Probabilistic Assessment of the Interaction between Weather, COVID-19 and Exchange rate of Mumbai City in India using Archimedean Copulas

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Abstract

Coronavirus disease 2019 (COVID-19) pandemic has caused an unprecedented health crisis across the world. When there is no specific solution available to tackle the pandemic, there is an urgency to know the pertinent factors like weather and its interaction with the number of daily cases and impact on the economy. The purpose of this investigation is to determine the probabilistic assessment of mean temperature and relative humidity on the number of COVID-19 infected cases and its effect on the Indian Rupees (INR) exchange rate against US dollar for the city of Mumbai. The bivariate Archimedean copulas were applied to assess the conditional probability of the number of cases given mean daily temperature and relative humidity and also the conditional probability of INR exchange rate given the number of daily new cases. Though the number of cases and mean temperature are positively correlated, but the maximum probability of occurrence is just about 20% for Tmean < = 30ºC, 35ºC in the interval of 101–200 cases. The pattern of the likelihood of occurrence of the number of COVID-19 cases to the mean relative humidity is similar to that of the mean daily temperature except for RHmean < = 45% when the probability is almost negligible while moving from one interval to another of the number of cases. The maximum probability of occurrence is about 20% for RHmean < = 75% in the interval of 101–200 cases. Our results also reveal that the probability of occurrence of the Indian rupee depreciating to INR 76–77 range remained high, irrespective of the number of cases. A note of caution is that these conditional probability figures are not the absolute probable of occurrence, rather a percentage change of the conditional probability while moving from lower end to higher end values for a given interval.

1. Introduction

The novel coronavirus 2019 disease (COVID-19), which was caused by severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) was reported on 12 December 2019 (Wu et al., 2020; Zhou et al., 2020) originating in the seafood and wet animal whole sale market in the capital city of Wuhan, Hubei province in the central part of China (Zhu et al., 2020). COVID-19 pandemic has created havoc and many lives are being lost worldwide. It has also taken a toll on world economy across different sectors creating unemployment problems leading to the announcement of economic- stimulus packages by the governments like the US government's US$ 2 trillion stimulus package (Tollefson, 2020) etc. It is also reported in media that many countries' debts might reach the world war-2 levels.

The contagious nature of this pandemic indicates that we may have to learn how to live with it for a considerable amount of time (Shi et al., 2020). In just little over a century, this pandemic has led to an unprecedented crisis and is changing the way we behave in public space in terms of isolating ourselves and social distancing to delay the surging of number of cases in the absence of vaccines (West et al., 2020). It has also caused interruptions on global supply chains (Guan et al., 2020). For a long time to come post COVID-19 will bring a lot of changes, particularly, the way we acquire knowledge at the institutes of higher learning (Wigginton et al., 2020; Witze, 2020) apart from schools; not just because of social distancing norms, but due to financial implications as well. However, stringent government lockdowns have not just slowed down the COVID-19 outbreak but also brought down pollution levels in cities (Berman and Ebisu, 2020 ; Chen et al., 2020; Dantas et al., 2020; Mahato et al., 2020) and vehicular accidental deaths (Chen et al., 2020).

Recent reports are available on the impact of climatic variables, especially mean temperature, and mean relative humidity on the number of COVID-19 cases or how they are attributable to the rise or fall in the number of new daily cases (Iqbal et al., 2020; Ma et al., 2020; Xie and Zhu, 2020). For example, Wu et al. (2020) used Generalized Additive Model (GAM) to study the effect of temperature on the number of COVID-19 cases for 166 countries (barring China) and reported that with the increase in temperature, the number of COVID-19 cases decreases. In the same study, the number of daily new cases reduced slightly with the increase in relative humidity. However, by using the same method, Xie and Zhu (2020) reported that, for 122 Chinese cities contrasting results are obtained showing with the increase in temperature the number of COVID-19 cases also increases(with a threshold limit of 3ºC). In another study, Iqbal et al. (2020) used wavelet coherence for the city of Wuhan, China and showed that mean temperature and mean relative humidity did not have influence on the number of COVID-19 cases. The study also reported on the limited impact of COVID-19 on the exchange rate of Chinese Yuan against US dollar.

India has also been hit hard due to the pandemic. Mumbai is known as the financial and commercial capital of India with a population of over 20 million and also home to one of the largest slums in Asia. However, probabilistic assessment of climatic variables on the number of COVID-19 cases and its impact on the economy in terms of the currency exchange rate is yet to be reported using copula. The most prominent advantage of copula is that it could be used to model joint distribution of two or more random variables, irrespective of the cumulative distribution functions of the variables under consideration (Genest and Favre, 2007; Nelsen, 2006).

The aim of this paper is to carry out probabilistic assessment of mean temperature and relative humidity on the number of COVID-19 cases and its effect on the Indian Rupees (INR) exchange rate against the US dollar.

2. Data

The state level daily data on the number of COVID-19 infected cases ($N_{COVID-19}$) for India is available by the Ministry of Health and Family Welfare, Government of India. Though some states report infection cases in their districts, city wise data is difficult to acquire. Therefore, $N_{COVID-19}$ data for the city of Mumbai, India (Fig. 1) was collected from different sources available online for the period 26th March, 2020 to 25th April, 2020 (Fig. 2). This time period was selected since India was placed under one of the most stringent lockdowns to contain the spread

of COVID-19. The lockdown was relaxed to certain extent beyond 4th May 2020 in certain sectors with many sectors still closed. Mean daily temperature, Tmean (^{0}C) and mean daily relative humidity (%) (RHmean) for the city of Mumbai were obtained from online source (https://www.timeanddate.com/weather/india/mumbai) for the same period. The Indian Rupee (INR) exchange rate (EXR) against US dollar was available at https://www.xe.com

3. Methods

3.1 Bivariate copula dependence modeling

Let $X$and Y be the continuous random variables. Then, according to Sklar's (1959) theorem, the joint probability distribution function $H_{X,\,Y}(x,y)$ is connected to copula $C\colon[0,1]^2 \to [0,1]$ in the following way:

$$H_{X,\,Y}(x,y) = F_{X,\,Y}(x,y) = C\left[F_X(x),\,F_Y(y)\right] = C(u,v),\,x,y \in R$$

1

where $F_X(x) and F_Y(y)$ are the marginal distributions of $X$and Y, respectively.

The joint probability distribution function could be used to derive conditional probability of a continuous random variable given a non-exceedance magnitude of another continuous random variable. For example, the probability function of Uconditioned on $V \le v$ is given by (Zhang and Singh, 2006):

$$C_{U|\,V\le v} = C(U \le u|\,V \le v) = \frac{C(u,v)}{v}$$

2

Continuous conditional probabilities using copula were also used to determine the fatalities due to heatwaves in India given summer mean temperature in a study by (Mazdiyasni et al., 2017). In this study, one parameter bivariate Archimedean copulas were applied to study the non-exceedance probability of the number of COVID-19 cases ($N_{Covid-19}$) for given daily mean temperature (Tmean) and daily relative humidity (RHmean). Also, the non-exceedance probability of Indian Rupees (INR) exchange rate (EXR) against US dollar for given $N_{Covid-19}$ was also determined.

Archimedean copulas are known to be flexible and easy to construct, making them being widely used in different fields. Archimedean copulas could be expressed as:

$$C(u,v) = \varnothing^{[-1]}[\varnothing(u) + \varnothing(v)],\,u,v\epsilon[0,1]$$

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where $\varnothing(\bullet)$ is a generator function of the copula and {\varnothing }^{\left[-1\right]}\left({\bullet }\right) is the pseudo-inverse of \varnothing \left({\bullet }\right). In this work, Clayton, Frank, and Gumbel-Hougaard copulas were used. These three families of copula are the most widely applied in different areas of research and are well established copula functions (Genest and Favre, 2007; Nelsen, 2006; Zhang and Singh, 2006).

In brief, the analysis involves the following steps:

1. Selection of two random variables. For example, $N_{COVID-19}$ and T_{mean} are required for assessing the probability of $N_{COVID-19}$ conditioned on T_{mean}.
2. Determination of the significant dependence measure using Spearman's rho for the two selected variables.
3. Determination of the dependence using Kendall's tau.
4. Determination of the copula parameter using the obtained Kendall's tau for all families of Archimedean copulas.
5. Obtaining the generating function of each Archimedean copula family.
6. Obtaining the copula from the generating function.
7. Obtaining the best fit copula based on Akaike Information Criterion (AIC), the lowest being the best.
8. Fitting different parametric univariate (marginal) distributions to each of the selected random variables. In this study, the parametric distributions, namely, Extreme value, gamma, normal, lognormal, and Weibull are fitted to each random variable. The best fit marginal distribution for each variable is obtained using Kolmogorov–Smirnov (KS) goodness of fit test and AIC values.
9. The best fit marginal distributions and the best fit copula are applied to derive conditional probability distribution of a random variable over the other.

4. Results And Discussion

The summary statistics of the weather variables, EXR and COVID-19 cases are listed in Table 1. The mean daily temperature of Mumbai ranged between 28.5ºC and 33ºC. It is an indication that the average daily temperature does not fluctuate much during a given day in the city of Mumbai during the study. Hence, the temperature measurements are close to the mean as indicated by low standard deviation value of 0.975ºC. The relative humidity on the other hand varies between 45.5% and 75.5% indicating a wide spread (standard deviation = 7.371%) of individual data from mean at 65.581%. The INR exchange rate against US dollar was observed to be not varying much due to COVID-19 cases. However, there is a very wide deviation (standard deviation = 156) of the number of cases from the mean at about 167. It may be mentioned here that the number of cases $N_{COVID-19}$ varies between 1 at minimum and 602 at maximum.

Table 1
Summary statistics of weather parameters, exchange rate and number of COVID-19 cases in Mumbai city (26 March – 25 April 2020)

Parameter	Mean	Standard deviation	Minimum	Maximum	Skewness	Kurtosis
T_{mean} (ºC)	30.5	0.975	28.5	33	0.029	0.685
RH_{mean} (%)	65.581	7.371	45.5	75.5	-1.345	1.61
EXR(INR)	76.117	0.516	74.89	77.01	-1.081	0.467
$N_{COVID-19}$	167.097	155.652	1	602	1.334	1.349

The dependence between any two variables may be assessed by using Spearman's rho (ρ) rank-based correlation at a particular significant level. The Spearman's ρ between $N_{Covid-19}$ and T_{mean} is 0.47 (Kendall's tau = 0.3), whereas the Spearman's ρ between $N_{Covid-19}$ and RH_{mean} is 0.45 (Kendall's tau = 0.32). For $N_{Covid-19}$ and EXR the Spearman's ρ is 0.50 (Kendall's tau = 0.36). All calculations were carried out at 5% level of significance. The scale-free ranked based Spearman's ρ correlations among the considered variables were found to have strong, non-linear correlations. Such correlations suggest applicability of copula dependence modeling.

From Fig. 3 (a), as mean temperature increases (positive anomaly) during the first three days (26–29 March, 2020), the number of COVID-19 cases decreases (negative anomaly). However, there is a direct relationship beyond March 29 until April 9, except on April 3 when temperature was at zero anomaly. Also, the number of cases seemed to be not much affected by the increase or decrease in temperature as evidenced by few crests and troughs like shapes. The dynamic relationship between humidity and the number of COVID-19 cases seemed to be different from that of between previous variables. When the humidity increases (positive anomaly) the number of cases decreases (negative anomaly) from April 4 through April 9 and the same trend could be noticed between April 8 through April 21. The relationship is apparently positive during other days of the study period.

In Fig. 3(b), the number of cases seemed to have negative influence (depreciation) on INR exchange rate against US dollar. There is an inverse relation between the two variables between April 1 and April 6. However, there is a strong direct relationship between March 26 and March 31 and also between April 18 and April 22.

4.1 Identification of parametric marginal distribution for copula modeling

The cumulative distribution function (CDF) plots are depicted in Figs. 4 and 5 and their performance metrics are shown (Table 2). The Extreme Value distribution fitted to the number of cases is the best performing CDF with the least value of AIC (– 278.38) and KS-test value (0.2284) (p-value = 0.07). The mean daily temperature is best represented by normal distribution with the least AIC (-281.08) and KS-test

(0.1452) (p-value = 0.49), whereas Gamma distribution fits relative humidity the best with a minimum AIC at -277.45 and KS-test at 0.1888 (p-value = 0.19). As per the p-value at 0.49, it is not significant at 10% level, therefore the performance is based on minimum AIC value as reported by Reddy and Ganguli (2012) and Uttarwar et al. (2020). The best fit CDF for INR exchange rate is lognormal distribution with a minimum AIC at -195.18 and KS-test at 0.1902 (p-value = 0.19).

Table 2
Performance metric of different marginal distributions fitted to the number of COVID-19 cases, weather parameters and exchange rate

Parameter	Marginal distribution	KS-test	AIC
$N_{COVID-19}$	Weibull	0.0788 (0.98)	-271.83
	Gamma	0.0929 (0.92)	-257.72
	Normal	0.1539 (0.41)	-258.73
	Extreme value	**0.2284** (0.07)	**-278.38**
T_{mean} (ºC)	Weibull	0.1616 (0.35)	-271.4
	Gamma	0.1493 (0.45)	-274.09
	Normal	**0.1452** (0.49)	**-281.08**
	Lognormal	0.1513 (0.43)	-275.32
RH_{mean} (%)	Weibull	0.1532 (0.42)	-216.1
	Gamma	**0.1888** (0.19)	**-277.45**
	Normal	0.1731 (0.28)	-261.76
	Extreme value	0.1441 (0.50)	-210.94
EXR (INR/US dollar)	Weibull	0.1345 (0.58)	-181.01
	Lognormal	**0.1902** (0.19)	**-195.18**
	Normal	0.1893 (0.19)	-194.95
	Extreme value	0.1335 (0.59)	-181.10

All bold figures indicate best marginal fit values and the figures in braces denote p-values.

4.2. Performance metric of bivariate copulas

The performance metrics of Archimedean families of bivariate copulas are listed in Table 3. The Frank copula for $N_{COVID-19}$ - T_{mean} pair is the best performing copula with the least AIC value at – 62.51, whereas $N_{COVID-19}$ - RH_{mean} pair is best represented by Gumbel-Hougaard copula with the minimum AIC value of -80.12. The Gumbel-Hougaard copula with an AIC of -70.1 is the best performing copula for EXR - $N_{COVID-19}$ pair.

Table 3
Performance metric of different bivariate combination of weather parameters, EXR and COVID-19

Bivariate parameters	AIC		
	Clayton	Frank	Gumbel-Hougaard
$N_{COVID-19}$ - T_{mean}	– 60.16	**– 62.51**	– 61.27
$N_{COVID-19}$ - RH_{mean}	– 77.58	– 79.27	**– 80.12**
EXR - $N_{COVID-19}$	– 69.49	– 68.91	**– 70.1**

Figures in bold indicate the best copulas for each pair of combination of the variables.

4.3. Copula-based Bivariate Conditional Distributions

4.3.1. Effect of mean daily temperature on the number of COVID-19 cases

A plot of Frank-based conditional probability distribution of the number of COVID-19 cases given the mean daily temperature of Mumbai city is shown in Fig. 6(a). For a given mean daily temperature, the probability of occurrence of the number of COVID-19 cases falling in a specific range increases with increase in the number of cases up to a certain threshold and then decreases beyond the threshold with an exception of Tmean < = 25ºC. For example, at Tmean < = 25ºC, the probability of occurrence of the number of COVID-19 cases falling in the range 1- 100 is 17.15%. Then it further decreases to 15.88% in the range 101–200 cases; however, there is a decrease by almost half to 8.57% in the range 201–300 cases. Similarly, in the range 301–400 cases, the decrease is at 4.58%. Beyond this, the chance of occurrence falls to 1.3% in the range 401–500 cases. For 501–600 case range there exists a negligible figure (0.19%).

With further increase in mean daily temperature to Tmean < = 30ºC, the likelihood of occurrence of COVID-19 cases in the lower range of 1- 100 cases is 17.73%. It increases to 19.46% in the range of 101–200 cases and reduces to 12.15% in the range of 201–300 cases. The likelihood of occurrence reduces further to 7.09% in the range of 301–400 cases. In the range of 401–500 cases, the likelihood of occurrence reduces slightly by more than half at 2.1%. After which, a negligible chance of occurrence (0.32%) is observed in the range of 501–600 cases.

At Tmean < = 35ºC, the probability of occurrence of the number of cases falling in the range of 1- 100 cases is 13.02% which increases to 19.52% in the range of 101–200 cases. The chance of occurrence reduces slightly to 18.77% in the range of 201–300 cases. In a similar manner, it decreases to 17.29%

while transitioning to 301–400 cases. In the range of 401–500 cases, the likelihood of occurrence drops to about half (7.19%), which further dropped to 1.24% in the range of 501–600 cases.

The results showed that with the increase in the mean daily temperature, the probability of occurrence of the number of COVID-19 cases falling in a particular range remains almost the same with slight variations for some of the ranges. Though a similar pattern is observed for all possible mean daily temperature, a slightly higher probability of occurrence of the number of COVID-19 cases at Tmean < = 30ºC, 35ºC is observed for cases falling in the range 101–200 as compared to Tmean < = 25 ºC. Therefore, one might have to pay more attention with the increase in temperature. Even with increase in temperature, the probability of occurrence is just about 1/5. These findings corroborate the results reported by Iqbal et al. (2020). However, Wu et al. (2020) showed that with the increase in temperature, there is a reduction in new cases. It might be due to the ability of the generalized additive model (GAM), which could include more variables than the bivariate copula. However, the study by Xie and Zhu (2020) showed positive relationship between the mean temperature and number of cases using the same method. Also, the main disadvantage of GAM is its additivity nature (Ravindra et al., 2019).

4.3.2. Effect of mean daily relative humidity on the number of COVID-19 cases

Gumble-Hougaard based conditional distribution curves are shown in Fig. 6(b). For a given mean daily relative humidity, the probability of occurrence of the number of COVID-19 cases varies differently. For example, at RHmean < = 45%, the chance of occurrence of the number of COVID-19 cases falling in all the intervals is almost zero as could be observed by a horizontal curve showing no changes while moving from one interval to another.

With the increase in the mean daily relative humidity at RHmean < = 60%, the likelihood of occurrence of the number of cases is 14.69% for the interval 1-100 cases, and it remains almost constant at 14.1% for the next range of 101–200. It decreases to 8.85% in the range of 201–300 cases. It is further observed that, the likelihood of occurrence reduces to 5.87% for higher range of 301–400 cases. As the number of cases ranges from 401–500, the likelihood of occurrence reduces to 1.99%, and then it falls to as low as 0.32% in the next range of 501–600 cases.

A similar pattern is observed while comparing Tmean < = 35ºC for with all the intervals of COVID-19 cases when RHmean < = 75%. The highest likelihood of occurrence is observed at 19.63% for cases 101–200 and the lowest likelihood of occurrence being 1.11% for 501–600 cases.

These results revealed that the probability of occurrence of the number of COVID-19 cases responded to the mean relative humidity similarly as to the mean temperature except for RHmean < = 45% when the probability is almost zero while moving from one interval to another. Hence, no such drastic steps would be required to monitor the number of cases irrespective of the comfort level of weather. Our findings are in contrast to the results reported by Wu et al. (2020), which showed that with the increase in relative humidity, there was a reduction in new cases. The difference in the results could possibly be due to the higher number of variables employed in their model, leading to more interactions between them.

4.3.3. Effect of the number of COVID-19 cases on INR exchange rate

A bivariate Gumbel- Hougaard based conditional distribution curves for INR exchange rate vs US dollar on COVID-19 cases is depicted in Fig. 7. For a certain number of COVID-19 cases, the likelihood of occurrence of INR exchange rate falling within an interval decreases with increase in exchange rate except for $N_{COVID-19} <= 500$ cases. For instance, for a given $N_{COVID-19} <= 100$ cases, the likelihood that INR exchange rate in the interval INR 75–76 is 62.74%. It reduces to 33.05% when the exchange rate is in the interval INR 76–77. However, the probability of occurrence is 52.13% when the exchange rate is in the interval INR 75–76 when $N_{COVID-19} <= 300$. Then for the same number of cases, the likelihood of occurrence drops to 44.55% in the interval of INR 76–77. When the number of cases rises to $N_{COVID-19} <= 500$, the chance of occurrence of exchange rate falling in the interval INR 75–76 is 43.52% and it increases to 51.4% in the interval INR 76–77.

From the above analysis, the probability of occurrence of INR is highly sensitive for all the possible number of cases and intervals. The sensitivity of exchange rate is highest when the number of cases is $N_{COVID-19} <= 100$ in the interval of INR 75–76. The results indicate that the probability of occurrence of INR depreciating to INR 76–77 interval remains high irrespective of the number of cases. It implies that the number of cases beyond 500 may not impact INR depreciation to a great extent. It also means that the number of COVID-19 cases ($N_{COVID-19}$) impacting the economy in the city of Mumbai and the country peaked at 100, beyond which its effect remains almost the same. This study also revealed that India's export could be encouraged, as long as India is not dependent on imported crude oil and high-end technology. However, with cases going up, the negative impact may be limited as reported by Iqbal et al. (2020).

The present investigation does not necessarily reflect true picture of the outbreak of COVID-19 cases due to the fact that the pandemic is contingent on many factors. Copula being data-driven model certainly needs more data length and also more parameters. This study gives a snapshot of how non-linear variables interact with each other using dependence measure. The present work could be refined by including more variables, namely COVID-19 fatality, sunshine hours, etc. using vine copulas, which can model more than two variables.

5. Conclusions

The mean daily temperature and relative humidity of Mumbai city, India are positively correlated to the daily new number of COVID-19 infected cases in contrast to some of the studies reported in literature. Also, the number of cases and Indian currency exchange rate against US dollar are also positively correlated. The results indicate that when the average daily temperature increases, the probability of occurrence of the number of COVID-19 cases falling in a particular range remains almost the same with slight variations for some ranges. A similar pattern is observed for all possible mean daily temperature with a slightly higher chance of occurrence of the number of cases at Tmean < = 30ºC, 35ºC falling in the range 101–200 in comparison to Tmean < = 25 ºC. Hence, with the increase in temperature, one might have to pay more attention to infection rate, but the probability of infection is just about 20%. The pattern of the likelihood of occurrence of the number of COVID-19 cases given the mean relative humidity is similar to that of occurrence of the number of COVID-19 cases given the mean daily temperature except for RHmean < = 45% when the change is almost negligible while moving from one interval to another cases of infection. The results also reveal that, the probability of occurrence of INR depreciating to INR 76–77 range remains high, irrespective of the number of infected cases. It implies that the number of cases beyond 500 may not have adverse impact on INR depreciation. The percentage figures do not indicate the absolute probability of occurrence, but the percentage of change in conditional probability while transitioning from lower end to upper end values of an interval of infected people or INR.

Declarations

Data Statement

All the data links/sources are stated in data section.

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CRediT authorship contribution statement

Surajit Deb Barma: Conceptualization, Methodology, Investigation, Writing – Original Draft, Writing - Review & Editing. **Sameer Balaji Uttarwar**: Formal analysis, Writing - Review & Editing. **Amai Mahesha:** Supervision, Writing - Review & Editing.

Declaration of competing interest

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

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Figures

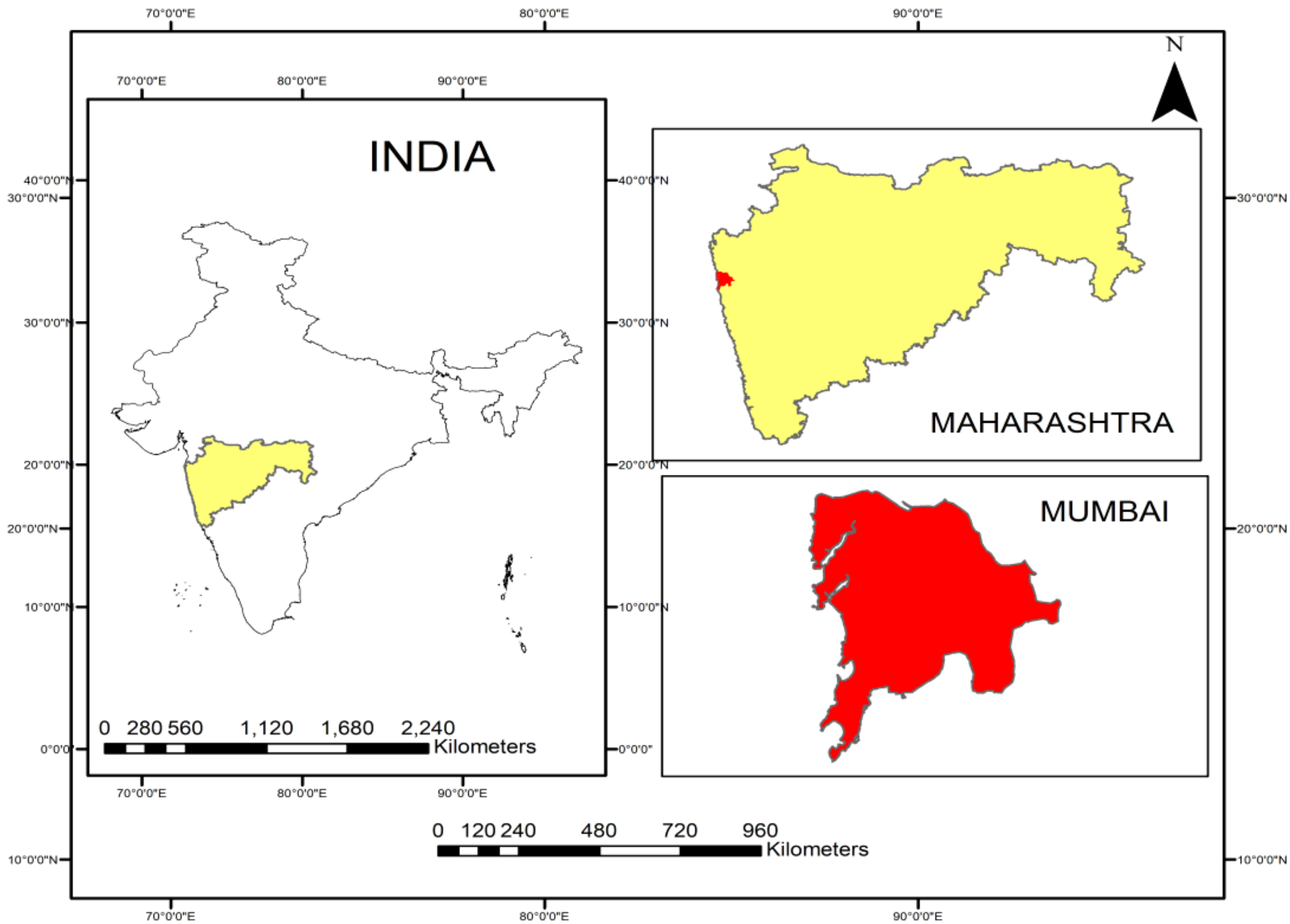

Figure 1

Map of Greater Mumbai, India

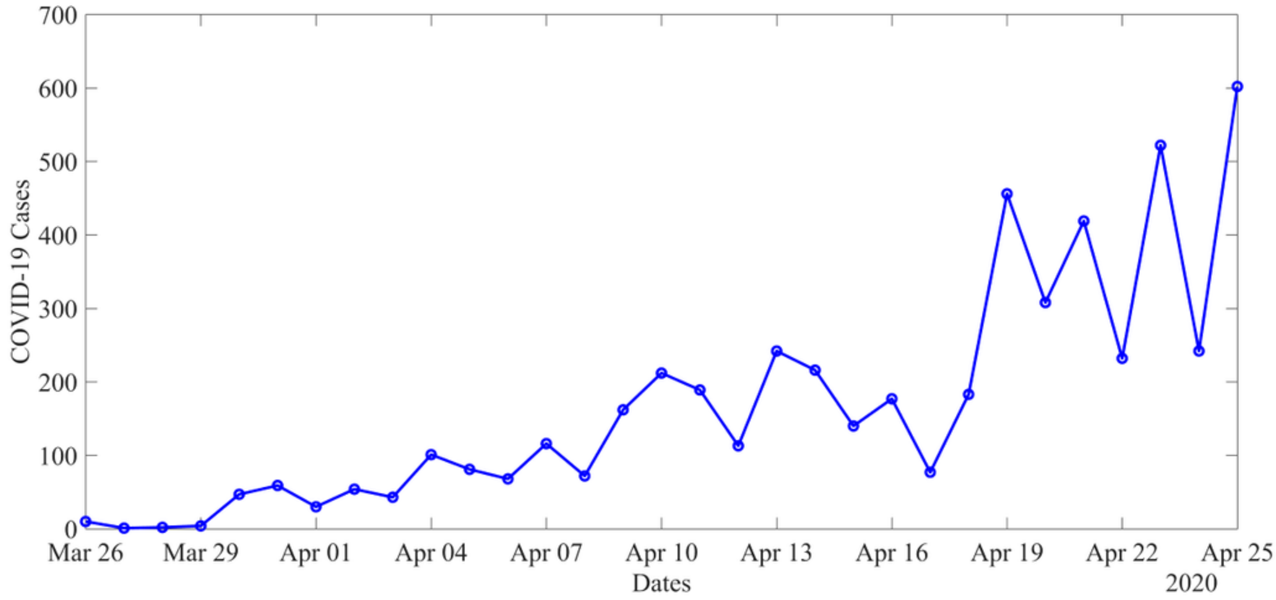

Figure 2

Daily new active COVID-19 cases

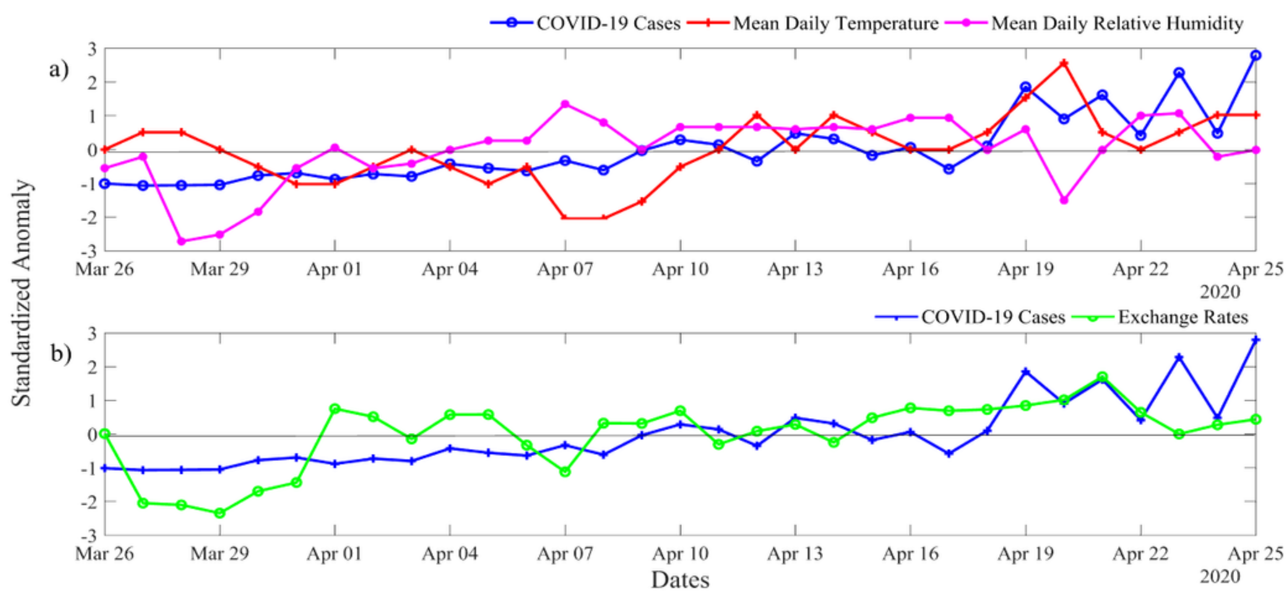

Figure 3

Standardized anomaly variation of COVID-19 cases with mean (a) daily temperature, relative humidity, and (b) INR EXR

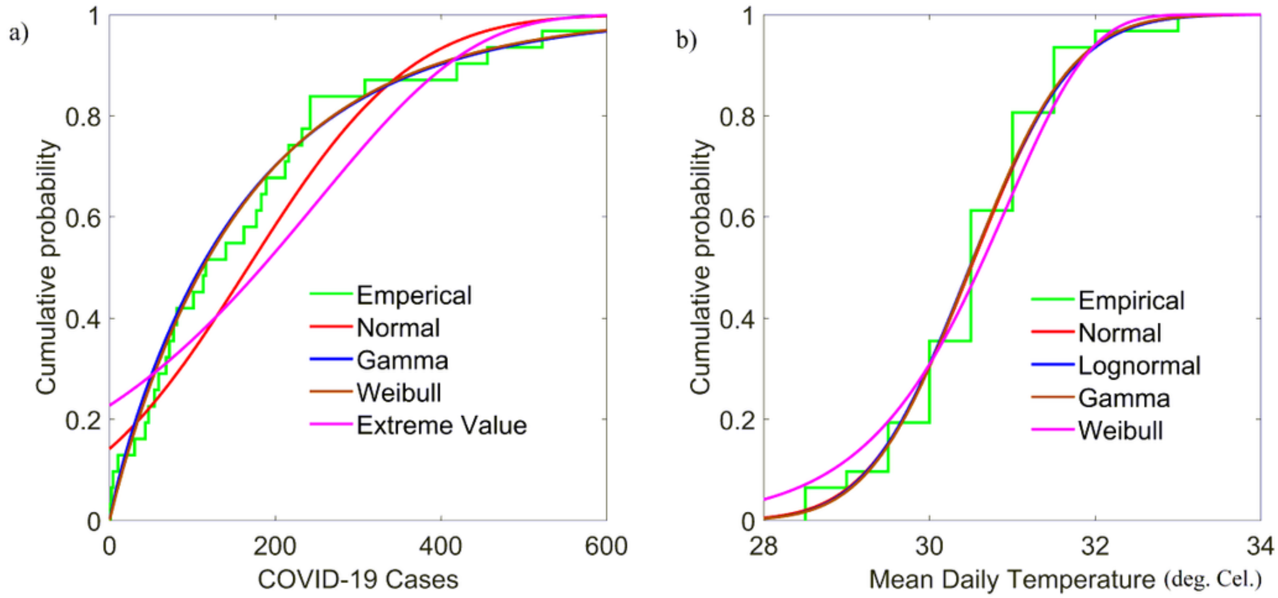

Figure 4

Cumulative distribution function plots of normal, lognormal, gamma, Weibull and Extreme Value distributions fitted to (a) COVID-19 cases and (b) mean daily temperature

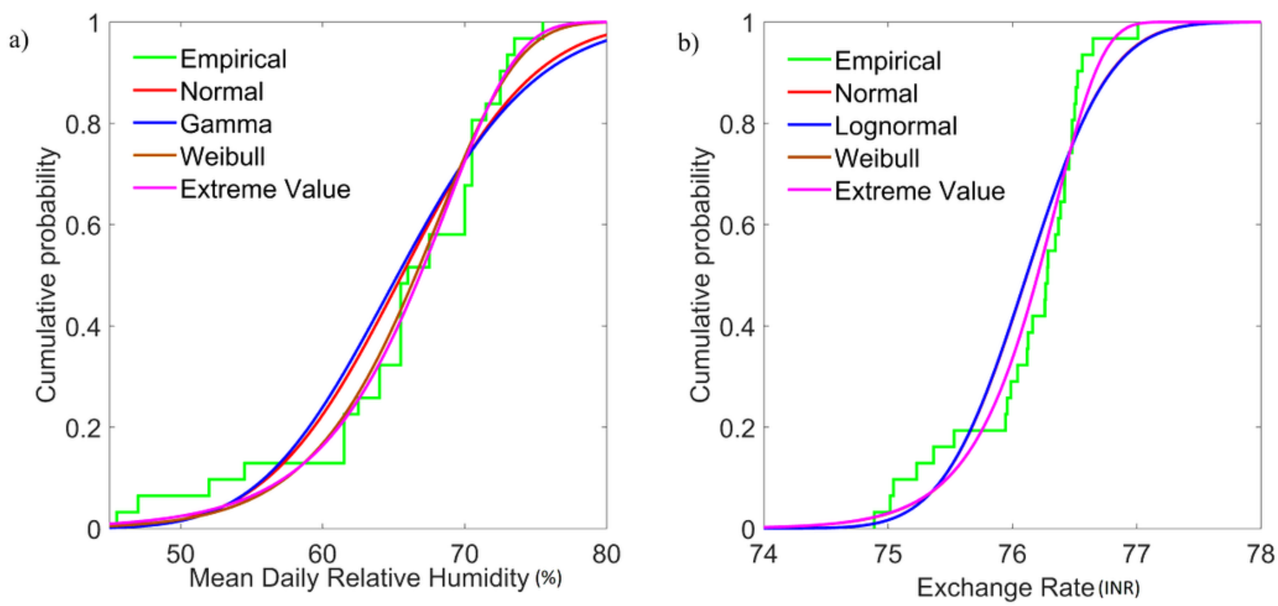

Figure 5

Cumulative distribution function plots of normal, lognormal, gamma, Weibull, and Extreme Value distributions fitted to (a) mean daily relative humidity and (b) INR EXR

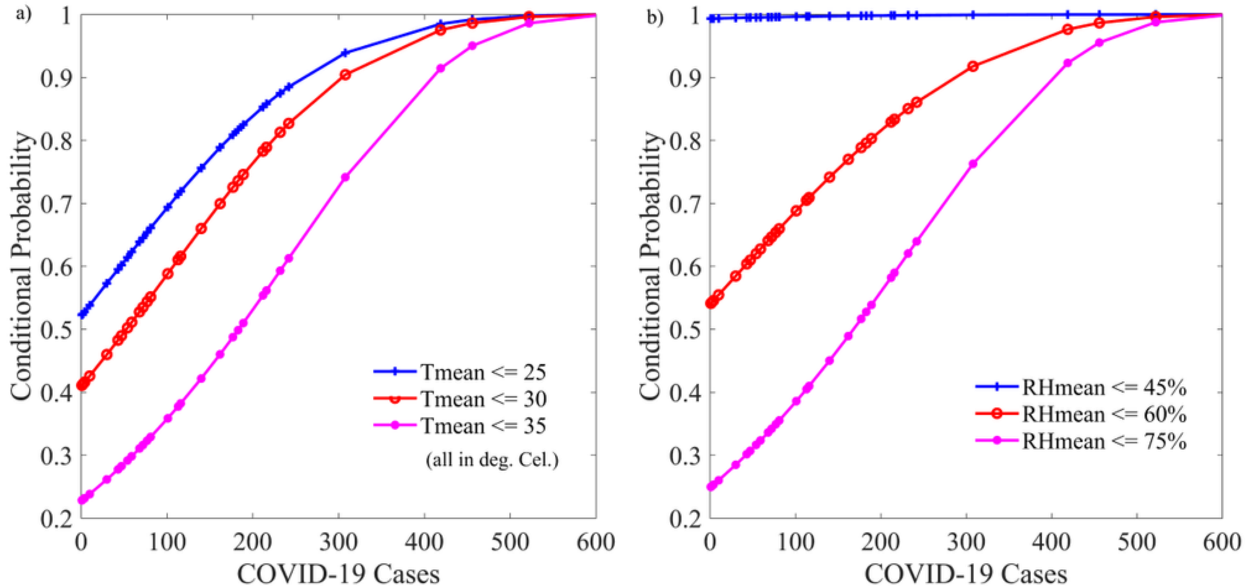

Figure 6

Conditional probability distribution of COVID-19 cases for given (a) mean temperature and (b) mean relative humidity

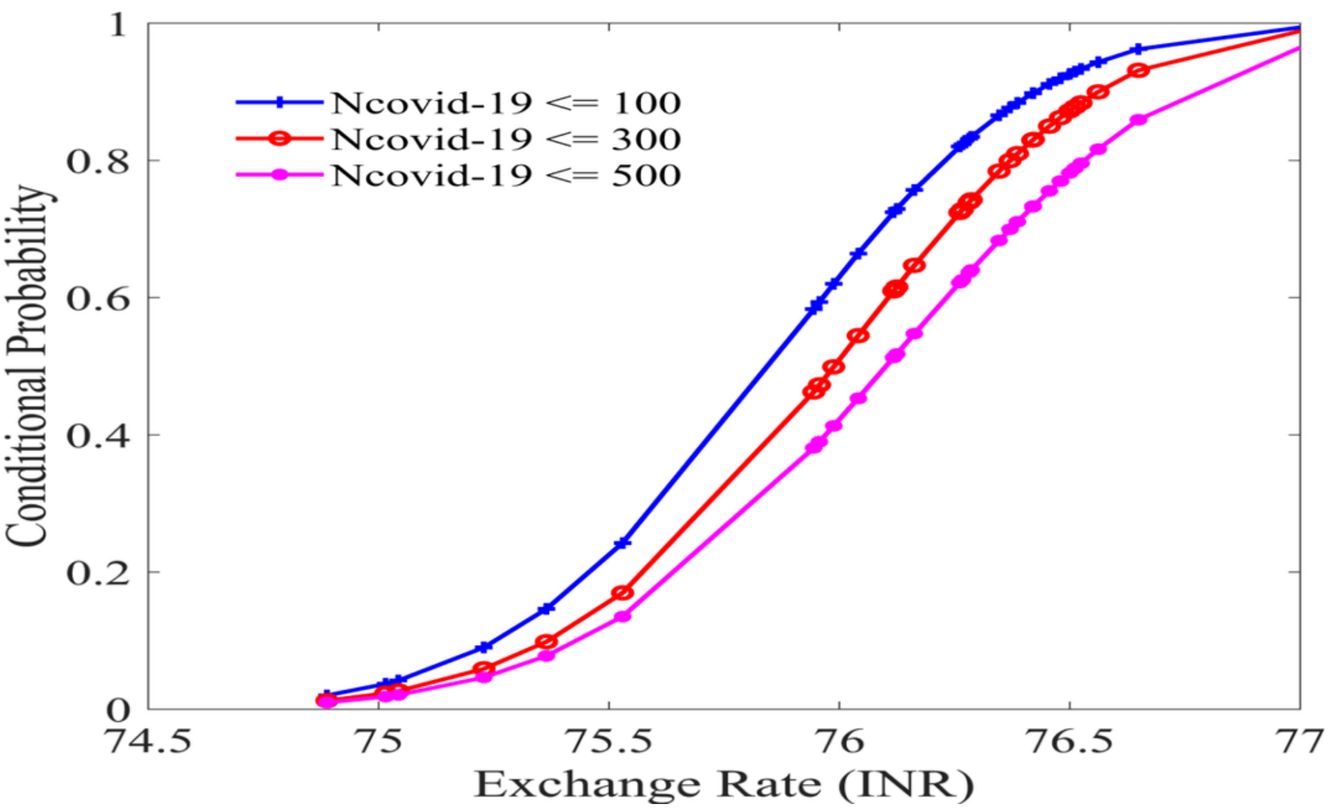

Figure 7

Conditional probability distribution of INR EXR for given COVID-19 cases