

# Estimation of the Reproductive Number Trend of the Novel Coronavirus “COVID-19” in Southern Iran from July to November 2020

Jafar Hasanzadeh<sup>1</sup>, MD, PhD;<sup>ORCID</sup>  
Fatemeh Rezaei<sup>2</sup>, PhD;<sup>ORCID</sup> Alireza  
Mirahmadizadeh<sup>3</sup>, MD, PhD

<sup>1</sup>Research Center for Health Sciences, Institute of Health, School of Health, Department of Epidemiology, Shiraz University of Medical Sciences, Shiraz, Iran;

<sup>2</sup>Department of Social Medicine, School of Medicine, Jahrom University of Medical Sciences, Jahrom, Iran;

<sup>3</sup>Non-communicable Diseases Research Center, Shiraz University of Medical Sciences, Shiraz, Iran

## Correspondence:

Fatemeh Rezaei, PhD;  
Jahrom University of Medical Sciences,  
Ostad Motahari St., Postal code:74148-  
46199, Jahrom, Iran

Tel: +98 71 54340405

Fax: +98 71 54331520

Email: Frezaeik@yahoo.com

Received: 02 March 2021

Revised: 06 July 2021

Accepted: 28 August 2021

## What's Known

- Due to the rapid spread of the COVID-19 virus, countries have faced a large number of infected people.
- The reproductive number can provide proper insight for designing control interventions.

## What's New

- The highest value of the reproductive number was related to public holidays and different occasions, on which there was a higher probability of people participating in ceremonies, communities, and gatherings.

## Abstract

**Background:** Effective measures to control COVID-19 should be based on an understanding of its epidemiological pattern and the evaluation of its prevalence in the community. This study aimed to examine the reproductive number (R) of COVID-19 and its trend in Fars Province in southern Iran.

**Methods:** In this ecological study, the R trend was examined from July to November 2020. Data were collected from the daily reports of Shiraz University of Medical Sciences. R is the product of three components, namely the number of infection-producing contacts per unit time, the probability of transmission per contact, and the contagiousness period. Incidence and prevalence rates were used to calculate R. The R value was calculated in Microsoft Excel 2016.

**Results:** The first and second peaks of COVID-19 were observed on July 6<sup>th</sup> and November 22<sup>nd</sup>, respectively. The median and mean of R were 1.42 and 1.41, respectively. The highest and lowest values of R were observed on October 20<sup>th</sup> (2.60) and September 1<sup>st</sup> (0.46), respectively. The values of R had a slightly decreasing trend in the second half of July and November than the first half. In the second half of August and September, an increasing trend was observed than the first half. There was not much change in the second half of October.

**Conclusion:** The highest value of R was related to the dates when there was a higher probability of exposure to the virus, including public holidays and different occasions on which the probability of people's participation in ceremonies, communities, and gatherings was higher.

Please cite this article as: Hasanzadeh J, Rezaei F, Mirahmadizadeh AR. Estimation of the Reproductive Number Trend of the Novel Coronavirus “COVID-19” in Southern Iran from July to November 2020. Iran J Med Sci. 2022;47(4):320-327. doi: 10.30476/IJMS.2021.90333.2118.

**Keywords** • Basic reproduction number • Epidemiology • COVID-19 • Iran

## Introduction

One of the important aspects of the COVID-19 disease is its extremely rapid spread through droplets released into the air, surfaces, and objects contaminated with respiratory droplets, which indicates the need to improve personal and social hygiene.<sup>1</sup> Due to the rapid spread of the COVID-19 virus, countries have faced a large number of infected individuals.<sup>2</sup> So far, 222,918,100 individuals have been infected with this virus, and 4,603,168 have died throughout the world.<sup>3</sup>

To prevent and control the COVID-19 virus promptly, it is necessary to know the correct pattern of the disease and to intelligently and continuously monitor its prevalence in communities. Therefore, the spread of the disease should be continuously monitored using epidemiology and epidemiological indicators.<sup>4,5</sup> One of the most important and practical indicators used to show the prevalence pattern of COVID-19 is the basic reproductive number or  $R_0$ .  $R_0$  refers to the average number of susceptible individuals, who develop the disease after having contact with a patient. This indicator basically shows how contagious an infectious disease can be.<sup>6</sup> The higher the value of  $R_0$ , the more contagious the disease will be. If  $R_0$  is less than one, it means that the disease will gradually disappear.<sup>7</sup> Recently, some researchers have examined the prevalence of COVID-19,<sup>8,9</sup> most of whom have estimated  $R_0$  as the main parameter to evaluate the virus transmission potential.<sup>10-12</sup> Since the study population in epidemiological studies might be functional groups of individuals in villages, towns, or cities, there is no general  $R_0$  for infection. In fact,  $R_0$  is a population-based indicator. The estimation of  $R_0$  for an infection in a population is essential for designing disease control and prevention strategies.<sup>13</sup>

There are several ways to calculate  $R$ , such as autonomous systems and non-autonomous systems.<sup>14</sup> These models require more complex calculations. Nishiura proposes a simpler model that includes incidence and prevalence.<sup>15</sup>

During an epidemic, the basic reproductive number is continuously adjusted using control measures to reduce the basic coefficient, namely the contagiousness period, the probability of infection per contact, and the number of contacts.<sup>16</sup> It should be noted that the  $R_0$  estimate assumes there is no difference in the number of secondary infections caused by a case.<sup>17</sup> However, it is possible for extremely large-scale events to occur, in which a person with no obvious symptoms may infect a large number of people, as in the case of SARS and MERS.<sup>18</sup> In different studies, different numbers have been reported for  $R_0$ : e.g., 2.32 to 3.63 in China, 3.47 to 3.54 in South Korea, and 2.06 to 2.52 in the Diamond Princess Cruise Ship.<sup>19-21</sup> Due to the high infectiousness of the virus in suspected individuals, it is necessary to calculate the basic reproductive number for preventive interventions.<sup>21</sup> Evidence has indicated that  $R_0$  can provide proper insight for designing control interventions.<sup>22</sup> Considering the rapid spread of COVID-19 and its changes, which can affect the reproductive number over time, the present study aims to examine the reproductive number trend from the beginning of July to the

end of November using the official data reported daily by Shiraz University of Medical Sciences.

## Materials and Methods

In this ecological study, the changes in the reproductive number trend were studied in Fars Province from the beginning of July to the end of November 2020. Fars Province is located in the South of Iran, and almost 6% of Iran's population lives in this Province. It is known as the fourth largest province in the country, with an area of about 122,608 Km<sup>2</sup>. According to the Statistics Center of Iran, in 2016, Fars Province had a population of 4,851,274 individuals. The capital of Fars Province is Shiraz.<sup>23</sup>

In this study, the data were collected from new daily cases, daily cumulative number, daily death rate, the cumulative number of deaths, daily recovery number, and the cumulative number of recoveries from COVID-19. The daily reports of Shiraz University of Medical Sciences were used for data collection. According to the report by Shiraz University of Medical Sciences, the definitive diagnosis of COVID-19 was made using throat and nose samples and the Real-Time Polymerase Chain Reaction (RT-PCR) test.

There are several ways to calculate  $R_0$ . In general,  $R_0$  is the product of three components, namely the number of infection-producing contacts per unit time, the probability of transmission per contact, and the contagiousness period. In this study, incidence (number of new infections) and prevalence (number of new and old infections) measurements were used to calculate  $R_0$  using the following formula:

$$R_0 = \frac{J(t)}{P(t)} \times D$$

Where  $j(t)$  was the incidence of the disease at the time ( $t$ ),  $P(t)$  was the prevalence of the disease at the time ( $t$ ), and  $D$  was the average contagiousness period of the disease.<sup>15</sup> Obviously, using this formula at the beginning of the epidemic, when everyone is susceptible, can help estimate the basic reproductive number  $R_0$ . However, as the proportion of the susceptible population gradually decreases to less than 100% of the population over time, this formula can estimate  $R_e$  or the effective reproductive number. The pre-assumption for this method is that the probability of transmission is independent of the time of infection. In this study, one-month time periods were considered, and the probability of disease transfer over one month was considered to be constant.  $R$  was calculated in Microsoft Excel 2016 for Windows (Microsoft Press, Redmond, WA, USA).

## Results

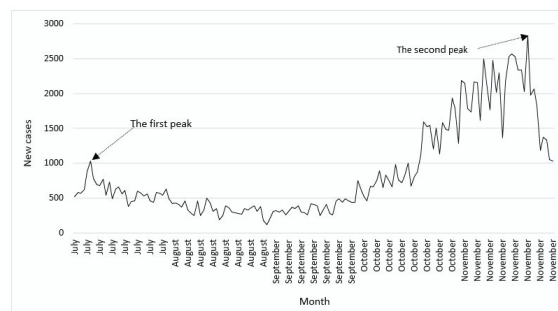
In this study, the R trend was examined in Fars Province from the beginning of July to the end of November 2020. The number of new cases, deaths, and recoveries of COVID-19 in Fars Province from July to November have been presented in table 1. During these five months, 133,058 new COVID-19 cases were reported in Fars Province, with the largest number of cases being reported in November (59,520). The largest number of deaths (1,082) and recoveries (59,298) were also reported in November.

The central indicators and the range of R changes during the five months of investigation have been presented in table 2. Accordingly, the highest mean of R was in October, and the lowest was in August (2.60 vs. 1.21). Moreover, the highest range of changes in R was observed in July, and the lowest was detected in November (1.58 vs. 1.16).

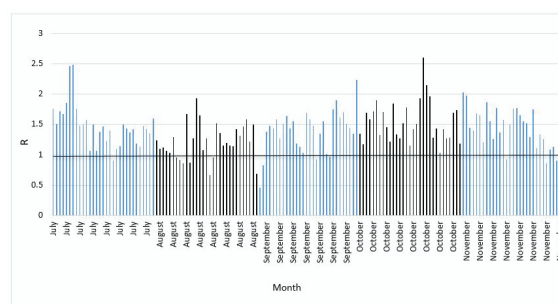
The R trend of new COVID-19 cases over the five months has been illustrated in figure 1. Accordingly, the first peak was reported on July 6<sup>th</sup> with 1,029 new cases, and the second peak was on November 22<sup>nd</sup> with 2,829 new cases.

The R trend over the five months under investigation has been depicted in figure 2. As the figure shows, the highest value of R was on October 20<sup>th</sup> (2.60), and the lowest was on September 1<sup>st</sup> (0.46). The R trend of COVID-19 in Fars Province from July to November has been presented in figure 3. In July, the median value of R was 1.47. The highest value of R was 1.48, and the lowest was 0.91. On two days (July 6<sup>th</sup> and 7<sup>th</sup>), the R value was greater than 2. The R values decreased slightly in the second half of July than its first half.

In August, the median value of R was 1.19.



**Figure 1:** This figure illustrates the trend of the new COVID-19 cases over the five months under study. The first peak was reported on July 6<sup>th</sup>, and the second peak was on November 22<sup>nd</sup>.



**Figure 2:** This figure illustrates the R trend over the five months under investigation. The highest value of R was on October 20<sup>th</sup> (2.60), and the lowest was on September 1<sup>st</sup> (0.46).

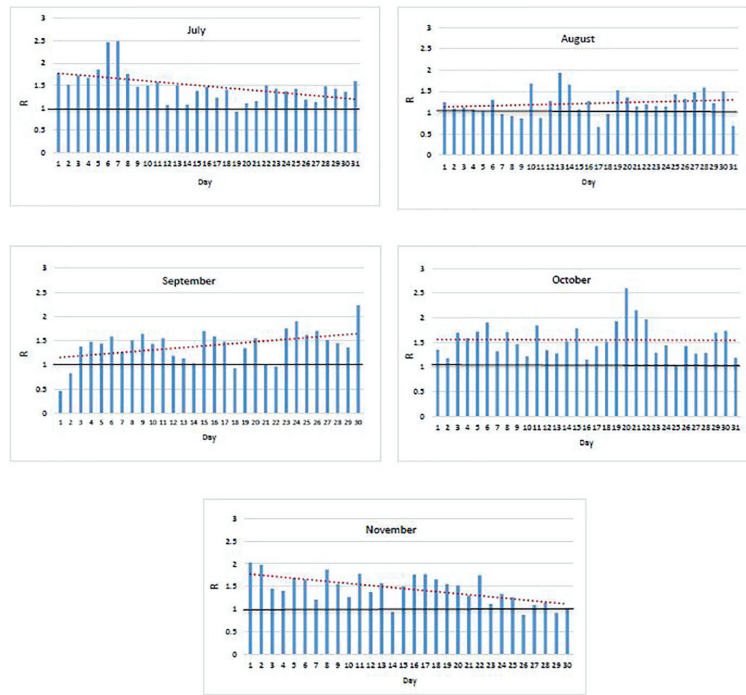
The highest value of R was 1.93, and the lowest was 0.67. In August, there were no days with R values greater than two. The mean of R decreased in August than in July. However, R values increased slightly in the second half of August than its first half. In September, the median R value was 1.46. The highest value of R was 2.23, and the lowest was 0.46. Only on September 30<sup>th</sup>, the value of R was greater than two. R values increased in the second

**Table 1:** New cases, deaths, and recoveries reported in Fars Province from July to November 2020

Month	New case N (%)	Death N (%)	Recovery N (%)
July	18704 (14.06)	330 (14.12)	7615 (6.69)
August	10739 (8.07)	312 (13.35)	11417 (10.03)
September	11449 (8.60)	188 (8.04)	10365 (9.11)
October	32646 (24.54)	425 (18.19)	25130 (22.08)
November	59520 (44.73)	1082 (46.30)	59298 (52.10)
Total	133058 (100)	2337 (100)	113825 (100)

**Table 2:** Central tendency and range of reproductive number in Fars Province from July to November 2020

Month	Minimum	Maximum	Mean±SD	Median	Range
July	0.91	2.49	1.48±0.35	1.47	1.58
August	0.67	1.93	1.21±0.29	1.19	1.26
September	0.46	2.23	1.40±0.35	1.46	1.77
October	1.04	2.60	1.55±0.34	1.46	1.56
November	0.87	2.02	1.44±0.32	1.47	1.16
Total	0.46	2.60	1.41±0.35	1.42	2.14



**Figure 3:** This figure illustrates the R trend of COVID-19 in Fars Province from July to November. In July, the R values decreased slightly in the second half of the month than its first half. In August, the R values increased slightly in the second half of the month than its first half. In September, the R values increased in the second half of the month than its first half. In October, the R values did not change much in the second half of the month compared with its first half. In November, the R values decreased in the second half of the month compared with its first half.

half of September than its first half. In October, the median R value was 1.46. The highest and lowest values of R were both greater than one (2.60 and 1.06, respectively). The value of R was greater than two on two days (20<sup>th</sup> and 21<sup>st</sup>). The R values did not change much in the second half of October than its first half. In November, the median R value was 1.47. The highest value of R was 2.02, and the lowest was 0.87. On November 1<sup>st</sup>, the R value was greater than two. The R values decreased in the second half of November than its first half.

In this study, the R trend was examined in Fars Province from the beginning of July to the end of November 2020. The number of new cases, deaths, and recoveries of COVID-19 in Fars Province from July to November have been presented in table 1. During these five months, 133,058 new cases of COVID-19 were reported in Fars Province, with the largest number of cases being reported in November (59,520). The largest number of deaths (1,082) and recoveries (59,298) were also reported in November.

The central indicators and the range of changes in R during the five months under investigation have been presented in table 2. Accordingly, the highest mean of R was in October, and the lowest was in August (2.60 vs. 1.21). Moreover, the highest range of changes in R was observed in July, and the lowest was

detected in November (1.58 vs. 1.16).

The trend of the new COVID-19 cases over the five months under study has been illustrated in figure 1. Accordingly, the first peak was reported on July 6<sup>th</sup> with 1,029 new cases, and the second peak was on November 22<sup>nd</sup> with 2,829 new cases.

The R trend over the five months under investigation has been depicted in figure 2. As the figure shows, the highest value of R was on October 20<sup>th</sup> (2.60), and the lowest was on September 1<sup>st</sup> (0.46). The R trend of COVID-19 in Fars Province from July to November has been presented in figure 3. In July, the median value of R was 1.47. The highest value of R was 1.48, and the lowest was 0.91. On two days (July 6<sup>th</sup> and 7<sup>th</sup>), the R value was greater than two. The R values decreased slightly in the second half of July than its first half.

In August, the median value of R was 1.19. The highest value of R was 1.93, and the lowest was 0.67. In August, there were no days with R values greater than two. The mean of R decreased in August than in July. However, the R values increased slightly in the second half of August than its first half. In September, the median R value was 1.46. The highest value of R was 2.23, and the lowest was 0.46. Only on September 30<sup>th</sup>, the value of R was greater than two. The R values increased in the second



half of September than its first half. In October, the median R value was 1.46. The highest and lowest values of R were both greater than one (2.60 and 1.06, respectively). The value of R was greater than two on two days (20<sup>th</sup> and 21<sup>st</sup>). The R values did not change much in the second half of October than its first half. In November, the median R value was 1.47. The highest value of R was 2.02, and the lowest was 0.87. On November 1<sup>st</sup>, the R value was greater than two. The R values decreased in the second half of November than its first half.

## Discussion

The current study presented the value of R for a five-month period based on available data. This study was the first to examine the changes in the R trend in Fars Province. During the five-month period under investigation, two peaks of COVID-19 occurred. The first peak was on July 6<sup>th</sup> with 1,029 new cases, and the second peak was on November 22<sup>nd</sup> with 2,829 new cases. During the five-month period of this study, the median and mean of R were 1.42 and 1.41, respectively. The R range was 2.14. In addition, the lowest and highest values of R were 0.46 and 2.60, respectively.

In the current study, the median of R was 1.42. Another study on the Diamond Princess Cruise Ship reported the  $R_0$  to be 2.28.<sup>21</sup> Other studies in China have reported  $R_0$  values of 2.2, 2.24-3.58, and 2.68.<sup>7, 8, 24</sup> In Iran,  $R_0$  was reported between 4 and 5.<sup>25</sup> Moreover, the  $R_0$  estimate ranged from two to three in Qom and from 3.94 to 5.14 in Tehran.<sup>25, 26</sup> The wide range and variability of  $R_0$  values reported in different studies indicate that an accurate estimation of  $R_0$  is quite challenging, as it is difficult to calculate the exact number of infected cases during an epidemic. On the other hand, the value of  $R_0$  is affected by environmental and demographic conditions, statistical caliber, and modeling methods.<sup>27</sup> Overall, the low consistency of  $R_0$  in different studies can be attributed to three possible reasons, including studying different variables, different modeling methods, and different estimation methods.<sup>17</sup> In addition to these statistical reasons, another reason can be the behavioral differences among populations. Family and social gatherings, degree of adherence to health instructions, and degree of adherence to protocols are the factors that can affect the number of contacts per day and, consequently, the value of R. Using different methods to estimate  $R_0$  might also play an important role in the differences observed in COVID-19 studies. According to Liu's findings,  $R_0$  was higher in the studies using mathematical

methods than in those making use of stochastic and statistical models.<sup>20</sup>

Based on a systematic review and meta-analysis, in which the 95<sup>th</sup> percentile of the incubation period (95% CI 9.7 to 14.2) was 11.7 days,<sup>28</sup> the incubation period was considered to be 9-14 days in the current study, and the approximate time of infection was computed accordingly. The results indicated that in July, the highest value of R was 2.49 on days 6<sup>th</sup> and 7<sup>th</sup>. Therefore, most infections had occurred between June 22<sup>nd</sup> and 28<sup>th</sup>, which coincided with the beginning of the summer holidays and family travels. Therefore, the beginning of summer vacations could be one of the reasons for the increase in the number of COVID-19 cases.

In August, the highest value of R was 1.93 on day 13<sup>th</sup>, which indicated that most infections had occurred between July 30<sup>th</sup> and August 4<sup>th</sup>. July 30<sup>th</sup> and 31<sup>st</sup> were public holidays for Eid al-Adha, and some people went on travels. Hence, travels caused the COVID-19 virus to spread. On the other hand, some people held wedding ceremonies during those holidays, and consequently, family and social gatherings resulted in the further spread of the virus.

In September, the highest value of R was 2.30 on day 30<sup>th</sup>. Therefore, most contacts with infectious cases had occurred during August 26<sup>th</sup>-31<sup>st</sup>, which coincided with the opening of schools, presence of students at schools, and people's referral to shopping centers to buy their requirements. Although the classes are now being held virtually in Iran, parents accompanied their children to schools during the early days.

In October, the highest value of R was 2.60 on day 20<sup>th</sup>, which demonstrated that most infections had occurred during October 6<sup>th</sup>-20<sup>th</sup>. October 8<sup>th</sup> was Thursday and a weekend (in Iran), as well as being an official religious holiday. Some people traveled on that holiday, which led to the spread of the disease. Some others also became infected due to their participation in religious ceremonies, family and social gatherings, and the distribution of votive offerings.

In November 1<sup>st</sup> and 2<sup>nd</sup>, the highest value of R was observed (2.02 and 1.97, respectively), which showed that most infections had occurred during the period from October 17<sup>th</sup> to 22<sup>nd</sup>.

According to the results, most infections had occurred during public holidays when people were able to travel. Therefore, travel restrictions or city lockdowns should be enforced by limiting social activities or just allowing the necessary trips. For example, all residential communities in most Chinese cities were closed down during the pandemic. In Wuhan, all people were

quarantined in their houses, and any necessary trip was made by government-designated vehicles. In Italy, France, and most European countries, individuals were required to show a printed permission to prove the necessity of their trips, and the violators were arrested. Monetary penalties (e.g., fines) can also be imposed to effectively enforce lockdowns and travel restrictions. This has been carried out in many cities in Europe and Canada.<sup>29</sup> In Vancouver, Canada, for example, individuals and businesses that do not follow social distancing and lockdown guidelines could be fined up to \$50,000.<sup>30</sup> In Iran, some restrictions were imposed to control the spread of COVID-19 since November 21<sup>st</sup>.

Overall, people should be provided with more information about how the disease could spread, especially while traveling. Additionally, they should be encouraged to follow the health protocols, such as wearing masks, observing social distancing, and handwashing, when attending ceremonies and family or social gatherings.

One of the limitations of the present study was that asymptomatic cases, undiagnosed cases, or those with false-negative test results, who were not included in the R calculation. Thus, the R value might have been underestimated.

To the best of our knowledge, this is the first study to examine the reproductive number of COVID-19 and its trend in Fars Province. However, in this study, we used the daily reports of Shiraz University of Medical Sciences. Therefore, we did not have any further information for other analyzes. Moreover, this study only included cases who were tested, and we had no access to the other cases, who were not tested. In the present study, the accuracy of the estimated R value largely depended on whether all infected cases were identified. Therefore, the R value estimation might have been biased, because a large number of infected cases might have not been identified. On the other hand, asymptomatic cases were not referred for testing, and as a result, the value of R might have been underestimated. Although a decreasing trend was observed in the value of R in late November, the results of those restrictions and the observance of health protocols could not be examined in this study, as more time is required to review the results of the abovementioned restrictions. Furthermore, other factors such as virus mutations, disease clusters, environmental factors, and demographic structure should also be considered.

## Conclusion

The first and second peaks of COVID-19 were reported on July 6<sup>th</sup> and November 22<sup>nd</sup>,

respectively. The highest and lowest values of R were observed on October 20<sup>th</sup> and September 1<sup>st</sup>, respectively. When traveling was possible due to the official holidays of the country, the value of R increased. People's participation in different events, such as celebrations, ceremonies, and family or social gatherings, also played an important role in the spread of the infection.

## Acknowledgment

The authors would like to thank Ms. Keivanshekouh at the Research Improvement Center of Shiraz University of Medical Sciences for improving the use of the English language in the manuscript.

## Authors' Contribution

J.H. and F.R. designed the project. J.H. contributed to data acquisition. F.R. and A.M. contributed to statistical analysis. F.R. and A.M. wrote the first draft of the manuscript. J.H. and F.R. critically and substantially revised the final article. All authors read and approved the final manuscript. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

## Conflict of Interest

Dr. Jafar Hasanzadeh, as the Editorial Board Member, was not involved in any stage of handling this manuscript. A team of independent experts were formed by the Editorial Board to review the editor's article without his knowledge.

## References

- 1 Zhai P, Ding Y, Wu X, Long J, Zhong Y, Li Y. The epidemiology, diagnosis and treatment of COVID-19. *Int J Antimicrob Agents*. 2020;55:105955. doi: 10.1016/j.ijantimicag.2020.105955. PubMed PMID: 32234468; PubMed Central PMCID: PMC7138178.
- 2 Doshmangir L, Ahari AM, Qolipour K, Azami S, Kalankesh L, Doshmangir P, et al. East Asia's strategies for effective response to COVID-19: lessons learned for Iran. *Quarterly Journal of Management Strategies in Health System*. 2019;4:370-3. doi:10.18502/mshsj.v4i4.2542.
- 3 Worldometers [Internet]. COVID-19 Coronavirus Pandemic. [Cited 8 September 2021]. Available from: <https://www.worldometers>.

- info/coronavirus/
- 4 Lipsitch M, Cohen T, Cooper B, Robins JM, Ma S, James L, et al. Transmission dynamics and control of severe acute respiratory syndrome. *Science*. 2003;300:1966-70. doi: 10.1126/science.1086616. PubMed PMID: 12766207; PubMed Central PMCID: PMCPMC2760158.
  - 5 Lipsitch M, Swerdlow DL, Finelli L. Defining the Epidemiology of Covid-19 - Studies Needed. *N Engl J Med*. 2020;382:1194-6. doi: 10.1056/NEJMp2002125. PubMed PMID: 32074416.
  - 6 Castillo-Chavez C, Feng Z, Huang W. *Mathematical approaches for emerging and reemerging infectious diseases: an introduction*. 1st ed. New York: Springer-Verlag; 2002.
  - 7 Zhao S, Lin Q, Ran J, Musa SS, Yang G, Wang W, et al. Preliminary estimation of the basic reproduction number of novel coronavirus (2019-nCoV) in China, from 2019 to 2020: A data-driven analysis in the early phase of the outbreak. *Int J Infect Dis*. 2020;92:214-7. doi: 10.1016/j.ijid.2020.01.050. PubMed PMID: 32007643; PubMed Central PMCID: PMCPMC7110798.
  - 8 Wu JT, Leung K, Leung GM. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. *Lancet*. 2020;395:689-97. doi: 10.1016/S0140-6736(20)30260-9. PubMed PMID: 32014114; PubMed Central PMCID: PMCPMC7159271.
  - 9 Zhao S, Musa SS, Lin Q, Ran J, Yang G, Wang W, et al. Estimating the Unreported Number of Novel Coronavirus (2019-nCoV) Cases in China in the First Half of January 2020: A Data-Driven Modelling Analysis of the Early Outbreak. *J Clin Med*. 2020;9. doi: 10.3390/jcm9020388. PubMed PMID: 32024089; PubMed Central PMCID: PMCPMC7074332.
  - 10 Anastassopoulou C, Russo L, Tsakris A, Siettos C. Data-based analysis, modelling and forecasting of the COVID-19 outbreak. *PLoS One*. 2020;15:e0230405. doi: 10.1371/journal.pone.0230405. PubMed PMID: 32231374; PubMed Central PMCID: PMCPMC7108749.
  - 11 Hermanowicz SW. Forecasting the Wuhan coronavirus (2019-nCoV) epidemics using a simple (simplistic) model. *MedRxiv*. 2020. doi: 10.1101/2020.02.04.20020461.
  - 12 Yang Y, Lu QB, Liu MJ, Wang YX, Zhang AR, Jalali N, et al. Epidemiological and clinical features of the 2019 novel coronavirus outbreak in China. *medrxiv*. 2020. doi: 10.1101/2020.02.10.20021675.
  - 13 Thomas JC, Weber DJ. *Epidemiologic methods for the study of infectious diseases*. Oxford: Oxford University Press; 2001.
  - 14 Mitchell C, Kribs C. A Comparison of Methods for Calculating the Basic Reproductive Number for Periodic Epidemic Systems. *Bull Math Biol*. 2017;79:1846-69. doi: 10.1007/s11538-017-0309-y. PubMed PMID: 28620881.
  - 15 Nishiura H. Correcting the actual reproduction number: a simple method to estimate R(0) from early epidemic growth data. *Int J Environ Res Public Health*. 2010;7:291-302. doi: 10.3390/ijerph7010291. PubMed PMID: 20195446; PubMed Central PMCID: PMCPMC2819789.
  - 16 Riley S, Fraser C, Donnelly CA, Ghani AC, Abu-Raddad LJ, Hedley AJ, et al. Transmission dynamics of the etiological agent of SARS in Hong Kong: impact of public health interventions. *Science*. 2003;300:1961-6. doi: 10.1126/science.1086478. PubMed PMID: 12766206.
  - 17 Bauch CT, Lloyd-Smith JO, Coffee MP, Galvani AP. Dynamically modeling SARS and other newly emerging respiratory illnesses: past, present, and future. *Epidemiology*. 2005;16:791-801. doi: 10.1097/01.ede.0000181633.80269.4c. PubMed PMID: 16222170.
  - 18 Al-Tawfiq JA, Memish ZA. Drivers of MERS-CoV transmission: what do we know? *Expert Rev Respir Med*. 2016;10:331-8. doi: 10.1586/17476348.2016.1150784. PubMed PMID: 26848513; PubMed Central PMCID: PMCPMC7103679.
  - 19 Choi S, Ki M. Estimating the reproductive number and the outbreak size of COVID-19 in Korea. *Epidemiol Health*. 2020;42:e2020011. doi: 10.4178/epih.e2020011. PubMed PMID: 32164053; PubMed Central PMCID: PMCPMC7285447.
  - 20 Liu Y, Gayle AA, Wilder-Smith A, Rocklöv J. The reproductive number of COVID-19 is higher compared to SARS coronavirus. *J Travel Med*. 2020;27. doi: 10.1093/jtm/taaa021. PubMed PMID: 32052846; PubMed Central PMCID: PMCPMC7074654.
  - 21 Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet*. 2020;395:497-506. doi: 10.1016/S0140-6736(20)30183-5. PubMed PMID: 31986264; PubMed Central PMCID: PMCPMC7159299.
  - 22 Diekmann O, Heesterbeek JA, Roberts MG. The construction of next-generation matrices

- for compartmental epidemic models. *J R Soc Interface*. 2010;7:873-85. doi: 10.1098/rsif.2009.0386. PubMed PMID: 19892718; PubMed Central PMCID: PMCPMC2871801.
- 23 Ranjbar K, Hosseinpour H, Shahriarirad R, Ghaem H, Jafari K, Rahimi T, et al. Students' attitude and sleep pattern during school closure following COVID-19 pandemic quarantine: a web-based survey in south of Iran. *Environ Health Prev Med*. 2021;26:33. doi: 10.1186/s12199-021-00950-4. PubMed PMID: 33691642; PubMed Central PMCID: PMCPMC7945607.
  - 24 Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, et al. Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus-Infected Pneumonia. *N Engl J Med*. 2020;382:1199-207. doi: 10.1056/NEJMoa2001316. PubMed PMID: 31995857; PubMed Central PMCID: PMCPMC7121484.
  - 25 Aghaali M, Kolifarhood G, Nikbakht R, Saadati HM, Hashemi Nazari SS. Estimation of the serial interval and basic reproduction number of COVID-19 in Qom, Iran, and three other countries: A data-driven analysis in the early phase of the outbreak. *Transbound Emerg Dis*. 2020;67:2860-8. doi: 10.1111/tbed.13656. PubMed PMID: 32473049; PubMed Central PMCID: PMCPMC7300937.
  - 26 Azimi SS, Koohi F, Aghaali M, Nikbakht R, Mahdavi M, Mokhayeri Y, et al. Estimation of the basic reproduction number ( $R_0$ ) of the COVID-19 epidemic in Iran. *Med J Islam Repub Iran*. 2020;34:95. doi: 10.34171/mjiri.34.95. PubMed PMID: 33315980; PubMed Central PMCID: PMCPMC7722950.
  - 27 Delamater PL, Street EJ, Leslie TF, Yang YT, Jacobsen KH. Complexity of the Basic Reproduction Number ( $R_0$ ). *Emerg Infect Dis*. 2019;25:1-4. doi: 10.3201/eid2501.171901. PubMed PMID: 30560777; PubMed Central PMCID: PMCPMC6302597.
  - 28 McAloon C, Collins A, Hunt K, Barber A, Byrne AW, Butler F, et al. Incubation period of COVID-19: a rapid systematic review and meta-analysis of observational research. *BMJ Open*. 2020;10:e039652. doi: 10.1136/bmjopen-2020-039652. PubMed PMID: 32801208; PubMed Central PMCID: PMCPMC7430485.
  - 29 Oum TH, Wang K. Socially optimal lockdown and travel restrictions for fighting communicable virus including COVID-19. *Transp Policy (Oxf)*. 2020;96:94-100. doi: 10.1016/j.tranpol.2020.07.003. PubMed PMID: 32834681; PubMed Central PMCID: PMCPMC7346821.
  - 30 Mangione K [Internet]. Vancouver can now enforce physical distancing with fines up to \$50K. [Cited 23 March 2020]. <https://bc.ctvnews.ca/vancouver-can-now-enforce-physical-distancing-with-fines-up-to-50k-1.4864402>.