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Prediction of peak and termination of novel coronavirus COVID-19 epidemic in Iran

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The growth and development of COVID-19 transmission have significantly attracted the attention of many societies, particularly Iran, that have been struggling with this contagious, infectious disease since late February 2020. In this study, the known "Susceptible-Infectious-Recovered (SIR)" and some other mathematical approaches were used to investigate the dynamics of the COVID-19 epidemic to provide a suitable assessment of the COVID-19 virus epidemic in Iran. The epidemic curve and SIR model parameters were obtained with the use of Iran's official data. The recovered people were considered alongside the official number of confirmed victims as the reliable long-time statistical data. The results offer important predictions of the COVID-19 virus epidemic such as the realistic number of victims, infection rate, peak time and other characteristics. Besides, the effectiveness of infection and immunization rates to the number of infected people and epidemic end time are reported. Finally, different suggestions for decreasing victims are offered.

Keywords: Model-identification; parameter identification; statistical methods; mathematical modeling of infection diseases; Susceptible-Infectious-Recovered (SIR) model; contamination models.

1. Introduction

The 2019 coronavirus (COVID-19) pandemic is a global outbreak of a novel type of coronavirus disease. Given the economic and social impacts of this pandemic, mathematical modeling and prediction are essential to bring awareness to people and decision-making managers of the consequences of this epidemic. Estimating the

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elements of coronavirus is crucial regarding the assessment of epidemic transmissibility, the prediction of the future trend of epidemic spreading, as well as the design of steering measures.[1] During the outbreak of an epidemic, due to the government and people works, the reduction of susceptible populations, and the seasonality of transmissibility, the basic reproduction number (R_0) is generalized to an effective reproduction number, which is defined as the average number of secondary cases generated by an infectious case at time t, and is denoted by R_t. The epidemic is considered to be under control when $R_t < 1$.[1,2] The basic reproduction number of the severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), Zika virus and smallpox was in the range of 2–5, 2–6.7, 1.4–6.6 and 3.5–6.0, respectively.[1] These ranges are pertaining to mathematical models for prediction. Albeit, the range of variation was almost the same for all of the mentioned diseases.

The pessimistic estimation for R_t in China was considered varying between 3.2 and 3.9.[1] This range for 2019 n-CoV was gathered from different statistics given by the Chinese official data.[3] The lowest reported value range was between 1.4 and 3.9 with an average of 2.2 and the highest reported value was 5.71–7.23 with an average of 6.47. This range was calculated between 2.4 and 2.8 with an average of 2.6 for Japan.[4] As can be interpreted, the range of coronavirus pandemic is almost similar all over the world but the different measures taken by the government and by the people can change the range between the optimistic and pessimistic estimates. In this paper, the R_t range of COVID-19 (2019 n-CoV) will be considered in the range of 2.8–3.3.

The present research team mathematically investigated the COVID-19 growth in Iran using the available statistical data, mathematical models, and epidemic curves. Available official long-time data of Iran were used to predict the number of victims (V) of this virus in this country. Different types of mathematical models can be used for predicting an epidemic infection, and many important unknown variables can be achieved by the use of real available data. The first predictions of an epidemic infection exponential growth, that is typical for the initial stages of all epidemics, have been presented in Ref. 4.

A complicated mathematical model was suggested called the "Susceptible-Infectious-Recovered (SIR)" model. SIR model is engaged upon anticipating the potential domestic and international spread of the COVID-19 outbreak.[5] The intricate models need more attempts for the man parameter identification. Accordingly, Nesteruk[6,7] developed an appropriate mathematical model of contamination and SIR-model of spreading an infection to predict the time dynamics of the unknown children's disease, which occurred in Chernivtsi, Ukraine, and COVID-19 China epidemic. Furthermore, improved and developed models based on the SIR model have been proposed by different papers.[8–11]

One of the most essential aspects that should be investigated for the COVID-19 pandemic is the analysis of the dynamic of this pandemic. Santos *et al.*[12] considered this subject by adding a time-dependent coefficient to the SIR model. They expressed a novel system of the ordinary differential equation (ODEs) to solve this dependence. By expressing this linear coefficient related to time denoted as the probability of contact, the dynamic of the COVID-19 outbreak has been captured in Italy, Brazil, and South Korea. Also, they determined different features effects that are crucial for decisions on intervention policies such as parameters to characterize the reduction of contact, in response to mitigation policies, the impact of border control, the percentage of positive cases that are reported, and the delay between the infection and the result of COVID-19 tests that confirm the disease. Maier and Brockmann[13] considered the containment efforts and quarantine results to constrain this pandemic. They added a new coefficient to the basic SIR model to capture the dynamic of the COVID-19 outbreak by solving their proposed system of the ordinary differential equation. They showed that containment behavior and mitigation strategy that target the susceptible population to end of the transmission process can be very effective in containing an epidemic. Crokidakis[14] considered the containment effort in Rio de Janeiro state in Brazil according to the compartmental mathematical model. He observed that the implementation of social distancing policies permuted the initial exponential trend to a sub-exponential one. He suggested a valuable work for keeping economic trade by taking a relaxation of the isolation policies. Also, he determined the infection rate, peak time, and the doubling time of the epidemics based on the data available at the website of the Brazilian department of health according to the compartmental mathematical model.[15]

In this paper, the SIR model for the dynamics of epidemics[16–19] is used to identify Iran (COVID-19) epidemic in Iran. In this respect, an exact solution of the SIR linear equations is considered simultaneously with a statistical approach based on the confirmed and recovered victims as the reliable long-time statistical data of Iran.[7] Main epidemic characteristics, such as epidemic victim numbers, infected, and recovered people, are estimated over time. Furthermore, Iran's official data[20,21] are fitted and compared with other country's epidemic curves[22,23] and also, compared with the results of the SIR model.

This paper is organized into six sections as follows. Section 1 is the prediction of peak and end times using a trend-curve-fitting approach to the Iran data. In Sec. 2, the number of victims, infected, recovered, and dead people is anticipated to the end of the epidemy. This prediction is according to confirmed data reported by the Iranian government combined with the SIR model. In Sec. 3, various functions were fitted to official confirmed data, and the most relevant function is distinguished for fitted and prediction as well. This section expresses that there will be no multiple peaks in the epidemy casualties in Iran. Section 4 is the authors' anticipation by using estimated reproduction numbers according to other countries and approximated values. In Sec. 5, different values of infection and immunization rates are compared together. In Sec. 6, herd immunization is considered and compared with the predicated condition. Eventually, different measures that should be considered by the government and the people are suggested by the authors.

2. Mathematical Approach and Results

- **SECTION 1**

The solid line in Fig. 1 shows the prediction of the trend-curve deaths in Iran based on the curve-fitting of the available data of Iran. Based on this scenario, 21/03/2020 was the COVID-19 epidemic peak in Iran. After this point, the outbreak and death would be reduced so that this epidemic would be terminated at the end of April 2020. However, the official data of Iran did not follow the trend of the estimated curve after 23 March. It is worth noting that the official data of Iran were quite different from other countries' data without a perceptible maximum but with a flat maximum. However, the behavior of data at the decline period is approximately similar. The vertical and horizontal axes represent the daily number of deaths in Iran and the time which started from 2 March 2020, respectively.

- **SECTION 2**

Exact solution of the SIR-equations

The nonlinear equations of the SIR-model are illustrated for an infectious disease[6,7] as follows:

$$\dot{S} = -\alpha SI, \tag{1}$$

$$\dot{I} = \alpha SI - \rho I, \tag{2}$$

$$\dot{R} = \rho I, \tag{3}$$

where the number of infected people is denoted by I, susceptible by S, recovered by R. Also, the immunization and infection rates are represented by ρ and α, respectively. Given that $\dot{S} + \dot{I} + \dot{R} = 0$, Eqs. (1)–(3), $N = S + I + R$ needs to be

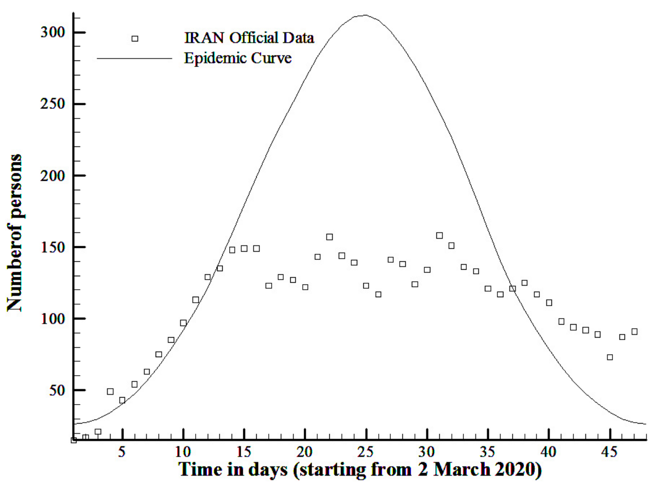


Fig. 1. The daily number of deaths due to COVID-19 in Iran.

unchanged over time and can be indicated as the number of susceptible people before the epidemic outbreak because of $I = R = 0$ at $t < t_0$. It is worth noting that N is not equal to the total population (N_{total}), but rather it stands for the initial number of sensitive people who are unprotectively prone to be infected by some special diseases. Particularly, N/N_{total} might be quite small. For instance, there are 3711 people on the board of Diamond Princess, with confirmed cases of 70 on 10/02/2020, i.e. the susceptible people can be estimated to be around 1.89% in this case.[7] This means that constant N is not equal to one territory's total population (N_{tot}). It is a fraction of the total population that has been captured by the basic reproduction number (R_0) value.

Equation (4) is supposed to define the initial conditions

$$I(t_0) = 1, \quad R(t_0) = 0, \quad S(t_0) = N - 1. \tag{4}$$

It follows from Eqs. (1) and (2) that

$$\frac{dI}{dS} = \frac{v}{S} - 1, \quad v = \frac{\rho}{\alpha}. \tag{5}$$

Integrating Eq. (5) with the initial conditions presented in Eq. (4) results, we get

$$I = v \ln S - S + N - v \ln(N - 1). \tag{6}$$

Function I reaches its maximum value at $S = v$ and vanishes at infinity. Also, the number of susceptible people at infinity ($S_\infty > 0$) can be calculated using Eq. (6) as follows:

$$S_\infty = (N - 1)e^{\frac{S_\infty - N}{v}}. \tag{7}$$

Equations (1)–(3) were solved by proposing $V(t) = I(t) + R(t)$, corresponding to the number of victims. The corresponding equation integration becomes

$$\dot{V} = \alpha SI = \alpha(N - V)[v \ln(N - V) + V - v \ln(N - 1)]. \tag{8}$$

Resulting in the following expression:

$$t = \frac{F_1(V, N, v) + \alpha t_0}{\alpha}, \tag{9}$$

$$F_1 = \int_1^V \frac{dU}{(N - U)[v(N - U) - v \ln(N - 1)]}. \tag{10}$$

Therefore, for every set of N, v, α, t_0 and a constant value of V, Eq. (10) can be solved, and the corresponding time can be calculated using Eq. (9). Then, I can be calculated using Eq. (6) by replacing $S = N - V$ and R out of $R = V - I$.

Furthermore, for more comprehensible and convenient predictions, two approximation analytics can be used to calculate random function $F_1(V, N, \nu)$ and time function (t), subsequently.[6]

The obtained solution of the differential equations (1)–(3) can be simplified with the use of these different approximations for the function $\ln(N - U) - \ln(n - 1)$.

If we assume $\ln(N-U) - \ln(n-1) \approx 0$ then $F_1 = \ln(\frac{V}{N})$ and ultimately, we get

$$V = \exp(\gamma(t - t_0)), \quad \gamma = \alpha N. \tag{11}$$

According to (11), epidemic starts exponentially and only two parameters (γ and t_0) describe the process.

If we would like to anticipate more appropriately and accurately, we can assume $\ln(N-U) - \ln(N-1) \approx (1-U)/N$, then $F_1 = N/\nu(N-\nu)N \times [\ln \frac{NV+\nu(1+\nu)}{N} - \ln \frac{N-V}{N-1}]$. The solution's form will be as follows:

$$V = \frac{EN - \nu}{E + N - \nu},$$
$$E = \frac{N}{N-1} \times \exp\left(\frac{\alpha(t-t_0)[\nu + (N-\nu)N]}{N}\right). \tag{12}$$

Finally, this approximation, Eq. (12), reached a limited amount of victims, since $V = I + R$ tends to N at infinity.[6] These assumptions were considered for easier calculation of random function. As can be observed, two methods can be used for approximation and the second one is more precise than the first one.

The optimal calculated values of parameters are shown in Table 1. The official statistical data of Iran for the susceptible and recovered people were used for the extrapolation process using the SIR model. The results depicted in Fig. 2 show the number of victims, infected, removed, and susceptible people according to Iran's

Table 1. The optimistic optimal values of parameters.

Amount on susceptible people before the epidemic outbreak	N	40000
Immunization/infection rate	v	10000
Infection rate	α	6.4×10^{-8}
Initial time	t_0	35 (day)

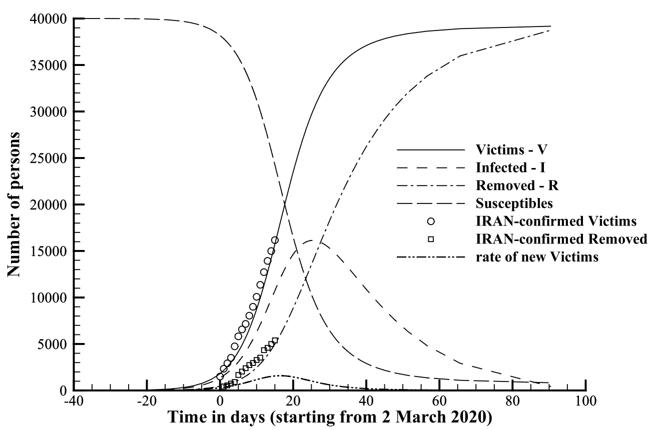


Fig. 2. The values obtained by the SIR model for the COVID-19 epidemic in Iran.

official data using Eqs. (1)–(10). The curved predicted that the maximum number of infected people would occur on 27 March 2020, and the disease peak would occur on 19 March 2020, which was obtained based on the calculation of infection rate. The infection rate would be zero at the beginning of May 2020, when the number of susceptible people would converge to its lowest value.

• SECTION 3

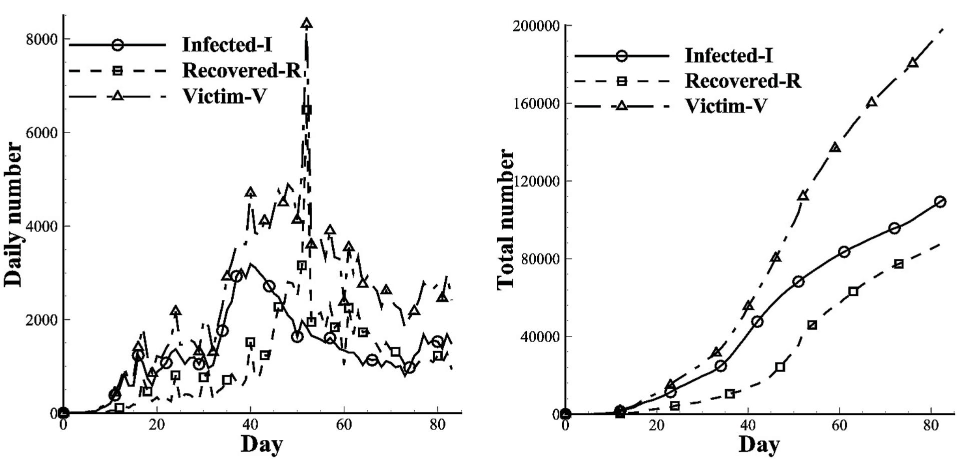
In this section, statistical data of people who have caught the disease have been depicted from 19 February 2020 to 24 March 2020 in Figs. 3 and 4.[21] The extrapolation of data was accomplished using the least square method in the background of the SIR model. Table 2 lists the daily numbers and total infected, recovered, and dead people according to confirmed official data for the COVID-19 epidemic in Iran.[21] The data in this table were used for plotting Figs. 3–5.

Here, we consider the least-square model of the official data. An exponential function is used for extrapolation.[24] The exponential function, Eq. (13), is a general function of the SIR method solution fitted to the official data of the infected people.

$$f(t) = K_1 \exp(K_2 t). \tag{13}$$

In the exponential formula, t is time, calculated as $t = t_{\text{Day}} - t_{\text{Turning}}$ and $t_{\text{Turning}} = 37$ is achieved. Table 3 reports the constants of the exponential function for curve fitting to infected people.

The purpose of providing this function is to determine the turning time and also, consider if there is a possibility of multiple peaks in the epidemic curve until the epidemic ends or no.[25] From Eq. (13), that is plotted in Fig. 5, it could be concluded



(a) (b)

Fig. 3. The number of infected, recovered, victim people in Iran,[21] (a) daily, (b) total.

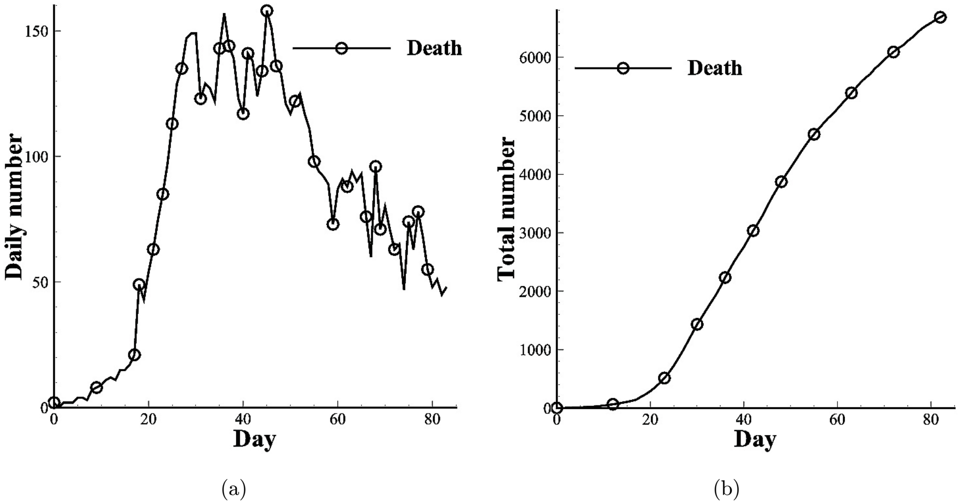


Fig. 4. The number of dead people in Iran,[21] (a) daily, (b) total.

that the possibility of having multiple numbers of peaks to the end of the epidemic is negligible.

- **SECTION 4**

In this section, we estimate the number of infected people by the disease in Iran with a total population of 84 million.[26] According to the articles on epidemics in China and Japan,[7,27] the proportion of people with the epidemic to the total population (N/N_{total}) is as low as 1.89% to 3.58%. As this subject, here, we consider 2.14%. This means that the total number of people caught in Iran will be approximately

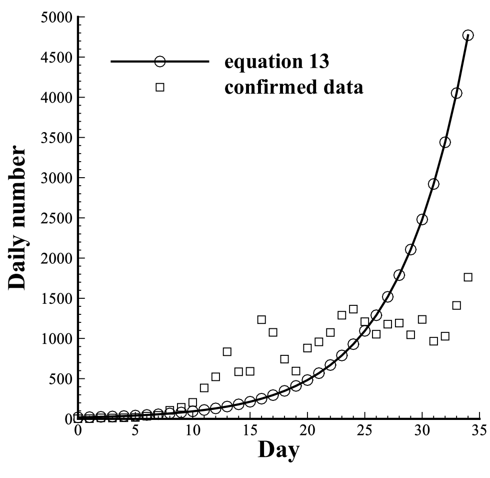


Fig. 5. Equation (13) and official data of the confirmed infected patients.

Table 2. Data of the epidemic caused by COVID-19 pneumonia in Iran.[21]

	Daily			Total		
Date	Infection	Recovered	Death	Infection	Recovered	Death
19 February 2020	2	0	2	2	0	2
	3	0	0	5	0	2
	13	0	2	18	0	4
	11	0	2	29	0	6
	14	1	2	43	1	8
24 February 2020	18	2	4	61	3	12
	34	22	4	95	25	16
	44	0	3	139	25	19
	106	29	7	245	54	26
	143	19	8	388	73	34
29 February 2020	205	50	9	593	123	43
	385	52	11	978	175	54
	523	116	12	1501	291	66
	835	144	11	2336	435	77
	586	117	15	2922	552	92
5 March 2020	591	187	15	3513	739	107
	1234	174	17	4747	913	124
	1076	756	21	5823	1669	145
	743	465	49	6566	2134	194
	595	260	43	7161	2394	237
10 March 2020	881	337	54	8042	2731	291
	958	228	63	9000	2959	354
	1075	317	75	10075	3276	429
	1289	253	85	11364	3529	514
	1365	810	97	12729	4339	611
15 March 2020	1209	251	113	13938	4590	724
	1053	406	129	14991	4996	853
	1178	393	135	16169	5389	988
	1192	321	147	17361	5710	1135
	1046	269	149	18407	5979	1284
20 March 2020	1237	766	149	19644	6745	1433
	966	890	123	20610	7635	1556
	1028	278	129	21638	7913	1685
	1411	463	127	23049	8376	1812
24 March 2020	1762	537	122	24811	8913	1934
25 March 2020	2206	712	143	27017	9625	2077
	2389	832	157	29406	10457	2234
	2926	676	144	32332	11113	2378
	3076	546	139	35408	11679	2517
	2901	712	123	38309	12391	2640
	3186	1520	117	41495	13911	2757
31 March 2020	3110	745	141	44605	14656	2898
1 April 2020	2988	817	138	47593	15473	3036
	2875	1238	124	50468	16711	3160
	2715	1224	134	53183	17935	3294
	2560	1801	158	55743	19736	3452

Table 2. (*Continued*)

	Daily			Total		
Date	Infection	Recovered	Death	Infection	Recovered	Death
5 April 2020	2483	2275	151	58226	22011	3603
	2274	2225	136	60500	24236	3739
	2089	2803	133	62589	27039	3872
	1997	2773	121	64586	29812	3993
	1634	2497	117	66220	32309	4110
10 April 2020	1972	3156	122	68192	35465	4232
	1837	6482	125	70029	41947	4357
	1657	1947	117	71686	43894	4474
	1617	2089	111	73303	45983	4585
	1574	2146	98	74877	48129	4683
15 April 2020	1512	1804	94	76389	49933	4777
	1606	2296	92	77995	52229	4869
	1499	1835	89	79494	54064	4958
	1374	1923	73	80868	55987	5031
	1343	1036	87	82211	57023	5118
20 April 2020	1294	2250	91	83505	59273	5209
	1297	1692	88	84802	60965	5297
	1194	2148	94	85996	63113	5391
	1030	1730	90	87026	64843	5481
	1168	1756	93	88194	66599	5574
25 April 2020	1134	1594	76	89328	68193	5650
	1153	1464	60	90481	69657	5710
	991	1276	96	91472	70933	5806
	1112	1506	71	92584	72439	5877
	1073	1352	80	93657	73791	5957
30 April 2020	983	1312	71	94640	75103	6028
1 May 2020	1006	1215	63	95646	76318	6091
	802	1032	65	96448	77350	6156
	976	1072	47	97424	78422	6203
	1223	957	74	98647	79379	6277
5 May 2020	1323	1096	63	99970	80475	6340
	1680	1112	78	101650	81587	6418
	1485	1157	68	103135	82744	6486
	1556	1093	55	104691	83837	6541
	1529	1227	48	106220	85064	6589
10 May 2020	1383	1079	51	107603	86143	6640
	1683	1279	45	109286	87422	6685
12 May 2020	1481	935	48	110767	88357	6733

Table 3. The constant value of extrapolation function (Eq. (13)).

	Infection
Equation (13)	$K_1 = 18.32992$ $K_2 = -0.163587$

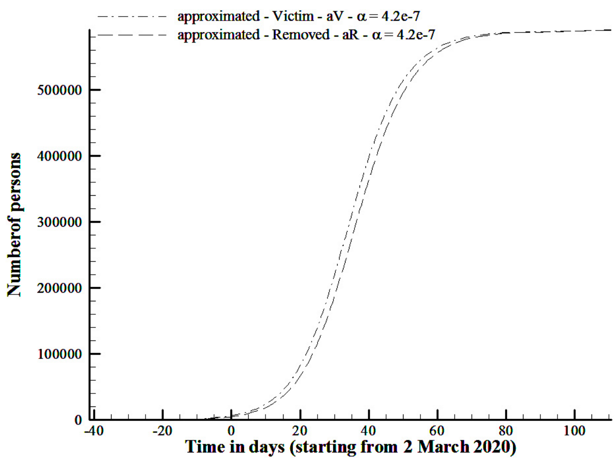


Fig. 6. The approximation calculation of victims and removed people in Iran.

1.8 million. According to Fig. 6, which depicts the number of the approximated victim and recovered according to time, the number of infected people to the disease will reach beside 550 000 but using a suitable diagnosis system and personal hygiene behavior of susceptible persons and quarantine conditions, it is anticipated that disease spreading will be stopped and most of the victims will be recovered. As can be seen in Fig. 7, which shows approximation infection and estimated Iran official infection according to time, the epidemic will continue up to the mid-June (late spring).

- **SECTION 5**

In this section, the infection and immunization rates are considered and compared together. Prediction is made according to the official reported data. According to

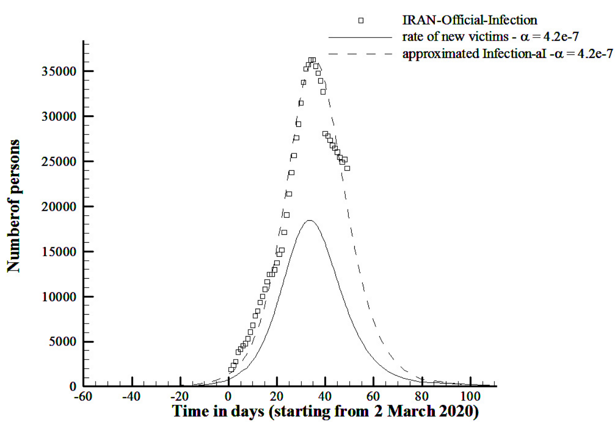


Fig. 7. The number of approximated infected people and the ultimate disease time in Iran.

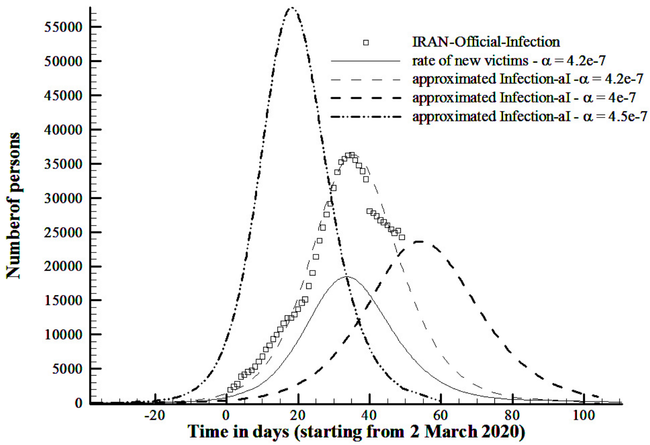


Fig. 8. The number of infected people according to different values of infection rates.

this, the value of infection and immunization rates was set equal to $\alpha = 4.2 \times 10^{-7}[\frac{1}{\text{day}}]$ and $\rho = 0.5[\frac{1}{\text{day}}]$, respectively.

As can be seen in Figs. 8 and 9, which show the number of infected people according to different values of infection rates, by increasing the value of infection rate, the number of infected, recovered and victim people increases. Indeed, the epidemic ending time decreases.

As can be seen in Figs. 10 and 11, which report the number of infections according to different values of the immunization rates, by increasing the value of immunization rate, the number of infected, recovered and victim people decreases and the epidemic ending time increases, as well.

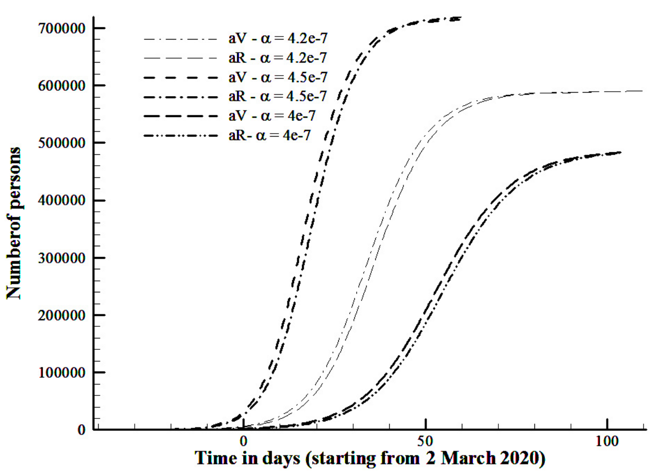


Fig. 9. The victim and recovered people according to different values of infection rates.

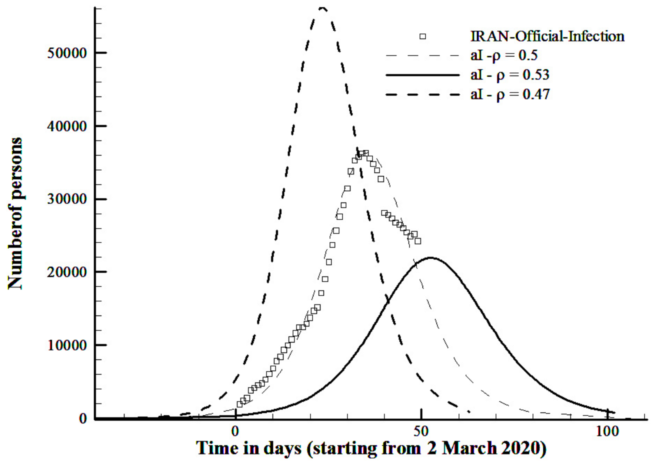


Fig. 10. The number of infected people according to different values of immunization rates.

These subjects show performing some measures by the government such as intervention, forbidding movements in the cities, and ordering to quarantine and by citizens such as keeping the quarantine, maintaining appropriate social-distance, the infection, and immunization rate have been decreasing and increasing, respectively. Evidently, these measures will reduce the number of infected and dead people.

• SECTION 6

In this section, herd immunity was considered. Chang *et al.*[19] worked on herd immunity. They showed that herd immunity can be obtained after at least $1 - \frac{1}{R_0}$ fraction of individuals being a victim from COVID-19. They analyzed the

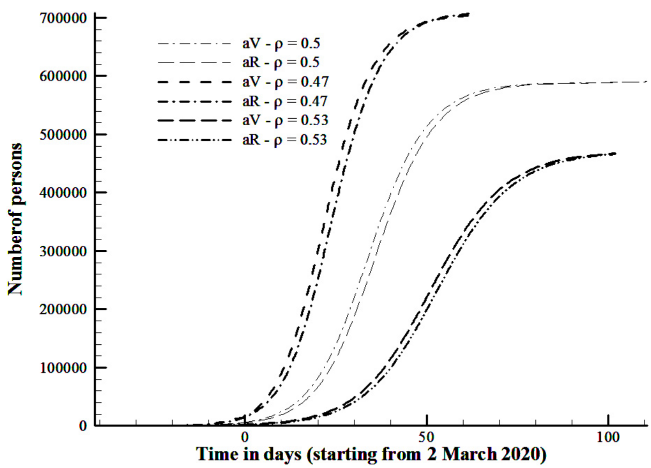


Fig. 11. The victim and recovered people according to different values of immunization rates.

independent cascade (IC) model for disease propagation in a random network specified by a degree distribution. By relating the propagation probabilities in the IC model to the transmission rates and recovering rates in the SIR model, they indicated two approaches of social distancing that can lead to a reduction of R_0.[28] They show the effects of social distance used two common approaches for controlling COVID-19. Firstly, allowing every person to keep its interpersonal contacts up to a fraction of its normal contacts, and secondly, canceling mass gatherings. They used the IC model for propagation in the random network then determined the transmission and recovering rates in the SIR model to show the effects of two approaches for social distance in the reduction of reproduction number. In the IC model, an infected node can transmit the disease to a neighboring susceptible node with a certain propagation probability. Repeatedly continuing the propagation, they depict a graph that contains the set of infected nodes in the long run. By relating the propagation probabilities in the IC model to the transmission rates and recovering rates in the SIR model, they show two results for social distancing. Firstly, for the social distancing approach that allows every person to keep its interpersonal contacts up to a fraction a of its normal contacts, the basic reproduction number is reduced by a factor of a^2, and secondly, for the social distancing approach that cancels mass gatherings by removing nodes with the number of edges larger than or equal to k_0, the basic reproduction number is reduced by a factor of $\frac{\sum_{k=0}^{0-2} kq_k}{\sum_{k=0}^{\infty} kq_k}$, where q_k is the excess degree distribution of p_k. If $(\frac{\sum_{k=0}^{0-2} kq_k}{\sum_{k=0}^{\infty} kq_k})R_0 < 1$, there is no outbreak in the zones.[28] The suppressing epidemic spreading in multiplex networks with concerns on social distance was considered in other references.[29,30]

We show a comparison between herd immunization which people have contacts together and cancel mass gathering in a similar time range. We recognize for having herd immunization, the number of victims must equal to $1 - \frac{1}{R_0}$. Considering our estimated reproduction number equal to 2.14, the number of victims equals almost 54% of the total population of Iran (almost 45 million people). By using herd immunization, predicting that the ending time is sooner than the common method (Sec. 3). On the other hand, the number of infected and dead people increased.

As can be seen in Figs. 12 and 13, by using herd immunization, the range of disease appearing is lower and the epidemic end sooner but the number of victims is higher than keeping the quarantine and canceling mass gathering. Albeit the ending time of vanishing disease is higher in canceling mass gathering for social distance method but the authors hope to order and keep quarantine by the government and people, respectively, to not observing a hazardous catastrophe by the high number of infected and dead people.

Eventually, by falling of infection rate or rising immunization rate, a longer time with fewer infected and dead people based on forecasting is expected. To occur this, the government should do some works such as intervention, controlling measures, finding susceptible persons, forbidden movement in the cities, and ordering to

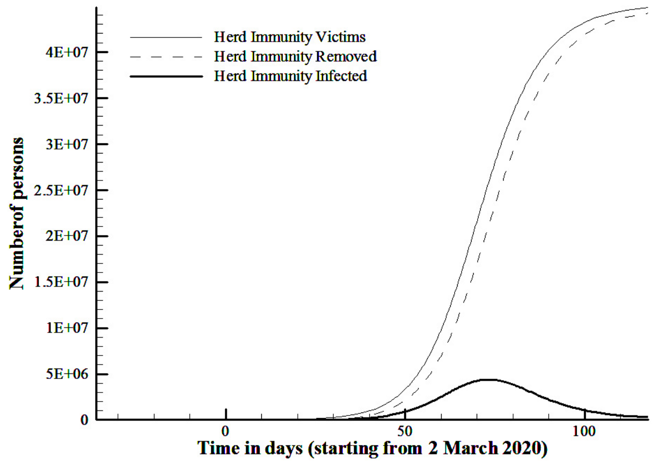


Fig. 12. The number of victims, recovered and infected people in herd immunization.

quarantine. Correspondingly, people can prevent from spreading the disease by doing some works such as keeping home quarantine and personal hygiene particularly washing hands repetitively[31,32] and maintaining appropriate social-distance since the infection rate has got low value. If any of the above subjects are not observed or not maintained and broken, the infection rate and the effective reproduction number will increase sharply and we will see a dramatic increase in the number of infected and dead people. By using the coefficient of the considered number to the total population, it is anticipated that the total number of infected people will reach to 550 000. Owning to Coronavirus incubation period time to show symptoms is varied, this may appear 2–14 days (known more as 11.5 days) after exposure,[33] it is better to determine an interval time for peak time. According to this investigation, this interval is

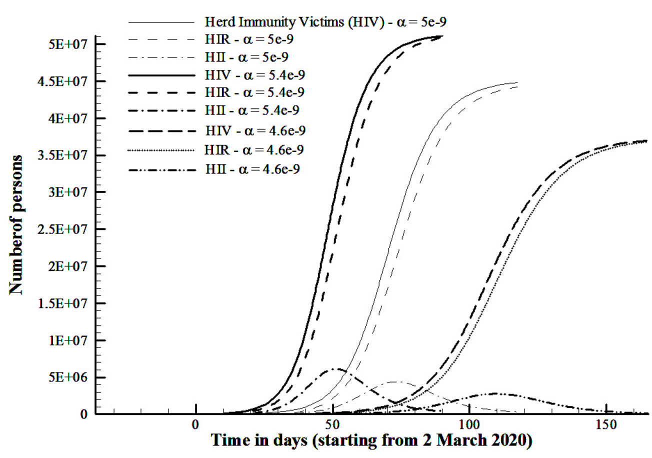


Fig. 13. The number of victims, recovered and infected people in herd immunization by different values of infection rate.

from 27 March 2020 to 7 April 2020. Hence, in this interval time, Covid-19 will be at its peak and the epidemic will disappear by mid-June.

3. Concluding Remarks

Here, we used various approaches to investigate the Covid-19 epidemy in Iran. We mainly used SIR mathematical model. In the previous studies, the number of recovered people was not considered, which led to a significant error in the calculations. However, by incorporating the available official statistical values of recovered people along with the number of susceptible people in this present study, the accuracy of results obtained by the SIR model was improved. Furthermore, another desirable feature of the current predictions is the fact that the estimation of susceptible people, who are still present in the population $S_\infty = N - V_\infty$, has a suitably lower value compared with the previous works. It means that these people would not catch the infection after the suppression of the epidemic. Also, a suitable agreement has been observed between the predictions obtained by fitting the official number of infected and deaths to the results of the SIR model (see Fig. 2). Different works should be accomplished by the government such as intervention, finding susceptible persons more rapidly and order to quarantine and by people such as keeping the quarantine, personal hygiene, and maintain appropriate social-distance that the range of reproduction number decreases. By falling into the reproduction number range, the number of infected and dead people will be decreased. Keeping the appropriate social distance such as canceling mass gathering and quarantine can be effective to have a lower reproduction number. Finally, according to this prediction, the peak time interval is from 27 March to 4 April 2020 and the epidemic will end in late spring.

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