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Original Article

Modeling the Dynamics and Forecasting the fourth Peak of COVID-19 in Iran Using PSO Algorithm

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Abstract

Background and aims: Iran had passed the third peak of COVID-19 pandemic, and was probably witnessing the fourth peak at the time of this study. This study aimed to model the spread of COVID-19 in Iran in order to predict the short-term future trend of COVID-19 from April 23, 2021 to May 7, 2021.

Methods: In this study, a modified SEIR epidemic spread model was proposed and the data on the number of cases reported by Iranian government from February 20, 2020 to April 23, 2021 were used to fit the proposed model to the reported data using particle swarm optimization (PSO) algorithm. Then the short-term future trend of COVID-19 cases were predicted by using the estimated parameters.

Results: The results indicated that the effective reproduction number increased in Nowruz (i.e., Persian New Year, 1400) and it was estimated to be 1.28 in the given period. According to the results from the short-term prediction of COVID-19 cases, the number of active confirmed cases in the fourth peak was estimated to be 516 411 cases on May 2, 2021.

Conclusion: Following the results from our short-term prediction, implementing strict social distancing policies was found absolutely necessary for relieving the Iran's health care system of the tremendous burden of COVID-19.

Keywords: SARS-CoV-2, Coronavirus, Epidemiology, Pandemics, Forecasting

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Introduction

Iran reported the first confirmed case of COVID-19 on February 19, 2020. In response to rapid growth of the pandemic, the government enforced social distancing policy in the majority of provinces. Closure of schools and universities, cancelation of religious gatherings and social events, business closure and the reduction of working hours, travel restrictions, as well as necessary instructions and advice were among the various interventions and policies implemented by the government to control the spread of COVID-19 in different periods. However, three peaks of COVID-19 had passed since the pandemic had taken effect. According to the reported official data, the number of daily cases started to increase in Nowruz holidays (i.e., Persian New Year, 1400), and the fourth peak of COVID-19 was likely ongoing at the time of this study.

In this study, SEIR epidemic model[1] was adapted to investigate the dynamics of the COVID-19 spread in Iran. To this end, a modified SEIR model was proposed and the dynamical equations of the proposed system were introduced. Then numerical simulation was performed using Runge-Kutta method in MATLAB under various generated epidemic parameters by using PSO algorithm to fit the model to the reported data. The estimated parameters were then used to predict short-term trends of COVID-19 under different scenarios.

Materials and Methods

Data

The official data reported by the Ministry of Health and Medical Education (MoHME)[2] from February 20, 2020 to April 23, 2021 were used to fit the proposed model to these data. The reported data included the number of new cases, new deaths, and new recoveries regarding the pandemic on a daily basis. The number of active cases as well as the cumulative number of the infected, dead, and recovered individuals were also calculated on a daily basis in order to include in model's fitting process.

Model

The proposed model was introduced using a set of ordinary differential equations. At any given time, each individual was in one of the following states:

- Susceptible (S): individuals who were vulnerable to disease.
- Exposed (E): individuals who were infected and had a potential to spread the virus to others, but their potential had not been officially confirmed.
- Infected (I): individuals who were officially confirmed

to be infected by coronavirus.

- Removed1 (R1): individuals who had been exposed but were not officially confirmed to have the disease and were not virus carrier anymore (i.e., a fraction of Exposed class who were either dead or recovered).
- Removed2 (R2): individuals who had already been confirmed to have the disease, but were either recovered or dead.

Figure 1 shows the state changing graph of the model. As shown in this figure, a susceptible case in contact with an exposed one might have turned to an exposed case with rate β. A proportion of exposed cases which were later found positive by COVID-19 test was considered as infected class. It was supposed that the confirmed cases (Infected class) were either in the hospitals or isolated at homes, hence their infectious rate was neglected.

When a susceptible individual was detected to contract the disease, s/he was added to exposed class in the model and was considered as a virus carrier to her/his contacts with rate β. An individual in the exposed class was either identified as an infected individual after $d = 1/\alpha$ days, or as a cured one who later was added to Removed1 class after $1/\gamma$ days.

The infected class members were supposed to be confirmed cases and, therefore, were isolated at homes or in the hospitals; it was also supposed that their contact with susceptible people could be ignored in the model. The parameters α and γ were considered equal in the proposed model.

S(t), E(t), I(t), $R_1(t)$ and $R_2(t)$ were considered as the numbers of susceptible, exposed, infected, removed1 (cases who had not been officially confirmed to have the disease and did not transmit it anymore), and removed2 (those who had been confirmed to have the disease, but were cured or died) nodes at time t, respectively. The equation $\beta = \tau\bar{c}$ was proposed where τ was the probability of infection due to a contact between exposed and susceptible individuals, and $\bar{c}$ was the average rate of the contact for each individual. Therefore, each exposed person was capable of infecting β susceptible individuals per unit time. The infection rate could be reduced by reducing infection probability (e.g., mandatory face mask in public) or by reducing contact rate (e.g., school and university closure).

The differential equations of the proposed model can be described as follows:

$$\begin{cases} \dfrac{dS}{dt} = -\dfrac{\beta ES}{N} \\ \dfrac{dE}{dt} = \dfrac{\beta ES}{N} - \alpha E - \gamma E \\ \dfrac{dI}{dt} = \alpha E - \mu I \\ \dfrac{dR_1}{dt} = \gamma E \\ \dfrac{dR_2}{dt} = \mu I \end{cases} \tag{1}$$

Where N is the population of Iran (83 992 949 people[3]).

Reproduction Number

The basic reproduction number, R_0, was the average number of secondary cases generated by a single case during infection period in a population, where all individuals were susceptible and there was no immunity to the disease among the population. However, the effective reproduction number, R_t, was defined as the average number of secondary cases generated by a single case when there was relative immunity to the disease among the population and it could be estimated by the product of R_0 and the fraction of the host population.

Considering the proposed model, the change in the number of exposed individuals was:

$$\frac{dE}{dt} = \frac{\beta ES}{N} - \alpha E - \gamma E = \beta E(t)\frac{S(t)}{N} - (\alpha + \gamma)E(t) \tag{2}$$

In a complete susceptible population, $\frac{S(t)}{N}$ could be approximated by 1; then the basic reproduction number of the proposed model could be calculated by the following equation:

$$R_0 = \frac{\beta}{\alpha + \gamma} \tag{3}$$

The same formula was used to calculate the effective reproduction number in different periods of time.

Error Estimation

The fitting of the proposed model to the data was performed in MATLAB by minimizing the root mean square error (RMSE) as follow:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}{N}} \tag{4}$$

The daily reported data were applied as the values of y, and the model generated data were used as the values of $\hat{y}$ to

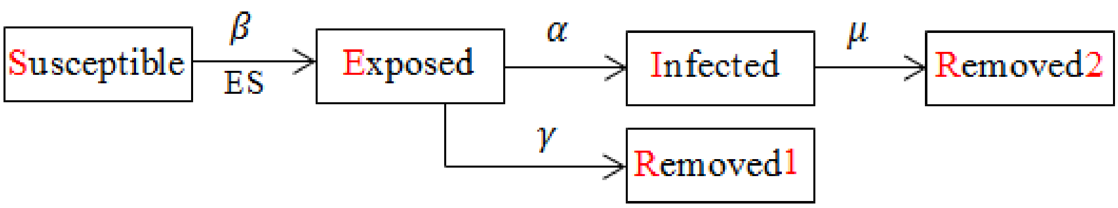

Figure 1. State Changing Graph of the Model.

calculate the error. This method provided the value of cost function with PSO algorithm to evaluate the set of model parameters that produced the best fit of model to the data.

PSO Algorithm

PSO is a population-based optimization technique originally proposed by Keneddy and Eberhart.[4] This algorithm was developed based on intelligent collective behaviors of some animals such as flocks of birds when they searched for food in a collaborative manner. The goal of an optimization problem is to determine a variable represented by a vector $X = [x_1 x_2 x_3 \ldots x_n]$ to optimize (i.e., minimize or maximize) an objective function $f(X)$.

The proposed model was calibrated based on the number of daily cases reported by the government using MATLAB, and the PSO algorithm was used to estimate the unknown parameters in order to provide the best fit. RMSE was adopted to measure the differences between the number of reported cases and those predicted by the proposed model. In order to minimize the uncertainty of parameter estimations, RMSE was applied as the cost function of PSO algorithm and, then, the process was iteratively continued by refitting the model. At each iteration, the parameters were estimated by PSO and were passed to a function to solve ODEs. The Runge-Kutta method was employed to solve the ODEs. Then the error was calculated based on Eq (4) and it was considered as the cost function of PSO for the next iteration. The process was continued until the best fit was achieved.

At the beginning of the process, all individuals were susceptible except those who were exposed in the initial state. The number of initially exposed cases was supposed to be two. The initial state was considered 10 days before the date when the first case was reported by the government. PSO algorithm was then run to estimate the epidemic parameters such that the number of infected cases in the model equaled to the number of first reported cases. The date of the first report to public, February 19, 2020, was considered as t_0 and the previous estimated exposed number was regarded as E(0). The number of the first reported cases was used as the initial numbers of each class. PSO algorithm was re-run and the same process was repeated to fit the model to the reported data in different time periods as well as to estimate epidemic parameters for different time periods. Note that the estimated number of *E* at the end of each period was used as the initial number of *E* at the next period.

Prediction

The estimated values for the parameters were employed to predict the short-term future trends of COVID-19 from April 23, 2021 to May 7, 2021. These values were estimated for different previous periods of time including the period when a strict social distancing policy was implemented by the government (i.e., from November 21, 2020 to January 8, 2021) as well as the period during Nowruz holidays (i.e., from March 17, 2021 to April 5, 2021).

Results

Figure 2 shows the curves of the reported data and the model generated curves in different periods. As can be seen in Figure 2, the model generated data are successively fitted on the reported data. The estimated parameter values of the model and the error of the fit are shown in Table 1.

According to Eq (3) and the estimated parameters in Table 1, the effective reproduction number was calculated in different periods. Figure 3 illustrates the curve of effective reproduction number. As shown in Figure 3, the effective reproduction number was increased during Newruz and it was estimated to be 1.28. The curve of effective reproduction number illustrates that it was consistent with the curves estimated by Joint Research Centre (JRC) [5] and Robert Koch Institute (RKI) [6] methods in the previous work.[7]

The estimated values of the fitted parameters were employed to predict the short-term future trends of COVID-19 in Iran. The prediction started from 429th day of the outbreak (April 23, 2021) when the model was successively fitted to its previous days. The Estimated value of the active exposed cases was adopted as the initial exposed cases, and the last reported data was used to initialize the other parameters. Different parameters of the model estimated by PSO algorithm in the previous time periods were then applied to estimate the values for the cases in the next days. The estimated parameters of two different periods were used for the prediction scenarios. Scenario 1 included the parameters of the period after Nowruz, while scenario 2 included the parameters of the period when lockdown was implemented (December, 2020).

Figure 4 displays the prediction of the infected cases' number (active confirmed case) for the following two

Table 1. The Estimated Parameters

Days of Outbreak	Error	β	μ	α = γ
[200-291]	8723	0.4417961174	0.0453617361	0.2030193035
[291-324]	1970	0.2067973824	0.0469734264	0.1122145214
[324-352]	1120	0.3219571380	0.0434597342	0.1519615433
[352-391]	986	0.3445013088	0.0400032719	0.1612623570
[391-415]	3630	0.2696158640	0.0380529788	0.1050200157
[415-429]	1840	0.3018346121	0.0319721078	0.1387626835

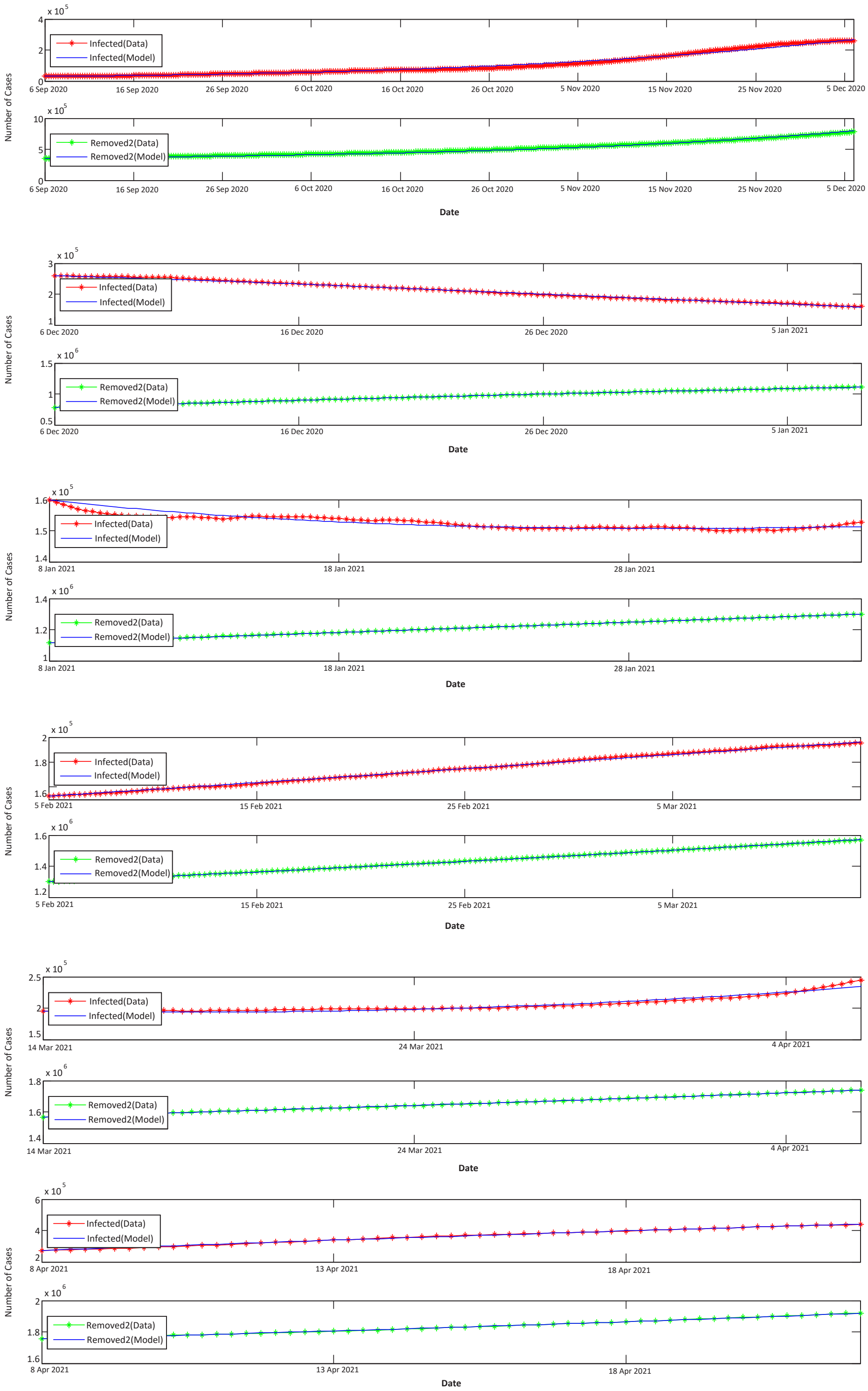

Figure 2. The Curves of Reported Data and Model Generated Curves in Different Periods.

weeks with different scenarios.

Discussion

By the time this study was conducted, several studies had been carried out on COVID-19 in Iran by researchers working in different disciplines.[7-10] Some studies had attempted to investigate the relationship between COVID-19 and meteorological and climatological factors.[11,12] Some other studies had employed mathematical models to analyze the epidemic curve and forecast the epidemic trend of COVID-19 in Iran.[13-15] The main goal of modeling COVID-19 spread was to estimate the parameters required for predicting the future trends of the epidemic, which was also capable of producing valuable results to control the epidemic.

In the present study, a modified SEIR epidemic spread model was proposed and the data on the number of cases reported by Iranian government from February 20, 2020 to April 23, 2021 were used to train the model in different periods. The PSO algorithm was employed in order to

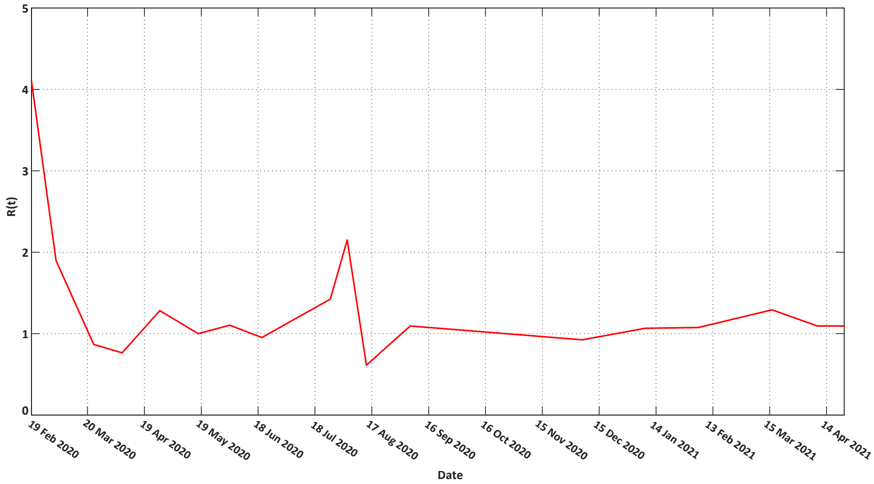

Figure 3. The Curve of Effective Reproduction Number.

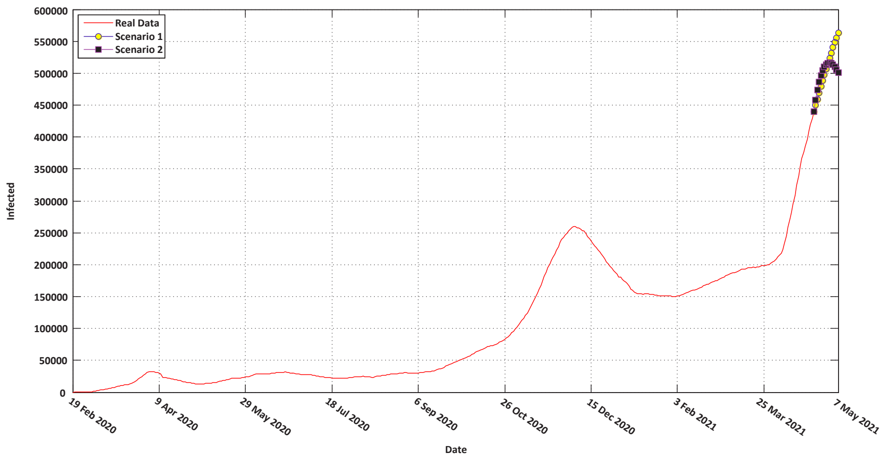

Figure 4. The Future Trends of the Fourth Peak of the Epidemic.

implement the fitting process. The RMSE which measures the differences between the number of reported cases and those predicted by the proposed model was used to evaluate the model. In order for minimizing the uncertainty of the parameter estimations, RMSE was used as cost function of PSO algorithm; then the process was iteratively continued by refitting the model, and the values of parameters were derived. Next, the estimated parameters were used to investigate the effective reproduction number and to predict the future trend.

As Figure 3 indicates, the effective reproduction number was increased during Nowruz holidays. At the time of this study, Iran had already passed three major peaks since the pandemic had taken effect. According to the officially reported data, the number of daily cases had started to increase after Nowruz holidays, and Iran was likely witnessing the fourth peak of COVID-19 pandemic at the given period.

According to the prediction results illustrated in Figure 4, two different trends were identified with two different scenarios. Scenario 1 suggested a trend with the parameters of the period after Nowruz with ongoing control policies, and Scenario 2 presented a trend with the parameter of the period when lockdown policies were implemented to control the third peak. As for the case when the lockdown was implemented immediately, the number of the fourth peak was estimated to be 516411 on May 2, 2021.

This study faced some limitations. First, the proposed model was set up based on a number of necessary assumptions. For example, it was assumed that officially confirmed cases were not carriers of the disease after confirmation due to their contact limitations; it was also assumed that the duration of confirmation and duration of transmission to the removed class due to self-quarantine were equal for exposed class. Second, the accuracy of the estimated exposed cases depended on the initial parameters such as the number of initial exposed cases. And finally, the previously estimated parameters were adopted for prediction in our model, assuming that the previous patterns would continue in the following months and years. However, the authorities often change their control strategies and the actual parameters primarily depend on these strategies, which can cause errors when making predictions using the model.

Conclusion

In sum, a modified SEIR epidemic model was proposed for modeling the spread of COVID-19 in Iran, and PSO algorithm was employed to investigate the epidemic parameters as well as to predict the future trends of the epidemic in this study. During the pandemic of COVID-19 – especially when there was an increase in the number of the reported cases, forecasting the future trend of the disease became the main focus of attention for health care planners and those responsible for controlling the disease.

Our study results indicated the probability of the fourth peak of COVID-19, which may have been attributed to the travelling and/or other activities during Nowruz holidays. According to our results, moreover, the fourth peak of COVID-19 could have placed a tremendous burden on the Iran health care system unless a strict social distancing policy was implemented immediately.

Authors' Contributions

ES planned the experiments and wrote the manuscript; and MAK implemented the algorithms and conducted the experiments. All authors read and approved the final manuscript.

Ethical Approval

Not applicable.

Competing Interests

The authors declare that they have no competing interests.

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