

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

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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 6th and November 22nd, 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 20th (2.60) and September 1st (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. 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.¹ Due to the rapid spread of the COVID-19 virus, countries have faced a large number of infected individuals.² So far, 222,918,100 individuals have been infected with this virus, and 4,603,168 have died throughout the world.³

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.^{4, 5} 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.⁶ 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.⁷ Recently, some researchers have examined the prevalence of COVID-19,^{8, 9} most of whom have estimated R_0 as the main parameter to evaluate the virus transmission potential.¹⁰⁻¹² 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.¹³

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

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.¹⁶ It should be noted that the R_0 estimate assumes there is no difference in the number of secondary infections caused by a case.¹⁷ 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.¹⁸ 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.¹⁹⁻²¹ Due to the high infectiousness of the virus in suspected individuals, it is necessary to calculate the basic reproductive number for preventive interventions.²¹ Evidence has indicated that R_0 can provide proper insight for designing control interventions.²² 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 square Kilometers. 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.²³

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.¹⁵ 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 6th with 1,029 new cases, and the second peak was on November 22nd 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 20th (2.60), and the lowest was on September 1st (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 6th and 7th), 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.

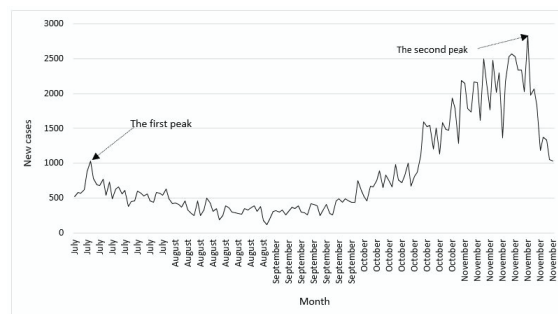


Figure 1: This figure illustrates the trend of the new COVID-19 cases over the five months under study. The first peak was reported on July 6th, and the second peak was on November 22nd.

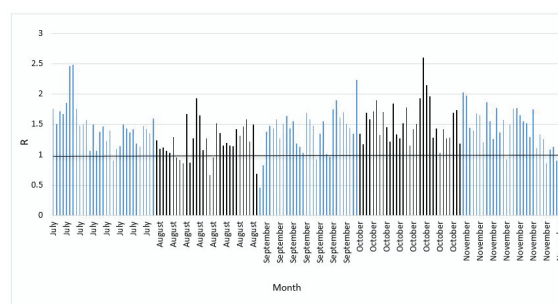


Figure 2: This figure illustrates the R trend over the five months under investigation. The highest value of R was on October 20th (2.60), and the lowest was on September 1st (0.46).

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 30th, 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

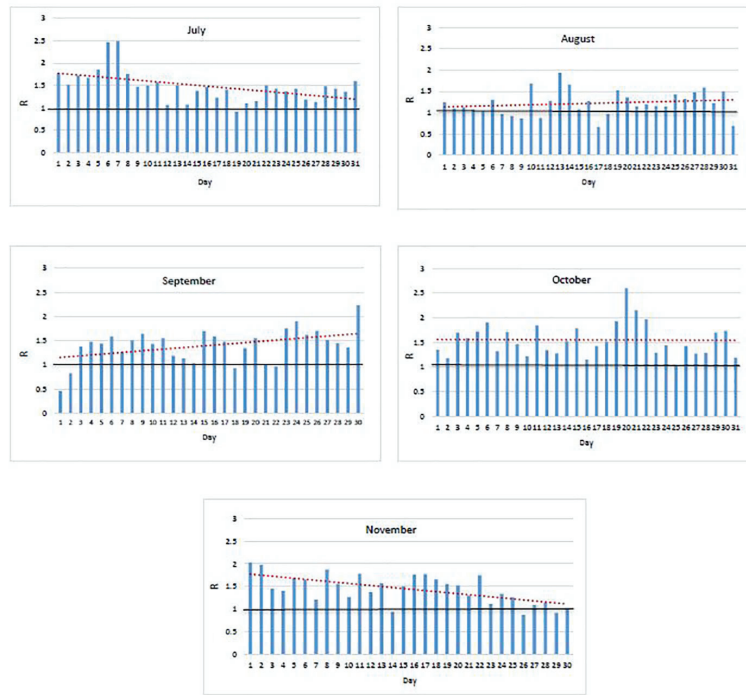


Figure 3: This figure illustrates the R trend of COVID-19 in Fars Province from July to November. In July, the R values decreased slightly in the second half of the month than its first half. In August, the R values increased slightly in the second half of the month than its first half. In September, 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 (20th and 21st). 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 1st, 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).

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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 6th with 1,029 new cases, and the second peak was on November 22nd 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 2.28.²¹ Other studies in China have reported R_0 values of 2.2, 2.24-3.58, and 2.68.^{7, 8, 24} In Iran, R_0 was reported between 4 and 5.²⁵ Moreover, the R_0 estimate ranged from two to three in Qom and from 3.94 to 5.14 in Tehran.^{25, 26} 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.²⁷ 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.¹⁷ 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.²⁰

Based on a systematic review and meta-analysis, in which the 95th percentile of the incubation period (95% CI 9.7 to 14.2) was 11.7 days,²⁸ 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 6th and 7th. Therefore, most infections had occurred between June 22nd and 28th, 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 13th, which indicated that most infections had occurred between July 30th and August 4th. July 30th and 31st 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 30th. Therefore, most contacts with infectious cases had occurred during August 26th-31st, 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 20th, which demonstrated that most infections had occurred during October 6th-20th. October 8th 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 1st and 2nd, 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 17th to 22nd.

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.²⁹ In Vancouver, Canada, for example, individuals and businesses that do not follow social distancing and lockdown guidelines could be fined up to \$50,000.³⁰ In Iran, some restrictions were imposed to control the spread of COVID-19 since November 21st.

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 6th and November 22nd,

respectively. The highest and lowest values of R were observed on October 20th and September 1st, 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.

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.

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