Estimating the reproduction number of COVID-19 in Iran using epidemic modeling

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Abstract

Background: As reported by Iranian governments, the first cases of coronavirus (COVID-19) infections confirmed in Qom, Iran on February 19, 2020 (30 Bahman 1398). The number of identified cases afterward increased rapidly and the novel coronavirus spread to all provinces of the country. This study aimed to fit an epidemic model to the reported cases data to estimate the basic reproduction number (R_0) of COVID-19 in Iran.

Methods: We used data from February 21, 2020, to April 21, 2020, on the number of cases reported by Iranian governments and we employed the SIR (Susceptible-Infectious-Removed) epidemic spreading model to fit the transmission model to the reported cases data by tuning the parameters in order to estimate the basic reproduction number of COVID-19 in Iran.

Results: The value of reproduction number was estimated 4.86 in the first week and 4.5 in the second week. it decreased from 4.29 to 2.37 in the next four weeks. At the seventh week of the outbreak the reproduction number was reduced below one.

Conclusions: The results indicate that the basic reproduction number of COVID-19 was significantly larger than one in the early stages of the outbreak. However, implementing social distancing and preventing travelling on Nowruz (Persian New Year) effectively reduced the reproduction number. Although the results indicate that reproduction number is below one, it is necessary to continue social distancing and control travelling to prevent causing a second wave of outbreak.

Keywords: COVID-19, coronavirus, Iran, basic reproduction number, epidemiolgy, SIR

Background

On December 31, 2019, the novel coronavirus (COVID-19) emerged in Wuhan, China [1] and the potential of transmitting virus via human travelling caused to spread the novel corona virus to other Chinese provinces as well as the other countries [2].

Iranian governments reported the first confirmed cases of novel coronavirus (COVID-19) infections in Qom, on February 19, 2020 (30 Bahman 1398) [3]. Tehran, Guilan and Markazi were the other provinces confirmed to be infected by coronavirus during the next days of the outbreak. After one week Iranian governments confirmed that 18 out of 31 provinces of Iran were infected by the novel coronavirus. After two weeks the number of reported cases increased to 2922 people of whom 92 cases died and 552 cases recovered [3].

The aim of this study is to estimate basic reproduction number (R0) of COVID-19 in Iran. For this purpose, we use the reported data by Iranian governments and develop an epidemic model to fit on the real data by tuning the model parameters. We then use the model parameters' values to calculate the basic reproduction number of COVID-19 in Iran.

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Methods

We employ the SIR (Susceptible-Infected-Removed) epidemic model to represent the spreading process of COVID-19 in Iran. SIR model is an epidemic spreading model proposed by Kermack and McKendric [4]. We estimate the parameters of model to get a best fit on reported data of COVID-19 outbreak in Iran. The differential equations of the SIR model are given as [5]:

$$\frac{dS(t)}{dt} = -\beta S(t)\frac{I(t)}{N} \tag{1}$$

$$\frac{dI(t)}{dt} = \beta S(t)\frac{I(t)}{N} - \gamma I(t) \tag{2}$$

$$\frac{dR(t)}{dt} = \gamma I(t) \tag{3}$$

$$S(t) + I(t) + R(t) = N \tag{4}$$

Where $S(t)$, $I(t)$ and $R(t)$ are the number of susceptible, infected and removed people. We assume that removed cases are the summation of recovered and dead cases. β is the infection rate, and γ is the remove rate which is the inverse of infectious period.

The basic reproduction number, R_0, is the average number of the secondary individuals in a complete susceptible population infected by a single infected person during its spreading life [6]. When $R_0 > 1$ virus spreads through the population and when $R_0 < 1$ the outbreak will stop due to decreasing the number of new cases. According to Eq. (2) when the number of infected people increases we have:

$$\frac{dI(t)}{dt} > 0 \Rightarrow \beta S(t)\frac{I(t)}{N} - \gamma I(t) > 0$$

$$\Rightarrow I(t)\left(\beta\frac{S(t)}{N} - \gamma\right) > 0 \tag{5}$$

In a complete susceptible population which $S(t) \approx N$ the Eq. (5) can be written as the following:

$$I(t)\left(\beta\frac{S(t)}{N} - \gamma\right) > 0 \xRightarrow{S(t)\approx N} I(t)\left(\beta - \gamma\right) \Rightarrow \beta - \gamma > 0$$

$$\Rightarrow \beta > \gamma \Rightarrow \frac{\beta}{\gamma} > 1 \tag{6}$$

According to Eq. 6 and definition of R_0 we have:

$$R_0 = \frac{\beta}{\gamma} \tag{7}$$

Due to the infection of all provinces of Iran, N is assumed to be the population of Iran (81800269 in 2018) which was obtained from the World Bank [7].

We model epidemic spreading in the period from February 21, 2020 to April 21, 2020. Table 1. Shows the number of reported infected cases and reported removed cases by Iran ministry of health and medical education (MOHME) [3]. MOHME reported the first two cases of COVID-19 infections and their death on 19 February, 2020 which is indicated as day zero in Table 1.

Results

The Runge-Kutta method is used to resolve the SIR model's ODEs to fit model on reported data. Numerical simulation is conducted in MATLAB and we tune the parameters β and γ to have the best fit plot on reported data plot. We then estimate the basic reproduction number by dividing β on γ. The SIR model fitting results are shown in Fig. 1 Through Fig. 4. The red and green plots are model plots and the blue and pink plots are reported data plots. As shown in Fig. 1, we estimated that the R_0 to be 4.86 in the first week of outbreak which is significantly larger than one. We then set $\beta = 0.585$ and $\gamma = 0.13$ to fit model to reported data of the second week and we obtained $R_t = 4.5$ which is smaller than the first week. In Fig. 3 we obtained $R_t = 4.29$ for the 13th day to 16th day of outbreak. Fig. 4 shows that the reproduction number significantly decreased to 2.37 between March 6, 2020 to April 3, 2020, which could be the consequence of self-quarantining and reducing working time by government. As Nowruz occurred on March 20, 2020, many businesses as well as government offices closed and the government restricted travelling between provinces for almost three weeks. As a consequence of this policy it can be seen at Fig 5. that the reproduction number declined to one between April 4 and April 6, 2020. Fig. 6 shows that since April 7, 2020 the reproduction number has been less than one which indicates that disease will decline.

Discussion

In this study, we employed SIR epidemic model, to fit the reported data in Iran and estimate the basic reproduction number of COVID-19 in Iran.

Previous studies estimated basic reproduction number between 2.2 and 4. Chen et.al [1] showed that the basic reproduction number of COVID-19 was 3.58 using the reported data in Wuhan City, China. Read et.al [8] showed that the R_0 of COVID-19 was between 3.6 and 4. Zhao et.al [9] estimated R_0 of COVID-19 to be between 2.24 and 3.58. Other researchers estimated R_0 to be 2.68 [10], 2.6 [2] and 2.2 [11].

The simulation results of this study indicated that the R_0 of COVID-19 was 4.86 in the first week of the outbreak which was significantly larger than one. The schools and universities closed in the first week and in the second week the effective reproduction number decreased to 4.5. In the second week the working time reduced and effective reproduction number decreased to 4.29 from 13th day to 16th. Comparing to the other researches, the results showed that R_0 of COVID-19 in Iran in the early stages were higher than the previous estimated basic reproduction number [1][2][8][9][10][11].

In the next weeks of outbreak people decided to stay at home spontaneously and the government reduced the working time. The effective reproduction number decreased to 2.37 between March 6, 2020 and April 3, 2020. In Nowruz, the government restricted travelling and many businesses closed for three weeks. Hence, the reproduction number was reduced and it has been less than one since April 7.

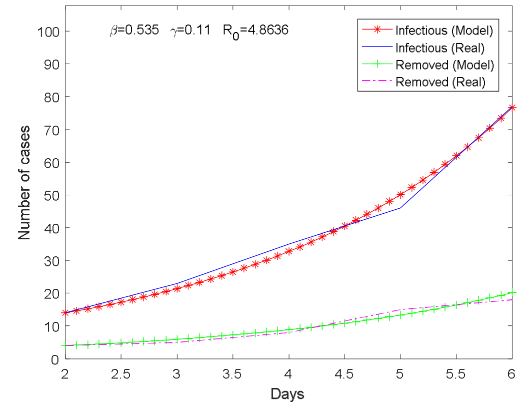

Fig. 1: Plot of COVID-19 outbreak on the first week

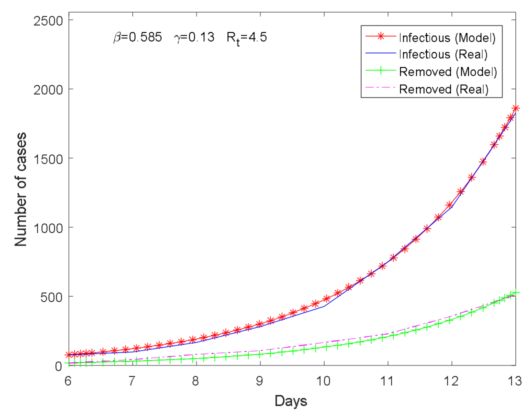

Fig. 2: Plot of COVID-19 outbreak on the second week

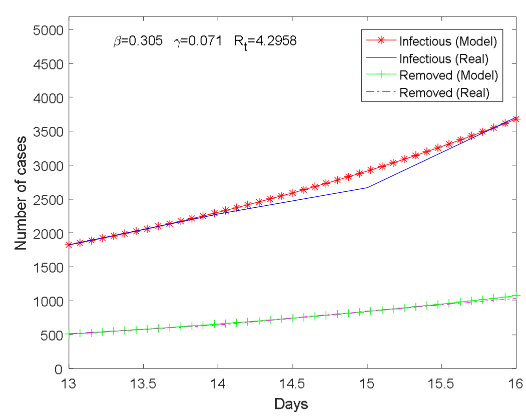

Fig. 3: Plot of COVID-19 outbreak from the 13th day to 16th.

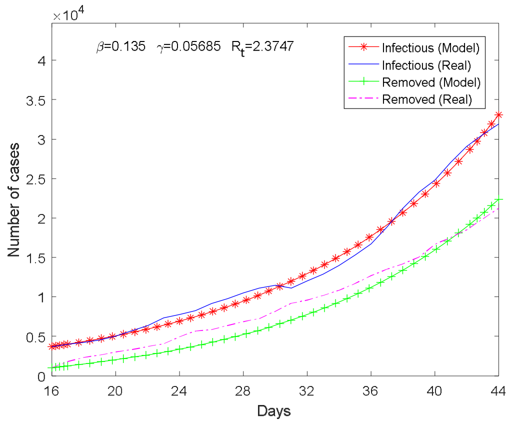

Fig. 4: Plot of COVID-19 outbreak from the 16th day to 44th.

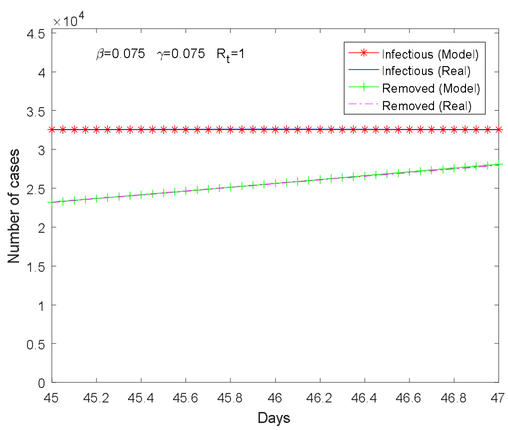

Fig. 5: Plot of COVID-19 outbreak from the 45th day to 47th.

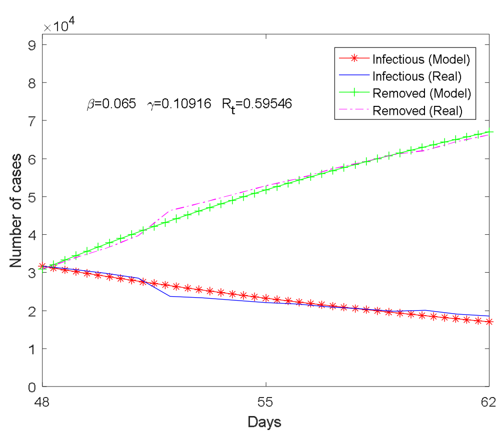

Fig. 6: Plot of COVID-19 outbreak from the 48th day to 62th.

Conclusion

Basic reproduction number of COVID-19 is an important parameter which is used to estimate the risk of COVID-19 outbreak. We estimated the basic reproduction number (R_0) of COVID-19 outbreak in Iran using SIR model by fitting the model to official reported data. According to the results, it is observed that reproduction number of COVID-19 in Iran in the early stages 4.86, 4.5 and 4.29 are higher than the previous estimated [1][2][10].

Self-quarantine and control strategies implemented by government reduced the effective reproduction number of COVID-19 below one. However, it is necessary to continue social distancing and control travelling to prevent causing a second wave of outbreak.

Abbreviations
Covid-19 coronavirus; basic reproduction number; Iran.

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Authors' contributions
ES conducted the experiments and analyzed the results and wrote the manuscript; SS collected the reported cases data and review and edited the manuscript. All authors read and approved the final manuscript.

Funding
The authors received no specific funding for this work.

Availability of data and materials
Information related to the study is in the manuscript.

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Table 1. The number of infectious and removed people reported by Iranian governments

Date	Day	Number of infected cases	Number of removed cases (recovered+dead)	Date	Day	Number of infected cases	Number of removed cases (recovered+dead)
19/02/2020	0	0	2	22/03/2020	32	12040	9598
20/02/2020	1	3	2	23/03/2020	33	12861	10188
21/02/2020	2	14	4	24/03/2020	34	13964	10847
22/02/2020	3	23	5	25/03/2020	35	15315	11702
23/02/2020	4	35	8	26/03/2020	36	16715	12691
24/02/2020	5	46	15	27/03/2020	37	18821	13511
25/02/2020	6	77	18	28/03/2020	38	21212	14196
26/02/2020	7	96	43	29/03/2020	39	23278	15031
27/02/2020	8	167	80	30/03/2020	40	24827	16668
28/02/2020	9	281	107	31/03/2020	41	27052	17554
29/02/2020	10	427	166	01/04/2020	42	29084	18509
01/03/2020	11	749	229	02/04/2020	43	30592	19871
02/03/2020	12	1144	357	03/04/2020	44	31936	21247
03/03/2020	13	1824	512	04/04/2020	45	32555	23188
04/03/2020	14	2278	644	05/04/2020	46	32612	25614
05/03/2020	15	2667	846	06/04/2020	47	32525	27975
06/03/2020	16	3710	1037	07/04/2020	48	31678	30911
07/03/2020	17	4009	1814	08/04/2020	49	30781	33805
08/03/2020	18	4238	2328	09/04/2020	50	29801	36419
09/03/2020	19	4530	2631	10/04/2020	51	28495	39697
10/03/2020	20	5020	3022	11/04/2020	52	23698	46331
11/03/2020	21	5687	3319	12/04/2020	53	23318	48368
12/03/2020	22	6370	3705	13/04/2020	54	22735	50568
13/03/2020	23	7321	4043	14/04/2020	55	22065	52812
14/03/2020	24	7779	4950	15/04/2020	56	21679	54710
15/03/2020	25	8624	5674	16/04/2020	57	20897	57098
16/03/2020	26	9142	5849	17/04/2020	58	20472	59022
17/03/2020	27	9792	6377	18/04/2020	59	19850	61018
18/03/2020	28	10516	6845	19/04/2020	60	20070	62141
19/03/2020	29	11144	7263	20/04/2020	61	19023	64482
20/03/2020	30	11466	8178	21/04/2020	62	18540	66262
21/03/2020	31	11119	9191				