Heliyon 10 (2024) e27900

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Investigating the impact of air pollution and temperature changes on emergency admissions (cardiovascular + respiratory) disease in the city of Bojnord, northeastern Iran

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A R T I C L E I N F O

Keywords:
Cardiovascular & respiratory diseases
Temperatures change
Lag nonlinear model
Air pollution

A B S T R A C T

Cardiovascular (CVD) + Respiratory diseases are recognized as the main cause of death worldwide. Fluctuations in temperature and air pollution have been reported as one of the most important causes of cardiovascular & respiratory diseases. Therefore, in the current study, we assessed the relationship between ambient air temperature and pollution on the number of total emergency hospital admission due to cardiovascular and respiratory conditions in the City of Bojnord, northeastern Iran. The meteorological data, including daily temperature, relative humidity and concentrations of five air pollutants CO, NO_2, NO_X SO_2, and PM_{10} were obtained from online electronic sensors at the Bojnurd meteorological station from 21th March 2018 to 20th March 2020. Statistical analysis, penalized distributed lag non-linear method was applied using R Software. Also, sensitivity analysis test was calculated by using appropriate application.

The results of the study revealed that the effect of higher and lower temperatures was observed immediately from the first day and the second week, respectively. Also result showed with increase and decrease temperature, significantly increased the risk of hospitalization by 36% (RR, 1.36; 95% CI (1), 0.95 to 1.95) and 17% (RR, 1.17; 95% CI (1), 0.88 to 1.55) until the lag 25th day, respectively. Based on the results, increasing temperature significantly increased the hospitalization rate of cardiopulmonary patients, but the effect of cold was not significant on the

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https://doi.org/10.1016/j.heliyon.2024.e27900
Received 10 December 2022; Received in revised form 1 March 2024; Accepted 7 March 2024
Available online 21 March 2024

population as well as age and gender subgroups. Study have also proved that there is no significance correlation between air pollutant and Cardiovascular & respiratory diseases.

1. Introduction

Industrial advances and the mechanization of human life in the past century have led to climate changes, which have emerged as critical challenges endangering the living conditions of people worldwide [1–3]. Climate changes and climate seasonal variability, there has been an increasing trend in public concerns about changes in the Earth's environment and its effects on human health. Fluctuation of temperature has been monitored by researchers and the epidemiological results in this regard confirmed a relationship between CVD & respiratory diseases and ambient temperature change [4–6]. Moreover, ambient temperature change has been reported as one of the main factors affecting the hospitalization rate in CVD & respiratory diseases [1,7,8]. Consequently, this finally may increase the total costs of health systems [2]. Dung Phung et al., published a meta-analysis and systematic review in 2016, and have been shown a relationship between exposure to daily temperature changes and the hospitalization rate risk of CVD & respiratory diseases [6,9].

Given that climate change models showed the trend of global warming and in this regard [10], Iran is one of the countries affected by severe temperature increase in 1987, 1988, and 2010, the models estimated that the average temperature in Iran will increase by approximately 2.7C° up to 2050 [11]. Previous studies have also shown that the relationship between temperature and daily mortality is parabolic, instead of linear, with lower mortality rate in locations with lower temperature compared to higher temperature [12–16]. However, a limited number of studies have been performed on the simultaneous effects caused by both air pollution and temperature changes [17]. Due to the simultaneous exposure to ambient temperature and air pollution, the synergistic effects of these factors on human physiology can be expected [15,18]. CVD & respiratory diseases are known as the leading cause of death worldwide, with an estimated 17.9 million deaths per year [19]. Accordingly, they are a group of CVD & respiratory diseases including coronary heart disease, cerebrovascular disease and some other types of diseases [20,21]. Above four out of five deaths due to CVD are caused by heart attacks and strokes, and one-third of these deaths occurs in those under 70 years old [2,5,22]. In Iran, CVD & respiratory diseases are ranked the first and fourth causes of death, respectively [23]. The rate of deaths due to CVD diseases in Iran is more than 44% [22]. Besides air pollution, many epidemiological studies have previously shown that temperature is significantly associated with CVD & respiratory diseases mortality [24,25], and it has a positive relationship with the admission of both CVD & respiratory diseases in hospital emergencies [9,20,26]. Since studies conducted in Iran's metropolitan areas only addressed the effects of air pollution, there is a need to confirm the simultaneous effect of temperature and air pollution in small cities in Iran where the effect of levels of air

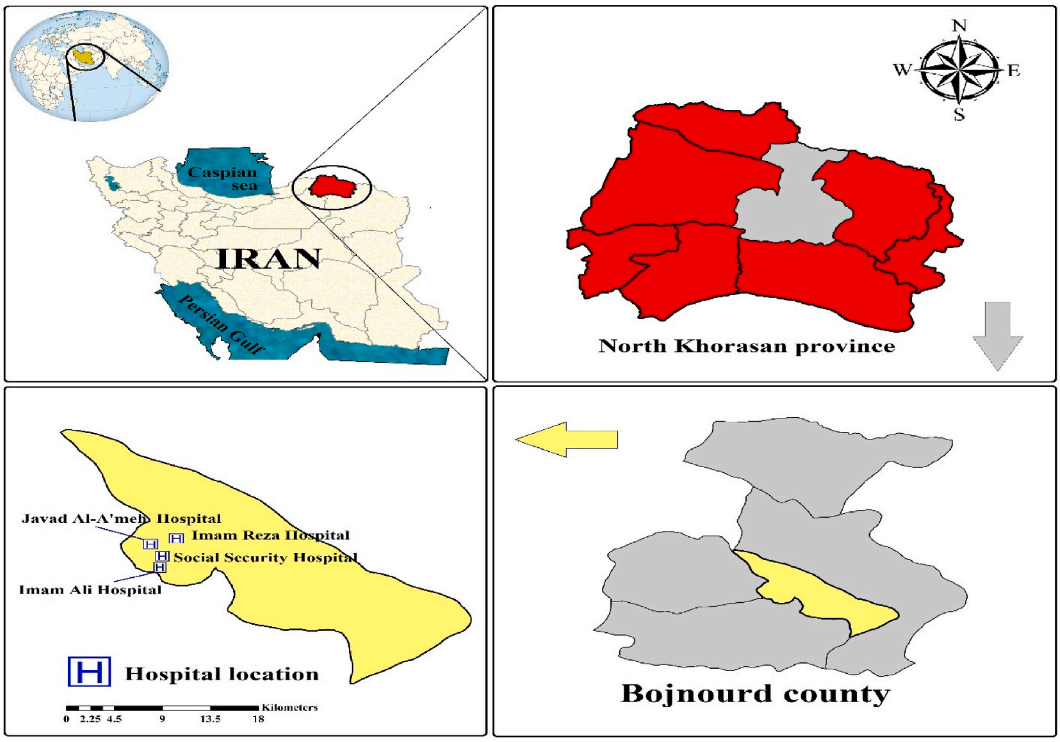

Fig. 1. Location of the study areas, Bojnord county, North Khorasan Province, Iran.

pollution and ambient temperature on the prevalence rates of CVD & respiratory diseases may vary from those of metropolitan areas [15]. Given that elevated mountains surrounded this city, the air flow is noticeably diminished, particularly on certain frigid days. Consequently, this can significantly contribute to the escalation of air pollution. However, no studies have been performed in this regard, Therefore, this study focused on city of Bojnord, the center of North Khorasan province, located in northeastern Iran. So, in this study, a time-series analysis was conducted to investigate the short-term relationship among air pollution, ambient temperature and risk of hospital admission in Bojnord hospitals using a generalized additive model with penalized distributed lag nonlinear model (DLNM), while estimating the nonlinear relationship between the exposure and outcome and showing a lag or lag effect.

2. Materials and methods

2.1. Study area

Bojnord city, the capital of North Khorasan province with an area of 36 square kilometers, is located in northeastern Iran (570 20' N and 370 28' S) (Fig. 1) and population of 257663 people Fig (1).

2.2. Meteorological data and air pollution data

In this study, the information of five air pollutants (CO, NO_2, SO_2, NOx and PM_{10}) and the meteorological (average daily temperature, relative humidity) during a two-year period from 21th March 2018 to 20th March 2020 were obtained from the meteorological station and Environmental Protection Organization in the City of Bojnord, northeastern Iran.

2.3. Health data

We extracted the CVD patient's information (International Classification of Disease, 10th revision 10th revision (1CD-10 codes I00-99) and respiratory diseases patient's information (ICD-10 codes J00-99) from the files archived in four hospitals in Bojnord (Imam Ali Hospital, Imam Reza Hospital, Javad Al-A'meh Hospital, and Social Security Hospital) that referred to the hospital emergency department from 21^{th} March 2018 to 20^{th} March 2020 Fig. 1. Thereafter, the total records of these patients were determined based on the international classification of diseases in the time unit of the day, gender, and age (<20, between 20 and 70 years old, and >70 years old).

2.4. Statistical analysis

The current study used the distributed lag nonlinear model (DLNM) for examining the nonlinear association of temperature with the temperature lag effects on the risk of hospital admission due to CVD & respiratory diseases. The trend of wind speed, relative humidity, and ambient air pollution (including CO, NO2, SO2, NOx and PM10) in the model were controlled as potential confounding factors. Moreover, the average amount temperature (14.89 ± 8.33 °C) was used to calculate the relative risk. We examined the effects of hot and cold separately on the relative risks of total cardiovascular & respiratory diseases admissions related to sex and age. Which was calculated in the 99th percentile compared to the 75th percentile and in the 1st percentile compared to the 25th percentile, respectively.

The sensitivity analysis was performed, and based on the restricted maximum likelihood (REML) index, 10 degrees of freedom in the lag dimension were used along with 10 degrees of freedom in the temperature dimension (as predictor). In addition, for controlling the trend over a long time, 9 degrees of freedom per year were considered [27]. Information on the number of daily emergency referrals in Bojnord hospitals (CVD & respiratory diseases) and the concentration of pollutants were analyzed using R software (version 3.0.1) and the DLNM package. In this study, penalized distributed lag non-linear model was used. The time-series analysis model was as follows:Eq (1-1):

Table 1
Descriptive indicators for hospital admission, meteorology variables.

Variable	Mean ± SD	Percentile								maximum
		Minimum	1	10	25	50	75	90	99	
CVD & respiratory (Total)	233.10	92	105.7	152.8	183	233	277	320	374.70	442
CVD & respiratory (Male)	120.83 ± 44.1	33	39.30	68.00	88.20	115	152.8	185	216.00	261
CVD & respiratory y (Female)	112.30 ± 32.9	0	41.30	70.00	89.00	114	136	151	193.4	251
<20 year	16.78 ± 4.63	7	8.00	11.00	13.00	17.00	20.00	23.00	27.00	32
20–70 year	183.00 ± 49.8	72	86.60	121	143.2	183	217	251	294	348
>70 year	33.46 ± 9.16	13	16.00	22.00	26.00	33.50	40.00	46.00	54.00	62
Temperature (°C)	14.89 ± 8.33	−3	0.70	4.6	7.6	13.9	22.10	26.20	30.20	32.20
Relative humidity	57.05 ± 16.18	20	24.60	34.50	44.50	57.50	69.50	78.00	88.00	91.50
Wind speed	6.62 ± 3.32	2.00	2.00	3.00	4.00	6.00	8.00	11.00	16.00	25

$$\text{Log}\ [E(Y_t)] = a + cbt,l + s\ (\text{time, d f.Time}) + s\ (\text{Humi t, d f.Rh}) + s\ (\text{Wind t, d f. Wind}) + s\ (PM_{10}, \text{df}.PM_{10}) + s\ (SO_2, \text{d f. } SO_2) + s\ (NO_2, \text{d f. } NO_2) + s\ (NO_x, \text{d f. } NO_x) + s\ (CO, \text{d f. } CO) + DOWt + Holidayt \quad (1\text{-}1)$$

In this equation, Yt indicates the number of hospital admission caused by CVD& respiratory diseases observed on day t, E(Yt) indicates the number of the expected hospital admission on day t, a indicates the intercept, l indicates the day (Lag) and s indicates the Spline function. cbt, l indicates the Cross-basis function in the dimensions of temperature and log (day) with the best degree of freedom. Time indicates the long-term time trend. NO_2, SO_2, NO_x, PM_{10}, and CO are air pollutants with degrees of freedom (df) and Wind and Rh are respectively wind speed and relative humidity with degrees of freedom (df). DOW and Holiday are a weekday and holiday, respectively.

3. Results

Table 1 shows the statistical summary for hospitalizations data and meteorological conditions. During the study, 233 people were admitted to the hospital due to CVD & respiratory disease. The gender of the patients was 51.85% male and 48.15% female. The rate of the patients admitted by age group <20, 20–70 and > 70 years old were approximately 7.2%, 78.5%, and 14.3%, respectively. The average daily temperature was calculated as 14.89 ± 8.33 °C (ranging from −3 to 32.2 °C), relative humidity was 57.05 ± 16.18% (from 20 to 91.5%), and wind speed was 6.62 ± 3.32 m/s (from 2 to 25 m/s).

As well, during the study period, the average daily concentration of air pollutants was 110.73 μg/m^3, 1.39 ppm, 11.29 ppb,10.51 ppb and 11.39 ppb for PM_{10}, CO, NO_2, NO_x and SO_2 respectively. The mean concentrations air pollution used in the present study are shown in Table 1 S. The results of this study show that the concentration of PM_{10} was more than the air quality standard of Iran during the study period. So, this air quality might endanger human health in Bojnord. However, the findings showed that daily admission of CVD & respiratory diseases in Bojnord has no positive significant relationship with air pollution.

Our results revealed that the temperature and hospital admission rate vary strongly with daily changes. There was a significant relationship between the hospital admission with high ambient temperature and during the study, a weak correlation was found between cold temperatures and daily counts of hospital admission. The daily counts of hospital admission have increased somewhat in the last 392 days, with more cases in the second year in comparison to the first year (Fig. 2).

Cumulative high temperature and cold effects on the admission of patients with CVD based on gender and age were estimated during the lag (Table 2). The results demonstrated that the most effects were observed at high temperatures and immediately, but the effects of the cold delayed by several days; such that in the total population, the effect of high temperature was observed immediately from the same day, which consequently increased the risk of hospital admission by 36% (RR, 1.36; 95% CI (1), 0.95 to 1.95) until the lag 25 day. However, no significant effect was observed in this regard. Of note, the effect of lower temperature was observed with a lag, which started from the second week and consequently increased the risk of hospital admission by 17% (RR, 1.17; 95% CI (1), 0.88 to 1.55) until the lag 25th day. However, no significant effect was observed in this regard. Among male patients, the effect of higher temperature was observed immediately from the first day, and the cumulative effect of heat until the lag 21st day significantly increased the risk of hospital admission by 73%. (RR, 1.73; 95% CI (1), 1.00 to 2.99); However, the effect of Lower temperature was observed with a delay and nearly from the second week, which then increased the risk of hospital admission by 30% (RR, 1.30; 95% CI (1),0.8 to 2.11) until the 25th day. However, no significant effect was observed in this regard. In addition, our results demonstrated that among women, no significant relationship was observed between the cumulative effects of temperature (Table 2).

The relationship between age and temperature changes related to diseases' admissions was as follows: In the group aged under 20 years old, the effect of heat was observed from the same day, which increased the risk of hospital admission by 37% until the 25th day, but the effect of Lower temperature was observed from the lag fifth day and consequently caused a 17% increase in the related risk.

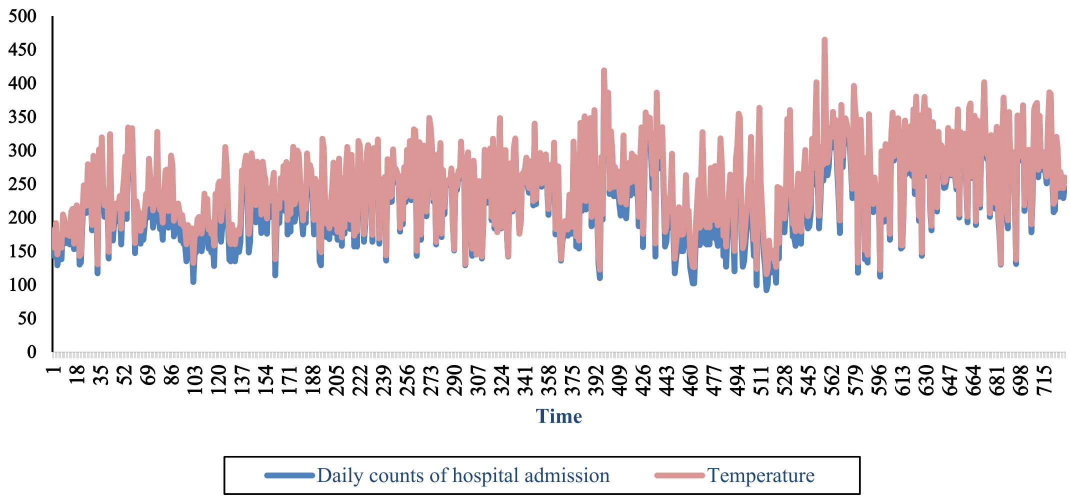

Fig. 2. Time series of temperature changes with the admission of emergency patient's CVD& respiratory diseases.

Table 2
The cumulative effects of heat and cold on hospital admission based on age and gender in different time lags for CVD & respiratory diseases.

Lag (Day)	Total	Male	Female	Age		
				<20	20–70	>70
Hot Effect						
0	1.01 (0.97 ± 1.06)	1.02 (0.96 ± 1.09)	1.00 (0.96 ± 1.03)	1.01 (0.97 ± 1.06)	1.01 (0.97 ± 1.06)	1.01 (0.97 ± 1.05)
0–3	1.09 (0.95 ± 1.24)	1.16 (0.95 ± 1.41)	1.01 (0.90 ± 1.13)	1.08 (0.95 ± 1.24)	1.09 (0.96 ± 1.24)	1.08 (0.95 ± 1.23)
0–5	1.13 (0.95 ± 1.35)	1.25 (0.96 ± 1.63)	1.03 (0.88 ± 1.20)	1.13 (0.95 ± 1.35)	1.14 (0.96 ± 1.36)	1.12 (0.94 ± 1.33)
0–7	1.18 (0.96 ± 1.46)	1.35 (0.98 ± 1.86)	1.05 (0.87 ± 1.26)	1.18 (0.95 ± 1.46)	1.19 (0.96 ± 1.47)	1.16 (0.95 ± 1.43)
0–14	1.32 (0.98 ± 1.79)	1.64 (1.03 ± 2.63)	1.12 (0.85 ± 1.47)	1.33 (0.97 ± 1.80)	1.33 (0.99 ± 1.81)	1.29 (0.96 ± 1.73)
0–21	1.37 (0.96 ± 1.94)	1.73 (1.00 ± 2.99)	1.15 (0.84 ± 1.58)	1.38 (0.96 ± 1.97)	1.39 (0.97 ± 1.97)	1.32 (0.94 ± 1.86)
0–25	1.36 (0.94 ± 1.95)	1.67 (0.94 ± 2.96)	1.16 (0.84 ± 1.61)	1.37 (0.94 ± 1.98)	1.37 (0.95 ± 1.98)	1.31 (1.87 ± 0.93)
Cold effect						
0	0.99 (0.96 ± 1.02)	0.98 (0.94 ± 1.03)	1.00 (0.97 ± 1.02)	0.99 (0.96 ± 1.02)	0.99 (0.96 ± 1.02)	0.99 (0.96 ± 1.02)
0–3	0.99 (0.91 ± 1.08)	0.98 (0.86 ± 1.12)	1.00 (0.93 ± 1.08)	0.99 (0.91 ± 1.08)	0.99 (0.91 ± 1.08)	0.99 (0.91 ± 1.08)
0–5	1.00(0.89 ± 1.12)	1.00 (0.83 ± 1.20)	1.01 (0.91 ± 1.12)	1.01 (0.90 ± 1.13)	1.01 (0.90 ± 1.13)	1.00 (0.90 ± 1.12)
0–7	1.02 (0.89 ± 1.18)	1.02 (0.82 ± 1.28)	1.02 (0.90 ± 1.15)	1.03 (0.89 ± 1.18)	1.03 (0.89 ± 1.18)	1.02 (0.89 ± 1.17)
0–14	1.09 (0.88 ± 1.35)	1.11 (0.78 ± 1.58)	1.05 (0.87 ± 1.26)	1.09 (0.88 ± 1.36)	1.09 (0.88 ± 1.36)	1.08 (0.88 ± 1.34)
0–21	1.15 (0.88 ± 1.49)	1.22 (0.78 ± 1.91)	1.06 (0.86 ± 1.31)	1.15 (0.88 ± 1.50)	1.15 (0.88 ± 1.50)	1.13 (0.87 ± 1.45)
0–25	1.17 (0.88 ± 1.55)	1.30 (0.80 ± 2.11)	1.06 (0.85 ± 1.32)	1.17 (0.88 ± 1.56)	1.17 (0.88 ± 1.56)	1.14 (0.87 ± 1.50)

Nevertheless, temperature change was not associated with patient's admission in those aged under 20 years old. These results of those aged between 20 and 70 and over 70 years old, were similar to those aged under 20 years old. Generally, in respect of emergency admission for CVD & respiratory diseases, female patients were less affected than males.

The 3D plots show non-linear relationships between the Relative Risk parameter (RR), temperature and hospital admissions for CVD& respiratory patients over a 25-day lag (Fig. 3). The estimation of the effects indicated that a nonlinear relationship exists among temperature changes and total population, age subgroups, and gender by the distributed nonlinear delay level. So, the greatest effect was observed at higher temperatures and immediately on the same day, but the effect of cold was characterized by a delay of several days.

Fig. 4 shows the cumulative effects of temperature in lags 0–7, 0–14, and 0–21, 0–25 for the total, men and women for the admission of CVD & respiratory diseases. The results show that with the increase in the lag, the risk of admission of CVD & respiratory

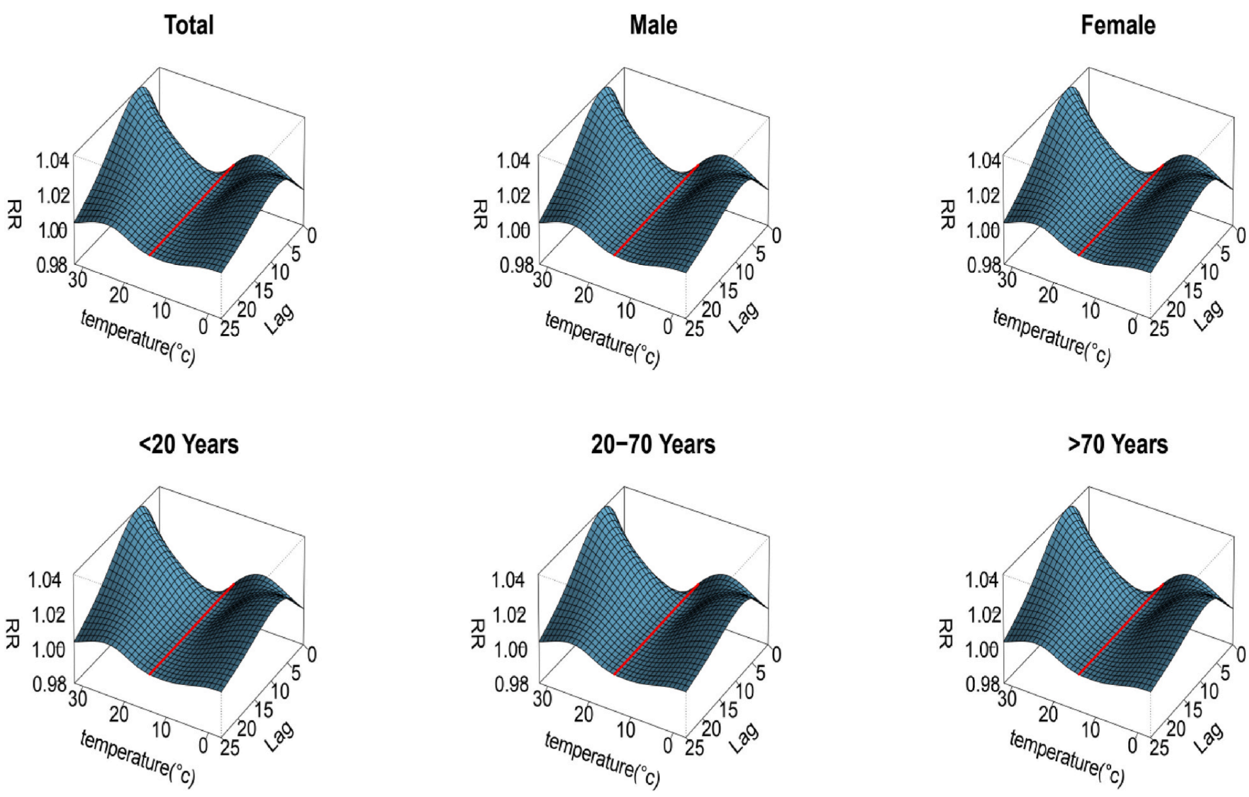

Fig. 3. Three-dimensional plot of the association between temperature and RR of CVD hospitalization over 25 lag days.

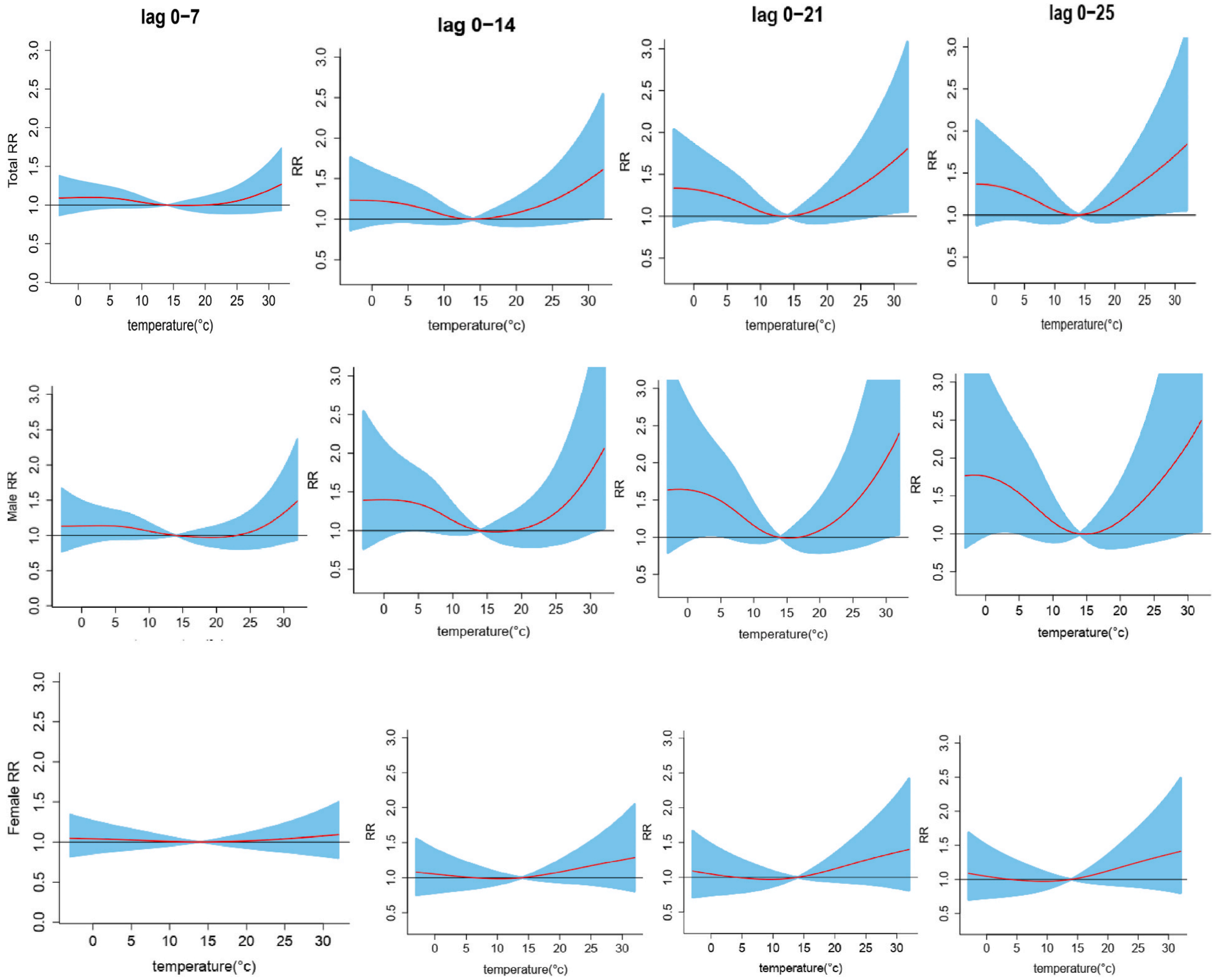

Fig. 4. Cumulative RR of CVD hospital admissions at different temperatures in gender and total population over 25 lag days.

diseases patients is increased compared to the low lag for the whole population. In men and the total population, the cumulative effect of high temperatures in the upper lags increased the risk of emergency admission. However, lower temperatures also caused a significant increase in risk from the second week onwards. So that the risk of hospitalization for cardiovascular patients was higher in the higher lag (0–25) compared to the lower lag in the total population.

The changes in the cumulative risk of hospital admission due to CVD & respiratory diseases among various age groups caused by different temperatures (relative to the mean value) are shown in Fig. 5. In all the three age groups, the most significant effects were observed at highest temperatures and lowest temperatures (especially higher temperatures). In the age groups under 20 years old and between 20 and 70 years old, higher temperatures significantly increased the risk of hospital admission. In the age group over 70 years old, the effect of higher temperatures on increasing the risk was also significant.

The effect of higher temperature on the risk of hospital admission due to CVD & respiratory diseases are shown in Fig. 6. In the total population and the age and sex subgroups, there was no significant effect of temperature increase on the risk, started from the same day and expanded in the following days and lasted for almost 18 days. A significant effect of temperature (from days 5–12) on the risk of hospital admission was observed only among men.

The effects of cold on the risk of hospital admission due to CVD & respiratory diseases are shown in Fig. 7. In the total population and the age and sex subgroups, the mild effect of cold started within a four-day lag, which then continued almost until the end of the study period (25 days). The effect of cold was not significant on the total population and none of the age and gender subgroups.

4. Discussion

The increased hospital admission rate due to CVD & respiratory diseases caused by meteorological conditions and different levels of air pollutants and ambient air temperature is a critical issue in public health [28,29]. The goal of this study was to investigate the

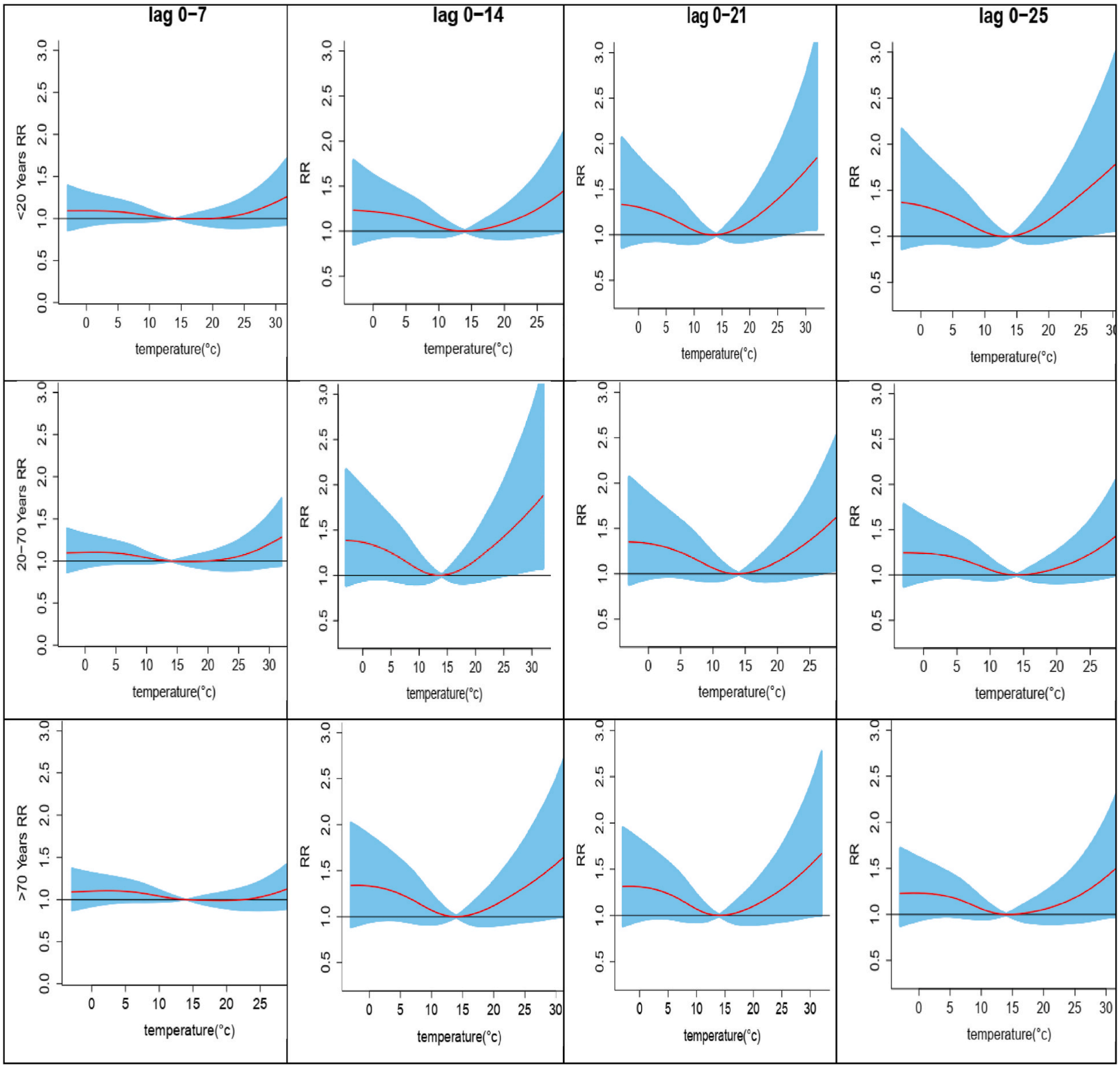

Fig. 5. Cumulative RR of CVD hospital admissions at different temperatures relative to the mean value in age subgroups (under 20, 20–70, and above 70 years old) over 25 lag days.

relationship between ambient air temperature and air pollution on the number of total emergency hospital admission due to cardiovascular and respiratory conditions in the city of Bojnord, northeastern Iran during 21th March 2018 to 20th March 2020 using a time-series analysis. Our result showed that higher temperatures increase the risk of hospital admission in comparison to the lower temperatures. Higher temperature was associated with increased total emergency room visits and hospitalizations in men and the total population. The cumulative effects of high and low temperatures both had an increasing trend. We also observed signs of increased vulnerability to high temperatures among males. This study is the first study that examines the relationship between Cardiovascular + Respiratory diseases and temperature changes in this region. In this study, it is well known that the cumulative effect of heat and cold was increasing from the first days of lag in men and women. Our findings suggest that patients with long-term chronic conditions should avoid exposure to outdoor temperature. Also, Delamater et al. reported that there is a significant relationship between climatic conditions (heat and cold) and admission of patients to the hospital [30]. In the present study, the role of cumulative effect of heat (total population and men) on increasing the number of hospitalizations in CVD & respiratory diseases patients in Bojnord was observed, which is consistent with the above-mentioned study. As well, no significant relationship was observed between the effects of temperature on hospital admission among women. Moreover, CVD & respiratory diseases patients may have expired before referring to the hospital and being registered in the list of CVD & respiratory diseases. This phenomenon can lead to an underestimation of the

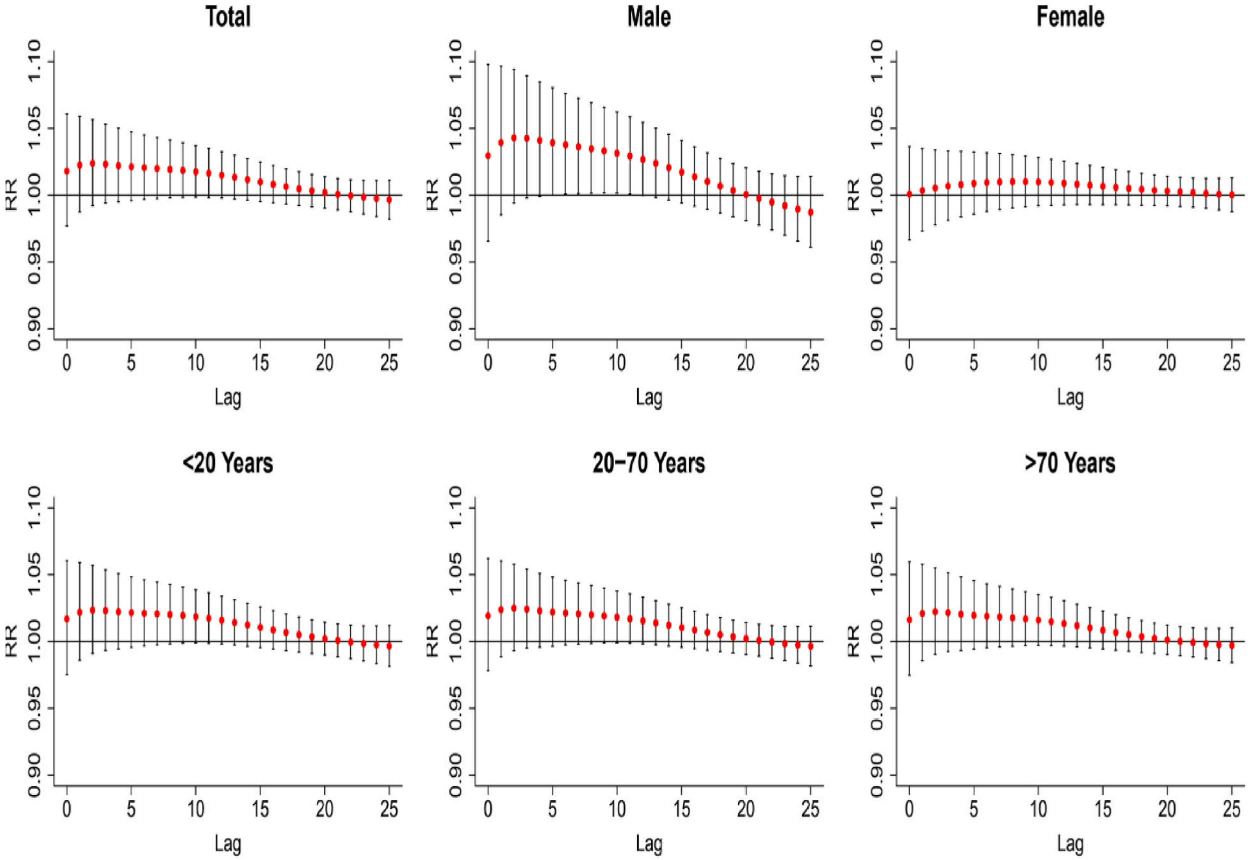

Fig. 6. Effect of high temperature on the risk of hospital admission due to CVD & respiratory diseases in gender and age subgroups.

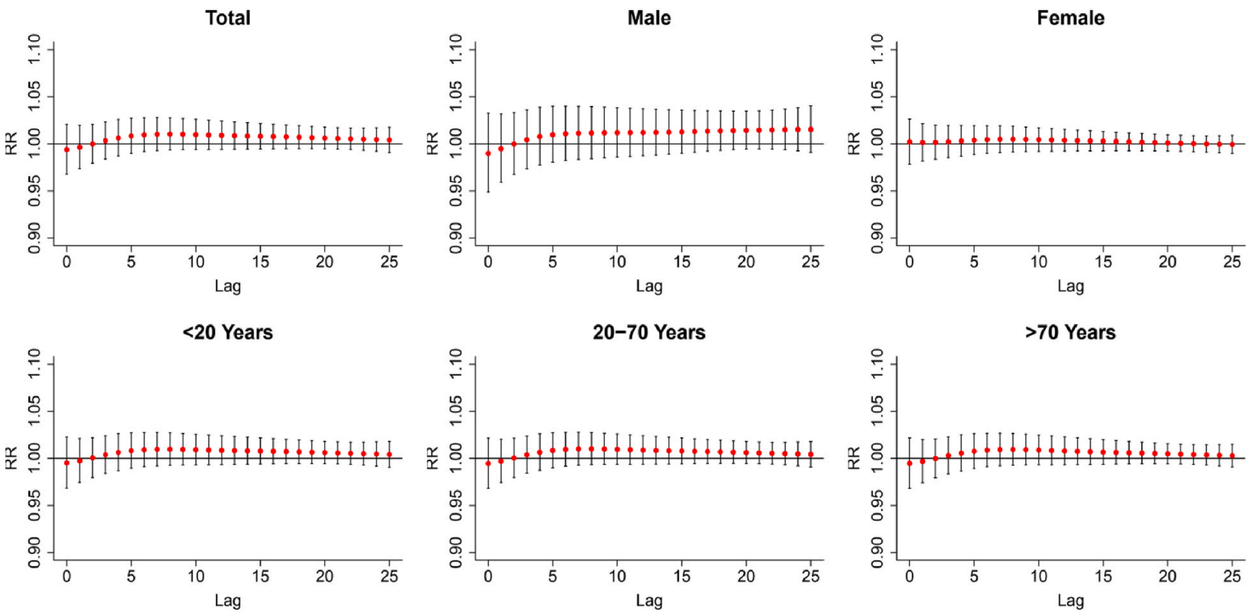

Fig. 7. Effect of cold on the risk of hospital admission due to CVD & respiratory diseases in gender and age subgroups.

effects of air pollution on CVD & respiratory diseases on hospital admission [31]. Other researchers also have reported the effects of ambient temperature on mortality and hospital admissions [32–34]. In this study, we observed the effect of heat and cold with a range of delay periods. The risk of higher temperature on hospital admission was highest for men and the total population. This was consistent with Vaneckova et al. and Khorshidost et al. study [35,36].

Also, the results of this study showed that the concentration of PM_{10} was more than the air quality standard of Iran during the study period. So, this air quality might endanger human health in Bojnord. However, the findings showed that daily admission of CVD & respiratory diseases in Bojnord has no positive significant correlation with air pollution. However, Hosseinpoor et al. in their study have concluded that daily admission of respiratory patients in Tehran has a positive and significant relationship with air pollution [37]. Furthermore, Matyasovszky et al. in their study in Hungary, by analyzing the effect of air pollutants on hospital admission of respiratory patients from 1999 to 2007, have stated that the impact of temperature parameters varies in different seasons [38]. Moreover, Delamater et al., in their study conducted in Los Angeles on the admission of hospital emergency patients with CVD & respiratory disease and the relationship between air pollution and climatic conditions (Hot and cold), have stated that there is a significant relationship in univariate studies. However, no significant association was observed in multivariate studies yet [30].

5. Conclusion

This study projected the relationship between ambient air temperature and five pollutant on the number of total emergency hospital admission due to cardiovascular and respiratory conditions in the City of Bojnord, northeastern Iran. The results of the study indicate that the effect of higher and lower temperatures was observed immediately from the first day and the second week, respectively. Also result showed with increase and decrease temperature, significantly increased the risk of hospitalization. Our findings show that there is no significance correlation between five air pollutant (CO, NO2, NOX SO2, and PM10) and Cardiovascular & respiratory diseases. Due to the climatic situation and population growth in Iran, local authorities should take precautionary measures to reduce the effects of temperature on public health, especially for people who are prone to CVD& respiratory diseases. The authors suggest that patients with long-term chronic conditions should avoid exposure to outdoor heat.

Funding statement

Not applicable.

Data availability statement

Data are available upon reasonable request.

CRediT authorship contribution statement

Ayoob Rastegar: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Mahdi Ghorbanian:** Writing – review & editing, Investigation. **Ali Hosseinzadeh:** Writing – original draft, Methodology, Investigation. **Mohammad Hossien Saghi:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Sohrab Iranpour:** Writing – review & editing, Investigation. **Ali Akbar Mohammadi:** Writing – review & editing, Methodology, Investigation. **Yousef Poureshgh:** Writing – review & editing, Methodology, Investigation. **Elham Rahmanzadeh:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation. **Reza Hekmatshoar:** Writing – review & editing, Writing – original draft, Investigation. **Ali Oghazyan:** Writing – review & editing, Writing – original draft, Methodology. **Mehdi Fattahi:** Writing – review & editing, Methodology, Investigation. **P.U. Nguyen:** Writing – review & editing, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research received funding from Sabzevar university of medical sciences (no. IR.MEDSAB.REC.1399.114) he authors are grateful for the financial supports from the Sabzevar University of Medical Sciences,Iran (grant no. IR.MEDSAB.REC.1399.114). The authors sincerely appreciate the Department of Environmental Protection of North Khorasan University of Medical Sciences.

List of abbreviations

CVD	Cardiovascular
ICD	International Classification of Disease
DLNM	Distributed lag Nonlinear Model

REML Restricted Maximum likelihood
PM Particulate matter
RR Relative risk
CI Confidence interval

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e27900.

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