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Modified SIRD Model for COVID-19 Spread Prediction for Northern and Southern States of India

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A B S T R A C T

The Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) is the strain of coronavirus that causes coronavirus disease (COVID-19), the respiratory illness that resulted in COVID-19 pandemic in early December 2019. Due to lack of knowledge of the epidemiological cycle and absence of any type of vaccine or medications, the Government issued various non-pharmacological measures to end the COVID-19 pandemic. Several researchers applied the Susceptible-Infected-Recovered-Deceased (SIRD) compartmental epidemiology process model to identifying the effect of different governments intervention methods enforced to mollify the spread of COVID-19 epidemic. In this paper, we aim to provide a modified SIRD model for COVID-19 spread prediction. We have analyzed the data of the Northern and Southern states of India from January 30, 2020, to October 24, 2020 using the proposed SIRD model and existing SIRD model. We have made the predictions with reasonable assumptions based on real data, considering that the precise course of an epidemic is highly dependent on how and when quarantine, isolation, and precautionary measures were imposed. The proposed method gives better approximation values of new cases, R0 (Reproductive Number), daily deaths, daily infectious, transmission rate, and recovered individuals. Through the analysis of the reported results, the proposed SIRD model can be an effective method for investigating the effect of government interventions on COVID-19 associated transmission and mortality rate at the time of epidemic.

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1. Introduction

The year 2020 will be remembered by the world as a calamitous year for humankind. The ingenious, newly developing, the agent was classified as a new betacoronavirus and named as Severe Acute Respiratory Syndrome virus coronavirus 2 (SARS-CoV2), genetically related to the SARS-CoV1 [1] that appeared in the year 2003. The SARS-CoV2 associated disease has been named COVID-19, which led to COVID-19, later formed a group of pneumonia cases in Wuhan, China. [2]. The outbreak was early detected in 2019 that induced a large epidemic in China with the first mortality reported on January 10, 2020, and, is declared a global pandemic by the World Health Organization (WHO) on March 11, 2020, [3] making it a worldwide threat. According to John Hopkins University, there are 42,395,907 confirmed cases of COVID-19 [4] worldwide as of October 24, 2020. The number of confirmed cases in India is 7,862,656, which is 18.5% of the total confirmed. The Case Fatality Rate(CFR) for India contributes to 1.5% with 86,700 deaths per 100k population [5]. Different protective measures are imposed by the government for reducing the transmission of COVID-19 such as social distancing, restricting travel, cancellations/postponing events, hard and soft lockdowns, quarantines, and testing [6]. The impact of coronavirus, especially on the economic and social front is even more disastrous than the number of casualties this virus has caused [7]. It is alarming to see the hazard COVID-19 may cause in India, as India contributes 18% of the total world population [8] with Mumbai being the most densely populated city with 32,303 people/km² [9]. This shows that novel coronavirus can spread very rapidly in the highly populated country like India. The SARS-CoV2 is transmitted from one individual to another basically by respiratory droplets and causes fever and...
respiratory symptoms such as shortness of breath, and cough [10]. The SARS-Cov2 incubation period ranges from 2 to 14 days, but typically 5 days [11], 50% of the people become ill, 5 days after they are infected. Very few cases of children who got infected by COVID-19 are reported [12]. Many precautionary measures were taken by the Government of India to reduce the spread of the virus. The government imposed multiple lockdowns:

1. **Phase 1**: March 25, 2020, to April 14, 2020 (Lockdown 1.0), 21 days. Complete lockdown except for essential services. [13]
2. **Phase 2**: April 15, 2020, to May 3, 2020 (Lockdown 2.0), 19 days. Conditional relaxations for areas with minimal spread [14].
3. **Phase 3**: May 4, 2020, to May 17, 2020 (Lockdown 3.0), 14 days. Depending on the spread of the virus, the districts were divided into three zones—green, red, and orange. The restrictions were imposed accordingly [15].
4. **Phase 4**: May 18, 2020 to May 31, 2020 (Lockdown 4.0), 14 days. Declared by National Disaster Management Authority [16].

The government also initiated the unlock:

1. **Phase 1**: June 1, 2020, to June 30, 2020, (Unlock 1.0), 30 days. Shopping malls, restaurants and hotels, religious places were allowed to open, with active night curfews from 9 P.M. to 5 A.M. [17].
2. **Phase 2**: July 1, 2020, to July 31, 2020, (Unlock 2.0), 31 days. All activities, with suitable restrictions, were permitted in non-contaminated areas. Schools and colleges remained closed. Night curfews were effective from 10 P.M. to 5 A.M. [18].
3. **Phase 3**: August 1, 2020, to August 31, 2020 (Unlock 3.0), 31 days. Night curfews were removed. Places like gymnasiums and centres for yoga were open again. Maharashtra and Tamil Nadu were under lockdown for the complete month, while West Bengal continued lockdown twice a week. The permission to celebrate Independence day was granted with all safety measures to be followed. [19].
4. **Phase 4**: September 1, 2020, to September 30, 2020 (Unlock 4.0), 30 days. Marriage functions and funerals up to 50 people and 100 people respectively, were permitted. 100 people were allowed to attend religious, political, entertainment, and academic functions with face masks and social distancing. [20].
5. **Phase 5**: October 1, 2020, to October 31, 2020 (Unlock 5.0), 31 days. Cinema halls, with 50% seating capacity was permitted to open form October 15. Swimming pools for training the sportsperson was allowed to open [21].
6. **Phase 6**: November 1, 2020, to November 30, 2020 (Unlock 6.0), 30 days. The Government of Kerala has opened the tourism sector from November 3, 2020. The Government of India has decided to open schools and colleges by January 2021. The schools will be open from November 16, in Tamil Nadu and by December 2020 in Kerala.

The Press Information Bureau observed that around 36-70 lakh cases and 78,000 deaths were abstained, due to the imposition of these lockdowns [22]. As given by WHO, though many medical organizations are heading fast towards vaccine development, currently, there is no vaccine or anti-viral treatments available and it may take at least 18-20 months before it is available [23] or even more to be available for everyone. In such a situation, it is very essential to understand the course of the epidemic. The predictive mathematical models for epidemics can be used to estimate the future of COVID-19 worldwide [24]. This may help to prepare control strategies in advance and was elucidated by the recent Ebola epidemic [25]. The compartmental models are the best way to understand the epidemic [26]. In these models, the population is divided among compartments: Susceptible (S), Infected (I) and Recovered (R) [27]. In such models, the epidemic outbreak ends once the threshold of “herd immunity” is achieved i.e. when the susceptible population impoverishes to a point where less than one person is infected by the infected person from the disease. Various mathematical models have been developed to understand the transmission dynamics of COVID-19. Chen et al. [28] proposed a Bats-Hosts-Reservoir-People network model to simulate the possible transmission from the infection source (probably bats) to human infection. Their results showed that the value of $R_0$ was 2.30 from source to person and 3.58 from person to person. Liu et al. [29] extended the basic SIR model by adding a new compartment that evaluates the state of exposed individuals that have been infected but are not yet infectious, named the SEIR model. After recovery, if a person again becomes susceptible, the SEIR model can be used.

Anwarud et al. [30] used random variables for predicting the impending states by using continuous time Markov Chain (CTMC) through stochastic model method. Naik et al. [31] analyzed the transmission of COVID-19 epidemic by implementing the fractional-order epidemic model having two different operators known as classical Caputo and Atangana-Baleanu-Caputo operators. Qureshi & Atangana [32] designed an epidemiological model with newly devised fractal fractional Caputo type operator for graphical analysis of diarrhea transmission dynamics that first appeared in Ghana during 2008-2018. Ahmed et al. [33] used both the Ordinary Differential Equation (ODE) and Fractional Differential Equation to describe the outbreak of COVID-19. Jajarmi et al. [34], extensively investigated the fraction version of SIRS model for HRSV disease. They used a new derivative operator with Mittag-Leffler kernel in Caputo sense (ABC) and applied the fixed-point theory to present the uniqueness of the solution for the model under consideration. Tuan et al. [35] proposed a new mathematical model with eight mutually different compartments with the help of Caputo type memory possessing operator. They showed that the proposed model had a unique solution when used with Banach fixed point analysis, with basic reproductive number $R_0$ equals to 6.5894, approximately. Ahmed et al. [36] proposed a fractional order model consisting of a system of five nonlinear fractional-order differential equations in the Caputo sense to analyse the significance of the lockdown in reducing the spread of coronavirus.

In case of large COVID-19 dataset, the predicted values of $\beta$ and coefficient of prediction $\text{pred}R^2$, fails to give better approximation using the models available in the literature. In COVID-19 mortality rate is lower whereas the infection spreading is higher as compared to previous diseases such as SARS, MERs, and even Ebola, therefore it is much more pervasive. The death rate from COVID-19 exceeded five times that of SARS after just 3 months. The results obtained by the proposed SIRD model predicts the near accurate values of daily deaths, daily infected, new cases, reproductive number and transmission rate. The predictions achieved from the proposed model can be used by the national and states government authorities, researchers, and service managers to plan the medical infrastructure and other strategies in advance.

In this paper, we have used the Susceptible-Infected-Recovered-Deceased (SIRD) compartmental epidemiology process model for analysis. In this model, a person recovers or dies once infected. Unlike the standard formulation, our model works on the following assumptions:

1. The individual transitions between the compartments changes dynamically and hence, it is time-dependent.
2. The frequency of non-pharmaceutical inferences, directly affects
the time-dependency. Hence, the estimation of simultaneous
decline in the transmission rate of the disease may help to evalu-
ate the performance of these inferences.

We have examined the progress of the COVID-19 epidemic
through the proposed model. We have applied this model on 17
States and Union-Territories(UT) of North and South parts of India.
The model is divided into four different stages of infection namely;
Susceptible (S), Infected (I), Recovered (R) and Dead (D).

The remaining paper is structured as follows: Section 2 explains
the Modeling framework and design. In Section 3, we have dis-
cussed the analysis results for all the states. Section 4 concludes
the work performed.

2. Modelling Framework and Design

We employ the standard SIRD Model (Fig. 1) where the total
population N is further divided into sub-population of Susceptible
(S), Infected (I), Recovered (R), and Dead (D) at time t.

2.1. The SIRD Model

The total population N is given by:

\[ N = S_t + I_t + R_t + D_t \]  
(1)

The change in total number of cases is given by:

\[ C_t = I_t + R_t + D_t \]  
(2)

The value of the total population from Eq. (1) is approximately
a constant. The value of SIRD compartments can be calculated by the
equations:

\[ S_{t+1} = S - \left( \frac{\beta SI}{N} \right) \]  
(3)

\[ I_{t+1} = I + \left( \frac{\beta SI}{N} \right) - \gamma I - \delta I \]  
(4)

\[ R_{t+1} = R + \gamma I \]  
(5)

\[ D_{t+1} = D + \delta I \]  
(6)

Initially, the total number of susceptibles (S) were nearly equal
to the total population (N). The exponential growth rate (\( r_0 \)) (per
day growth rate) and the basic Reproductive Number (\( R_0 \)) (dimen-
sionless) can be evaluated by the following equation:

\[ r_0 = \beta - (\gamma + \delta) \]  
(7)

\[ R_0 = \frac{\beta}{\gamma + \delta} \]  
(8)

The epidemic evolves when \( R_0 > 1 (r_0 > 0) \), otherwise perishes.

**Evaluating the impact of government measures on the epide-
mic**

Assume that the daily change in number of susceptibles is for-
mulated as \(\Delta S = S_{t+1} - S_t \). The daily change in number of Infected,
Recovered and Deaths can be calculated similarly by the following equa-
tions:

\[ \Delta S = -\frac{\beta SI}{N} \]  
(9)

\[ \Delta I = \left( \frac{\beta SI}{N} \right) - \gamma I - \delta I \]  
(10)

\[ \Delta R = \gamma I \]  
(11)

\[ \Delta D = \delta I \]  
(12)

Determining the above equations for transmission coefficient,
recovery and death rates.

In the earlier days of data collection \( C_t = I_t + R_t + D_t \) is very
small as compared to N, making \( N \) very close to \( S_t \), then we can
take \( \beta = \Delta C/I \), but for large data, which is the case that we are
considering in our analysis, the value of \( C_t \) is not that small and
we need more accurate values. Hence, we have modified the exist-
ing model and the new value of \( \beta \) is derived as:

From Eq. (9),

\[ \Delta I + \gamma I - \delta I = \frac{\beta SI}{N} \]  
(13)

From Eq. (2), (11) and (12),

\[ \Delta C = \frac{\beta SI}{N} \]  
(14)

From Eq. (1),

\[ \Delta C = \frac{\beta (N - C) I}{N} \]  
(15)

\[ \beta = \left( \frac{\Delta C}{I} \right) * N/(N - C) \]  
(16)

\[ \gamma = \frac{\Delta R}{I} \]  
(17)

\[ \delta = \frac{\Delta D}{I} \]  
(18)

In the case when \( N = S \), beta values will be smaller (implying
smaller \( R_0 \) values) than the beta values obtained by taking \( N = S + C \)
(implying larger \( R_0 \) values). This will result in incorrect pre-
diction decisions when \( N=5 \), especially when \( R_0 \) is very close to
1.

We can determine the SIRD parameters for each day with the
help of N, C, I, R, and D values. Table 1 illustrates the SIRD model
parameters used for analysis of COVID-19 epidemic.

The values of parameters obtained will have a lot of noise due to
the process and measurement.

| S. No. | Parameter | Definition |
|--------|-----------|------------|
| 1.     | N         | Total Population |
| 2.     | S         | Susceptible Individuals |
| 3.     | I         | Infected Individuals |
| 4.     | R         | Recovered Individuals |
| 5.     | D         | Number of Deaths |
| 6.     | C         | Change in number of cases |
| 7.     | \( \beta \) | Coefficient of Transmission |
| 8.     | \( \gamma \) | Rate of Recovery |
| 9.     | \( \delta \) | Rate of Deaths |

1. **Process Noise:** As long as the number of infected individuals
is comparatively small in the initial phase of the pandemic, the
process noise is predicted to be approximately high.

2. **Measurement Noise:** Fundamentally, measurements are never
splendid. The measurement/observation noise can occur due to
many reasons:

(a) Interruption in reporting daily cases.
(b) As the realization of epidemic escalates, identification of
new COVID-19 cases is expected to increase deliberately.
Since many cases of COVID-19 are asymptomatic, the pro-
portion of asymptomatic cases tested will highly affect the
number of cases reported as many cases maybe wrongly
classified as pneumonia or influenza.
(c) The understanding of “Infected” and “Recovered” by the government authorities while collecting data.

The process and measurement noise can be reduced by smoothing the data of daily changes. This will also help to reduce the complications in data pattern, as the results are only informative till we can filter the effects of various errors caused due to imprecise reports.

### 2.2. Model Specifications

#### 2.2.1. Data set description

In this paper, the dataset of COVID-19 is collected from COVID19 INDIA [37] and is highly contingent due to dependency of increment/decrement in total cases on physical variables. The dataset comprises 37 exclusive time-series data of confirmed, recovered and deceased cases of States (28) and Union Territories (9) of India. Table 2 shows that we have analyzed the State and Union Territories data of North India and South India in this paper from January 30, 2020, to October 24, 2020.

#### 2.2.2. Methodology

With the help of available time-series data of daily cases we can calculate some extra time-series:

1. The number of New Cases
   \[ \Delta C = C_{t+1} - C_t \]  
   (19)

2. The number of Infected/Active Cases
   \[ \Delta I = C_t - (R_t + D_t) \]  
   (20)

3. The number of Daily Deaths
   \[ \Delta D = D_{t+1} - D_t \]  
   (21)

We use the above equations to calculate the daily estimates of SIRD parameters.

Further, we smooth the data to remove the process and measurement noise. For smoothing data, we use the Locally Weighted Scatterplot Smoothing (LOWESS) [38]. It is a popular tool used in Regression Analysis that creates a smooth line through a time-plot/scatterplot to see the relationship between variables and foresee trends. We have used the fraction of 0.1 for \( \beta \) and \( \delta \) and fraction of 0.2 for \( \gamma \). The fraction values are estimated on the basis that if we increase the value of fractions, we will move towards the straight line instead of curves.

The parameters are smoothed only after \( C_t \) exceeds 100 cases, as the data is very noisy for small values. The value of parameters is constant until \( C_t \) reaches 100 cases and is set equal to the first smoothed value.

Applying the smoothed estimation of model parameters, we have solved the SIRD model ahead of time for the duration of the epidemic. The initial values of SIRD model is assumed as: \( S(0)=N \), \( R(0)=D(0)=0 \), and the value \( I(0) \) is estimated from data.

The coefficient of prediction \( R^2 \) is used to measure the fit of our model and is calculated using the following equation:

\[
predR^2 = 1 - \frac{\sum(Y - \hat{X})^2}{\sum[(X - \text{mean}(X))^2]} 
\]  
(22)

where: \( Y \) represents Confirmed and Recovered cases for model predictions and \( X \) is the data. The coefficient of prediction can reach negative values when the model prediction is worst as compared to the mean of data. For perfect prediction, \( predR^2 \) reaches 1.

The value of \( predR^2 \), before smoothing and after smoothing is illustrated in Table 3. The after smoothing value shows that our model best fits the given data.

### 3. Experimental Results

The first case of Covid-19 in India was reported on January 30, 2020, to WHO [39]. Based on the behaviour of the number of confirmed cases in North India and South India, the states are divided into three categories:

1. States Badly Hit by Covid-19
2. State showing a second and third wave of new cases
3. States showing similar trends

#### 3.1. Results Analysis and Observations of the States Badly Hit by Covid-19

**3.1.1. Kerala**

The first case of the COVID-19 was confirmed on January 30, 2020, in Thrissur district of Kerala (also first case of India). From Fig. 2, we can observe that the number of active infected cases began to escalate from the mid of March and reached the highest point by end of September with 67,140 cases. Despite the fact that, Kerala was exalted both nationally and internationally at the beginning for containing Covid-19, a major hike can be seen in the number of cases in late-October. The number of daily deaths increased subsequently from the end of July and reached the spike in the end of September with 29 deaths on September 30, 2020. The case fatality ratio (CFR) of Kerala is 0.34%, the lowest in India compared to other states. The highest number of new cases were confirmed on October 9, 2020, with 11,755 cases, which started declining later. The epidemic thrive in Kerala in mid of May resulting in

| S. No. | State/UT Name                  | Confirmed | Recovered | Deceased | Tested | Date Range         | Population |
|-------|-------------------------------|-----------|-----------|----------|--------|-------------------|------------|
| 1.    | Andaman and Nicobar Islands   | 4225      | 3968      | 58       | 81880  | Mar 26, 2020 Oct 24, 2020 | 4L         |
| 2.    | Andhra Pradesh                | 804026    | 765991    | 6566     | 7502933| Mar 12, 2020 Oct 24, 2020 | 5.2Cr      |
| 3.    | Chandigarh                    | 13977     | 13087     | 216      | 100797 | Mar 19, 2020 Oct 24, 2020 | 11.8L      |
| 4.    | Delhi                         | 352520    | 319828    | 6225     | 4315339| Mar 02, 2020 Oct 24, 2020 | 2Cr        |
| 5.    | Haryana                       | 157064    | 145196    | 1720     | 2505052| Mar 04, 2020 Oct 24, 2020 | 2.9Cr      |
| 6.    | Himachal Pradesh              | 20213     | 17296     | 285      | 365838 | Mar 14, 2020 Oct 24, 2020 | 73L        |
| 7.    | Jammu and Kashmir             | 91329     | 82219     | 1430     | 2153529| Mar 09, 2020 Oct 24, 2020 | 1.3Cr      |
| 8.    | Karnataka                     | 798378    | 700737    | 10873    | 7281090| Mar 09, 2020 Oct 24, 2020 | 6.6Cr      |
| 9.    | Kerala                        | 386088    | 287261    | 1307     | 4280204| Jan 30, 2020 Oct 24, 2020 | 3.5Cr      |
| 10.   | Ladakh                        | 5913      | 5052      | 71       | 71063  | Mar 07, 2020 Oct 24, 2020 | 2.9L        |
| 11.   | Paducherry                    | 34112     | 29634     | 586      | 289689 | Mar 17, 2020 Oct 24, 2020 | 15L        |
| 12.   | Punjab                        | 130640    | 122256    | 4107     | 2457574| Mar 09, 2020 Oct 24, 2020 | 3Cr        |
| 13.   | Rajasthan                     | 184422    | 165496    | 1826     | 3609151| Mar 03, 2020 Oct 24, 2020 | 7.7Cr      |
| 14.   | Tamil Nadu                    | 706138    | 663456    | 10893    | 9436817| Mar 03, 2020 Oct 24, 2020 | 7.6Cr      |
| 15.   | Telangana                     | 230274    | 209034    | 1303     | 4052633| Mar 03, 2020 Oct 24, 2020 | 3.7Cr      |
| 16.   | Uttar Pradesh                 | 468238    | 433703    | 6854     | 13908303| Mar 04, 2020 Oct 24, 2020 | 22.5Cr     |
| 17.   | Uttarakhand                   | 60155     | 54169     | 984      | 9672558| Mar 15, 2020 Oct 24, 2020 | 1.1Cr      |
a “second wave” of new cases with the Reproductive Number\( (R_0) \) greater than 1. The current recovery rate is 77% with 2,87,261 recoveries.

3.1.2. Haryana

The first case of the COVID-19 was reported on March 4, 2020. From Fig. 3, we observe that the highest active infected cases are on September 16, 2020, with 21,334 cases which declined to 10,148 cases by October 24, 2020. The number of daily deaths is observed to be highest on September 19, 2020, with 29 deaths in one day. So far, 1720 deaths have been reported in Haryana due to the COVID-19 pandemic. The number of new cases is observed highest in the third week of September with 2783 cases on September 11, 2020. The value of \( R_0 \) was greater than 1 from the mid of March to the second week of September and started declining at the end of September. The current recovery rate of Haryana is 81.9% with 1,45,196 recoveries.

3.2. Results Analysis and Observations of the State showing second and third wave of new cases

3.2.1. Delhi

The first case of Covid-19 was reported on March 2, 2020, in Delhi. From Fig. 4, we observe that the third-highest number of confirmed cases are reported in Delhi with 3,52,520 cases. The total number of active infected people reported are first observed highest on June 27, 2020, with 28,329 infected people resulting in a "second wave" of new cases. The number of cases started declining at the end of June. The hike in active infected cases was again observed on September 20, 2020, with 32,097 cases, resulting in a third wave of new cases.

- 1\(^{st}\) Wave: From the beginning to July.
- 2\(^{nd}\) Wave: July to September.
- 3\(^{rd}\) Wave: September to present.

The number of daily deaths in Delhi is highest in June with 437 deaths on June 15, 2020, gradually declining thereafter. The maximum number of new cases was observed on June 22, 2020, with 3947 cases, and September 15, 2020, with 4473 cases. As of June 27, 2020, the exponential growth rate of Covid-19 epidemic in Delhi began to decrease below 1 and remained the same. The epidemic started thriving again on October 4, 2020. The recovery rate in Delhi is 90% with 3,19,828 recoveries on October 24, 2020.

3.3. Results Analysis and Observations of States showing similar trends

The Figs. 5–18 respectively shows the COVID-19 situation in the states Andaman and Nicobar Islands, Andhra Pradesh, Chandigarh, Delhi, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Ladakh, Puducherry, Punjab, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh, and Uttarakhand. It is observed that there is a similar trend in active infected cases, the number of deaths, new cases reported, recoveries, and the growth of the epidemic in the figures. The highest number of infected cases in these states can be seen at the beginning of September and gradually decreasing thereafter. The highest number of daily deaths are observed in the first week of August with around 97 deaths on October 7, 2020. The highest number of new cases were observed in early September. The exponential growth parameter \( R_0 \) started to decline from first week of September, showing that the epidemic is under control in these states. The recovery rate is around 95%. The lockdown and unlock, along with masks use, social distancing and other preventive measures used by the government has relatively good effects in bringing the value of \( R_0 \) below 1 for these 14 States/UT with similar improving trends. The peaks attained by the above 14 States/UT in the number of daily new cases, infected (active) cases, and number of daily deaths can be observed from Table 4.

The comparative analysis of actual value and predicted values of confirmed, recovered and deceased cases for all states/UT are discussed in Table 5.
Fig. 2. Graphs of Kerala.
Fig. 3. Graphs of Haryana.
Fig. 4. Graphs of Delhi.
Fig. 5. Graphs of Andaman and Nicobar Islands.
Fig. 6. Graphs of Andhra Pradesh.
Fig. 7. Graphs of Chandigarh.
Fig. 8. Graphs of Himachal Pradesh.
Fig. 9. Graphs of Jammu and Kashmir.
Fig. 10. Graphs of Karnataka.
Fig. 11. Graphs of Ladakh.
Fig. 12. Graphs of Puducherry.
Fig. 13. Graphs of Punjab.
Fig. 14. Graphs of Rajasthan.
Fig. 15. Graphs of Tamil Nadu.
Fig. 16. Graphs of Telangana.
Fig. 17. Graphs of Uttarakhand.
Fig. 18. Graphs of Uttar Pradesh.
Table 4
Dates and Number of Cases for which peak values of $\Delta C$, $I$ and $\Delta C$ were attained.

| S. No. | State/UT Name | Daily New Cases ($\Delta C$) | Infected (Active) ($I$) | Daily Deaths ($\Delta \Delta$) |
|--------|---------------|-------------------------------|-------------------------|-------------------------------|
| 1.     | Andaman and Nicobar Islands | 13/8/2020, 149 cases | 15/8/2020, 1154 cases | 25/8/2020, 5 cases |
| 2.     | Andhra Pradesh | 25/8/2020, 10,830 cases | 3/9/2020, 10,370 cases | 21/8/2020, 97 cases |
| 3.     | Chandigarh | 12/9/2020, 449 cases | 16/9/2020, 3174 cases | 7/9/2020, 377 cases |
| 4.     | Himachal Pradesh | 15/9/2020, 460 cases | 21/9/2020, 4477 cases | 18/9/2020, 12 cases |
| 5.     | Jammu and Kashmir | 11/9/2020, 1698 cases | 20/9/2020, 22,032 cases | 20/9/2020, 23 cases |
| 6.     | Karnataka | 12/9/2020, 5094 cases | 9/10/2020, 1,18,870 cases | 17/9/2020, 179 cases |
| 7.     | Ladakh | 4/10/2020, 120 cases | 8/10/2020, 1289 cases | 23/9/2020, 3 cases |
| 8.     | Puducherry | 23/9/2020, 668 cases | 26/9/2020, 5327 cases | 3/9/2020, 20 cases |
| 9.     | Punjab | 16/9/2020, 2848 cases | 19/9/2020, 22,399 cases | 1/9/2020, 106 cases |
| 10.    | Rajasthan | 30/9/2020, 2193 cases | 13/10/2020, 21,924 cases | 1/10/2020, 16 cases |
| 11.    | Tamil Nadu | 26/7/2020, 6993 cases | 31/7/2020, 57,968 cases | 21/7/2020, 518 cases |
| 12.    | Telangana | 2/8/2020, 3018 cases | 4/9/2020, 32,994 cases | 30/7/2020, 14 cases |
| 13.    | Uttar Pradesh | 18/9/2020, 2078 cases | 20/9/2020, 12,644 cases | 16/10/2020, 95 cases |
| 14.    | Uttarakhand | 10/9/2020, 7016 cases | 17/9/2020, 68,235 cases | 14/9/2020, 113 cases |

Table 5
Comparative analysis of actual predicted values of confirmed, recovered, and deceased cases for all States/UT of Northern and Southern India.

| S. No. | Name of State/UT | Confirmed | Predicted Confirmed | Recovered | Predicted Recovered | Deceased | Predicted Deceased |
|--------|------------------|-----------|---------------------|-----------|---------------------|----------|--------------------|
| 1.     | Andaman and Nicobar Islands | 4225 | 4413 | 3968 | 4131 | 78 | 52 |
| 2.     | Andhra Pradesh | 804026 | 789324 | 765991 | 748595 | 6566 | 6453 |
| 3.     | Chandigarh | 13977 | 14073 | 13087 | 13171 | 216 | 183 |
| 4.     | Delhi | 352250 | 368146 | 319828 | 322569 | 6225 | 4868 |
| 5.     | Haryana | 157064 | 155405 | 145196 | 143032 | 1720 | 1679 |
| 6.     | Himachal Pradesh | 20213 | 20667 | 17296 | 17445 | 285 | 271 |
| 7.     | Jammu and Kashmir | 91329 | 90724 | 82219 | 80052 | 1430 | 1379 |
| 8.     | Karnataka | 79378 | 77495 | 700737 | 682760 | 10873 | 10672 |
| 9.     | Kerala | 386088 | 395791 | 287261 | 295443 | 1307 | 1317 |
| 10.    | Ladakh | 5913 | 6306 | 5052 | 5412 | 71 | 36 |
| 11.    | Puducherry | 34112 | 32189 | 29614 | 28119 | 586 | 537 |
| 12.    | Punjab | 130640 | 129570 | 122256 | 120946 | 4107 | 4091 |
| 13.    | Rajasthan | 184422 | 194162 | 165496 | 175230 | 1826 | 1925 |
| 14.    | Tamil Nadu | 706136 | 727879 | 663456 | 686319 | 10893 | 10901 |
| 15.    | Telangana | 230274 | 231766 | 209034 | 208120 | 1303 | 1195 |
| 16.    | Uttar Pradesh | 468238 | 477439 | 433703 | 441822 | 6854 | 6195 |
| 17.    | Uttarakhand | 60155 | 60103 | 54169 | 55193 | 984 | 897 |

4. Conclusion

In this paper, a modified SIRD model is proposed to analyze the effect of different government interventions, implemented to reduce the spread of COVID-19 in Northern and Southern States/Union Territories of India. Depending upon the number of cases and growth rate of the epidemic, the states are categorized into three categories: states badly hit by Covid-19, states showing a second and third wave of new cases, and states showing similar trends. The smoothing function is used to reduce the process and measurement noise. The data from March 2, 2020, to October 24, 2020, is analyzed for near-future prediction. Through analysis, it is observed that the predicted values are nearly to the actual values and further, it is established that the states Kerala and Haryana were severely affected by Covid-19 whereas Delhi generated a second and third wave of new cases. The remaining states showed a moderate impact of COVID-19. The proposed SIRD model can further be enhanced to make predictions of weekly data by keeping the window size 7. The predictions achieved from the proposed model can be used by the national and state government authorities, researchers, and service managers to plan the medical infrastructure and other strategies in advance.

Declaration of Competing Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Credit authorship contribution statement

Sakshi Shringi: Data curation, Software, Writing – original draft.
Harish Sharma: Conceptualization. Pushpa Narayan Rathie: Visualization, Investigation. Jagdish Chand Bansal: Methodology, Writing – review & editing. Atulya Nagar: Validation, Supervision.

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