

MATHEMATICAL ANALYSIS ON THE DYNAMICS OF THE COVID-19 IN INDIA

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**SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited with Grade “A” by NAAC
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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **AARTHI C (39060001)**, **VINOTH K (39060014)** who carried out the project entitled "**MATHEMATICAL ANALYSIS ON THE DYNAMICS OF COVID-19 IN INDIA**" under our supervision from November 2021 to May 2022

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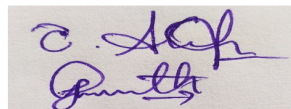
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DECLARATION

I **AARTHI C (39060001)**, **VINOTH K (39060014)** hereby declare that the Project Report entitled “**MATHEMATICAL ANALYSIS ON THE DYNAMICS OF COVID-19 INDIA**” done by me under the guidance of **Dr. PRIYA SHIRLEY MULLER** (Internal) and (External) at **Sathyabama Institute of Science and Technology** is submitted in partial fulfillment of the requirements for the award of Bachelor of Science degree in **Mathematics**.

DATE:29.4.22



PLACE: Chennai

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ABSTRACT

The highly infectious coronavirus disease (COVID-19) was first detected in Wuhan, China in December 2019 and subsequently spread to 212 countries and territories around the world, infecting millions of people. In India, a large country of about 1.3 billion people, the disease was first detected on January 30, 2020, in a student returning from Wuhan. The total number of confirmed infections in India as of May 3, 2020, is more than 37,000 and currently it has alarmingly risen to 4,30, 49, 974 confirmed cases.

Most of the prior research and media coverage focused on the number of infections in the entire country. However, given the size and diversity of India, it is important to look at the spread of the disease in each state separately, wherein the situations are quite different. In this paper, we aim to analyze data on the number of infected people in each Indian state (restricted to only those states with enough data for prediction) and predict the number of infections for that state in the next 30 days. We hope that such state-wise predictions would help the state governments better channelize their limited health care resources.

CONTENT

CHAPTER NO	TITLE	PAGE NO
	BONAFIDE CERTIFICATE	ii
	DECLARATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
1	INTRODUCTION	1
	1.1. INTRODUCTION	1
	1.2 PANDEMIC	4
	1.3 WHAT IS CORONA VIRUS?	4
	1.4 HIGH-RISK POPULATIONS	6
	1.5 PREVENTING TRANSMISSION	7
	1.6 DIAGNOSTIC PROCEDURES	7
2	LITERATURE SURVEY	9
	2.1 RESEARCH PAPERS REFERRED	9
3	AIM AND SCOPE OF THE RESEARCH	16
4	MATERIALS AND METHODOLOGY	17
5	RESULTS AND DISCUSSION, PERFORMANCE ANALYSIS	21
6	SUMMARY AND CONCLUSION	39
	REFERENCES	40

CHAPTER 1

INTRODUCTION

1.2. INTRODUCTION

Everyone has been affected by the current COVID-19 pandemic. However, the impact of the pandemic and its consequences are felt differently depending on our status as individuals and as members of society. While some try to adapt to working online, homeschooling their children and ordering food via Instacart, others have no choice but to be exposed to the virus while keeping society functioning. Our different social identities and the social groups we belong to determine our inclusion within society and, by extension, our vulnerability to epidemics.

This pandemic continues to challenge medical systems worldwide in many aspects, including sharp increases in demands for hospital beds and critical shortages in medical equipment, while many healthcare workers have themselves been infected. Thus, the capacity for immediate clinical decisions and effective usage of healthcare resources is crucial. The most validated diagnosis test for COVID-19, using reverse transcriptase polymerase chain reaction (RT-PCR), has long been in shortage in developing countries. This contributes to increased infection rates and delays critical preventive measures.

The corona virus COVID-19 was originated from Wuhan, the city in central China. The symptoms of corona virus are fever, cough and shortness of breath. It typically causes flu-like symptoms. In some patients particularly the elders and others with other chronic health conditions- these, symptoms can develop into pneumonia, with chest tightness, chest pain and shortness of breath. It seems to start with a fever, followed by a dry cough. After a week it can lead to shortness of breath, with about 20% patients requiring hospital treatment.

According to WHO-China Joint Mission published the following median time to clinical recovery:

- Mild cases: Approximately 2 weeks.
- Severe or critical disease: 3-6 weeks.
- Time from onset to the development of severe disease: 1 week.

The coronavirus COVID-19 is affecting 192 countries and territories around the world and one international conveyance (the Diamond Princess Cruise Ship harbored in Yokohama, Japan).

Wuhan, the city in Central China was where the virus originated. The city on January 23, shutdown transport links. The attack rate (how rapidly the disease spreads) of a virus is indicated by its reproductive number, denoted by R_0 . The reproductive rate represents the average number of people to which a single infected person will transmit the virus. According to WHO, the estimate of the rate on 23, June, 2020 to be between 1.4 and 2.5.

In India, the first case was reported on 30, January 2020 from Kerala. The number of corona virus infected in India crossed the 200 number after a spike in cases over the past days. The challenge for India versus its peers is starker if infections spread rapidly considering the higher density of population per capita and weaker health infrastructure. Day by day total number of corona virus cases have been increasing in folded. The centre and state governments have decided to completely shutdown 75 districts across the country where corona virus cases have been reported. It has also been decided to suspend the interstate bus services. Major train services are also suspended, including sub-urban rail services, exempting goods trains. All metro rails services are also suspended. At present it is extended to 3, May 2020. Millions of people across the country stays indoors.

India is at second rank as per the area and the population density. Compared to other developing countries of the world, India possess a good control on the spread of corona virus. It will be worth interesting to know the attack rate, and rate of finished cases (recovered and death).

Various types of analysis have been made on COVID-19 data.

The virus is primarily spread between people during close contact, most often via small droplets produced by coughing, sneezing and talking. The droplets usually fall to the ground or onto surfaces rather than travelling through air over long distances. Less commonly, people may become infected by touching a contaminated surface and then touching their face. It is most contagious during the first three days after the onset of symptoms, although spread is possible before symptoms appear and also from people who do not show symptoms.

The virus has inflicted billions of lives across the globe in many ways such as physically, psychologically, socially. Compared to MERS and SARS, COVID-19 has had: significantly higher transmissibility; worst post-recovery implications; frequent mutations (from the initial SARS-CoV-2 strain) leading to higher mortalities and uncontrolled virulence.

The clinical manifestations of this particular virus has exhibited deleterious impacts on systems other than the respiratory systems (primary target organ) eg. brain, hematological system, liver, kidneys, endocrine system, etc. Lack of emergency treatments and shortage of life-saving drugs has promoted the repurposing of existing therapeutics along with the emergence of vaccines with the combined efforts of scientists and industrial experts in this short span.

The data consist of daily total cases, daily new cases, daily recovered cases and daily deaths. The attack rate for day t is calculated from the ratio of DNC of day t to DTC of day $t-1$.

This work was aimed to develop a model to predict attack rate and total finished cases for future and to find out the breakeven point for total cases and total finished cases. That means a time point after which there will not be any new active cases of corona virus in India under the assumption that the current environmental situations remains same.

1.2 PANDEMIC

The COVID-19 pandemic, also known as the coronavirus pandemic, is an ongoing pandemic of coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The outbreak was first identified in Wuhan, China, in December 2019. The World Health Organization declared the outbreak a Public Health Emergency of International Concern on 30 January, and a pandemic on 11 March.

A global coordinated effort is needed to stop the further spread of the virus. A pandemic is defined as “occurring over a wide geographic area and affecting an exceptionally high proportion of the population.” The last pandemic reported in the world was the H1N1 flu pandemic in 2019.

Coronavirus are important human and animal pathogens. At the end of 2019, a novel coronavirus was identified as the cause of a cluster of pneumonia cases in Wuhan, a city in the Hubei Province of China. It rapidly spread, resulting in an increasing number of cases in other countries throughout the world. On 30th January 2020 India recorded its first COVID-19 cases in state of Kerala. It was a student who had travel history to China. And till the start of June India has over 200 thousand confirmed cases.

1.3 WHAT IS CORONA VIRUS?

Coronaviruses are a family of viruses that cause illness such as respiratory diseases or gastrointestinal diseases. Respiratory diseases can range from the common cold to more severe diseases eg.

- Middle East Respiratory Syndrome (MERS-CoV)
- Severe Acute Respiratory Syndrome (SARS-CoV).

A novel coronavirus (nCoV) is a new strain that has not been identified in humans previously. Once scientists determine exactly what coronavirus it is, they give it a name (as in the case of COVID-19, the virus causing it is SARS-CoV-2).

Coronaviruses got their name from the way that they look under a microscope. The virus consists of a core of genetic material surrounded by an envelope with protein spikes. This gives it the appearance of a crown. The word Corona means “crown” in Latin. Coronaviruses are zoonotic, meaning that the viruses are transmitted between animals and humans. It has been determined that MERS-CoV was transmitted from dromedary camels to humans and SARS-CoV from civet cats to humans. The source of the SARS-CoV-2 (COVID-19) is yet to be determined, but investigations are ongoing to identify the zoonotic source to the outbreak.

Typically Coronaviruses present with respiratory symptoms. Among those who will become infected, some will show no symptoms. Those who do develop symptoms may have a mild to moderate, but self-limiting disease with symptoms similar to the seasonal flu. Symptoms may include:

- Respiratory symptoms
- Fever
- Cough
- Shortness of breath
- Breathing difficulties
- Fatigue
- Sore throat

A minority group of people will present with more severe symptoms and will need to be hospitalized, most often with pneumonia, and in some instances, the illness can include ARDS, sepsis and septic shock. Emergency warning signs where immediate medical attention should be sought include:

- Difficulty breathing or shortness of breath
- Persistent pain or pressure in the chest
- New confusion or inability to arouse
- Bluish lips or face

1.4 HIGH-RISK POPULATIONS

The virus that causes COVID-19 infects people of all ages. However, evidence to date suggests that three groups of people are at a higher risk of getting severe COVID-19 disease:

- Older people (people over 70 years of age)
- People with serious chronic illnesses such as:
 - Diabetes
 - Cardiovascular disease
 - Chronic respiratory disease
 - Cancer
 - Hypertension
 - Chronic liver disease
- People who are physically inactive

The WHO has issued and published advice for high-risk groups (older people and people with serious chronic illness) and community support. This is to ensure that these high-risk populations are protected from COVID-19 without being isolated, stigmatised, left in positions of

increased vulnerability or unable to have access to basic provisions and social care.

1.5 PREVENTING TRANSMISSION

The WHO suggests the following basic preventative measures to protect against the new coronavirus

- Get vaccinated as soon as it's your turn and follow local guidance on vaccination.
- Keep physical distance of at least 1 metre from others, even if they don't appear to be sick. Avoid crowds and close contact.
- Wear a properly fitted mask when physical distancing is not possible and in poorly ventilated settings.
- Clean your hands frequently with alcohol-based hand rub or soap and water.
- Cover your mouth and nose with a bent elbow or tissue when you cough or sneeze. Dispose of used tissues immediately and clean hands regularly.
- If you develop symptoms or test positive for COVID-19, self-isolate until you recover.

1.6 DIAGNOSTIC PROCEDURES

A COVID-19 diagnostic testing kit has been developed and is available in clinical testing labs. The gold standard for testing for COVID-19 is Reverse Transcription Polymerase Chain Reaction (RT-PCR). However, current data suggest that RT-PCR is only 30-70% effective for acute infection, this may be due to incorrect use of lab kits

or not enough virus in the blood at the early stages of testing. Plus, the availability of testing will vary from country to country.

The CDC recommends that any person who may have had contact with a person who is suspected of having COVID-19 and develops a fever and respiratory symptoms listed above are advised to call their healthcare practitioner to determine the best of course of action. The main criteria for testing are:

- Location
- Age
- Medical history and risk factors
- Exposure to the virus and contact history
- Duration of symptoms

CHAPTER 2

LITERATURE SURVEY

2.1 RESEARCH PAPERS REFERRED

1. APPLICATION OF THE ARIMA MODEL ON THE COVID-19 EPIDEMIC MODEL:

Coronavirus disease 2019 (COVID-2019) has been recognized as a global threat, and several studies are being conducted using various mathematical models to predict the probable evolution of this epidemic. These mathematical models based on various factors and analyses are subject to potential bias. Here, a simple econometric model that could be useful to predict the spread of COVID-2019 was proposed. Auto Regressive Integrated Moving Average (ARIMA) model prediction on the Johns Hopkins epidemiological data was performed to predict the epidemiological trend of the prevalence and incidence of COVID-2019. For further comparison or for future perspective, case definition and data collection have to be maintained in real time.

2. STATISTICAL ANALYSIS OF COVID-19 CASES IN INDIA:

The COVID-19 outbreak spreads are largely influenced by each country's policy and social responsibility. According to WHO, the estimate of attack the rate on 23, June, 2020 to be between 1.4 and 2.5. In India the situation is somehow controllable compared to the situations of developed countries. It will be worth interesting to know about the fact and figures of corona cases in India. The different types of data are available on worldometers. Such data for India was analyzed and different kinds of prediction regarding affected rate, daily new cases, daily total finished cases etc. were made. From the study, it was observed that the affected rate may decrease after 31-03-2020. Daily new cases will be under control

and decrease from the end of April, 2020. After 23-06-2020 there may not be any pending effective cases.

3. STATISTICAL ANALYSIS AND VISUALIZATION OF THE POTENTIAL CASES OF PANDEMIC CORONAVIRUS:

A local outbreak of initially unknown cause pneumonia was detected in Wuhan (Hubei, China) in December 2019 and a novel coronavirus, the severe acute respiratory syndrome coronavirus 2, was quickly found to be causing it. Since then, the epidemic has spread to all of China's mainland provinces as well as 58 other countries and territories, with more than 87,137 confirmed cases around the globe, including 79,968 from China, 7169 from other countries as of 1 March 2020, as stated by the World Health Organization in the COVID-19 situation report-41. In response to this current public health emergency, this study performed a statistical analysis and visualized reported cases of coronavirus disease 2019 (COVID-19) based on the open data collection provided by Johns Hopkins University. Where the location and number of confirmed infected cases have been shown, there have also been deaths, recovered cases and comparisons of the growth rates between the Globe countries. This was intended to provide researchers, public health officials and the general public with exposure to the epidemic.

4. FORECAST AND PREDICTION OF COVID-19 USING MACHINE LEARNING:

COVID-19 outbreaks not only affect the lives of people, they result in a negative impact on the economy of the country. On Jan. 30, 2020, it was declared as a health emergency for the entire globe by the World Health Organization (WHO). By Apr. 28, 2020, more than 3 million people were infected by this virus and there was no vaccine to prevent. The WHO released certain guidelines for safety, but they were only precautionary measures. The use of information technology with a focus on fields such as data Science and machine learning can help in the fight against this pandemic. It is important to have early warning methods through which one

can forecast how much the disease will affect society, on the basis of which the government can take necessary actions without affecting its economy. In this chapter, methods for forecasting future cases based on existing data is included. Machine learning approaches are used and two solutions, one for predicting the chance of being infected and other for forecasting the number of positive cases, are discussed. A trial was done for different algorithms, and the algorithm that gave results with the best accuracy are covered in the chapter. The chapter discusses autoregressive integrated moving average time series for forecasting confirmed cases for various states of India. Two classifiers, random forest and extra tree classifiers, were selected; both have an accuracy of more than 90%. Of the two, the extra tree classifier has 93.62% accuracy. These results can be used to take corrective measures by different governmental bodies. The availability of techniques for forecasting infectious disease can make it easier to fight COVID-19.

5. STATISTICAL ANALYSIS OF NOVEL COVID-19 BASED ON REAL-TIME DATA AND FUTURE EPIDEMICS:

The buzzword in the health sector globally was COVID-19 alias coronavirus. Present all over the world, the virus spread rapidly from one person to another. The outbreak was first reported in Wuhan, China, in December 2019, exponentially spreading to the entire China. In the past months, COVID-19 becomes an outbreak throughout the world. The impact of this new virus brought horror to several countries as cities are quarantined and locked down and hospitals are overcrowded. A high infectious ailment that compromises the worldwide world, part of things isn't completely comprehended. The study focuses on COVID-19-infected cases in India. Sickness classification is one of the significant and more time-consuming tasks in medical diagnosis system. In India, COVID-19 cases are slowly increasing day by day. Compared to advanced countries, the spread is under control. Here, the prepared dataset based on the government of India's data provided by ICMR was customized. Statistical analysis on COVID-19-infected, death and recovered cases among India's

various states is based on the real-time data. To forecast the coronavirus's epidemic peak, compartmental model in epidemiology was used, the SEIR method, to forecast the number of confirmed cases based on the current scenario and population. Further, machine learning methods such as ARIMA and SEIR models were implemented to forecast India's confirmed cases in the coming days and to start to forecast the decrease of infected cases by the end of the year 2020. The study can predict the infected patients based on symptoms using ARIMA and SEIR model. At the last comparison of the cases based on prediction and with lockdown cases. Finally, preventive measures were suggested to minimize COVID-19 infections. The work is expected to predict and forecast COVID-19 cases, deaths and recoveries through predictive modelling. The model helps to interpret public sentiment patterns on scattering related health information and assess the political and financial impact of the spread of the infection.

6. THE OUTBREAK OF COVID-19: AN OVERVIEW:

In late December 2019, a previous unidentified coronavirus, currently named as the 2019 novel coronavirus and resulted in a formidable outbreak in many cities in China and expanded globally, including Thailand, Republic of Korea, Japan, United States, Philippines, Viet Nam, and our country (as of 2/6/2020 at least 25 countries). The disease is officially named as Coronavirus Disease-2019 (COVID-19, by WHO on February 11, 2020). It is also named as Severe Pneumonia with Novel Pathogens on January 15, 2020 by the Taiwan CDC, the Ministry of Health and is a notifiable communicable disease of the fifth category. COVID-19 is a potential zoonotic disease with low to moderate (estimated 2%–5%) mortality rate. Person-to-person transmission may occur through droplet or contact transmission and if there is a lack of stringent infection control or if no proper personal protective equipment available, it may jeopardize the first-line healthcare workers. Currently, there is no definite treatment for COVID-19 although some drugs are under investigation. To promptly

identify patients and prevent further spreading, physicians should be aware of the travel or contact history of the patient with compatible symptoms.

7. STATISTICAL ANALYSIS OF COVID-19 DATA IN INDIA AND ITS DIFFERENT STATES:

The whole world has got a great impact of novel Coronavirus COVID-19. India is currently at second place in the countries of the world. This paper is trying to analyze the data of India and its states with respect to death rate, recovery rate and the number of active cases. The work intends to identify the current trend of Coronavirus spread in India and its different states. For this work we have statistically analyzed data from eleven states of India along with data for the whole country. Overall a decreasing trend in the number of active cases is observed. However it is found that the peak in the number of active cases is not reached in Karnataka, Gujarat and Kerala. In a month in the following states, the situation will be within control (less than 500 cases): Assam, Himachal Pradesh, Jharkhand, Orissa, Tripura and Uttar Pradesh. The entire analysis is under the assumption that the present trend will continue for next few months and there will not be second wave upto January.

8. STATISTICAL ANALYSIS OF COVID CASES IN INDIA:

The novel coronavirus SARS-COV-2(COVID 19) has been considered as pandemic in the month of February, 2020 as declared by World Health Organization. The cause of Coronavirus is due to group of RNA Viruses that mainly causes diseases in animals where this disease can be transferred to humans by droplets which ultimately results to death if it is not cured at early stages. But, in India, COVID cases has begun towards the end of February as the cases has been spiked in the month of March. In this paper, a complete analysis of Statistics for COVID cases has been demonstrated till the month of August. Using Statistical Measures, inferences are being drawn on the basis of COVID data on confirmed, recovered, active as well as death cases.

9. THE RISE AND IMPACT OF COVID IN INDIA:

The coronavirus disease (COVID-19) pandemic, which originated in the city of Wuhan, China, has quickly spread to various countries, with many cases having been reported worldwide. As of May 8, 2020, in India, 56,342 positive cases were reported. India, with a population of more than 1.34 billion and the second largest population in the world, will have difficulty in controlling the transmission of severe acute respiratory syndrome coronavirus 2 among its population. Multiple strategies would be highly necessary to handle the current outbreak; those include computational modeling, statistical tools and quantitative analyses to control the spread as well as to rapidly develop a new treatment. The Ministry of Health and Family Welfare of India has created awareness about the recent outbreak and has taken necessary actions to control the spread of COVID-19. The central and state governments are taking several measures and formulating several wartime protocols to achieve this goal. Moreover, the Indian government implemented a 55-day lockdown throughout the country that started on March 25, 2020, to reduce the transmission of the virus. This outbreak is inextricably linked to the economy of the nation, as it has dramatically impeded industrial sectors because people worldwide are currently cautious about engaging in business in the affected regions.

10. A MATHEMATICAL ANALYSIS OF ONGOING OUTBREAK COVID-19 IN INDIA THROUGH NONSINGULAR DERIVATIVE:

Throughout the globe, mankind is in vastly infected situations due to a cruel and destructive virus called coronavirus (COVID-19). The pivotal aim of the present investigation is to analyze and examine the evolution of COVID-19 in India with the available data in two cases first from the beginning to 31st March and beginning to 23rd April, 2020 in order to show its exponential growth in the crucial period. The present situation in India with respect to confirmed, active, recovered and deaths cases have been illustrated with the aid of available data. The species of novel virus and its

stages of growth with respect to some essential points are presented. The exponential growth of projected virus by the day-to-day base is captured in two-dimensional plots to predict its developments and identify the needs to control its spread on mankind. Moreover, the SEIR model is considered to present some interesting consequences about COVID-19 within the frame of fractional calculus. A newly proposed technique called q -Homotopy analysis transform method (q -HATM) is hired to find the solution for the nonlinear system portraying projected model and also presented the existence and uniqueness of the obtained results with help of fixed point theory. The behavior has been captured with respect to fractional order and time. The present study exemplifies the importance of fractional operator and efficiency of the projected algorithm.

CHAPTER 3

AIM AND SCOPE OF THE RESEARCH

AIM:

Most of the prior research and media coverage focused on the number of infections in the entire country. However, given the size and diversity of India, it is important to look at the spread of disease in each state separately, wherein the situations are quite different. In this research work, we aim to analyze data on number of infected people in each Indian state. It is believed that such state-wise predictions would help the state governments better channelize their limited health care resources.

SCOPE:

The scope of the research is to bring the right awareness among the people, as this pandemic has brought about fear and anxiety among the public and to help in the control of spread of COVID-19, which would be immensely beneficial for society.

CHAPTER 4

MATERIALS AND METHODOLOGY

Methods And Algorithms

Methods:

Data Source:

Indian COVID-19 data has been used which is available publicly. The three primary sources of the data are the Ministry of Health and Family Welfare; COVID-19 India; and Wikipedia.

Statistical models:

In this work, the exponential model, the logistic model and the susceptible-infectious-susceptible (SIS) model for COVID-19 pandemic prediction at the state level were considered. These models have already been used to predict epidemics like COVID-19 around the world, including in China, and for the Ebola outbreak in Bomi, Liberia in 2014.

The previously mentioned three models will provide a different prediction perspective for each state. The exponential model-based prediction will give a picture of what could be the cumulative number of infected people in the next 30 days if we do not take any preventive measures. The forecast from the exponential model as an estimate of the upper bound of the total number of infected people in the next 30 days can be considered. The logistic model-based prediction will capture the effect of preventive measures that have already been taken by the respective state governments as well as the central government. The logistic model assumes that the infection rate will slow down in the future with an overall “S” type growth curve. In other words, the logistic model tries to explore a situation where there is a full lockdown in the country, leading to an extreme restraint on the people’s movement, hence reducing the rate of

infection considerably. Under the effective implementation of the lockdown, it is appropriate to use a logistic model. In this scenario, many people have already been infected; the virus may find it hard to spot more susceptible people. Thus, the virus slows down its spread, causing the flattening in the S-curve at a later stage. Several research papers have used the logistic model in the context of COVID-19.

The purpose of the SIS model is to reflect the effect of the major preventive measure like the nationwide 21-day lockdown from March 25 to April 14, 2020. The lockdown was extended in two phases: (1) until May 3 and (2) then until May 17, 2020, with some relaxation. The SIS model is critically dependent on the infection-rate parameter (β). It is defined as the number of people infected per unit time from an infected person. Note that this parameter is subject to change due to the effect of lockdown and other preventive measures to ensure social distancing. When people are at home, the infection rate is expected to be on the lower side. The other parameter in the SIS model is $\gamma = \frac{1}{D}$ with D being the recovery time. We have considered $D = \frac{1}{\gamma} = 14$ days. In this study, to make the SIS model simple, we assumed that the number of births and deaths in a state are the same.

However, despite nationwide lockdown, banks, hospitals, and grocery stores are still open to cater to the essential needs of people. Two approaches are considered here to study the effect of lockdown and other preventive measures jointly in each state. First, we plot the daily infection rates (DIRs) for each state. The DIR for a given day is defined as:

$$\text{DIR} = \frac{\text{Total active cases in the given day} - \text{Total active cases in the previous day}}{\text{Total active cases in the previous day}}$$

The DIR takes a positive value when an increase is seen in active COVID-19 cases from yesterday, the zero value in case of no change in the number of active cases from yesterday, and a negative value when the

total number of active cases decreases from the previous day. A DIR value can be more than 1 also, particularly during initial days of infection in a state. For example, when the total number of active cases increases from 5 yesterday to 20 today, then the DIR value is $(20 - 5) / 5 = 3$. The visual trends in infection rates can explain whether the COVID-19 situation is under control or not in a specific state. A state where DIRs are declining for the last few days indicates that the situation is improving. However, a certain jump in infection rates could inform us that there could be cases of COVID-19 that are underreported. There is a need to search for infected clusters as quickly as possible. Second, a fitted SIS curve (fitted via a nonlinear least squares approach) has been incorporated, a close representation of the observed number of cases (red curve) for each state. The estimated values of the basic reproduction number (R_0) from the SIS model are also reported for each state. Here, $R_0 = \frac{\beta}{\gamma}$ from the SIS model. Using the SIS model, four predicted curves of active infected patients with different infection rates are also considered. The four different infection rates used in the SIS model for prediction are the 25th, 50th, 75th, and 80th percentiles of the observed DIRs. The observed active infected patients over time were also plotted. A declining curve of observed active infected patients (red curve) can ensure that measures like lockdown and social distancing are working when all the infected cases are reported and tested. The different predicted lines, using the SIS model, may serve as reference frames to indicate whether the government needs to enforce the social distancing more stringently. For example, if the current part of the graph of observed active infected patients (red curve) is above the 75th percentile line, then there is a major concern for that state. There may be a possibility of increasing the lockdown period in a state if we do not see a declining trend of observed active infected patients (red curve).

India implemented a nationwide lockdown on March 25, 2020. The incubation period of the novel coronavirus to study the effect of the lockdown was first considered. The incubation period of an infectious disease is defined as the time between infection and the first appearance of

signs and symptoms. Using the incubation period, health researchers can decide on the quarantine periods and halt a potential pandemic without the aid of a vaccine or treatment. The estimated median incubation period for COVID-19 is 5.1 (95% CI 4.5-5.8) days, and 97.5% of those who develop symptoms will do so within 11.5 (95% CI 8.2-15.6) days of infection. The WHO recommends that a person with laboratory-confirmed COVID-19 be quarantined for 14 days from the last time they were exposed to the patient. Therefore, if a person was infected before the lockdown (March 25, 2020), they should not infect others except their family members if that person is entirely inside their house for more than 14 days. The WHO also recommends common people to maintain a distance of at least 1 meter from each other in a public place to avoid COVID-19 infection. The effective implementation of social distancing can stop the spread of the virus from an infected person, even when they are outside for some essential business. However, given a highly dense population in most of India, particularly in cities, it may not always be possible to maintain adequate social distance.

CHAPTER 5

RESULTS AND DISCUSSION, PERFORMANCE ANALYSIS

Why State-wise Consideration?

India is a vast country with a geographic area of 3,287,240 square kilometers and a total population of about 1.3 billion. Most of the Indian states are quite large in geographic area and population. Analyzing coronavirus infection data, considering the entirety of India to be on the same page may not provide us the right picture. This is because the first infection, new infection rate, progression over time, and preventive measures taken by state governments and the common public for each state are different. We need to address each state separately. It will enable the government to use the limited available resources optimally. For example, currently, Maharashtra already has more than 10,000 confirmed infected cases, whereas West Bengal has less than 800 confirmed cases (May 1, 2020). The approaches to addressing the two states must be different due to limited resources. One way to separate the state-wise trajectories is to look at when each state was first infected.

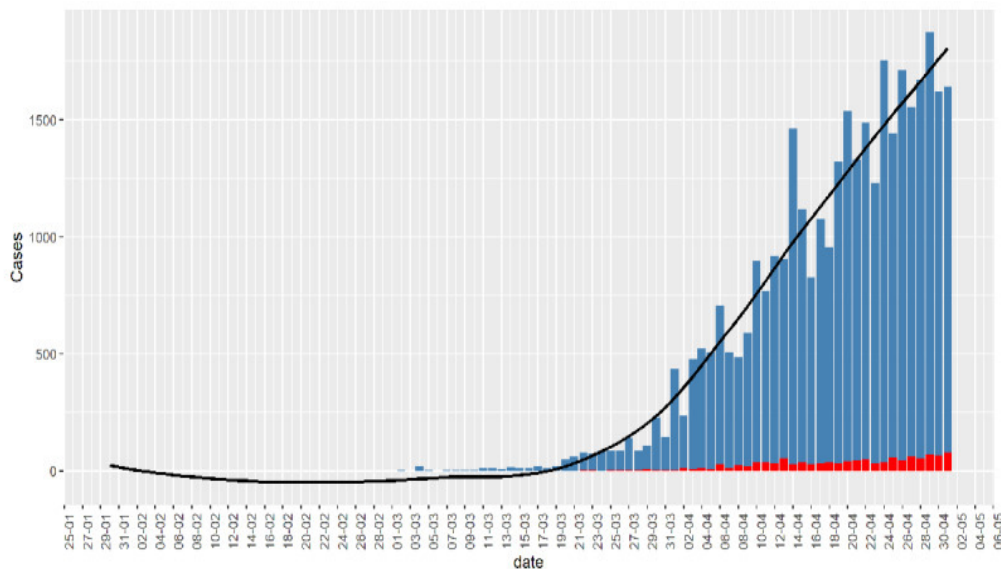


Figure.1

The total (cumulative) number of confirmed infected people is more than 37,000 to date across India. The bar chart in [Figure 1](#) shows the daily growth of the COVID-19 cases in India. After the first 3 cases from January 30 to February 3, 2020, there were no confirmed COVID-19 cases for about a month. The COVID-19 cases appeared again from March 2, 2020, onwards. These cases are related to people who have been evacuated or have arrived from COVID-19-affected countries. From March 20, 2020, onwards, there is an exponential growth in the daily number of COVID-19 cases at the pan-India level.

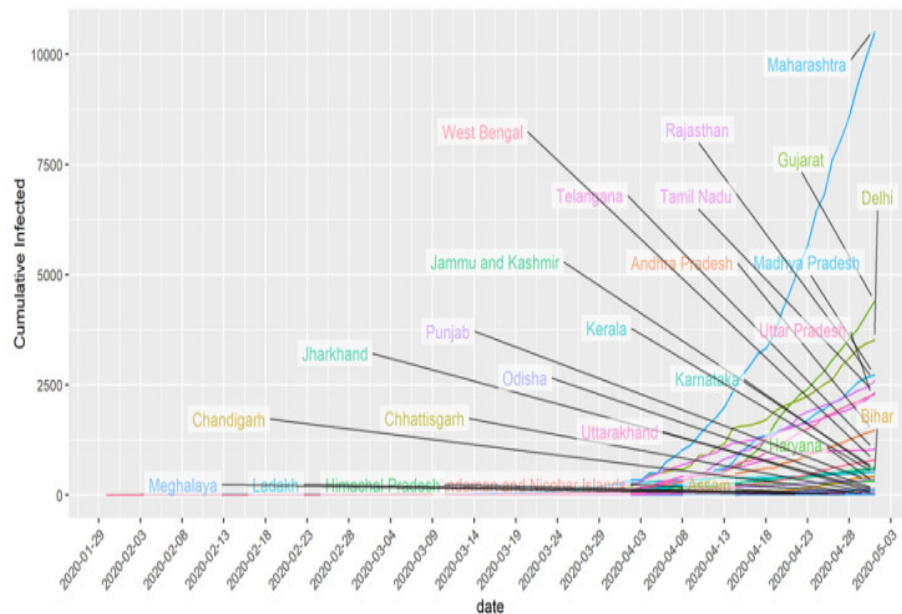


Figure 2

Figure 2 shows the curve of the cumulative number of infected people in those Indian states having at least 10 total infected people. Currently, Maharashtra, Delhi, Gujarat, Tamil Nadu, Madhya Pradesh, Rajasthan, and Uttar Pradesh are the states where the cumulative number of infected people have crossed the 2000 mark, with Maharashtra having more than 10,000 cases. Kerala, the first state to have a COVID-19 confirmed case, seems to have restricted the growth rate. There are few states with cumulative infected people in the range of 500-1500. Depending on how those states strictly follow the preventive measures, a rise may be seen in the confirmed cases.

STATEWISE ANALYSIS RESULTS:

In this section, different states with at least 300 cumulative infected cases were considered. For each state, we present four graphs. We have used the state-level data until May 1, 2020. The first and second graphs are based on the logistic and the exponential models, respectively, with the next 30-day predictions. The third graph is the plot of DIRs for a state. Finally, the fourth graph is showing the growth of the active infected patients using SIS model prediction along with the observed active infected patients.

MAHARASHTRA:

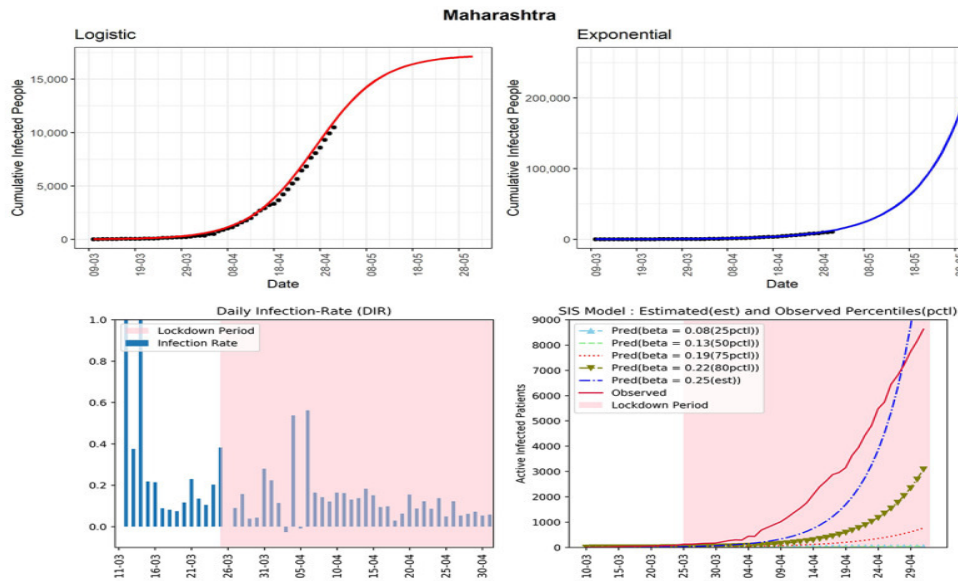


Figure 3

The situation in Maharashtra is currently very severe with respect to the active number of cases (see Figure 3). As of May 1, 2020, the total number of infected cases is 10,498. The logistic model indicates that, in another 30 days from now, the state could observe around 17,100 cumulative infected cases. The DIRs for this state were between 0.03 and 0.15 in the last 2 weeks, and it was more than 0.4 for 2 days at the beginning of April. Note that, for Maharashtra, the lower DIR values of 0.03 may not indicate a good sign since the total number of *active infected*

cases is above 8000. Thus, a DIR value of 0.03 for a day implies $8000 \times 0.03 = 240$ new infected cases. The curves from the SIS model are alarming as the observed active infected patients (red line, fourth panel) line is far above the predicted line with estimated infection rate at the 80th percentile of observed DIRs ($\beta=0.22$). It is apparent from the graphs that even after 30 days of lockdown, Maharashtra has not seen any decline in the number of active cases. The estimated R_0 for Maharashtra obtained from the fitted SIS model is 3.5, which is the highest among all the states. This may also indicate that there could be a large number of people who are in the community without knowing that they are carrying the virus.

DELHI:

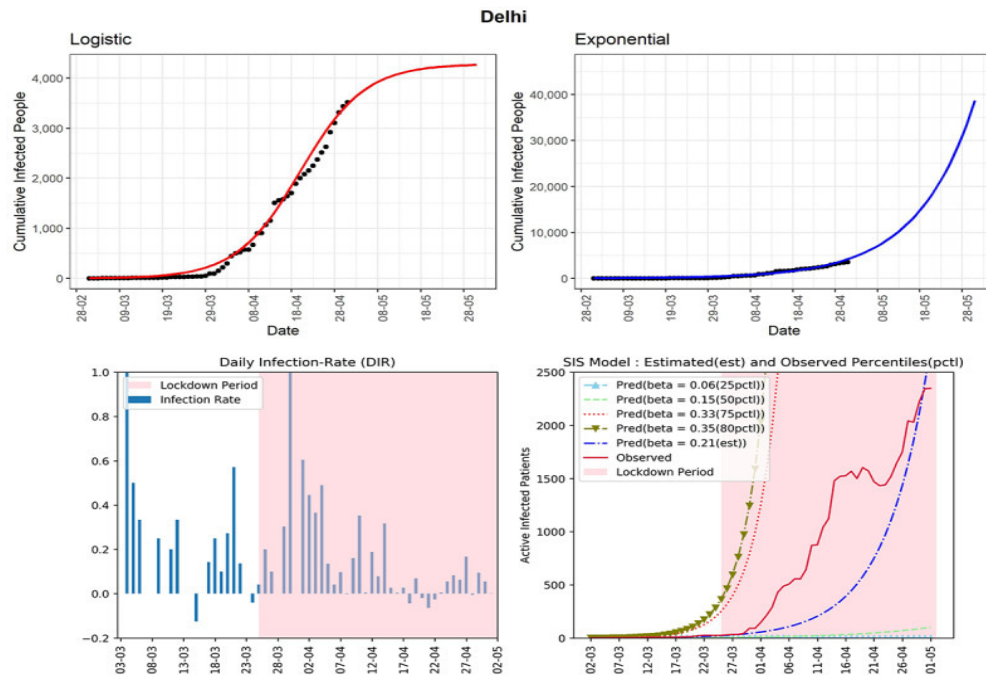


Figure 4

Delhi, being a state of high population density, has already observed 3515 confirmed COVID-19 cases (see Figure 4). Based on the logistic model, the predicted number of cumulative infected cases could reach around 4200 in the next 30 days. The DIR has not seen a downward trend in the past few days. The curve (red line, fourth panel) of observed active infected patients was showing a downward trend from April 20 to April 23,

2020. However, the same graph has picked up exponential growth in the last few days. This is an important observation that illustrates why we need a continuous downward trend of active cases for at least 14 days and that a slight relaxation may put a state in the same severe condition where it was earlier. The estimated R_0 for the state obtained from the fitted SIS model being 2.94 is quite alarming. The observed DIR has been currently fluctuating between -0.06 and 0.17 in the last 2 weeks. The occasional high DIR may suggest that there could be many people who are in the community without knowing that they are already infected with COVID-19. The state could be heading to community spread of COVID-19.

TAMIL NADU:

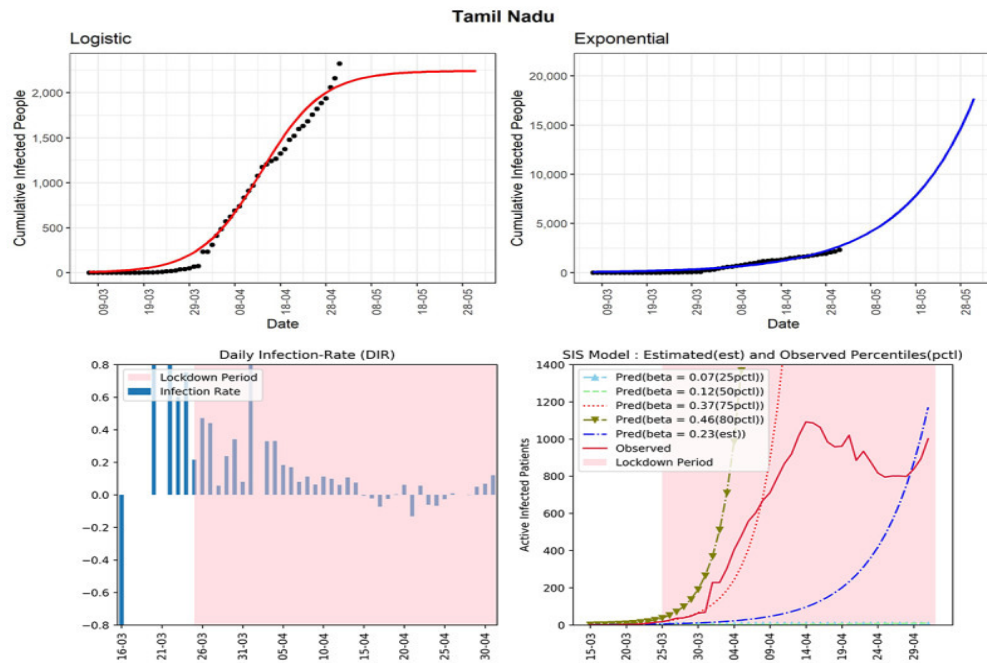


Figure 5

The cumulative infected cases in Tamil Nadu is 2323 (see Figure 5). The state has observed a high DIR of more than 0.7 for some days in March. Tamil Nadu is one of the states where the effect of lockdown is visible from the declining DIRs from the beginning to the end of April. However, there was again an increasing trend in DIR over the last 3 days. The DIRs were between -0.13 and 0.12 over the previous 2 weeks. The

latter part of the curve (red line, fourth panel) of observed active infected patients is showing a decreasing trend first but then an increasing trend again. The estimated R_0 for this southern state obtained from the fitted SIS model is 3.22, which is quite high. The preventive measures need to be maintained to bring down the active cases as well as to stop new infections in this state.

MADHYA PRADESH:

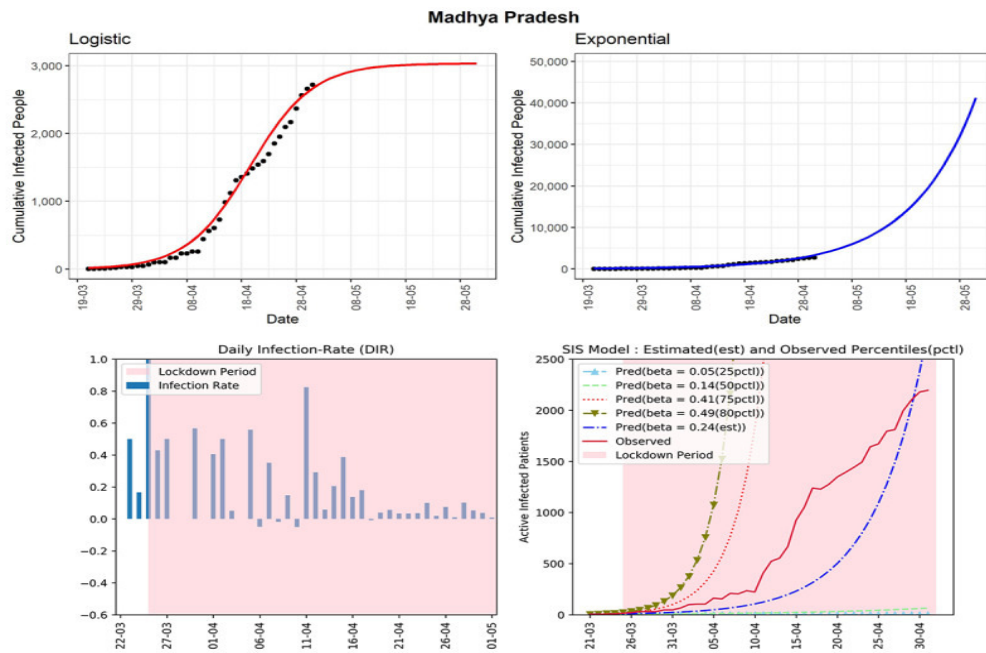


Figure 6

This state currently has 2719 cumulative COVID-19 cases (see Figure 6). In the later part of the lockdown, after April 10, 2020, the state observed a few days with a DIR more than 0.4. Until now, there is no sight of a declining trend in the DIRs. The same type of conclusion can be drawn from the curves of the SIS model. The curve (red line, fourth panel) of observed active infected patients is in between the curves of the SIS model corresponding to the 50th-75th percentiles' curves. The same curve is maintaining an exponential growth after April 10. Note that, for Madhya Pradesh, the 50th percentile of observed DIRs was 0.14, which is higher than the 50th percentile of some other states. The estimated R_0 for this

state obtained from the fitted SIS model was 3.36, which is pretty high. The high growth of active cases in the latter part of the lockdown is a major concern for this state. It could be a signal of a community spread of COVID-19.

RAJASTHAN:

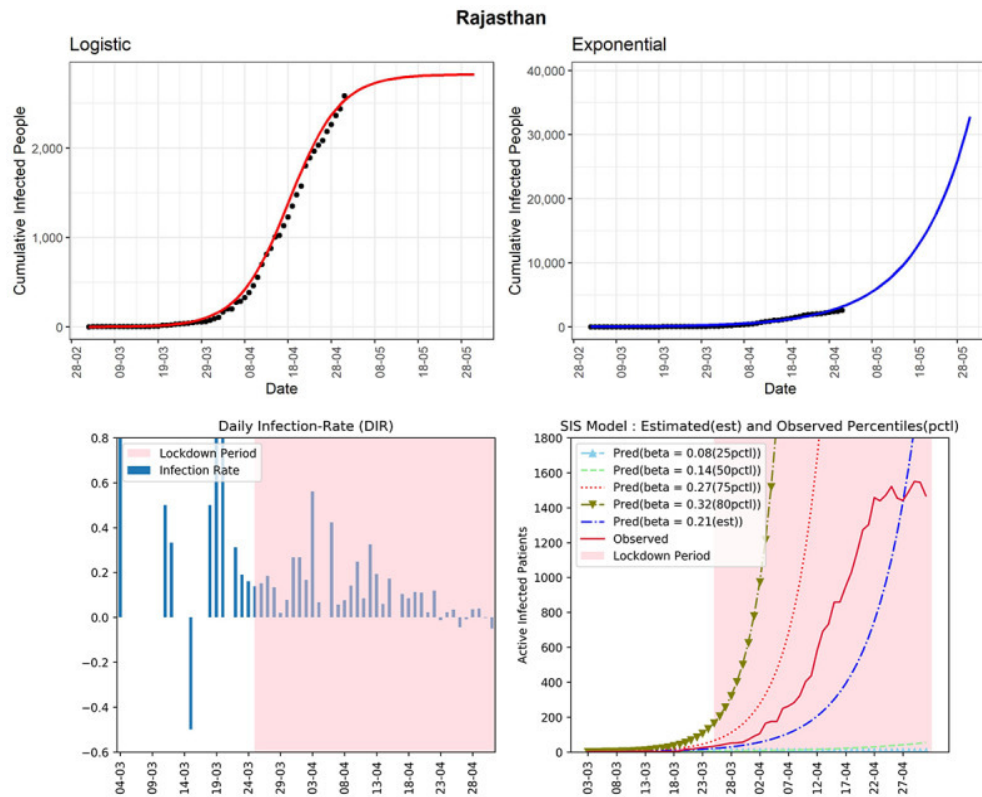


Figure 7

The western state of India, Rajasthan, reported 2584 cumulative infected COVID-19 cases (see Figure 7). The logistic model indicates that in another 30 days from now, the state could observe around 2800 cumulative infected cases. The state has seen a declining trend in the DIRs during the last part of April. The curve (red line, fourth panel) of observed active infected patients is increasing and is in between the curves of the SIS model corresponding to the 50th-75th percentiles of observed DIRs (0.14-0.27) using the SIS model. In the last 2 weeks, the DIRs for Rajasthan have been fluctuating between -0.05 and 0.12 . The active cases in this state have not increased too much in the latter part of April. An

increase in recovery cases is one of the reasons. The estimated R_0 for Rajasthan obtained from the fitted SIS model was 2.94. Therefore, the current COVID-19 situation in the state is not controlled yet.

GUJARAT:

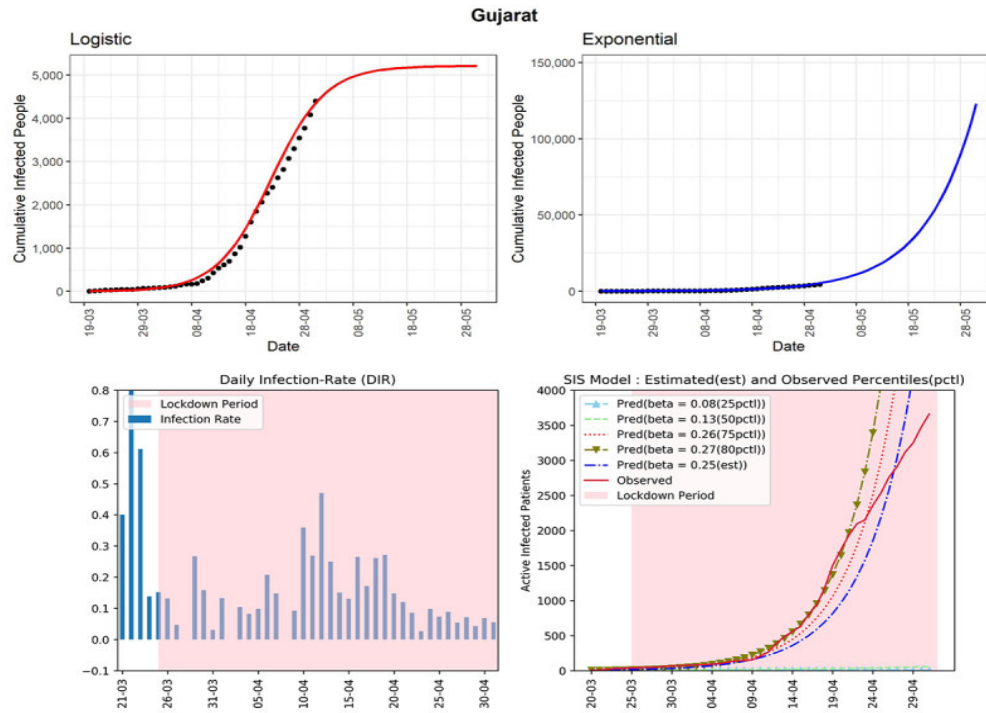


Figure 8

The state is currently experiencing exponential growth with 4395 as the cumulative number of COVID-19 cases (see Figure 8). Using the logistic model, the cumulative infected cases could reach around 5206 in the next 30 days. There is apparently a stable rather than a declining trend in the DIRs in the last few days. The DIRs were in the range of 0.03-0.27 in the last 2 weeks, which are on the higher side. The curve (redline, fourth panel) of observed active infected patients is close to the curve of the SIS model corresponding to the estimated 75th percentile of observed DIR ($\beta=0.26$). Surprisingly, in the latter part of the lockdown, the red line is experiencing exponential growth. The estimated R_0 for Gujarat obtained from the fitted SIS model was 3.5, which is one of the highest. This state

needs immediate intervention to implement all the preventive measures already taken by the Government strictly.

UTTAR PRADESH:

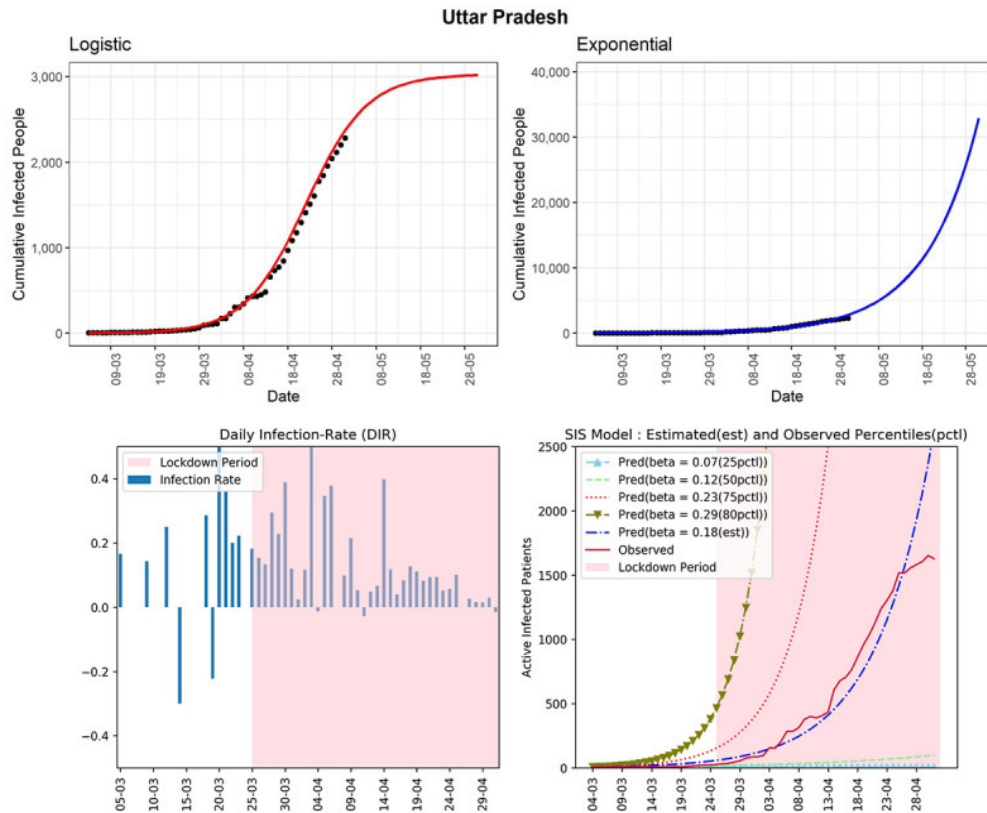


Figure 9

This northern state of India has experienced 2281 cumulative COVID-19 cases (see Figure 9). Using the logistic model, the predicted number of cumulative confirmed cases could be around 3000 in the next 30 days. The curve (red line, fourth panel) of observed active infected patients was in between the curves of the SIS model corresponding to the 50th and 75th percentiles of observed DIRs ($\beta=0.12$ and 0.23 , respectively). The DIR was in the range of -0.02 to 0.13 without a moderately decreasing trend in the last 2 weeks. The overall growth of active cases was still exponential, which is a major concern for the state. The estimated R_0 for the state obtained from the fitted SIS model was 2.52 . There could be many

unreported cases in the state. In the absence of preventive measures, unreported cases can contribute to spreading the virus in the community.

TELANGANA:

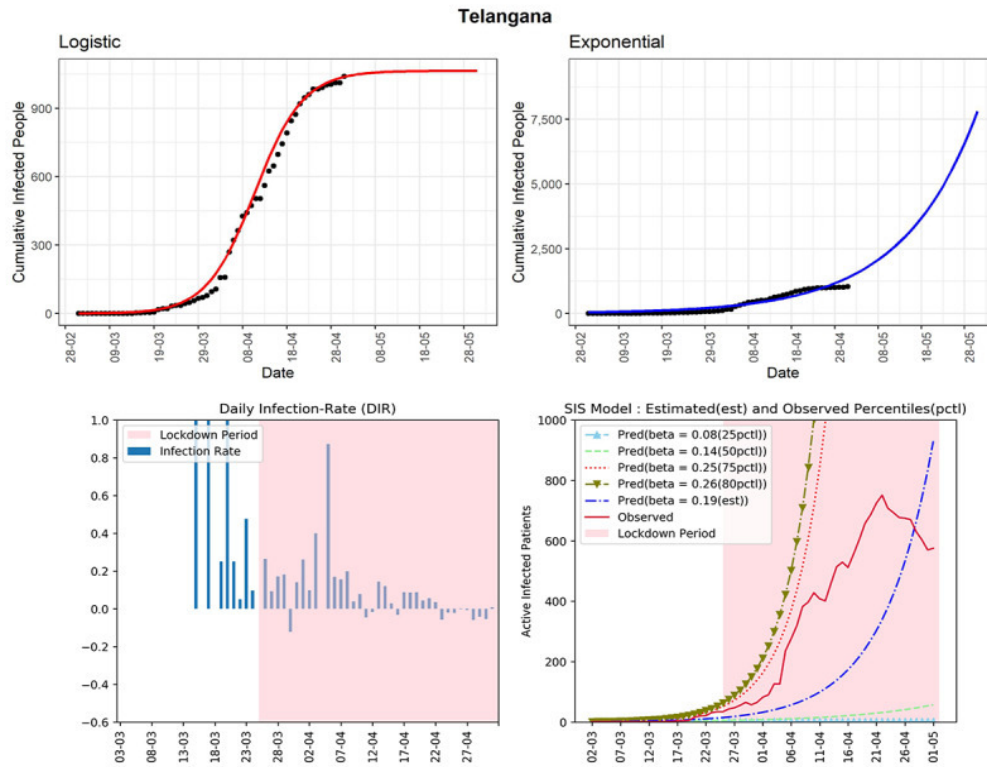


Figure 10

The southern Indian state of Telangana has reported 1039 cumulative infected cases until now (see Figure 10). The logistic model predicts that the number of cases for the state will be around 1063 in the next 30 days. In the fourth graph, the curve (red line, fourth panel) shows that the active number of cases has continuously remained below the curve of the SIS model corresponding to the 75th percentile of the observed DIRs ($\beta=0.25$). The estimated R_0 for Telangana obtained from the fitted SIS model was 2.66. From April 23, 2020, onwards, there is a visible downward trend in the same line graph. This evidence is also supported by a clear decreasing trend in the DIR for more than 2 weeks. The state is going in the right direction to control the COVID-19 pandemic. However, preventive measures need to be in place to see long-term success against the virus.

ANDHRAPRADESH:

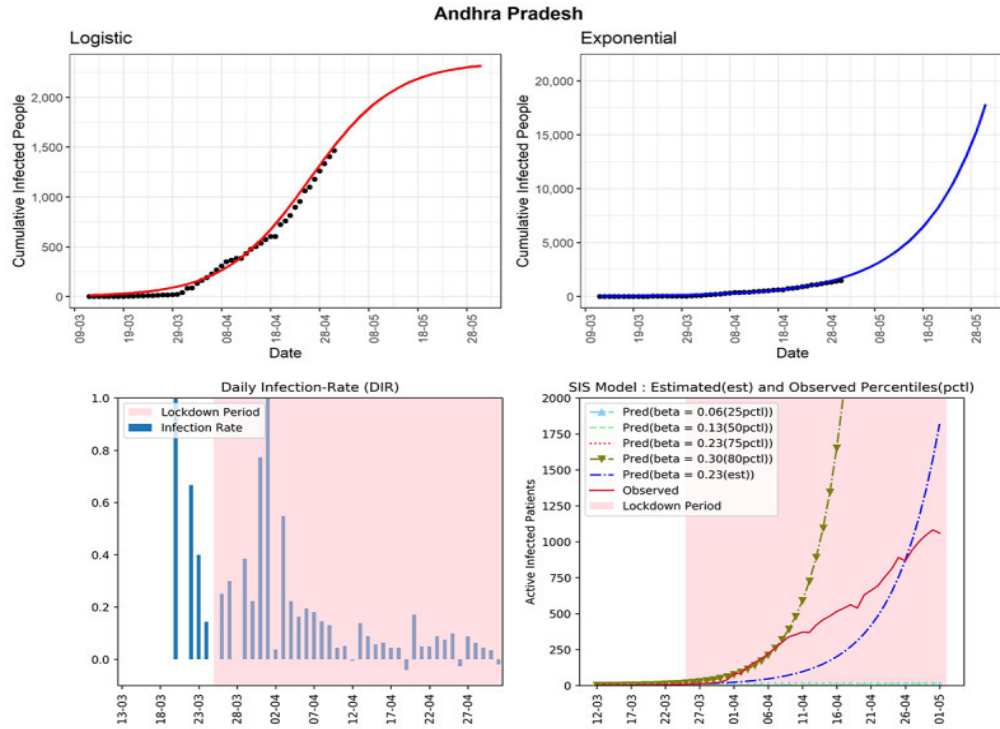


Figure 11

This state has observed 1463 confirmed cumulative infected cases so far (see Figure 11). The curve (red line, fourth panel) shows that the number of active cases is now below and close to the curve of the SIS model corresponding to the 75th percentile of the observed DIR ($\beta=0.23$). The logistic model predicted that the maximum number of cumulative infected people will be around 2313 in the next 30 days. Despite showing good progress in mid-April, the state is again showing an exponential type growth rate. This state has seen DIRs between -0.04 and 0.17 during the last 2 weeks. The estimated R_0 for this state obtained from the fitted SIS model was 3.22, which is quite high. The state has shown a few short declining trends, without any long-term declining trend in the DIR values. It could be due to many unreported infected cases in the community that is spreading the virus.

KERALA:

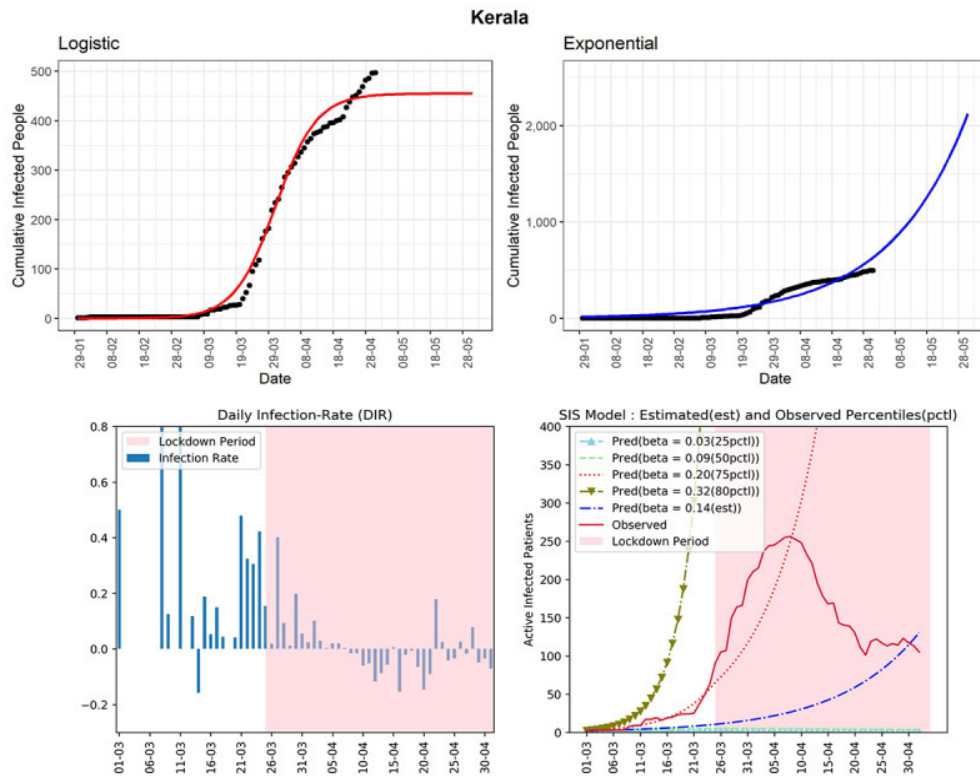


Figure 12

The southern state of Kerala is one of the few states of India where the effect of the lockdown is observed strongly. The state reported the first COVID-19 case in India. However, Kerala has been able to control the spread of the virus to a large extent to date. The cumulative number of cases reported until now is 497 (see Figure 12). It is a state where the curve (red line, fourth panel) of observed active infected patients is going down, which shows that the lockdown and other preventive measures have been effective for this state. The DIR has declined steadily from positive to negative values. However, some spikes in the DIR values can be noticed in the last few days. The estimated R_0 for Kerala obtained from the fitted SIS model was 1.96, which is quite low compared to other states. It can be expected that with the present scenario of the extended lockdown the number of active cases will be few at the end of May.

KARNATAKA:

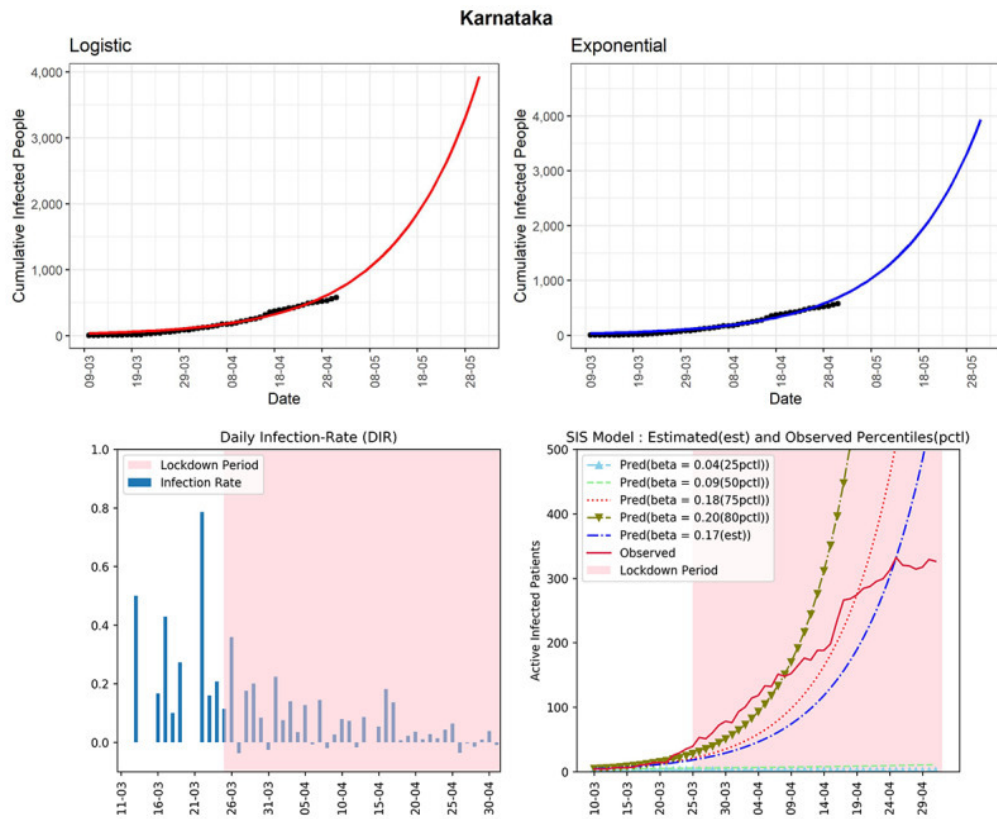


Figure 13

The state has managed to restrict the cumulative infected cases to 576 until now (see Figure 13). The curve (red line, fourth panel) of observed active infected patients is now below the curve of the SIS model corresponding to the 75th percentile of the observed DIRs ($\beta=0.18$). Compared to other states, the 75th percentile DIR is on the lower side. The estimated R_0 for the state obtained from the fitted SIS model was 2.38. We can observe the ups and downs of the DIR with an upper bound of 0.2 from early April. This state has seen DIRs between -0.04 and 0.06 during the last 2 weeks. However, the preventive measures need to be maintained to control the spread of the virus.

JAMMU AND KASHMIR:

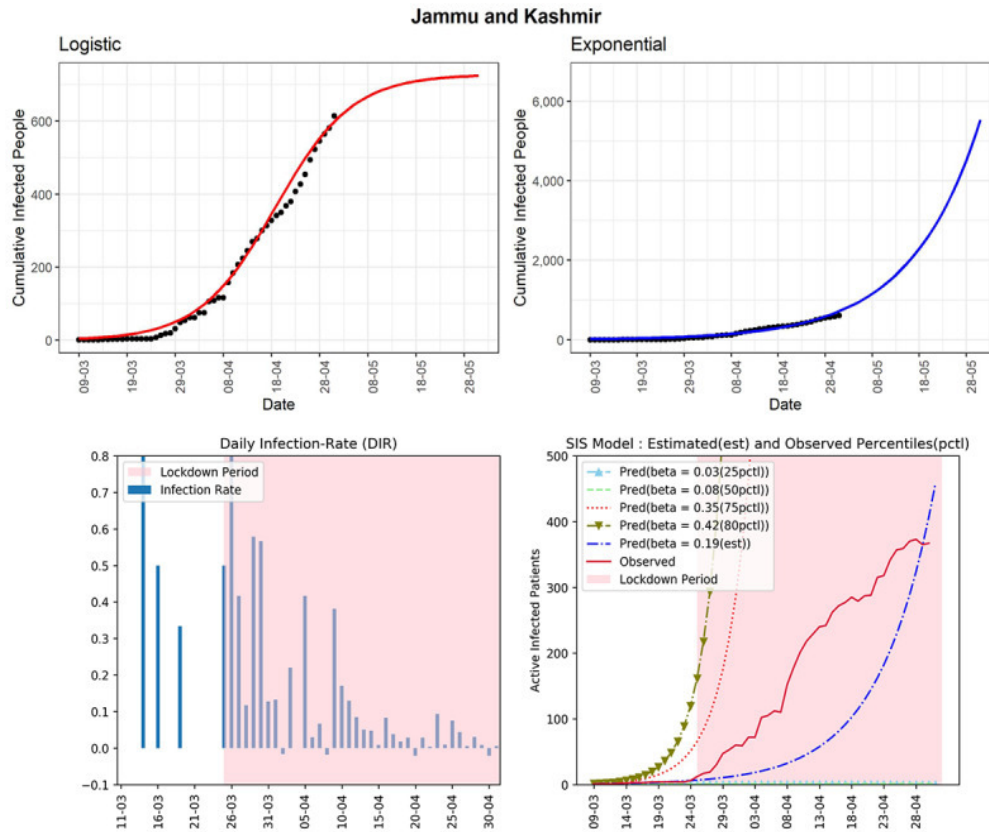


Figure 14

The northernmost state of Jammu and Kashmir has seen 614 cumulative infected cases so far (see Figure 14). The curve (red line, fourth panel) of observed active infected patients has been far below the curve of the SIS model corresponding to the 75th percentile of the observed DIR ($\beta=0.35$). The estimated R_0 for the state obtained from the fitted SIS model was 2.66. From April 9, 2020, onwards, the DIR was apparently decreasing. There are some spikes in DIR values occasionally. It could be due to many unreported cases, which are allowing the infection to spread even during the lockdown period. The DIR was in the range of -0.02 to 0.09 in the last 2 weeks.

WEST BENGAL:

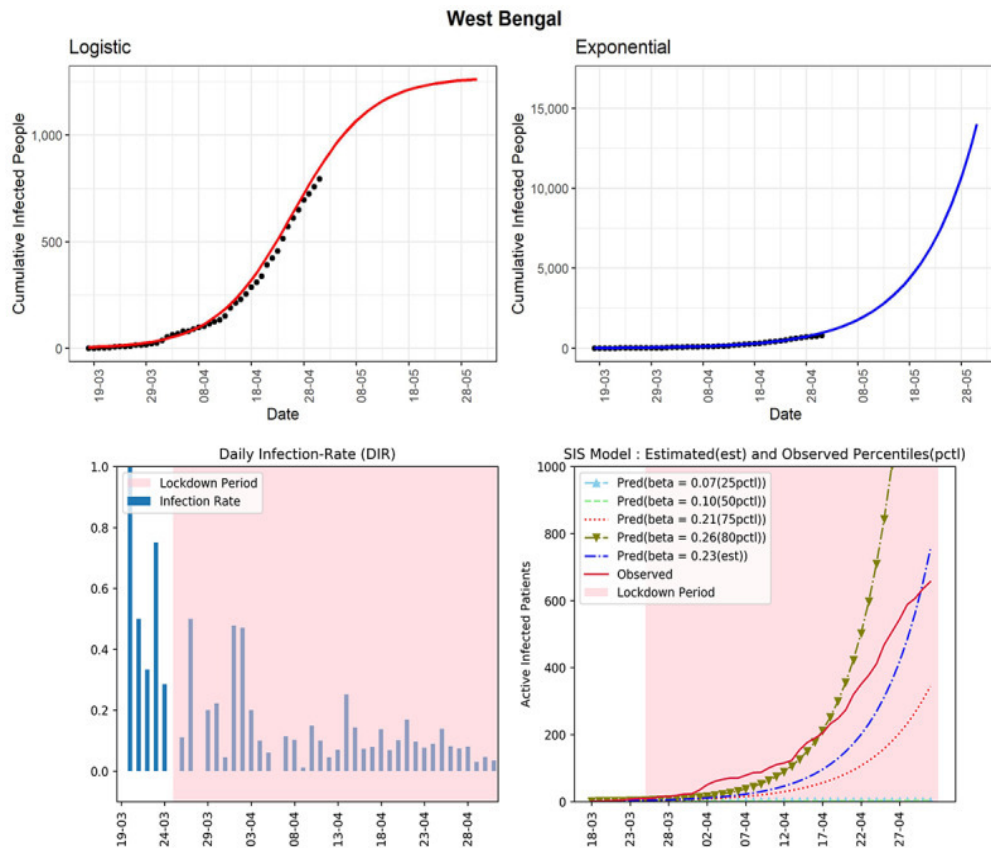


Figure 15

The state of West Bengal is standing at 795 cumulative infected cases as of now (see Figure 15). The DIR values do not show any trend of slowing down in recent times. Based on the logistic model, the predicted cumulative infected cases could be around 1261 in the next 30 days. The curve (red line, fourth panel) of observed active infected patients was above the curve of the SIS model corresponding to the 75th percentile of the DIR ($\beta=0.21$). The DIRs were between 0.03 and 0.17 in the last 2 weeks. The cumulative infected cases graphs based on logistic and exponential models (first and second panels), as well as the active cases–based curve (red line, fourth panel) were all showing exponential type growth rates. The estimated R_0 for West Bengal obtained from the fitted SIS model was 3.22, which is quite high. Strict implementation of

preventive measures is needed to control the spread of COVID-19 in the state.

HARYANA:

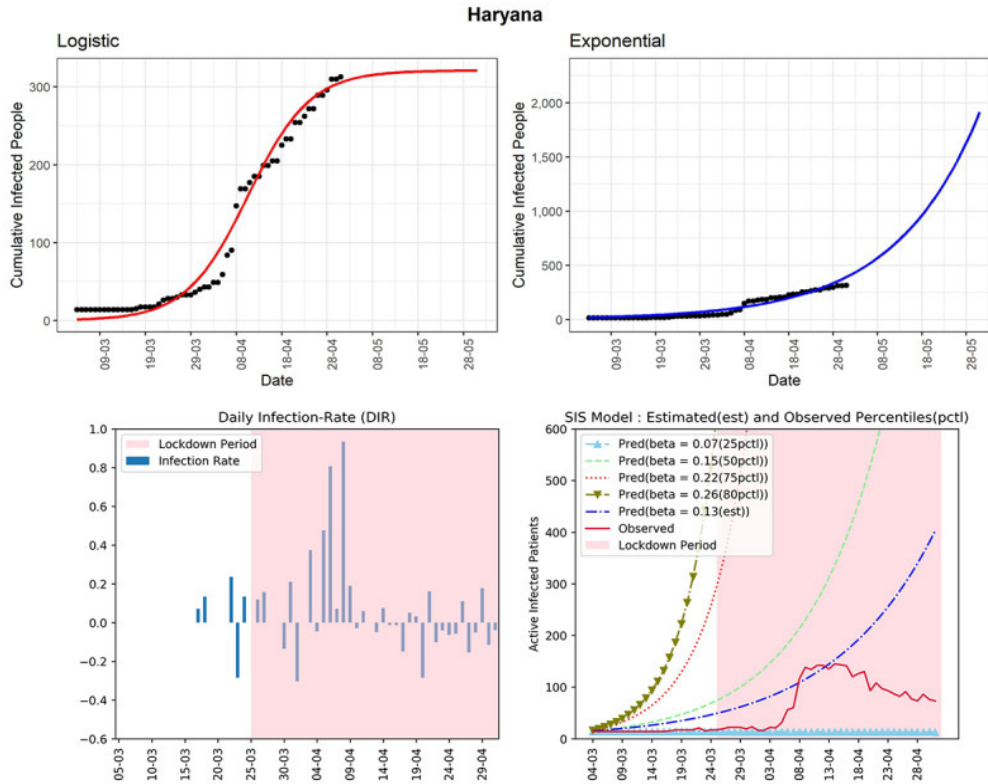


Figure 16

The state of Haryana has observed 313 cumulative infected COVID-19 cases so far (see Figure 16). It has reported a very low rate of infection in the latter part of the lockdown except for the last reported day. In the fourth panel, the curve (red line) of observed active infected patients is now far below the curve of the SIS model corresponding to the 50th percentile of observed DIRs ($\beta=0.15$) and is showing a decreasing trend in the latter part. The estimated R_0 for the state obtained from the fitted SIS model was 1.82, which is on the lower side. The DIRs were between -0.28 and 0.18 in the last 2 weeks. Under the assumption that there are not too many unreported cases, the situation in Haryana seems to be under control.

PUNJAB:

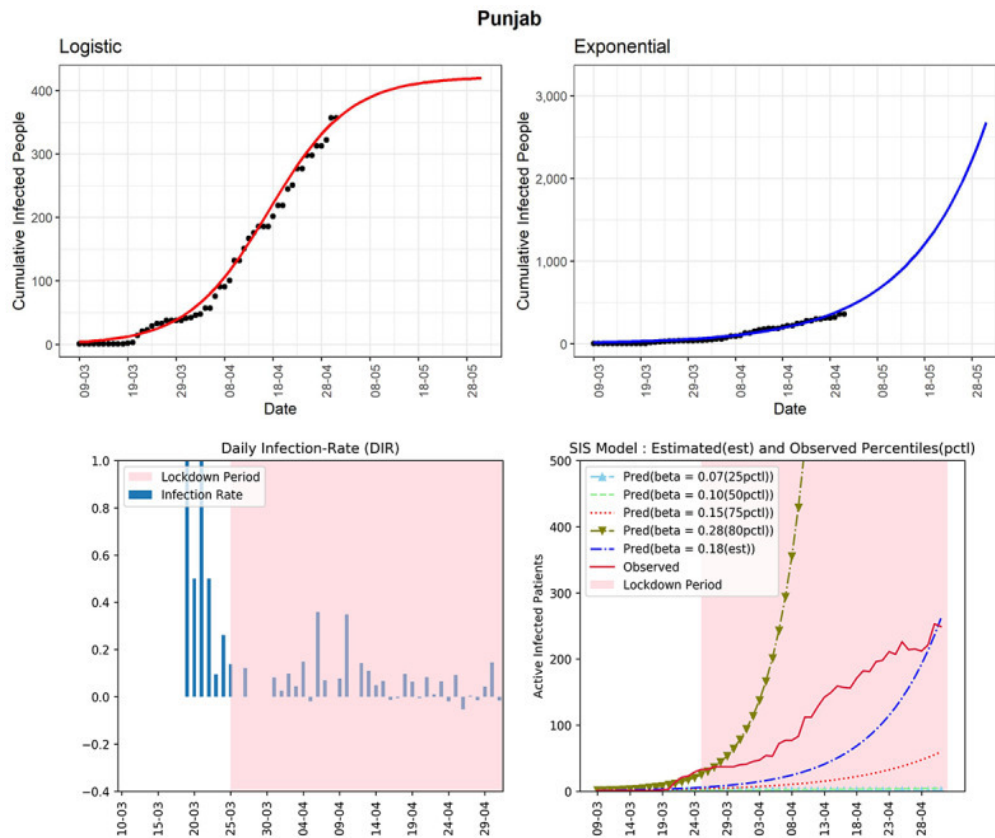


Figure 17

The state of Punjab has reported 357 cumulative infected cases until now (see Figure 17). Based on the logistic model, the predicted cumulative confirmed cases could be around 419 in the next 30 days. The curve (red line) of observed active infected patients was in between the SIS model curves corresponding to the estimated 75th and 80th percentiles of observed DIRs ($\beta=0.15$ and 0.28 , respectively). The estimated R_0 for Punjab obtained from the fitted SIS model was 2.52 . The DIRs were between -0.05 and 0.14 in the last 2 weeks, which is good given the low number of active infected cases in the state.

BIHAR:

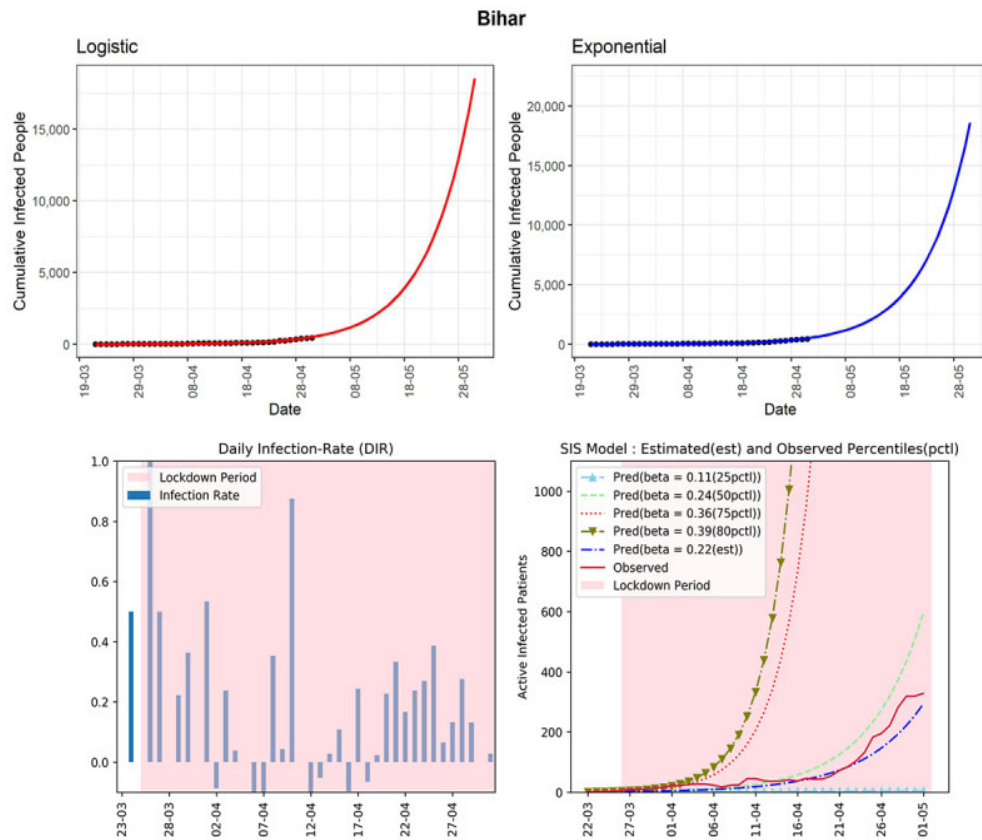


Figure 18

The state has reported 426 cumulative infected cases until now (see Figure 18). Based on the logistic model, Bihar could see 16,452 total infected cases in the next 30 days. The estimated R_0 for the state obtained from the fitted SIS model was 3.08. It may be an overestimate. However, the DIRs showed no sign to decline in the last 2 weeks, with the highest reported value of 0.39. It may indicate many unreported cases in the state. However, the cumulative infected cases are still low for this state. Effective implementation of preventive measures is needed for the state.

CHAPTER 6

SUMMARY AND CONCLUSION

CONCLUSION:

Though the spread of Covid-19 pandemic has been slow in India compared to other countries like USA and Italy due to the social distancing measures taken by the government, still it has had drastic effects in India too. Also, this analysis showed that a pandemic like this affects economy the most. Slowing down the economy then unemployment, job losses and this chain reaction seems to continue.

Analysis has been performed for the data for each state. It was determined that the 7 states, namely, Maharashtra, Delhi, Gujarat, Madhya Pradesh, Andhra Pradesh, Uttar Pradesh, and West Bengal are in the severe category. Among the remaining states, Tamil Nadu, Rajasthan, Punjab, and Bihar are in the moderate category, whereas Kerala, Haryana, Jammu and Kashmir, Karnataka, and Telangana are in the controlled category. The actual predicted numbers from various models for each state were also tabulated.

States with non-decreasing DIR values need to immediately ramp up the preventive measures to combat the COVID-19 pandemic. On the other hand, the states with decreasing DIR can maintain the same status to see the DIR slowly become zero or negative for consecutive 14 days to be able to declare the end of the pandemic.

The study and the results of the analysis made will definitely prove useful for the people living in the respective states in India and help in spreading the right awareness among the public.

REFERENCES

- T, Murhekar MV, Soneja M, Gupta N, Giri S, Wig N, Gangakhedkar R. Lopinavir/ritonavir combination therapy amongst symptomatic coronavirus disease 2019 patients in India: protocol for restricted public health emergency use. *Indian J Med Res.* 2020
- Dey S, Sinha S. Covid-19: govt bans all international flights to India from March 22 to 29. *The Times of India.* 2020. Mar 20, [2020-03-28)
- Considerations for quarantine of individuals in the context of containment for coronavirus disease (COVID-19) *World Health Organization.* 2020. Mar 19, [2020-04-19].
- Bowerman, B.L., O Connell, R.T., 1979. time series and forecasting applied approach. Duxbury Press, Bosto, Massachusetts
- Campous Domeico Bevenuto-Unit of Medical Statistic and Molecular Epidemiology, University Bio-Medico of Rome, Italy.
- Marta Giovanetti-Laboratorio de Flavivirus, Instituto Oswaldo Cruz, Rio de Jeneiro,Brazil.
- R.Muthusami-Department of Computer Applicatios ,Dr.Mahaligam College of Engnieering and Techology, Anna University, Coiambatore Tamil Nadu,India.
- The Analysis of Time Series: An Introduction, Sixth Edition, Chris Chatfield, CRC Press (2016).
- Holdan-Day, San Francisco I., 2020. Statistics-based predictions of coronavirus Epidemic spreading In mainland China. *Innovation bio systems and bioengineering* 4(1),13-18

- Time Series Analysis, Fourth Edition George E.P.Box, Gwilym M.Jenkins, Gregory C. Reisel(2016)
- Box, G., Jenkins, G.M, 1970. Time series Analysis Forecasting and control.
- Tuite, A.R., Ng, V., Rees, E., 2020. Estimation of COVID-19 outbreak size in Italy.
- The Lancet, Infections diseases, 20(5), 537.1016 S1473-3099 (20) 30227-9.
- Anastassopoulou, C., Russo, L.,2020. Modelling and forecasting of the COVID-19 Outbreak. 15(3), e0230405
- Bhatnagar T, Murhekar MV, Soneja M, Gupta N, Giri S, Wig N, Gangakhedkar R. Lopinavir/ritonavir combination therapy amongst symptomatic coronavirus disease 2019 patients in India: protocol for restricted public health emergency use. *Indian J Med Res.* 2020; 151(2):184–189. doi: 10.4103/ijmr.ijmr_502_20.
- Viboud C, Simonsen L, Chowell G. A generalized-growth model to characterize the early ascending phase of infectious disease outbreaks. *Epidemics.* 2016 Jun;15:27–37. doi: 10.1016/j.epidem.2016. 01.002.
- Nakamura GM, Martinez AS. Hamiltonian dynamics of the SIS epidemic model with stochastic fluctuations. *Sci Rep.* 2019 Nov 01;9(1):15841. doi: 10.1038/s41598-019-52351-x.