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MODELING AND FORECASTING NOVEL CORONA CASES IN INDIA USING TRUNCATED INFORMATION: A MATHEMATICAL APPROACH

Brijesh P. Singh

Associate Professor, Department of Statistics, Institute of Science, Banaras Hindu University, Varanasi-221005, India

ABSTRACT

Background: *Novel corona virus is declared as pandemic and India is struggling to control this from a massive attack of death and destruction, similar to the other countries like China, Europe, and the United States of America. The first case of novel corona is reported in India on January 30, 2020.*

Methods: *The growth in the initial phase is following exponential. In this study an attempt has been made to model the spread of novel corona infection. For this purpose logistic growth model with minor modification is used and the model is applied on truncated information on novel corona confirmed cases in India.*

Results: *The result is very exiting that till date predicted number of confirmed corona positive cases is very close to observed on. This provides the carrying capacity is about 20 lakh cases and time of point of inflexion is July 15th, 2020 with a maximum number of new cases on a day is about 15000. Also the various lockdowns plays important role to reduce the progression of corona positive cases significantly.*

Conclusions: *India is in the comfortable zone with a lower growth rate than other countries studied. Our mathematical model shows that, the epidemic is likely to stabilize with 20 lakh cases by the end of January, 2021. If several protective measures such as social distancing, lockdown will be taken effectively, then country will be successful to reduce the rate of this pandemic.*

KEYWORDS: *Novel Corona Virus, Growth Rate, Logistic Curve, Lockdown*

Article History

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INTRODUCTION: BACKGROUND

A novel corona virus responsible for epidemic, popularly known as COVID-19 is a new strain that has not been identified previously in humans. WHO declared COVID-19 a pandemic on March 11, 2020.[1] The virus that caused the incidence of Severe Acute Respiratory Syndrome (SARS) in 2002, in China; Middle East Respiratory Syndrome (MERS) in 2012, in Saudi Arabia, and the viruses that cause COVID-19 are genetically related to each other, but the diseases they caused are quite different[2]. These viruses, in general, are a family of viruses that target and affect mammal's respiratory systems. The SARS corona virus spread to humans via civet cats, while the MERS virus spread via dromedaries. In case of the novel corona virus, typically happens via contact with an infected animal, perhaps the common carriers are bats; initial reports from seafood market in central Wuhan, China.

Novel corona virus is spreading throughout the world at alarming speed. Worldwide, it has exploded to 1118684 cases and caused 58909 deaths by April 3, 2020[3]. Developed countries like Italy, Spain, France and United State of America etc. are struggling to overcome from the pressure created by novel corona virus. India, with a huge population of about 1.3 billion, amongst majority of the people are living in poor hygienic condition, and the medical facilities like number of doctors and hospitals are less in India as compared to developed countries, which indicates that the situation of India will become very critical, but comparatively better public health system and political control than the above developed countries. India reported 2545 cases of novel corona confirmed cases as of April 2, 2020, and out of which, 191 cases were reported recovered and 72 deaths occurred. The first case of novel corona was reported in India on January 30, 2020 when a student returned from Wuhan, China [4]. The Government of India was quick to launch various levels of travel advisories beginning from February 26, 2020, with restrictions on travel to China and non-essential travel restrictions to Singapore, South Korea, Iran and Italy.[5] The efforts to control by the Hon'ble Prime Minister Narendra Modi Ji through Janata Curfew (public curfew) on March 22, 2020, can be seen as the beginning of wide-scale public preventive measures. India has launched several social distancing measures and personal hygiene measures during the second week of March [6].

Since huge population of about 1.3 billion, thus India has chosen a flexible strategy of large-scale quarantine and limited testing, because of less number of testing kits and also the cost of testing is too much. The country is relying on the people power; thousands of health-care workers are working out across the country to trace and quarantine people, who might have had contact with those with novel corona. People are typically only tested, if they develop symptoms. Countries such as South Korea isolated infected people based on widespread testing, but some scientists say that India's mass surveillance approach could achieve a similar goal, and be relevant for other low and low-middle income countries facing kit shortages. Under the lockdown, people are allowed out for essentials, such as food and medical care, but in most states people under quarantine are closely monitored by social workers and cannot leave their homes in some places. If public health workers do not trace all infected individuals during the lockdown, India will need to continue its period of stringent physical distancing.

For the spread of novel corona virus, when disease dynamics are still unclear, mathematical modeling helps us to estimate the cumulative number of positive cases in the present scenarios. Now, India is entering the mid stages of the epidemic. It is important to predict how the virus is likely to grow amongst the population. The corona virus pandemic presents a challenge for data scientists to model it; however, the epidemiological characteristics of the corona virus are yet to be fully explained. The uncertainty around the corona virus with no vaccine and effective medicine available until today, create additional pressure on the epidemiologists and policy makers. In such a crucial situation, it is very important to predict infected cases to support prevention of the disease and support in the preparation of healthcare service. A mathematical modeling approach is a suitable tool to understand the dynamics of epidemic. In the study, some mathematical approach to understand the dynamics of novel corona virus in India has been discussed.

METHODOLOGY

We obtained the truncated information on cumulative number of corona positive confirmed cases in India, from covid19india.org [4]. All cases were laboratory confirmed, following the case definition by the Government of India. Some studies modeled the epidemic curve, obeying the exponential growth [7, 8]. The nonlinear least square framework was adopted for data fitting and parameter estimation for COVID-19 at this early stage. In this study, first exponential and then logistic growth curve has been used to model the novel corona epidemic, since epidemics grow exponentially not linearly.

But, it is surprising that exponential growth curve always provide increasing number of daily new cases. There is no saturation point. Another deterministic model used for understanding the dynamics of epidemic is the Susceptible-Infectious-Recovered (SIR) model, which has been used to accurately predict incidence like SARS. In the SIR model, we need to know the input parameters first; the status we feed into the model [9, 10, 11]. The first one is $R_{0,}$ called the basic reproduction Number. It is essentially the number of new cases, a single infected person will cause during their infectious period. It is one of the most important parameters for assessing any epidemic. Corona virus has an R_0~2.4. In contrast, the swine flu virus had an R_0~1.5 in the 2009 swine flu epidemic [12]. The R_0 will inform us about how many people will get infected with one infected person. Other one is the case fatality rate (CFR), which is the percentage of infected people that will die due to the infection. The CFR for corona virus has been reported between 0.5–4 percent. The lower values are more appropriate in resource better settings of medical facility. But, SIR model assumes that every person is moving and has equal chance of contact with each and every other person among the population, irrespective of the space or distance between different people. It is assumed that the transmission rate remains constant throughout the period of pandemic. Also, this model is considered to have the same transmission rate for those, who have been diagnosed and are in quarantine, or those who have not been quarantined. The harmonic analysis methods and dynamic model estimates show that the number of COVID-19 infected would be 9225 (if there were 10 infected individuals as of March 1, 2020, who was not taking any precautions to spread), 17,986 (if there were 20) and 44,265 (if there were 50)[13].

GROWTH MODELS

A growth curve is an empirical model of the evolution of a quantity over time. Growth curves are widely used in biology for quantities such as population size in population ecology and demography for population growth analysis, individual body height in physiology for growth analysis of individuals. Growth is also a key property of many systems such as an economic expansion, spread of an epidemic, the formation of a crystal, an adolescent's growth and the condensation of a stellar mass.

Linear Growth

This is the simplest growth model, in which population grows at a constant rate over time. Linear growth is described by the equation

$$P_{t+1} = P_t + A \qquad (1)$$

Where P_t represents the numbers or size of the system at time t, P_{t+1} represents the system's numbers or size of the system one time unit later, and A is the system's (linear) growth rate. Many times, this model fails to explain natural phenomenon.

Exponential Growth (Unlimited Population Growth)

Another simple model describes exponential growth, in which, population grows at a constant proportional rate over time. The relation may be expressed in either of two forms, depending on whether reproduction is assumed to be continuous or periodic [14]. Exponential growth results in a continuous curve of increase or decrease, whose slope varies in direct relation to the size of the population.

$$P_t = y = P_0 e^{rt} \qquad (2)$$

Where, r is the constant rate of growth, P_o is the initial population size, and the variables t and P_t respectively represent time and the population at time t (Method 1). Another form of exponential curve is as follows

$$P_t = y = P_0 k^t \tag{3}$$

Where $k = \left(\frac{P_n}{P_0}\right)^{1/n}$ and that therefore, the growth rate in (3) does not a constant growth rate. David A. Swanson, University of California, USA used this type equation for prediction (Method 2).

We have used truncated information i.e. only 30 days information (from March 4 to April 2, 2020) on number of corona confirmed cases for the prediction purpose. We have used two equations of exponential curve, as given below:

- $28e^{0.14t}$ up to March 31, 2020
- $28e^{0.15t}$ from March 31, 2020onward (adjusting faster rate of occurrence of corona cases due to Tablighi spread)

With the current incidence of the novel corona virus going on, we hear about exponential growth. In this study, an attempt has been made to understand and analyze the data through exponential growth curve. The reason for using exponential growth curve for studying the pattern of novel corona virus incidence is that, epidemiologists have studied these types of happenings, and it is well known that the first period of an epidemic follows exponential growth. The exponential growth function is not necessarily the perfect representation of the epidemic. I have tried to fit exponential curve first, and at the next point to study the logistic growth curve, because exponential curve only fits the epidemic at the beginning. At some point, recovered people will not spread the virus anymore and when someone is or has been infected, the growth will stop. Logistic Growth is characterized by increasing growth in the beginning period, but a decreasing growth after point of inflexion. For example, in the corona virus case, the maximum limit would be the total number of exposed people in India because when everybody is infected, the growth will be stopped. After that the increasing rate of curve starts to decline and reach to the minimum.

In the figure 1, predicted values of the cumulative number of novel corona positive cases obtained by method 1 and 2, is drawn along with observed cumulative number of novel corona positive cases. Both the methods provide moderately good estimates, but the tendency of both the curves is unlimitedly increasing. The rate of growth of Method 2 is slightly lesser than the rate of growth of Method 1. The number of total infected cases by April 30, 2020 would be about 144700 (Method 1) and 127700 (Method 2). If we do not adjust the Method 1 for Tablighi spread, then the total infected cases by April 30, 2020 would be about 81810. Thus, we can obtain the effect of Tablighi spread is about 75 percent.

Logistic Growth (Sigmoidal)

The logistic model reveals that the growth rate of the population is determined by its biotic potential and the size of the population as modified by the natural resistance, or, in other words, by all the various effects of inherent characteristics, that are density dependence [15]. Natural resistance increases as population size gets closer to the carrying capacity. Logistic growth is similar to exponential growth, except that it assumes an essential sustainable maximum point. In exponential growth curve, the rate of growth of y per unit of time is directly proportional to y, but in practice the rate of growth cannot be in the same proportion always. The logistic curve will continue up to certain level, called the level of saturation, sometimes called the carrying capacity, after reaching carrying capacity it starts declining. A system far below its carrying capacity will at first grow almost exponentially, however this growth gradually slows as the system expands, finally bringing it to a halt specifically at the carrying capacity [14, 15]. The logistic relationship can be expressed as

$$P_t = y = \frac{k}{1+e^{a+bt}}\ ;\ b<0 \tag{4}$$

Where a, b and k are constant and y_t is that value of the time series at the time t. The reciprocal of y_t follows modified exponential law. Hence, the given time series observation y_t will follow Logistic Law if their reciprocal $1/y_t$ follows modified exponential law. Thus in general, we may take

$$\frac{dy}{dt} = \alpha y(k-y); \alpha > 0, k > 0$$

The factor y is called the momentum factor which increases with time t and the factor $(k-y)$ is known as the retarding factor that decreases with time. When the process of growth approaches the saturation level k, the rate of growth tends to zero. Now we have

$$\frac{dy}{y(k-y)} = \alpha dt \Rightarrow \frac{1}{k}\left[\frac{1}{y}+\frac{1}{k-y}\right]dy = \alpha dt \Rightarrow \left[\frac{1}{y}-\frac{1}{k-y}\right]dy = \alpha k dt$$

Integrating, we get

$\log(\frac{y}{k-y}) = \alpha kt + \gamma$, where γ is the constant of integration.

$\frac{k}{y} = 1+e^{-\alpha kt}.e^{-\gamma} \Rightarrow y = \frac{k}{1+e^{-(\gamma+\alpha kt)}}$, This equation is same as equation (4) where $a=-\gamma$ and $b=-\alpha k$.

Logistic curve has a point of inflexion at half of the carrying capacity *k*. This point is the critical point, from where the increasing rate of curve starts to decline. The time of point of inflexion can be estimate as $\frac{-a}{b}$. For the estimation of parameter of logistic curve, method of three selected points has been used. The estimate of the parameters can be obtained with equation given as:

$$k = \frac{y_2^2(y_1+y_3)-2y_1y_2y_3}{y_2^2-y_1y_3} \tag{5}$$

$$b = \frac{1}{t_2-t_1}\ln\left[\frac{(k-y_2)y_1}{(k-y_1)y_2}\right] \tag{6}$$

$$a = \ln\left[\frac{k-y_1}{y_1}\right]-bt_1 \tag{7}$$

Where, $y_{1,}\, y_2$ and y_3 are the cumulative number of corona positive cases at a given time $t_{1,}\, t_2$ and t_3 respectively, provided that $t_2 - t_1 = t_3 - t_2$. You may also estimate the parameter *a* and *b* by method of least square after fixing *k*.

To predict confirmed corona cases on different day, logistic growth curve has been also used and found very exciting results. The truncated information (means not from the beginning to the present date) on confirmed cases in India has been taken from March 13 to April 2, 2020. The estimated value of the parameters are as follows *k*=18708.28, *a*=5.495 and *b*=-0.174, with these estimates predicted values have been obtained and found considerably lower values than what we observed. On April 1 and 2, 2020 the number of confirmed corona cases were drastically increasing in some part of India due to some unavoidable circumstances, thus there is an earnest need to increase carrying capacity of the model, thus it is increased and considered as 22000 and the other parameters *a* and *b* are estimated again, which are *a*=5.657 and *b*=-0.173. The predicted cumulative number of cases is very close to the observed cumulative number of cases till date. The time of point of inflexion is obtained as 32.65 i.e. 35 days after beginning. We have taken data from March 13, 2020 so that the time of point of inflexion should be April 14, 2020 and by May 30, 2020 there will be no new cases found in the country. The distribution of the new cases is in the red color in the figure 2, which is quite normal and obvious. As mentioned in the above paragraph, Method 1 provided natural estimate of the total infected cases by May 30, 2020 that is 192400. This estimate is obtained when no preventive measure would be taken by the Government of India. The testing rate is lower in India than many western countries, so our absolute numbers is low. When government initiates faster testing process, then we have observed more number of cases and found this logistic model fail to provide cumulative number of corona confirm cases after April 17, 2020 thus there is a need to modify this model.

In order to the modification, I have taken natural log of cumulative number of corona confirm cases instead of cumulative number of corona confirmed cases, as taken in the previous model. This model provides, the carrying capacity is about 80000 cases and time of point of inflexion is April 30, 2020. The present model provides reasonable estimate of the cumulative number of confirmed cases and by the end of July, 2020 there will be no new cases found in the country. Further, the number of corona positive cases increases and the model estimate does not match to the observed number of case, therefore we need to change the data period, since the logistic curve is data driven model that provide new estimate of point of inflexion and maximum number of corona positive cases by date when disease will disappear, that helps us to plan our strategies. Finally, in this study, we changed the data period i.e. we have taken data from April 15th to May 11th 2020. This provides, the carrying capacity is about 20 lakh cases and time of point of inflexion is July15th, 2020 with a maximum number of new cases on a day is about 15000. The model based on this data (from April 15th to May 11th 2020) provides reasonable estimate of the cumulative number of confirmed cases (See Table 1, which is given predicted value along with number of new cases on a particular date, 95 percent confidence interval up to June 30th, 2020), and by the end of January, 2021 we hope there will be no new cases in the country.

LOCKDOWN IMPACT

To know the impact of lockdown, we define the corona case propagation is as $c_t = \dfrac{x_t}{\sum_{i=0}^{t} x_i}$, where x_t is the number of confirm cases on t^{th} day. We have calculated c_t and the doubling time of the corona case propagation in India. The doubling time is calculated as $\frac{Ln2}{c_t} = \frac{0.693}{c_t}$.

We have calculated corona case propagation c_t on the basis of 5 days moving average of daily confirmed cases (in the beginning the data in India is very fluctuating) and it is found gradually decreasing in India. This indicates the good sign of government attempts to combat this pandemic through implementing lockdown. These findings indicate that in future, the burden of corona will be expectedly lowering down if the current status remains same. In Table 2, an attempt has been made to show the summary statistics of corona case propagation c_t during various lockdown periods in India. It is observed that average corona case propagation is maximum (0.17 with standard deviation 0.033) in the period prior to the lockdown. During the first lockdown period the average corona case propagation is 0.14 with standard deviation 0.032, however in lockdown 2 it is 0.07 with standard deviation 0.009, and in lockdown 3 corona case propagation is 0.06 with standard deviation 0.006, thus it is clear that both average propagation and standard deviation are decreasing. Table 3 represents the results of ANOVA testing for mean of c_t during various lockdown periods, which significantly means that the average corona case propagation is significantly different is various lockdown periods considered. A group wise comparison of the average corona case propagation c_t during various lockdown periods is shown in Table 5, which reveals that lockdown significantly affects the spread of corona case propagation. Figure 4 shows, corona case propagation and doubling time in India. The corona case propagation in decreasing and doubling time is increasing day by day.

CONCLUSIONS

India is in the comfortable zone, with a lower growth rate than other countries studied. Our mathematical model shows that, the epidemic is likely to stabilize with 20 lakh cases by the end of January, 2021. A study advocated for 49 days single lockdown i.e. lockdown up to May 13, 2020 reduced infected cases below 10, but our study contradict it [11]. The government has adopted a strategy of large scale quarantine and limited testing to flatten the epidemic curve and reduce the death rate. The projections produced by the model and after their validation can be used to determine the scope and scale of measures that government need to initiate. In conclusion, if the current mathematical model results can be validated within the range provided here, then the social distancing and other prevention, treatment policies that the central and various state governments and people are currently implementing, should continue until new cases are not seen. The spread from urban to rural and rich to poor populations should be monitored, and control is an important point of consideration. Mathematical models have certain limitations that there are many assumptions about homogeneity of population in terms of urban/rural or rich/poor that does not capture variations in population density. This study can help health professionals and policy maker to make appropriate policy. Finally, it should be accepted that the above observations are a model based observations of the corona pandemic, and the estimates are calculated from available limited information. If several protective measures will not be taken effectively, then this rate may be changed. However, the government of India under the leadership of Modi Ji has already taken various protective measures such as lockdown in several areas, make possible quarantine facility to reduce the rate of corona, thus we may hopefully conclude that, the country will be successful to reduce the rate of this pandemic.

ABBREVIATIONS

SARS: Severe Acute Respiratory Syndrome; MERS: Middle East respiratory syndrome; WHO World Health Organization; SIR: Susceptible-Infectious-Recovered; CFR: Case Fatality Rate; ANOVA: Analysis of Variance

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APPENDICES

Tables and Figures

Table 1: Some Observations about Corona Positive Cases

Month	Date	Observed	Predicted	95% LCI	95% UCI	New Cases
April	15	12372	12372	12145	12599	882
	16	13434	13336	13107	13566	964
	17	14353	14368	14137	14600	1032
	18	15724	15471	15239	15704	1103
	19	17304	16650	16417	16883	1178
	20	18543	17907	17674	18140	1258
	21	20080	19249	19016	19481	1341
	22	21372	20678	20445	20910	1429
	23	23039	22199	21967	22432	1522
	24	24447	23818	23584	24052	1619
	25	26282	25539	25302	25776	1721
	26	27889	27366	27124	27608	1827
	27	29458	29305	29054	29555	1939
	28	31360	31360	31097	31623	2055
	29	33063	33537	33256	33817	2177
	30	34866	35841	35537	36144	2304
May	1	37262	38276	37944	38609	2436
	2	39826	40849	40481	41217	2573
	3	42778	43565	43155	43974	2715
	4	46434	46428	45970	46886	2863
	5	49405	49444	48931	49958	3016
	6	53007	52619	52044	53194	3175
	7	56351	55958	55314	56601	3339
	8	59690	59465	58747	60184	3507
	9	62865	63147	62346	63947	3682
	10	67176	67007	66118	67897	3861
	11	70768	71052	70067	72037	4045
	12	74329	75286	74199	76374	4234
	13	78056	79714	78517	80912	4428
	14	82047	84341	83026	85656	4627
	15	85855	89171	87731	90610	4830
	16	90649	94208	92636	95779	5037
	17	95698	99456	97745	101167	5248
	18	100326	104920	103062	106777	5464
	19	106480	110603	108591	112615	5683
	20	112200	116508	114335	118682	5906
	21	118223	122640	120297	124983	6131
	22	124793	129000	126480	131520	6360
	23	131422	135592	132888	138296	6592
	24	138535	142417	139521	145313	6826
	25	144949	149479	146384	152574	7062
	26	150856	156778	153477	160079	7299

	27	158102	164317	160802	167831	7539
	28	165356	172096	168361	175830	7779
	29	173494	180116	176154	184077	8020
	30	181829	188377	184182	192572	8262
	31	190649	196881	192446	201316	8504
June	1	198373	205626	200945	210307	8745
	2	207186	214612	209679	219545	8986
	3	216875	223838	218648	229029	9226
	4	226722	233303	227850	238757	9465
	5	236101	243005	237284	248727	9702
	6	246602	252943	246949	258937	9937
	7	257484	263113	256842	269384	10170
	8	266020	273513	266961	280065	10400
	9	275999	284140	277304	290977	10627
	10	287154	294991	287867	302116	10851
	11	298289	306062	298647	313478	11071
	12	309595	317350	309641	325059	11287
	13	321630	328849	320845	336853	11499
	14	333012	340555	332254	348857	11706
	15	343071	352464	343864	361064	11909
	16	354157	364570	355671	373469	12106
	17	367265	376867	367669	386066	12298
	18	381094	389351	379853	398850	12484
	19	395834	402015	392218	411813	12664
	20	411752	414854	404758	424950	12838
	21	426902	427860	417466	438253	13006
	22	440450	441027	430338	451716	13167
	23		454349	445318	463381	13322
	24		467819	458552	477086	13470
	25		481430	471929	490930	13611
	26		495174	485443	504905	13744
	27		509045	499086	519004	13871
	28		523035	512852	533218	13990
	29		537137	526733	547541	14102
	30		551343	540723	561964	14206

Table 2: Summary of c_t during Various Lockdown Period

Lockdown Period	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
No	08	0.17	0.033	0.012	0.144	0.199
1	22	0.14	0.032	0.007	0.121	0.149
2	20	0.07	0.009	0.002	0.064	0.072
3	24	0.06	0.006	0.0017	0.049	0.054
Total	74	0.10	0.049	0.006	0.083	0.105

Table 3: ANOVA Test for Mean of c_t during Various Lockdown Period

Source of Variations	Sum of Squares	df	Mean Square	F	p value
Between Groups	0.142	03	0.047	1080.341	0.000
Within Groups	0.031	70	0.000		
Total	0.172	73			

Table 4: Group Wise Comparison of Means of r_t during Various Lockdown Periods

(I) Group	(J) Group	Mean Difference (I-J)	Std0. Error	p value	95% Confidence Interval	
					Lower Bound	Upper Bound
No	1	0.036	0.009	0.000	0.013	0.060
	2	0.103	0.009	0.000	0.080	0.127
	3	0.120	0.009	0.000	0.096	0.143
1	2	0.067	0.006	0.000	0.050	0.085
	3	0.083	0.006	0.000	0.067	0.100
2	3	0.016	0.006	0.079	-0.001	0.033

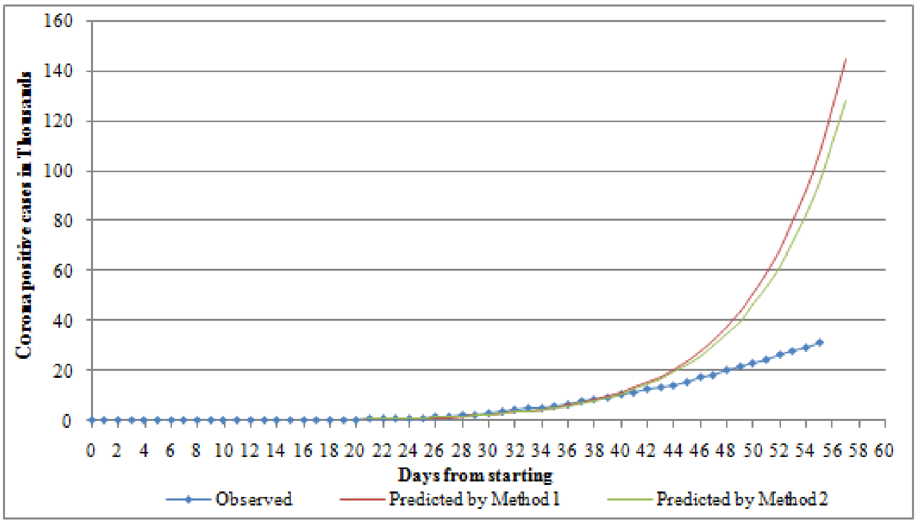

Figure 1: Exponential Growth Curve.

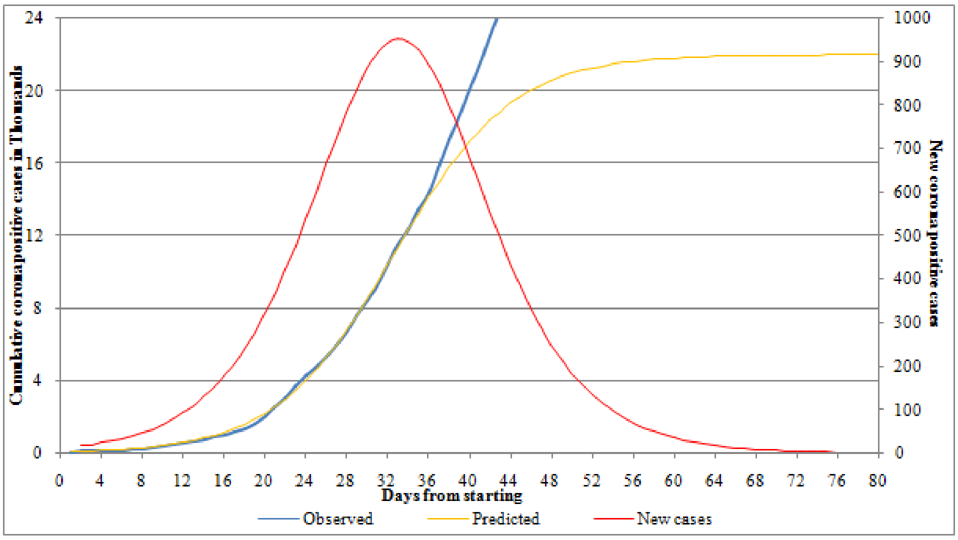

Figure 2: Logistic Growth Curve (Considering Actual Number Cumulative Corona Positive Cases as y_t).

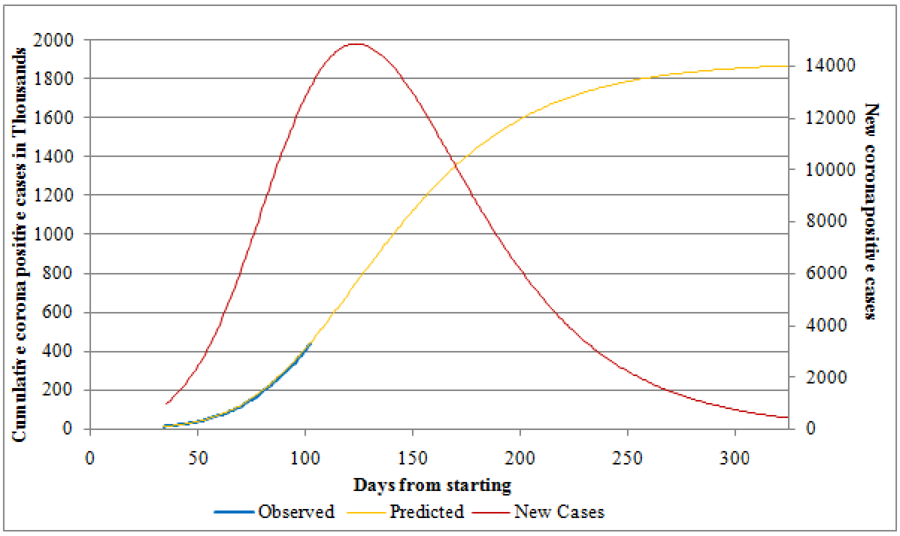

Figure 3: Logistic Growth Curve (Considering Natural Log of Actual Number Cumulative Corona Positive Cases as y_t).

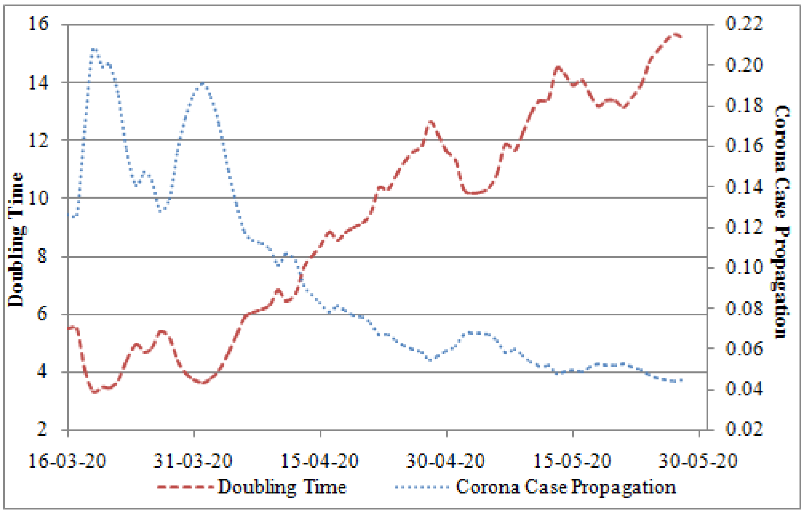

Figure 4: Corona Case Propagation and Doubling Time.