 17 February 2021 (2021)
- Genome sequencing by INSACOG shows variants of concern and a novel variant in India, ministry of health and family welfare, Government of India, release id: 1707177 (2021)
- Organization, W.H., et al.: Covid-19 weekly epidemiological update, 11 May 2021. World Health Organization (2021)
- Delhi, P.: Update on novel coronavirus: one positive case reported in Kerala. Ministry of Health and Family Welfare **1601095**,(2020)
- Guidelines for phased re-opening (unlock-1), Ministry of Home Affairs, order no. 40-3/2020-dm-i(a), 30 may 2020 (2020)
- Perappadan, B.S.: First phase of vaccination to start on January 16. The Hindu (2021)
- COVID-19: only six states to begin vaccination for 18+ from today, 1 May 2021. India News—Times of India (2021)
- Ranjan, R., Sharma, A., Verma, M.K.: Characterization of the second wave of COVID-19 in India. medRxiv (2021) <https://doi.org/10.1101/2021.04.17.21255665>

12. General election to the legislative assemblies of Assam, Kerala, Tamil Nadu, West Bengal and Puducherry. Election Commission of India (2021)
13. List of states government tenure and tentative date of upcoming elections in India. Elections.in (2021)
14. Bhuyan, A.: Experts criticise india's complacency over covid-19. *The Lancet* **397**(10285), 1611–1612 (2021). [https://doi.org/10.1016/S0140-6736\(21\)00993-4](https://doi.org/10.1016/S0140-6736(21)00993-4)
15. Madhav, P.: Madras HC says election commission responsible for 2nd Covid wave, says officials should be booked for murder, 26 april 2021. *IndiaToday* (2021)
16. Reiterating guidelines for strict observance of covid protocols during election rallies, meetings, campaigning, etc- reg, order no: 4/2021/sdr/vol.i, 9 april 2021 (2021)
17. General election to legislative assemblies of west bengal, assam, tamil nadu, kerala and puducherry, 2021-prohibition of victory procession, order no: 464/inst/2021/eps, 27 april 2021 (2021)
18. Broad guidelines for covid-safety during counting of votes on 2nd may 2021, election commission of india, order no.464/inst/2021/eps (2021)
19. Mandal, M., Patra, S., Pal, S., Acharya, S., Hazra, M.: Study of the dependence of effective reproduction number of COVID-19 on the temperature and humidity: a case study with the Indian states. *medRxiv* (2020). <https://doi.org/10.1101/2020.07.05.20146324>
20. Kermack, W.O., McKendrick, A.G.: A contribution to the mathematical theory of epidemics. *Proceedings of the royal society of london. Series A, Containing papers of a mathematical and physical character* **115**(772), 700–721 (1927). <https://doi.org/10.1098/rspa.1927.0118>
21. Ndiaye, B.M., Tendeng, L., Seck, D.: Comparative prediction of confirmed cases with covid-19 pandemic by machine learning, deterministic and stochastic sir models (2020) [arXiv:2004.13489](https://arxiv.org/abs/2004.13489) [q-bio.PE]
22. Li, M.: *An Introduction to Mathematical Modeling of Infectious Diseases*. Springer, Cham (2018)
23. Faranda, D., Alberti, T.: Modeling the second wave of COVID-19 infections in France and Italy via a stochastic SEIR model. *Chaos: An Interdisciplinary. J. Nonlinear Sci.* **30**(11), 111101 (2020). <https://doi.org/10.1063/5.0015943>
24. Piccolomini, E.L., Zama, F.: Preliminary analysis of covid-19 spread in italy with an adaptive seird model (2020) [arXiv:2003.09909](https://arxiv.org/abs/2003.09909) [q-bio.PE]
25. Goswami, G., Prasad, J., Dhuria, M.: Extracting the effective contact rate of covid-19 pandemic (2020) [arXiv:2004.07750](https://arxiv.org/abs/2004.07750) [q-bio.PE]
26. Daddi, E., Giavalisco, M.: Early forecasts of the evolution of the covid-19 outbreaks and quantitative assessment of the effectiveness of countering measures (2020) [arXiv:2004.08365](https://arxiv.org/abs/2004.08365) [q-bio.PE]
27. Hotz, T., Glock, M., Heyder, S., Semper, S., Böhle, A., Krämer, A.: Monitoring the spread of covid-19 by estimating reproduction numbers over time (2020) [arXiv:2004.08557](https://arxiv.org/abs/2004.08557) [q-bio.PE]
28. Lipsitch, M., Cohen, T., Cooper, B., Robins, J.M., Ma, S., James, L., Gopalakrishna, G., Chew, S.K., Tan, C.C., Samore, M.H., et al.: Transmission dynamics and control of severe acute respiratory syndrome. *science* **300**(5627), 1966–1970 (2003). <https://doi.org/10.1126/science.1086616>
29. Cobey, S.: Modeling infectious disease dynamics. *Science* **368**(6492), 713–714 (2020). <https://doi.org/10.1126/science.abb5659>
30. Fanelli, D., Piazza, F.: Analysis and forecast of COVID-19 spreading in China, Italy and France. *Chaos, Solitons Fract.* **134**, 109761 (2020). <https://doi.org/10.1016/j.chaos.2020.109761>
31. Ponce de León, U.E., Perez, A.G., Avila, E.: A data driven analysis and forecast of an SEIARD epidemic model for COVID-19 in Mexico. *Big Data Inf. Anal.* **5**, 14–28 (2020). <https://doi.org/10.3934/bdia.2020002>
32. Dong, E., Du, H., Gardner, L.: An interactive web-based dashboard to track COVID-19 in real time. *Lancet Infect. Dis.* (2020). [https://doi.org/10.1016/S1473-3099\(20\)30120-1](https://doi.org/10.1016/S1473-3099(20)30120-1)
33. Newville, M., Stensitzki, T., Allen, D., Ingargiola, A.: LMFIT: Non-linear least-square minimization and curve-fitting for python. *Astrophys. Source Code Libr.* (2014). <https://doi.org/10.5281/zenodo.11813>

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