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Research Letter

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# Rising summer temperatures do not reduce the reproduction number of COVID-19

**Ebrahim Sahafizadeh**[1,*] **and Samaneh Sartoli**[2]

[1]Department of Computer Engineering, Persian Gulf University, Persian Gulf, Bushehr 7516913817, Iran and [2]Department of Humanities, Payame Noor University, PO Box 19395-4697 Tehran, Iran

*To whom correspondence should be addressed. Email: sahafizadeh@pgu.ac.ir

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On 31 December 2019, the novel coronavirus (COVID-19) emerged in Wuhan, China and rapidly spread globally.[1] The aim of this study is to investigate the effect of summer temperature on the reproduction number and the spread of COVID-19. For this purpose, we use COVID-19 reported cases and weather data of Bushehr, one of the warmest provinces of Iran, from April to 12 June 2020, reported by Bushehr Province University of Medical Science (http://www.bpums.ac.ir/En) and Bushehr meteorological organization (http://www.bushehrmet.ir), respectively, to investigate the effect of rising temperature and humidity on the reproduction number and the spread of COVID-19.

The first confirmed cases of COVID-19 in Iran were reported on 19 February 2020 in Qom. Although the outbreak quickly moved to other provinces of Iran and the initial basic reproduction number was estimated to be more than four,[2] Bushehr was the last province confirmed to be infected in the third week of the outbreak (on 5 March 2020). Bushehr is one of the warmest provinces of Iran and attracts many tourists in winter and Nowruz (Persian New Year) holidays every year. In this case, according to the idea that high temperature and humidity slow down the spread of COVID-19, after the outbreak in Iran, many people rushed to Bushehr. This phenomenon led to a strong travelling ban in this province and visitors were forced to get back to their cities before entering Bushehr; and inhabitants of Bushehr spontaneously quarantined themselves, which effectively controlled the spread of COVID-19. Till the end of March 2020, the cumulative number of reported cases remained below 100. On 5 April 2020, the president announced Bushehr as the white province and authorized the local authorities to reopen schools and universities; however, schools and universities remained close. As the temperature increased not only was the number of COVID-19 cases not reduced but it also increased such that Bushehr was announced as a 'red' province on 13 June 2020.

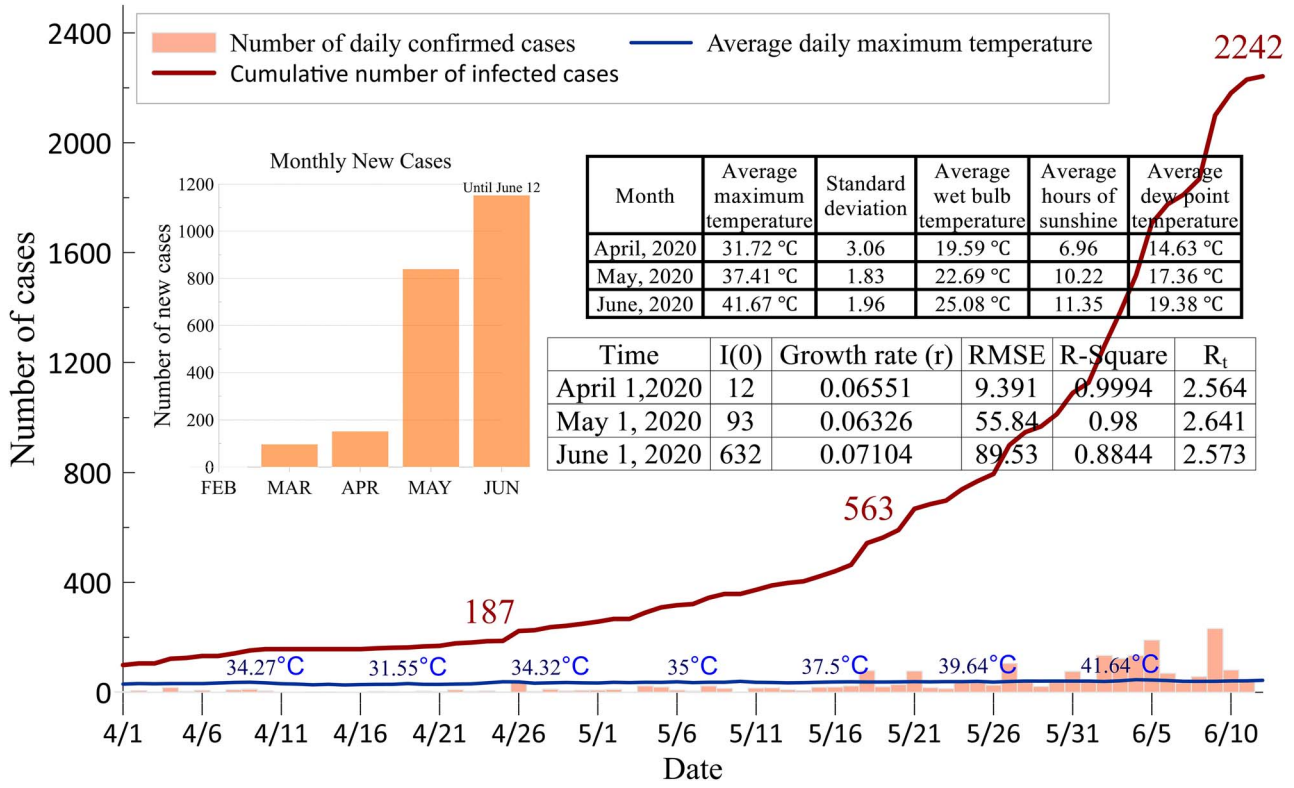
We employ SIR (Susceptible-Infected-Removed)[3] epidemic modelling and exponential growth rate[4] to model the spreading process of COVID-19 in Bushehr and estimate the effective reproduction number. We use root mean squared error (RMSE) to quantify the accuracy of the exponential regression. The exponential function is a widely used function to predict the trend of epidemics as follows.

$$I(t) = I(0)e^{rt}, \tag{1}$$

where $I(t)$ and $I(0)$ are the number of infected cases at time $t$ and time 0, respectively. In this case, $R_0 = \frac{r}{\gamma} + 1$,[5] where $R_0$ is the basic reproduction number, and $\gamma$ is the remove rate. We set $I(0) = 12$ as the number of infected cases on 31 March 2020 to fit the exponential function to reported data. We estimate the parameter $r = 0.06551$ with 95% confidence bound. To estimate $\gamma$ we use SIR model as follows:

$$\frac{dS(t)}{dt} = -\beta S(t)\frac{I(t)}{N}, \frac{dI(t)}{dt} = \beta S(t)\frac{I(t)}{N} - \gamma I(t),$$
$$\frac{dR(t)}{dt} = \gamma I(t), S(t) + I(t) + R(t) = N, \tag{2}$$

where $S(t)$, $I(t)$ and $R(t)$ represent the number of susceptible, infected and removed people and $N$ is assumed to be the population of Bushehr province 1163 400 in 2016.[6] We set $\gamma = \beta - 0.06551$ and fit SIR curve to reported data with the least RMSE, and $\gamma$ is estimated to be 0.04188, Hence, $R_t = \frac{0.06551}{0.04188} + 1 = 2.564$. We repeated the same process and estimated $R_t$ for different time periods. We also used the average maximum temperature, wet bulb temperature, hours of sunshine and dew point of Bushehr province during April, May and June to investigate the effect of rising temperature and humidity on the spread of COVID-19. Figure 1 shows that increasing the temperature




| Month | Average maximum temperature | Standard deviation | Average wet bulb temperature | Average hours of sunshine | Average dew point temperature |
|---|---|---|---|---|---|
| April, 2020 | 31.72 °C | 3.06 | 19.59 °C | 6.96 | 14.63 °C |
| May, 2020 | 37.41 °C | 1.83 | 22.69 °C | 10.22 | 17.36 °C |
| June, 2020 | 41.67 °C | 1.96 | 25.08 °C | 11.35 | 19.38 °C |

| Time | I(0) | Growth rate (r) | RMSE | R-Square | $R_t$ |
|---|---|---|---|---|---|
| April 1,2020 | 12 | 0.06551 | 9.391 | 0.9994 | 2.564 |
| May 1, 2020 | 93 | 0.06326 | 55.84 | 0.98 | 2.641 |
| June 1, 2020 | 632 | 0.07104 | 89.53 | 0.8844 | 2.573 |

**Figure 1.** Epidemic curves and parameters, and the average monthly temperatures.

and humidity has no impact on reproduction number and the spread of COVID-19. As can be seen in Figure 1, the dry and wet bulb temperature, hours of sunshine and dew point in May is significantly higher than April; however, the number of new cases in May is four times greater than that in April. Although the value of $R_t$ decreases 0.068 from May to June, it is still higher than that of April despite the lower temperature in April. We believe this reduction is not related to the effect of temperature, and it may be rather caused by the size of data in June, which are officially reported until June 12.

The effect of temperature on COVID-19 transmission has been widely studied. Some of these studies show that high temperature reduces the spread of COVID-19,[7,8], whereas some others indicate no association between temperature and transmission of COVID-19.[9,10] The results of this study showed that rising summer temperatures do not reduce the reproduction number and the spread of COVID-19, which is also compatible with the higher incidence of cases in the USA (https://covid19.who.int/region/amro/country/us).

This study has limitations. First, our study is concerned with a specific region. Second, it may be argued that the sample size is small. However, this study contradicts the findings that suggest the possibility of seasonal variation in temporal patterns of COVID-19 outbreak. Rising summer temperature may impact the behaviour of people that cause to increase the new cases in tropical climate regions such as Bushehr. People may be bothered by face mask as the weather gets hot, so they may stop using face mask. High temperature and humidity also cause perspiring and people may touch their faces and eyes. For saving energy, they also close the doors and windows of homes, offices and shops, and turn on air conditioner which may circulate virus. Hence, any policy to control the spread of COVID19 based on climate alone should be cautiously implemented.

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## Conflict of interest

The authors declare that they have no conflict of interest.

## Author contributions

E.S. analysed the data and wrote the manuscript; S.S. collected data and revised and edited the manuscript. All authors read and approved the final manuscript.

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