Exploring Dependence of COVID-19 on Environmental Factors and Spread Prediction in India

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Abstract

The pandemic of “Corona Virus Disease 2019” or COVID-19 has taken the world by storm. Majority of nations of the world have been challenged by the novel coronavirus, which is supposedly of zoonotic origin and is known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The present work attempts to evaluate the spread of COVID-19 in India. The methodology of assessment uses SEIR (Susceptible-Exposed-Infectious-Removed) model to establish the impact of socio-behavioural aspect, especially social distancing, affecting the numbers of COVID-19 cases per day. The lockdown initiated by Government of India (GoI) scenario is weighed against a scenario with a possible initiation of community spread due to crowded gatherings in India. The resultant changes, as against the lockdown scenario, has been reported in terms of the increase in the number of cases and stretch of the timeline to mitigate the COVID-19 spread. Impact of environmental factors like temperature and relative humidity have also been analyzed using statistical methods, including Response Surface Methodology (RSM) and Correlation. It has been found that the spread of cases is dependent on environmental conditions, i.e. temperature and relative humidity. This study is expected to help the policymakers and stakeholders to device an improved action plan to alleviate the COVID-19 spread, especially in India.

Keywords: COVID-19, Coronavirus, SEIR, SARS-CoV-2, Response Surface Methodology, Environment, Temperature, Relative humidity
Introduction

During the end of December 2019, an outbreak of atypical pneumonia [now being called as coronavirus disease 2019 (COVID-19)] started in Wuhan, China [1-4]. The virus is being considered of zoonotic origin. It is being referred to as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) or in general referred to as novel coronavirus, and the disease-associated is being called COVID-19 [3-5]. With the onslaught of SARS-CoV-2 in India, major interventions in epidemic preparedness started. These interventions include, but not limited to, public awareness, deployment of widespread testing facilities, medical institutions preparedness, and surveillance and tracking of individual movement and quarantines of suspected cases [6]. Presently social distancing and regularly washing of hands are some of the best ways to keep this virus at bay [7].

Countries all over the world are challenged with this virus and have declared lockdowns in their various cities and states [8-11]. In India, nationwide lockdown is declared for 21 days starting 25th March 2020 [12, 13]. People are instructed to stay indoors unless for emergency services [14]. All tourist visas and e-visas for travellers are suspended till 15 April 2020. Travellers, who returned after 15 February 2020, are quarantined for a minimum of 14 days upon their arrival in India [15]. The researchers estimate that the virus proliferates to more than two persons from every infected person, highlighting the possibility to infect millions [16]. The effectiveness of lockdown is contingent on people avoiding social gatherings and limiting population movement. India reported its first COVID-19 case, originating from China, on 30th January 2020 in Kerala [17]. Government of India (GoI) reported its first COVID-19 death on 10th March 2020 in Karnataka. Till April 5th 2020, India has reported 3577 confirmed cases with 275 recoveries and 83 deaths by COVID-19 [18-20].

Researchers are trying to understand the trend of the SARS-COV-2 movement, to predict the scenarios of new potential cases and to plan effective remediations for their country [21-22]. The role of environmental conditions in the survivability of this virus has also emerged as a potential factor impacting the spread [23-26]. Few studies have suggested that virus should behave similar to most influenza or flu, or also Severe Acute Respiratory Syndrome (SARS), commonly suggesting its reduced activity in hot and humid conditions [27-29]. However, it is essentially necessary to investigate the impact of local environmental conditions, on the virus spread. The alarming community spread of SARS-CoV-2 majorly impacts the public health, economics and behavioural aspect of the society [30]. The susceptible-exposed-infectious-recovered (SEIR models) has been reported as a successful tool to understand the pandemic dynamics and to evaluate the impact of environmental and social conditions on the spread of
COVID-19 [31-34]. Hence, the present work focuses on highlighting the impact of behavioural aspects of the society, and local environmental condition on COVID-19 spread using the SEIR model and statistical tools

**Methodology**

The present assessments have been carried out in two folds. First is to predict the number of confirmed cases of COVID-19 for India and the time period for its subsidence. Secondly, to evaluate the dependency of COVID-19 spread on environmental factors namely temperature, and relative humidity

The prediction is of COVID-19 cases is based on the SEIR (Susceptible-Exposed-Infectious-Removed) model, which has been used to simulate two practical implementation conditions related to societal behavioural issue. The first case is where the lockdown is followed diligently and the other being with community breaches and failure of social distancing. Both of these scenarios actually happened in India and have been considered accordingly.

The SEIR model for the spread of Infectious disease is simulated, similar to severe acute respiratory syndrome [35]. Immunity, infected, exposure probability and recovery/removal are the compartments of the model [36]. The simple SEIR model with its codes and governing equations are stimulated for India having maximum number of reported COVID-19 cases for understanding efficacy of measures in the current time and future. Governing equations along with the data for various values for S-E-I-R model are given as supplementary data in Annexure I. World Health Organization (WHO), India reported the numerals of COVID-19 pandemic spread in India on a day-to-day basis [17-20]. The primary sources of the data are WHO situation reports for India [37, 38]. Daily migration index has been computed on the basis of mass movements of people from one city to another through various mode of transportation like air, road and rail [16]. SEIR equations are modelled using python program v2.7.5 (open source) to predict the forthcoming Susceptible [S], Exposed [E], Infected [I], Recovery [R] cases for India [39]. The parameters considered with respect to the model are given as follows:

**SEIR Model Parameters**

Table 1 below gives the SEIR model parameters. Detailed equations and corresponding values are given as supplementary data in Annexure-I

| Parameter              | Brief Data Definition       | Source/Reference                  |
|------------------------|------------------------------|----------------------------------|
| Suspected people (S[t])| The total number of          | Ministry of Health and            |
suspected people in India are taken from WHO highlights showing a number of suspected samples for testing out of which some have positive results (SARS-CoV-2).

| Table |
|-------|
| **Population (N)** | Total population data is as per the census report. The population of India is about 133.92 crores |
| **Rate of transmission (β₁ and β₂)** | The mortality rate of COVID-19 is about 3.434% in China and about 1.1% outside China. Rate of transmission is 1.5 - 4.5 for SARS-CoV-2, which is more than SARS rate of transmission. |
| **Incubation rate (σ)** | 2 to 14 days has been publicly reported for SARS-CoV-2 |
| **Number of contacts per person (r[t])** | The number of contacts per person can be considered as the number of exposed people during inflow and outflow of the population it is estimated depending upon population, age group, household size, etc |
| **Exposed People (E[t])** | The number of exposed people can be calculated by the inflow rate of people coming from other places and the outflow rate of people flowing out of the country. |
| **Infected People (I[t])** | The total number of infected people in the country from January 2020 data is collected from online sources till April 3rd 2020. |

The data on confirmed cases for India which have been used in the above model is shown as supplementary data in Annexure-II.

While studying the relation of environmental factors with COVID-19, relative humidity and temperature are considered as the base parameters. The daily rise in COVID-19 cases in various cities of India are correlated with above parameters to understand the relation. In
addition to simple correlation, Response Surface Methodology (RSM) is used to establish an empirical association between the metrological parameters, which included Temperature and Relative humidity, over the rising COVID-19 cases in India. The raw data related to statistical modelling is given as supplementary data in Annexure III.

A response surface is used to map the entire cases of the particular region using a full quadratic function. The association of the parameters can be depicted as a second-order polynomial equation.

\[
R = \beta_0 + \sum_{i=1}^{i=n} \beta_i x_i + \sum_{i=1}^{i=n} \beta_i x_i^2 + \sum \sum_{i<j} \beta_{ij} x_i x_j
\]

where, R is the predicted response; \( \beta_0 \) a constant; \( \beta_i \) the linear coefficient; \( \beta_{ii} \) the squared coefficient; and \( \beta_{ij} \) the product-coefficient, \( n \) is the number of factors [46-48]. The significance of the respective parameters is established by Analysis of Variance (ANOVA), which can interpret in terms of P values [47]. The lower the P-value, the higher is the significance of the corresponding parameters. A good model fit can be affirmed with high R² value [46-48], which help check the competency of the model. Response surface modelling is carried using statistical software MINITAB 14 [49].

Results and Discussion

1. SEIR Model Output

SEIR Model is simulated for two cases. Case A, where the model has considered the input data till 23rd March 2020 and Case B was modelled with data up to 2nd April 2020. The difference between the two datasets is that India had declared Lockdown on 25th March 2020 after understanding the situation that possible community spread of the COVID-19 cases has started and it is to be curbed almost immediately to flatten the curve [50]. Later on, it emerged that the case is true, as a large number of gatherings were happening during the first and second week of March, the spillover of which is seen at the end of March and early April, given the incubation period of novel coronavirus varies from 2-14 days. [51].

For Case A, within the limit of the available datasets, the rise of the number of COVID-19 cases was gradual. The results for Case A are shown below in Table 2 and Figure 1. Referring to SEIR model equations as supplementary data in Annexure-I, S[t] data is taken from COVID-19 cases in India from supplementary data in Annexure-II and S[t+1], i.e. for the day plus one, is computed through the model.

| Table 2: Simulation Result of SEIR model for Case A |
|-------|-------|-------|-------|-------|
| Date  | S[t+1] | E[t+1] | I[t+1] | R[t+1] |


From Table 2 and Figure 1, it can be inferred that if social distancing is strictly implemented to control the community spread, the total number of infected cases is restricted to 15,005. Wherein for Case B, with lapses in social distancing and marking the possible entry to community spread (in the first and second week of March), has given the rise in the number of cases, which is reflected with increased cases at the end of March and start of April. Table 3 and Figure 2 shows that the number of infected cases showed an increasing trend with
infection numbers exceeding 18,402 amongst other factors of S, E and R. Not only the number of cases increased but also the overall timeline for stabilization of cases extended by a minimum of 20 days.

Table 3: Simulation Result of SEIR model for Case B

| Date    | S[t+1] | E[t+1] | I[t+1] | R[t+1] |
|---------|--------|--------|--------|--------|
| 31-Jan  | 826    | 19800  | 2240   | 18     |
| 08-Feb  | 1191   | 14300  | 1400   | 20     |
| 16-Feb  | 3864   | 20300  | 2000   | 25     |
| 24-Feb  | 4396   | 16400  | 1500   | 33     |
| 27-Feb  | 4446   | 12800  | 1200   | 52     |
| 03-Mar  | 7112   | 10980  | 1000   | 66     |
| 10-Mar  | 8977   | 11590  | 1039   | 258    |
| 17-Mar  | 10653  | 16084  | 1439   | 289    |
| 24-Mar  | 5207   | 14239  | 1270   | 156    |
| 31-Mar  | 6054   | 8858   | 790    | 820    |
| 07-Apr  | 7739   | 13411  | 1200   | 1451   |
| 14-Apr  | 2513   | 10729  | 945    | 457    |
| 21-Apr  | 2369   | 8956   | 791    | 177    |
| 28-Apr  | 1505   | 7191   | 634    | 64     |
| 05-May  | 683    | 5400   | 486    | 57     |
| 12-May  | 136    | 3200   | 284    | 85     |
| 19-May  | 82     | 2100   | 184    | 35     |

Figure 2: Trend of Rise and Fall of Cases in each category of the SEIR Model (Case B)

2. Environmental Parameters
The average state data of temperature and relative humidity are considered to study its relationship in the rising COVID cases in two Indian states, namely; Maharashtra and Karnataka. The range of the parameters under study in these states is tabulated in Table 4. These two states have a significant difference in their metrological condition with respect to temperature and relative humidity with \( T=4.01, P <0.001 \) and \( T= 2.71, P\text{-Value} = 0.011 \), obtained from a two-tailed t-test. Table 5 delineates the results of ANOVA for the cumulative number of COVID-19 cases in the states of Maharashtra and Karnataka, under the varied temperature and relative humidity conditions. From Table 4, it can be inferred that the main effect of the temperature and relative humidity was significant for Maharashtra (F=29.96, P=0.001) and Karnataka (F=6.28, P=0.014). However, the squared effect of the input parameters was seen prominently in Karnataka (F=4.23, P=0.041), which is found negligible for Maharashtra (F=1.54, P=0.254). Also, no significant interaction between the input variables is observed affecting the total number of COVID-19 cases in Maharashtra with F=1.22, P=0.291. However, Karnataka depicts significant interactions between the temperature and relative humidity, impacting the number of cases with F=3.57, P=0.083. The response surface mapped over the cumulative number of COVID-19 cases reflects a good model fit R-Sq of 85.25% and 88.89 % for Maharashtra and Karnataka, respectively. The model fit is also confirmed with low standardized residuals, with good fits for both Maharashtra and Karnataka with lack-of-fit P values as 0.362 and 0.763, respectively. Figure 3 depicts that modelled inputs data points are in close agreement with normal distribution curve line and residuals are closely distributed at different levels of the independent variable, and hence it can be said that equality of variance exists between varied levels of the response.

### Table 4. Range of variable and Coded Units

| Parameters | Range | Classifications | Coded Unit |
|------------|-------|-----------------|------------|
| States     |       |                 |            |
| Temperature (°C) | Relative humidity (%) | Relative humidity | [-1 to 1] |
| Maharashtra | 27 – 30 | 37 – 87 | < 50 : Low [50-70]: Mid > 70 : High | Low: -1 Mid: 0 High: +1 |
| Karnataka  | 26 - 28 | 29 - 88 | <50: Low [50-70]: Mid >70: High | Low: -1 Mid: 0 High: +1 |

### Table 5. Summary of ANOVA results for COVID-19 cases in states of India: (a) Maharashtra (b) Karnataka and (c) T and P values for Maharashtra and Karnataka

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|--------|----|--------|--------|--------|---|---|
| a) Maharashtra | Linear | 2 | 28486.9 | 26155.2 | 13077.6 | 29.96 | 0.001 |
|         | Square | 2 | 1242.7 | 1342.6 | 671.3 | 1.54 | 0.254 |
|         | Intraction | 1 | 533 | 533 | 533 | 1.22 | 0.291 |
|         | Residual Error | 12 | 5237.7 | 5237.7 | 436.5 | | |
Pure Error  8  3215.9  3215.9  402  
Lack- of-Fit  4  2021.7  2021.7  505.4  1.26  0.362  
S = 20.8919  PRESS = 12808.4  R-Sq = 85.25%  R-Sq(pred) = 63.92%  R-Sq(adj) = 79.10%  

b) Karnataka  
Linear  2  4700.86  678.73  339.36  6.28  0.014  
Square  2  292.78  457.28  228.64  4.23  0.041  
Interaction  1  192.63  192.63  192.63  3.57  0.083  
Residual Error  12  648.18  648.18  54.01  
Pure Error  11  642.58  642.58  58.42  
S = 7.34948  PRESS = 1279.17  R-Sq = 88.89%  R-Sq(pred) = 78.08%  R-Sq(adj) = 84.26%  

| Terms | Maharashtra | Karnataka |
|-------|-------------|-----------|
|       | T           | P         | T           | P         |
| c) T and P values | | | |
| Constant | 4.187   | 0.001    | 1.191       | 0.257    |
| X1 | 7.369       | 0.001    | 2.577       | 0.024    |
| X2 | 0.976       | 0.348    | 0.221       | 0.829    |
| X1*X1 | 1.377     | 0.194    | 2.537       | 0.026    |
| X2*X2 | -0.661    | 0.521    | 1.534       | 0.151    |
| X1*X2 | 1.105    | 0.291    | -1.888      | 0.083    |

*Note: X1: Temperature, (°C) ; X2: Relative humidity, %*
ANOVA, tabulated in Table 6, has been performed for Kasaragod city of India also which is supported by the availability of consistent data. The ANOVA results depict the noteworthy impact of the temperature and relative humidity on rising cases per day in Kasaragod. The main effect and interaction effect of relative humidity and temperature are found to be significant with low p-values of 0.054 and 0.035, respectively. Also, as the input parameters are modelled in the coded unit [-1,1], the value of regression coefficients also reflect that the interaction between relative humidity and temperature is dominant on the main effect of the individual factor. The response surface mapped over the new cases in Kasaragod also reflects a good model fit with R-Sq 63.63% (R-S Adj – 53.71%) with low standardized residuals and with lack-of-fit P values as 0.424. Figure 4 depicting the residual plot of RSM model, confirms that the inputs parameters are in arrangement with the normal distribution line and residual being evenly distributed at all levels of input parameters.

**Table 6. ANOVA for new cases per day in Kasaragod**

| Source            | DF | Seq SS | Adj SS  | Adj MS  | F    | P    |
|-------------------|----|--------|---------|---------|------|------|
| * ANOVA           |    |        |         |         |      |      |
| Main Effect       | 2  | 473    | 270.91  | 135.46  | 3.85 | 0.054|
| Interaction Effect| 1  | 203.36 | 203.36  | 203.36  | 5.79 | 0.035|
Residual Error  11  386.57  386.57  35.14
Pure Error  1  12.5  12.5  12.5
Lack- of-Fit  10  374.07  374.07  37.41  2.99  0.424

$S = 5.92815 \quad PRESS = 13036.2 \quad R-Sq = 63.63\% \quad R-Sq(adj) = 53.71\%$

| Coef. | SE Coef. | T     | P   |
|-------|----------|-------|-----|
| e) Regression Coefficients | | | |
| Constant | 8.194 | 3.783 | 2.166 | 0.053 |
| X1 | -4.418 | 4.347 | -1.016 | 0.331 |
| X2 | 5.939 | 4.383 | 1.355 | 0.203 |
| X1*X2 | -14.921 | 6.203 | -2.406 | 0.035 |

Note: X1: Temperature, (°C); X2: Relative humidity, %

![Figure 4. Residual Plot for Kasaragod](image)

In addition to the exploration of the above state and city cases dependency on temperature and relative humidity, statistical correlation is explored for other city cases. Indian cities considered for analysis are Mumbai, Srinagar and Kasaragod. The correlation matrix for each city is shown in Table 7. New York, which has seen unprecedented growth in COVID cases, is also correlated for temperature and relative humidity and validates similar results as Indian cities.
Table 7. Correlation Matrix for Srinagar (A), Kasaragod (B), Mumbai (C) and New York (D)

| Srinagar (A) | Temperature | Relative Humidity | Cases/day |
|--------------|-------------|-------------------|-----------|
| Temperature  | 1.000       |                   |           |
| Relative Humidity | -0.815 | 1.000             |           |
| Cases/day    | -0.713      | 0.363             | 1.000     |

| Kasaragod (B) | Temperature | Relative Humidity | Cases/day |
|---------------|-------------|-------------------|-----------|
| Temperature   | 1.000       |                   |           |
| Relative Humidity | -0.645 | 1.000             |           |
| Cases/day     | -0.605      | 0.607             | 1.000     |

| Mumbai (C)    | Temperature | Relative Humidity | Cases/day |
|---------------|-------------|-------------------|-----------|
| Temperature   | 1.000       |                   |           |
| Relative Humidity | 0.442 | 1.000             |           |
| Cases/day     | 0.495       | 0.139             | 1.000     |

| New York (D)  | Temperature | Relative Humidity | Cases/day |
|---------------|-------------|-------------------|-----------|
| Temperature   | 1.000       |                   |           |
| Relative Humidity | -0.006 | 1.000             |           |
| Cases/day     | -0.277      | 0.256             | 1.000     |

From Table 7, it is observed that most of the cities, except Mumbai, show a similar correlation for the rise in the number of cases per day and environmental parameters, i.e. temperature and relative humidity. The strength of these correlations varied from strong to weak relations, as indicated in Table 7. Within the studied datasets, Srinagar shows the strongest negative correlation with temperature indicating the reduction in the COVID cases with the increase of temperature and a positive correlation with relative humidity. It has been well established that with the increase in temperature, the relative humidity should drop given that the holding capacity of air will increase [52]. Similar correlations can be seen for Kasaragod and New York. However, Mumbai shows a positive correlation with both temperature and relative humidity. This might be due to the fact that as Mumbai is a coastal city and a densely packed one with respect to population and land use. Another reason could be that Mumbai being a metropolitan city and depends on public commutes, making the implementation of social distance practically very difficult. In such cases, the dominance of other factors, for disease spread, on environmental factors cannot be ignored and need separate detailed research. Further, this also confirms that only environmental factors may not be able to mitigate this particular strain of novel coronavirus and other behavioural attributes are bound to pay a major role in its alleviation.
Conclusion
In current time, when every COVID-19 affected nation is making efforts to mitigate and alleviate the spread of this virus, it becomes essential to study the correlations of the rising cases of COVID-19 with respect to behavioural and environmental attributes. India, similar to other countries, is making efforts to curb the spread by strictly monitoring the lockdowns and ensuring social distancing apart from the quest for targeted medical solutions. In a country like India, where the population exceeds 1 billion, social distancing remains a challenging but potential and practically implementable solution. In the current research, an effort is made to establish the impact social distancing to subside the rising cases in India through simulating multiple cases using the SEIR model. The model concluded that breach of social distancing by people engagement in crowded gatherings, with the onset of possible community spread, might result in extending the time to control the spread by minimum 20 days, with a total number of infected cases exceeding 18,40, compared to the normal case of strict compliance of lockdown. The above scenario is considering only a few of the gatherings which occurred in start and middle of March; however, if there are continued gatherings like this, the outcome can be disastrous in terms of number of people infected and respective deaths. Hence, the decision of GoI of nationwide lockdown is very timely to control the spread of the virus. The finding of SEIR helps to conclude that social distancing is one of the best tools available with governments right now to control the spread of this disease.
Also, the impact of environmental conditions is found to be significantly affecting the spread of COVID-19, established through statistical models like RSM and correlation matrices. As temperature rise has been reported to mitigate the spread of viruses, similar trends are observed in most of the Indian cities under the study for SARS-CoV-2. With the present analysis, it is inferred that the hot climate should reduce the spread of COVID-19, whereas relative humidity correlates positively with the number of infected cases. Although a common trend may not be visible right now with respect to environmental factors, it will be wise to find out and understand their correlation in order to support the future action plans. It should also be noted that a single model or one prediction methodology may not fit to understand the impact of environmental factors for all the cases of such a geographically large and diverse country like India. The established correlations of COVID cases on environment conditions would aid to prioritize the intervention in the susceptible cities. In future, the model uncertainties should also be explored to continually evolve newer trends to formulate improved predictive sets. It is also important to add environmental parameters into
epidemiological models like SEIR to bring out more holistic and unified conclusions assisting policymakers and stakeholder in formulating a comprehensive action plan.

Data availability
The data used in the manuscript is publicly available:

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**Code availability**

Any codes used in the paper available upon request from h.bherwani@neeri.res.in

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**Contributions**

RK and HB conceived the idea and designed the study with inputs from AA and AG.
SA prepared the data.
HB and AG conducted the analysis and worked on the models using datasets.
AA and SA compiled the results and wrote the initial draft.
HB, AG, AA, and RK improved the discussion and results.

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Ethics declarations

Competing interests

The authors declare no competing interests.

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Supplementary Data

Annexure I

Governing Equations for S-E-I-R model (Susceptible-Exposed-Infectious-Removed) are given as below.

1) $S[t + 1] = S[t] + S_{in}[t] - S_{out}[t] - \frac{\beta_1 \times r[t] \times l[t] \times S[t]}{N[t]} - \frac{\beta_2 \times r[t] \times E[t] \times S[t]}{N[t]}$

2) $E[t + 1] = E[t] + E_{in}[t] - E_{out}[t] - \frac{\beta_1 \times r[t] \times l[t] \times S[t]}{N[t]} + \frac{\beta_2 \times r[t] \times E[t] \times S[t]}{N[t]} - \sigma \times E[t]$

3) $I[t + 1] = \sigma \times E[t] + I[t] - Y[t]$

4) $R[t + 1] = \gamma[t] + R[t]$

5) $S_{in}[t] = In[t] \times (1 - P_{out}[t])$

6) $S_{out}[t] = Out[t] \times (1 - P_{out}[t])$

7) $E_{in}[t] = In[t] \times P_{out}[t]$

8) $E_{out}[t] = Out[t] \times P_{out}[t]$

Where,

$S[t]$ = Number of susceptible people in India

$S_{in/out}[t]$ = Inflow / outflow of susceptible people based on migration index

$\beta_1$ = Rate of transmission from susceptible to infected, 1.5 - 4.5

$\beta_2$ = Rate of transmission from infected to imposed

$r[t]$ = Number of contacts per person per day

Before March 9, $r = 16$, after March 20, $r = 6$, and after March 23, $r = 1$

$N[t]$ = The total population of India, 133.92 crores

$E[t]$ = The number of exposed people initially

$E_{in/out}$ = The number of inflowing/outflowing exposed people

$\sigma$ = The incubation rate (2-14 days)

$I[t]$ = The number of infected people initially a total of 15 people get affected up till 3rd March

$R[t]$ = The number of recovery or death

$P_{out}[t]$ = The probability of the outflowing exposed people

$\gamma$ = The probability of recovery or death
## Annexure-II

Data on Confirmed Cases of COVID-19 for India, used in the SEIR Model

| Date    | Infected $I_t$ | Death | Susceptible $S_t$ | Incubation Rate | $r_t$ | Exposed $E_t$ |
|---------|----------------|-------|-------------------|----------------|-------|--------------|
| 31-Jan  | 1              | 0     | 49                | 14             | 12    | 8000         |
| 02-Feb  | 2              | 1     | 1200              | 14             | 11    | 16000        |
| 03-Feb  | 3              | 0     | 1741              | 14             | 12    | 20000        |
| 02-Mar  | 5              | 1     | 900               | 14             | 12    | 19500        |
| 03-Mar  | 6              | 0     | 1021              | 14             | 10    | 18500        |
| 04-Mar  | 28             | 0     | 200               | 14             | 10    | 20000        |
| 05-Mar  | 30             | 4     | 321               | 14             | 8     | 42000        |
| 06-Mar  | 31             | 0     | 420               | 14             | 8     | 48000        |
| 07-Mar  | 34             | 7     | 120               | 14             | 8     | 16000        |
| 08-Mar  | 39             | 0     | 280               | 14             | 8     | 10000        |
| 09-Mar  | 44             | 1     | 358               | 14             | 8     | 12000        |
| 10-Mar  | 50             | 2     | 850               | 14             | 8     | 6000         |
| 11-Mar  | 60             | 0     | 650               | 14             | 4     | 7200         |
| 12-Mar  | 73             | 3     | 120               | 14             | 4     | 1200         |
| 13-Mar  | 81             | 2     | 110               | 14             | 4     | 3000         |
| 14-Mar  | 97             | 0     | 180               | 14             | 4     | 2000         |
| 15-Mar  | 107            | 6     | 426               | 14             | 3     | 1000         |
| 16-Mar  | 118            | 13    | 550               | 14             | 3     | 1200         |
| 17-Mar  | 137            | 3     | 80                | 14             | 3     | 1200         |
| 18-Mar  | 151            | 0     | 80                | 14             | 3     | 1520         |
| 19-Mar  | 173            | 0     | 180               | 14             | 3     | 1010         |
| 20-Mar  | 223            | 0     | 177               | 14             | 3     | 880          |
| 21-Mar  | 283            | 0     | 142               | 14             | 3     | 652          |
| 22-Mar  | 360            | 3     | 152               | 14             | 3     | 750          |
| 23-Mar  | 434            | 0     | 162               | 14             | 3     | 850          |
| 24-Mar  | 519            | 1     | 330               | 14             | 3     | 925          |
| 25-Mar  | 606            | 2     | 520               | 14             | 3     | 555          |
| 26-Mar  | 694            | 0     | 410               | 14             | 3     | 625          |
| 27-Mar  | 834            | 0     | 456               | 14             | 3     | 555          |
| 28-Mar  | 918            | 1     | 520               | 14             | 3     | 80           |
| 29-Mar  | 1024           | 2     | 440               | 14             | 3     | 20           |
| 30-Mar  | 1251           | 3     | 450               | 14             | 3     | 15           |
| 31-Mar  | 1397           | 1     | 149               | 14             | 3     | 12           |
| 01-Apr  | 1834           | 1     | 142               | 14             | 3     | 8            |
| 02-Apr  | 2069           | 1     | 120               | 14             | 3     | 8            |
Annexure III

Raw data for Statistical Models, used in models. Wherever cases reported are zero, that data point is not considered.

| Date  | Srinagar | Kasaragod | Mumbai | New York |
|-------|----------|-----------|--------|----------|
|       | Temperature (°C) | Relative humidity (%) | COVID Cases | Temperature (°C) | Relative humidity (%) | COVID Cases | Temperature (°C) | Relative humidity (%) | COVID Cases |
| 01-Mar | NU | NU | NU | NU | NU | NU | 4.5 | 36.5 | 1 |
| 02-Mar | NU | NU | NU | NU | NU | NU | 9.5 | 49.5 | 1 |
| 03-Mar | NU | NU | NU | NU | NU | NU | 12.0 | 73.0 | 2 |
| 04-Mar | NU | NU | NU | NU | NU | NU | 10.5 | 36.0 | 11 |
| 05-Mar | NU | NU | NU | NU | NU | NU | 7.5 | 38.0 | 22 |
| 06-Mar | NU | NU | NU | NU | NU | NU | 5.0 | 80.5 | 44 |
| 07-Mar | NU | NU | NU | NU | NU | NU | 8.5 | 27.0 | 89 |
| 08-Mar | NU | NU | NU | NU | NU | NU | 5.5 | 33.0 | 105 |
| 09-Mar | NU | NU | NU | NU | NU | NU | 15.0 | 27.0 | 142 |
| 10-Mar | NU | NU | NU | NU | NU | NU | 15.0 | 49.5 | 173 |
| 11-Mar | NU | NU | NU | NU | NU | NU | 9.5 | 41.0 | 216 |
| 12-Mar | NU | NU | NU | NU | NU | NU | 8.0 | 66.5 | 325 |
| Date   | Column 1 | Column 2 | Column 3 | Column 4 | Column 5 | Column 6 | Column 7 | Column 8 | Column 9 | Column 10 | Column 11 |
|--------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|
| 13-Mar | NU       | NU       | NU       | NU       | NU       | NU       | NU       | NU       | 15.5     | 78.0      | 421       |
| 14-Mar | NU       | NU       | NU       | NU       | NU       | 25.5     | 46.5     | 1        | 9.5      | 33.5      | 613       |
| 15-Mar | NU       | NU       | NU       | NU       | NU       | 26.0     | 71.5     | 3        | 9.0      | 35.0      | 729       |
| 16-Mar | NU       | NU       | NU       | NU       | NU       | 28.0     | 69.5     | 1        | 4.0      | 41.5      | 950       |
| 17-Mar | NU       | NU       | NU       | NU       | NU       | 27.0     | 81.5     | 2        | 9.0      | 79.0      | 1374      |
| 18-Mar | NU       | NU       | NU       | NU       | NU       | 27.0     | 81.5     | 2        | 9.0      | 79.0      | 1374      |
| 19-Mar | NU       | NU       | NU       | 30.0     | 66.0     | 1        | 27.0     | 63.5     | 3        | 8.5       | 84.5      | 5711      |
| 20-Mar | NU       | NU       | NU       | 30.5     | 62.0     | 6        | 27.0     | 78.0     | 1        | 16.5      | 79.5      | 8402      |
| 21-Mar | NU       | NU       | NU       | 30.0     | 57.0     | 6        | 26.5     | 75.5     | 8        | 8.5       | 36.5      | 10356     |
| 22-Mar | NU       | NU       | NU       | 29.0     | 62.0     | 5        | 26.5     | 85.5     | 6        | 4.0       | 34.5      | 15168     |
| 23-Mar | NU       | NU       | NU       | 30.0     | 62.0     | 19       | 28.0     | 84.5     | 13       | 3.0       | 89.5      | 20875     |
| 24-Mar | 10.5     | 83.5     | 1        | 31.0     | 61.0     | 6        | 27.5     | 80.5     | 5        | 7.5       | 58.0      | 25665     |
| 25-Mar | 10.0     | 79.0     | 2        | NU       | NU       | NU       | NU       | NU       | NU       | 6.0       | 74.0      | 30811     |
| 26-Mar | 10.5     | 65.0     | 5        | 31.0     | 58.0     | 3        | 28.5     | 86.5     | 1        | 7.0       | 48.0      | 37258     |
| 27-Mar | 7.5      | 90.0     | 8        | 26.5     | 84.0     | 34       | 28.0     | 83.5     | 3        | 15.0      | 43.0      | 44635     |
| 28-Mar | 7.5      | 79.5     | 5        | 30.5     | 70.0     | 1        | 28.0     | 64.0     | 4        | 8.5       | 70.0      | 52318     |
| Date     | Column 1 | Column 2 | Column 3 | Column 4 | Column 5 | Column 6 | Column 7 | Column 8 | Column 9 | Column 10 | Column 11 |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|
| 29-Mar   | 13.0     | 53.5     | 2        | 31.0     | 66.0     | 7        | 28       | 74.5     | 8        | 7.0       | 94.0      | 59513     |
| 30-Mar   | NU       | NU       | NU       | 31.5     | 62.0     | 17       | 27.5     | 78.5     | 5        | 8.5       | 79.0      | 66497     |
| 31-Mar   | NU       | NU       | NU       | 31.0     | 66.0     | 2        | 28       | 82.5     | 30       | 7.0       | 69.5      | 75795     |
| 01-Apr   | NU       | NU       | NU       | 31.5     | 67.0     | 12       | 29       | 74       | 54       | 8.0       | 44.5      | 83712     |
| 02-Apr   | NU       | NU       | NU       | 30.3     | 64.8     | 8        | NU       | NU       | NU       | 1.5       | 50        | 92381     |
| 03-Apr   | NU       | NU       | NU       | 30.3     | 64.8     | 7        | NU       | NU       | NU       | NU        | NU        | 92381     |

*NU: Not Used in models, due to zero cases or unavailability of data*
