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Environmental risk factors of the mortality of COVID-19 in Shiraz: Distributed lag nonlinear model

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Abstract

Introduction: COVID-19 is an infectious disease first reported in Wuhan, China on December 31, 2019. Environmental factors are considered important risk factors due to the infectiousness of the disease of COVID-19. The purpose of this study is to investigate the environmental risk factors of COVID-19 in Shiraz, Iran.

Materials and Methods: This study is based on daily scale data of COVID-19 disease cases and environmental variables from February 2020 to December 2022, using a distributed lag nonlinear model (DLNM) with a zero-inflated Poisson (ZIP) link function to assess the nonlinear and lag effects of temperature on the death of COVID-19.

Results: The average daily deaths were 2.2±2.3. A significant effect was reported between temperature and its delays, the number of hospitalized patients, and the spatial-temporal effects on the number of daily deaths due to the COVID-19 disease. The effect of average wind speed was not statistically significant.

Conclusion: The findings of the present study showed the negative effect of high temperatures on increasing the number of deaths within the next two weeks. This effect can be assigned to the increase in people's movements in pleasant weather. Therefore, it is necessary to control the movement of people when the weather is pleasant.

Keywords: Infectious disease, COVID-19, distributed lag nonlinear model, environmental factors, temperature, time series

1. Introduction

The COVID-19 disease was first identified in December 2019 in Hubei province and Wuhan City of China and led to one of the biggest threats to global health after the Spanish flu (1918) in the last two centuries[1].

In general, there were two methods of direct and indirect transmission for the transmission of COVID-19. The direct mode includes transmission through respiratory suspended particles, other body fluids and secretions, and mother-to-child. Indirect transmission may occur through the surfaces in the close environment of the infected patient [2].The incubation period of the COVID-19 disease refers to the period when the sick person has no symptoms between the time he is infected with the COVID-19 virus and the time the symptoms of the disease begin. This period may last an average of 5 to 6 days (similar results for the median), with a range of 1 to 14 days (interquartile range of 5% and 95%) [3, 4]. The combination of the multiplicity of transmission methods with the long incubation period has led to the dangerousness of this disease. Therefore, according to the reports until September 1402, more than 772 million confirmed cases and nearly seven million deaths due to the disease of COVID-19 were reported in the world. In Iran, more than seven million confirmed cases and more environmental variables such as temperature are complex factors that can have multiple effects on COVID-19 death [5].

One of these methods is changing the behavior of human societies in the face of temperature. For example, in different seasons, people's behavior against COVID-19 may change. In warmer seasons, people may be more outdoors and generally move their activities outside [6].

Another way to examine the effect of temperature on mortality due to COVID-19 is to change the behavior of the COVID-19 disease. Due to the effect of temperature on the virus, the behavior and characteristics of the disease may change at different temperatures [7].

In addition, the change in the body's resistance at different temperatures can also play a role in the effect of temperature on the mortality of COVID-19. In general, the body's resistance to diseases and destructive factors in high and low temperatures may vary. At high temperatures, the body's resistance to diseases may decrease, thus increasing the possibility of death due to COVID-19 [8].

However, there is a need for more studies in this field to summarize and examine more precisely these factors and their effects. These studies can help policymakers and health managers identify the best strategies to deal with the disease in different temperature conditions.

In a similar study, Zhu et al [9]. Investigated the effect of temperature on death due to the COVID-19 disease. In this study, it was acknowledged that the effect of temperature on death is U-shaped and both low and high temperatures can lead to an increase in the number of deaths.

This study aimed to investigate the relationship between environmental variables and the number of daily deaths. The results of this research can be used to estimate the number of daily deaths using variables that can be easily collected.

2. Materials and Methods

Data collection

Data related to COVID-19 was collected from hospitals in Shiraz, Fars, from February 2020 to December 2022. Data for each patient included age, gender, date of hospitalization, date of discharge or death, and duration of hospitalization. Daily information on COVID-19 was calculated using individual information. Therefore, variables such as the number of hospitalized patients and the number of daily deaths were calculated based on individual hospital information. Information related to the environment, including temperature and wind speed, was received from the Iranian Meteorological Organization. Several reported the effect of temperature on the survival rate of the COVID-19 virus in a laboratory environment. For this reason, this variable was chosen to determine the effect of temperature on human mortality due to the COVID-19 disease. Considering the viral nature of the COVID-19 disease, it seems important to consider the spatial and spatio-temporal effects. Because the COVID-19 virus is airborne, wind speed can be an important factor in the spread of this disease and as a result increase the death rate caused by COVID-19. It is also obvious that as the number of people hospitalized due to COVID-19 increases, the number of people who die due to COVID-19 will also increase. It should be noted that the collected information was cleaned without bias, and there was no intervention in data collection. Regarding data cleaning, the people who were not the citizens of Shiraz were removed from the study. In addition, considering that all data was calculated from individual information, there was no missing data.

Statistical analysis

Because there were many days without deaths of COVID-19in the period February 2020 to December 2022; In the modeling, the link function was considered as zero-inflated Poisson (ZIP). ZIP is used when the number of zero observations is greater than the expected value in the Poisson distribution [10].

It has been pointed out in many studies that the effect of air temperature on health usually has a delayed effect and this relationship is not linear [11-13]. For this reason, a Distributed lag non-linear model (DLNM) [14,15]. along with a generalized additive model (GAM) [16,17] was suggested to analyze the non-linear relationship, the effect of average temperature and the effect of its delays, as well as other variables in the research on daily mortality due to COVID-19.

In the collected individual data, the average length of hospitalization was 21 days, and the incubation period of COVID-19 was reported between 5–7 days in other studies [3,4]. According to the hospitalization period and the incubation period, the maximum delay for the temperature variable was considered to be 30 days. It is also worth pointing out that the Akaike information criterion (AIC) also indicates the appropriateness of a 30-day delay.

We selected equation as the final model:

$$\log[E(Y_t)] = \beta + \sum_{k=0}^{30} f(temp_{t-k}) + f(\text{Occupation}_t) + f(\text{Meanfm}_t) + f(day) + t(lat, long) + tp\big(t(lat, long), f(day)\big)$$

Occupation, temp, Meanfm, and E(Y) represent the number of hospitalized cases, average temperature, average wind speed, and average number of deaths on day t, respectively. Lat and long indicate longitude and latitude. The functions f(), t(), and tp() represent the cubic spline[18], the regression thin plane spline [19], and the tensor product spline [20]. Regarding basis functions with more than one variable, mainly when the variables are of the same type (such as two measurements of volume or longitude and latitude), the smoothing function of the regression thin plane or Duchon is used. Also, when the variables are not the same, the tensor product is used. Because the tensor product is relatively stable to scale change, but regression thin plane or Duchon smoothing functions if the variables are not the same; modifying the scale in a variable can change the results. Regarding similar basis functions, such as Duchon and regression thin plate or cubic spline and adaptive spline, etc., the AIC criterion was used.

P-values <0.05 were considered statistically significant. All statistical analyses and graphical charts were performed with the R software environment (version 4.3.1). The software packages "mgcv", "tsModel" and "dlnm" were used to investigate the effects of nonlinear delay effects.

3. Results

Descriptive analysis

From February 2020 to December 2022, the number of people infected with COVID-19 in Shiraz was reported to be 41,076. Of these, 2,257 people died. The average number of daily deaths was 2.2 and the highest number of daily deaths was 14. Other descriptive statistics are listed in Table 1. Also, the descriptive diagrams of the research variables and the two-by-two effect of the research variables are set in Figure 1. Figure 1 shows the relationship between two variables. Pearson's correlation value is inserted above the diameter of the figure. Also, below the diameter of the figure, the two-by-two distribution diagram of the variables is drawn. The combination of the histogram and the density of each variable is also drawn on the diameter. For example, Figure 1 provides information including the relationship between the number of daily deaths and the number of daily hospitalizations, as well as the trend of the number of hospitalizations and the temperature trend over time.

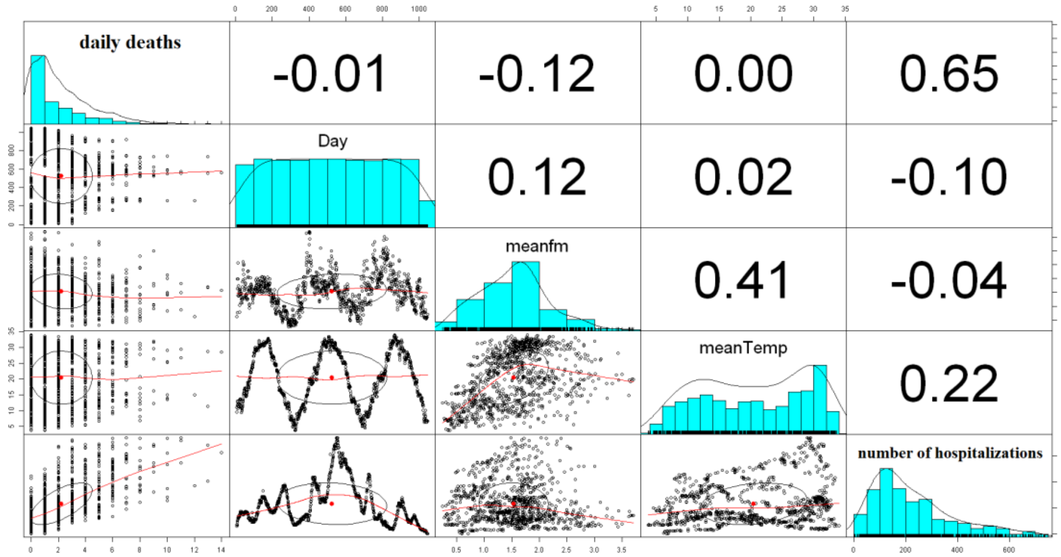

Figure 1. Description of two-by-two relationship between continuous research variables. The Figure shows the relationship between two variables, Pearson's correlation value is inserted above the diameter of the figure. Also, below the diameter of the figure, the two-by-two distribution diagram of the variables is drawn. The combination of histogram and density of each variable is also drawn on the diameter.

Table 1. Summary statistics for daily variables in Shiraz

Variable	Symbol	Mean±SD	Median	Minimum	Maximum
Average temperature	MeanTemp	20.5±8.4	20.6	3.8	34.0
Average wind speed	Meanfm	1.5±0.6	1.6	0.2	3.7
Number of hospitalizations	Occupati on	230.5±161.0	177.5	1	737
Number of deaths	Death	2.2±2.3	2.0	0	14

Zero-inflated Poisson distributed lag nonlinear model

A significant effect was reported between the variables of temperature and its delay, the number of hospitalized patients, and spatial-temporal effects on the number of daily deaths caused by the disease of COVID-19. The effect of average wind speed was not statistically significant [Table 2].

With the increase in the number of hospitalizations, the effect of this variable on the number of daily deaths due to the COVID-19 disease increased exponentially, and this relationship was observed in a non-linear way [Figure 2].

The variable effect of temperature and its delays on daily death is shown in a three-dimensional figure [Figure 3]. To interpret and better understand this figure, cuts were taken at temperatures of 15°C and 30 °C [Figures 4 and 5]. At a temperature of 15 °C, over time (delay), the effect of temperature on daily death decreases [Figure 4]. At a temperature of 30°C, the effect of temperature changes completely, and over time, the effect of temperature on death increases [Figure 5].

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Table 2. Significance of estimates of the model

Variable	edf	F	P-value
Day	5.4	9.7	0.001>
Occupation	5.0	45.6	0.001>
MeanTemp and delays	8.5	3.0	0.001>
Meanfm	1.0	0.1	0.720
Spatial (lat, long)	1.0	3.1	0.077
Spatial- Day	4.1	2.6	0.014

‘‘edf’’ represents the effective degrees of freedom of the functional parameters

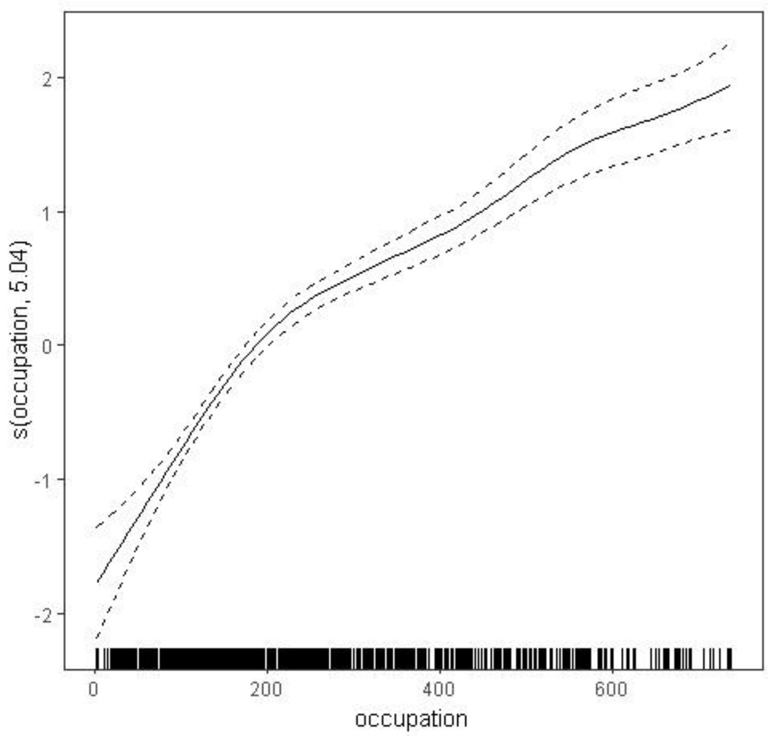

Figure 2. The non-linear effect of the number of hospitalizations in Shiraz hospitals on the number of COVID-19 deaths

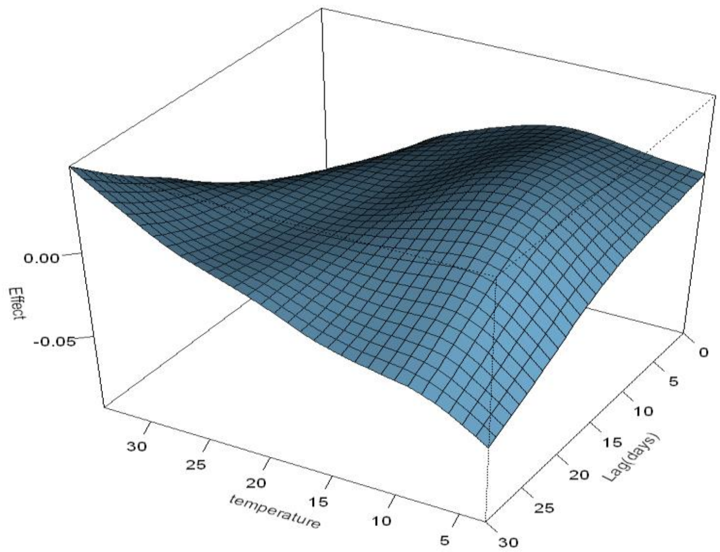

Figure 3. The non-linear effect of temperature and temperature delays on the number of COVID-19 deaths in Shiraz

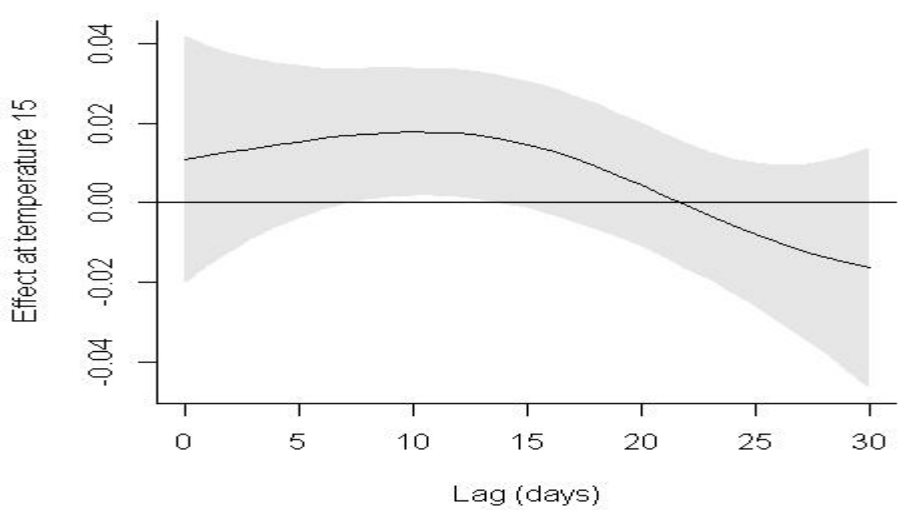

Figure 4. Non-linear effect of temperature delay at 15 °C temperature on the number of deaths due to COVID-19 disease in Shiraz city

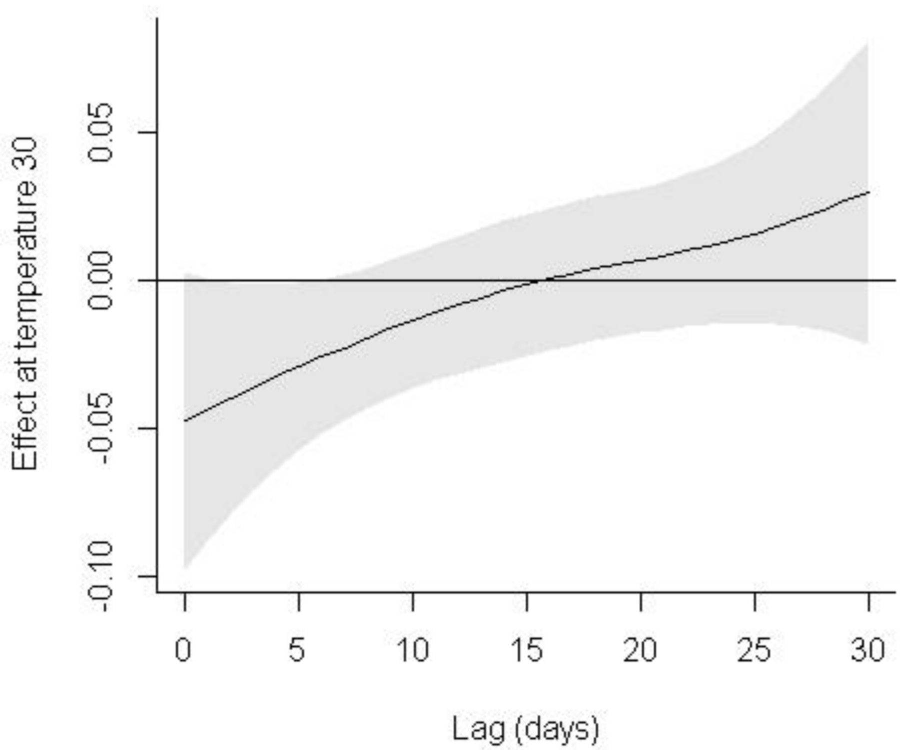

Figure 5. Non-linear effect of temperature delay at 30 °C temperature on the number of deaths due to COVID-19 disease in Shiraz city

4. Discussion

The exponential effect observed in the variable of the number of hospitalized people can be justified due to the fatigue of the treatment staff and the lack of resources in the face of the increase in the number of hospitalized patients.

In examining the variable effect of temperature and its delays, the risk of death is high at low temperatures, and after that, the trend decreases. At high temperatures, the opposite is also observed. The fact that in short delays, low temperatures are more dangerous than higher temperatures can be explained by the change in the behavior of the COVID-19 virus at different temperatures. In many studies, there has been evidence of a reduction in the lifespan of the COVID-19 virus at high temperatures [6,7,21].

The decreasing effect of the risk of death due to COVID-19 in low temperatures over time can be due to the decrease in the movement of people at low temperatures, because the increase in movement leads to an increase in the number of infected people daily and, as a result, an increase in the number. Also, a similar argument, the increase in the risk of death due to COVID-19 in high temperatures over time can be due to the increase in the movement of people in suitable and pleasant temperatures. In general, regarding the temperature variable, both low and high temperatures can lead to an increase in the number of deaths. This issue is mentioned in the study by Zhu et al. [9].

The non-significance of the wind speed variable can be due to the greater importance of other variables, and also a strong correlation between the temperature variable and the wind speed is observed (Figure-1) and the presence of the temperature variable leads to a decrease in the importance of the wind speed variable.

5. Conclusion

Despite the limitations of the research, such as the lack of information about the movement of people and information on the vaccination status of people, the result of the research indicates a non-linear and complex relationship between temperature and mortality due to COVID-19 in Shiraz and Fars province. In addition, it has become clear that low temperatures can potentially reduce the risk of death, while high temperatures appear to be the opposite. Overall, this study may help in decision-making in different temperature scenarios about the control of COVID-19.

In many studies, the temperature variable has been considered as non-linear. However, there are conflicting results across these studies [22-25]. Among the causes of these differences, cultural differences and climate can be mentioned.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Shiraz University Medical of Sciences Ethics Committee (IR.SUMS.MED.REC.1401.488). In addition, we confirm that there is no intervention in this study. Also, we can confirm that all the methods used in this study are following relevant guidelines and regulations of the AAB journal.

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Author's contributions

All authors equally contributed to preparing this article. All authors have read and approved the final manuscript.

Conflict of interest

The authors declare no conflict of interest.

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