

Featured Article

The impact of air pollutant exposure on diabetes hospital admissions in a city of Xinjiang

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Abstract: Objective: To explore the influence of air pollution on the daily hospitalization admissions of diabetic patients in a certain city of Xinjiang and the differences among the population, providing a reference basis for formulating prevention and control policies for diabetes in response to air pollution in the future. **Methods:** Daily hospitalization admissions of 10 comprehensive hospitals in a certain city of Xinjiang from 2021 to 2022 were collected, along with air pollutants and meteorological monitoring data during the same period. The relationship between air pollutant concentrations and the daily hospital admission rates of diabetes patients was analyzed using a distribution lag nonlinear model. **Results:** There was no statistically significant difference in the impact of PM_{2.5} and PM₁₀ exposure on daily hospital admission rates, with RR values reaching peak values at lag5, lag0, as follows: 1.06 (95% CI: 1.00, 1.12), 1.08 (95% CI: 1.00, 1.16); NO, SO₂, O₃, and CO affected the daily hospital admission rate of diabetes patients, with RR values reaching peak values at lag6, lag1, lag2, and lag5 days, respectively, as follows: 1.21 (95% CI: 1.11, 1.31), 1.69 (95% CI: 1.43, 1.99), 1.23 (95% CI: 1.14, 1.34), 1.36 (95% CI: 1.21, 1.53). PM_{2.5} had no statistically significant impact on the daily hospital admission rates of each subpopulation; PM₁₀ had an immediate effect only on the daily hospital admission rate of males, reaching a peak at lag0 day at 1.16 (95% CI: 1.05, 1.28); NO₂ had the largest RR values for the daily hospital admission rates of males and those under 65 years of age, respectively, at 1.22 (95% CI: 1.09, 1.35) and 1.19 (95% CI: 1.08, 1.32); the largest RR values for females and those over 65 years of age were 1.26 (95% CI: 1.11, 1.44) and 1.23 (95% CI: 1.07, 1.41), respectively, and these were statistically significant. SO₃ and O₃ showed an increasing trend in the daily hospital admission rates of each subpopulation before decreasing, with peaks appearing in lag1–lag3, which were statistically significant. **Conclusion:** Exposure to NO₂, SO₂, O₃, and CO increased the risk of hospitalization for diabetes. The diabetic population of women and those over 65 years of age were more vulnerable to exposure to NO₂ and CO, resulting in an increased hospitalization risk. During the entire day and the period from 9 to 21 h, the trend of the influence of NO₂ on the daily hospitalization admission of diabetic patients varies the most, while there is no obvious change trend for the other pollutants.

Keywords: air pollution; type 2 diabetes; hospital admissions; distributed hysteresis nonlinear model

1. Introduction

The air pollution problem has gradually become prominent with the increase in energy consumption. Air pollutants are easily inhaled, accumulate toxic substances, and spread widely. As a result, air pollution has become a serious public health problem [1]. In 2019, the Global Burden of Disease Study showed that air pollution

was the fourth leading risk factor for increased death and disability-adjusted life among many risk factors [2]. The study found that air pollution increases morbidity and mortality from respiratory diseases, cardiovascular and cerebrovascular diseases, and metabolic syndrome and is a major contributor to diabetes [3,4].

Diabetes mellitus is one of the major chronic noncommunicable diseases in the world. It has become one of the most important public health problems threatening the health of people due to the increasing incidence and number of cases [5,6]. According to data from the International Diabetes Federation, about 537 million people were living with diabetes worldwide in 2021. This number is expected to rise to 643 million by 2030 and 783 million by 2045 [7]. The disease burden of diabetes is also increasing worldwide, with the rapid growth of diabetes and the number of people with diabetes. According to statistics, the annual medical expenses of countries due to diabetes management and treatment have exceeded 760 billion US dollars, and the cost is expected to exceed 845 billion US dollars by 2045 [8]. Presently, the number of diabetics in China is 140.9 million, ranking first in the world, and it is expected to reach 174 million by 2045 [7]. The prevalence rate of diabetes in China has increased from 2.6% to 10.4% in the past decade, showing a rapid growth trend [9]. Diabetes is one of the five high-ranking causes of death in China [10]. Diabetes and its complications not only affect the quality of life of patients but also impose a heavy economic burden on society.

Previous studies on the relationship between air pollution and diabetes have been controversial, and most studies have been conducted in North America or Europe [11–13]. Xinjiang is located in the hinterland of Eurasia, with a large temperature difference between day and night. The annual heating season lasts for six months, and the amount of coal fuel increases, controlled by cold high pressure in Mongolia. Consequently, urban airflow is difficult to flow horizontally, and the diffusion and dilution of pollutants are difficult, making one of the cities in Xinjiang severely polluted in the winter. Based on this background, this study evaluated and studied the concentration of air pollutants for two consecutive years and built a distributed lag nonlinear statistical model to explore the lag effect of air pollutants and the daily hospitalization of diabetes patients to analyze the relationship between air pollutants and the daily hospitalization of diabetes patients. Specifically, this study provides data support and scientific guidance for evaluating the health effects of air pollution and improving a comprehensive health management policy for diabetes.

2. Materials and methods

2.1. Resident health data

This study is based on A System of Health Accounts 2011 edition [14] to calculate the national health expense using the functional method. According to the requirements of the state, a multi-stage stratified sampling method was adopted, and the sampling was conducted according to the level and classification of health institutions.

In-patient data of type 2 diabetes mellitus (T2DM) patients from 10 general hospitals in a city of Xinjiang Province from 1 January 2021, to 31 December 2022,

were collected, including gender, age, date of admission, and other data, according to the ICD-10 code of the International Classification of Diseases (E10-E14).

2.2. Atmospheric pollutant data

The air pollution data comes from the real-time automatic monitoring data of urban air quality monitoring stations across the country published by China General Environmental Monitoring Station, which collects air pollutant data during 2021–2022 in a city in Xinjiang, including the average daily and hourly concentrations of Particulate Matter 2.5(PM_{2.5}), Particulate Matter10 (PM₁₀), Nitrogen dioxide(NO₂), Sulfur Dioxide(SO₂), and Carbon Dioxide(CO) and the average Ozone Maximum Daily 8-Hour Average(O₃–8 h) concentrations.

2.3. Meteorological data

The meteorological data source originated from the National Climatic Data Center, selecting the observation station data in the Xinjiang region of China to obtain the daily meteorological data of a city in Xinjiang. The data mainly included daily average temperature (°C), daily average wind speed (m/s), and daily average air pressure (hPa) data.

2.4. Research methods

2.4.1. Processing of missing data

There are missing data on individual days for air pollutants and meteorological data. This study adopted the mean prediction and matching method in the multiple interpolation method to fill in the missing data [15,16].

2.4.2. The definition range of the analysis time

According to relevant studies [17,18], there is a significant difference in the variation of atmospheric pollutant concentration between day and night, and the concentration of pollutants at night is high. A study from *Nature Geoscience* also pointed out [19] a continuous increase in NO₃ oxidation at night in China, which impacts ozone and fine particulate matter pollution levels. Because of the natural law of “work at sunrise and rest at sunset,” humans are more likely to be exposed to air pollutants during daytime production activities. In contrast, the intensity of activities at night is lower, and the concentration of air pollutants presents the characteristics of diurnal differences. This study will be based on the circadian rest time of Xinjiang and set the analysis period from 9 AM to 9 PM. Based on this, the average concentrations of different air pollutants during this period were calculated and compared with the average concentrations throughout the day. This procedure revealed the degree of impact of day and night differences on air quality more accurately. It comprehensively reflects the correlation between air quality and the daily outpatient volume of diabetes mellitus in Xinjiang and the actual degree of impact.

2.4.3. Establishment and analysis of the statistical model

In this study, the dose-effect relationship between the concentration of air pollutants and the number of inpatients with diabetes was evaluated using a

distributed hysteresis nonlinear model. The model is as follows:

$$Y_t \sim \text{Poisson}(\mu_t),$$

$$E[g(Y_t)] = \alpha + \beta \sum_{l=10}^L (lpollution_t - l) lpollution_t - l + ns(meterological\ factor_t, df = 3) + ns(time, df = 7 * 4) + dowl_t,$$

where Y_t is the daily outpatient in-patient volume, t is the time, l is the lag days, and the maximum lag days were set to seven days. $pollution_{t-l}$ represents a certain air pollutant; $meterological\ factor_t$ for different meteorological factors; $dowl_t$ stands for the “day of the week effect,” which controls for both weekday and non-weekday effects.

2.4.4. Subgroup population and season division

The subjects were stratified according to gender and age to explore the effects of air pollutants on different populations. The seasons were divided into 15 October to 15 April each year for the heating season and 16 April to 14 October for the non-heating season to explore the harmful effects of air pollutants in the heating and non-heating seasons, respectively.

3. Results

3.1. General characteristics

3.1.1. Air pollutants and meteorological data

Tables 1 and 2 show the average daily time series of air pollutants and meteorological factors for each subgroup divided into “all-day” and “Period 9–21 h,” according to different periods and the difference between the two groups. The results showed that the mean values of PM_{2.5}, PM₁₀, NO₂, CO, average temperature, average pressure, and average wind speed in the whole-day period were higher than those in the 9–21 period, while the mean values of SO₂ and O₃-8 h in the entire day period were lower than those in the 9–21 period. The differences were statistically significant ($P < 0.05$). There were obvious seasonal differences and regularities between the mean values of air pollutants and meteorological factors.

Table 1. Descriptive analysis of the mean concentration of air pollutants and meteorological factors.

Pollutants and meteorology	Period	Med	Min	Max	P ₂₅ –P ₇₅	Season (mean)	
						Unheated	Heating
PM _{2.5} (μg/m ³)	9–21	19.73	5.23	304.15	12.85–55.27	15.41	66.15
	All day	20.21	6.79	320.67	13.49–55.94	16.01	66.81
PM ₁₀ (μg/m ³)	9–21	51.96	8.69	672.85	34.37–92.87	50.52	95.16
	All day	56.5	10.41	488.08	38.80–91.45	54.99	95.64
NO ₂ (μg/m ³)	9–21	22.08	3.62	80.08	15.15–42.52	16.57	42.70
	All day	30.08	6.83	84.25	21.06–46.31	23.07	46.25
SO ₂ (μg/m ³)	9–21	7.15	3.58	17.55	6.08–8.48	7.48	7.47
	All day	6.79	3.70	14.63	5.88–7.96	7.11	7.01

Table 1. (Continued).

Pollutants and meteorology	Period	Med	Min	Max	P ₂₅ –P ₇₅	Season (mean)	
						Unheated	Heating
O ₃ -8h (µg/m ³)	9–21	75.58	20.23	139.50	45.54–102.37	98.21	50.20
	All day	65.21	17.88	134.13	38.29–84.49	82.11	43.19
CO (µg/m ³)	9–21	0.54	0.23	2.40	0.40–0.99	0.43	1.08
	All day	0.55	0.24	2.50	0.42–1.01	0.44	1.10
Average temperature (°C)	9–21	10.65	–23.16	33.50	–3.75–21.97	20.52	–3.06
	All day	10.66	–22.18	32.31	–3.55–21.78	20.45	–2.87
Average air pressure (Pa)	9–21	102026	99562	105700	100981–103059	101087	103035
	All day	102048	99655	105686	101002–103040	101112	103047
Average wind speed (m/s)	9–21 hours	2.00	0.52	8.00	1.59–2.40	2.37	1.69
	All day	2.00	0.88	8.25	1.63–2.38	2.38	1.79

Table 2. Comparison of differences between daily mean concentrations of air pollutants and meteorological factors at different periods.

	Period 9–21 (<i>n</i> = 730)	All-day (<i>n</i> = 730)	<i>P</i>
PM _{2.5} (µg/m ³)	40.57 ± 44.01	41.21 ± 44.29	0.009 *
PM ₁₀ (µg/m ³)	72.65 ± 59.31	75.15 ± 58.31	0.000 *
NO ₂ (µg/m ³)	29.53 ± 18.71	34.57 ± 18.06	0.000 *
SO ₂ (µg/m ³)	7.48 ± 2.08	7.06 ± 1.70	0.000 *
O ₃ -8h (µg/m ³)	74.41 ± 31.40	62.81 ± 25.84	0.000 *
CO (mg/m ³)	0.75 ± 0.48	0.77 ± 0.49	0.000 *
Average temperature (°C)	8.83 ± 14.16	8.89 ± 13.97	0.000 *
Average air pressure (Pa)	102053.37 ± 1311.31	102071.30 ± 1294.23	0.000 *
Average wind speed (m/s)	2.03 ± 0.76	2.09 ± 0.69	0.000 *

Note: Values are expressed as mean ± standard deviation. * indicates the difference is statistically significant (*P* < 0.05).

3.1.2. Daily hospitalization of diabetic patients

A total of 38,590 T2DM patients were admitted to various general hospitals in the city of Xinjiang from 2021 to 2022, with an average of 52 daily T2DM patients. The number of male patients hospitalized is higher than that of female patients; the number of people hospitalized in the age group of ≤65 years old is higher than that in the age group of >65 years old. Hospitalizations during the heating season were higher than during the non-heating season. Hospitalized patients declined significantly during the COVID-19 lockdown period from August to December 2022.

Table 3. Descriptive analysis of the distribution of daily inpatients with T2DM (730 days).

Variables	Total	Mean $\pm$ standard deviation	Med	The biggest value	P ₂₅ –P ₇₅	Season (mean)	
						Mid-April - mid-October	Mid-October - Mid-April
Total	38590	52.86 $\pm$ 35.23	52	152	24.00–80.00	52.26	53.47
Sex							
male	22091	30.26 $\pm$ 20.13	30	105	14.00–45.00	29.40	31.14
female	16499	22.60 $\pm$ 16.24	21	72	9.00–35.00	22.87	22.33
Age							
≤ 65	25212	34.54 $\pm$ 23.12	34	96	15.00–53.00	33.24	35.86
> 65	13378	18.33 $\pm$ 13.31	17	70	7.00–28.00	19.02	17.62

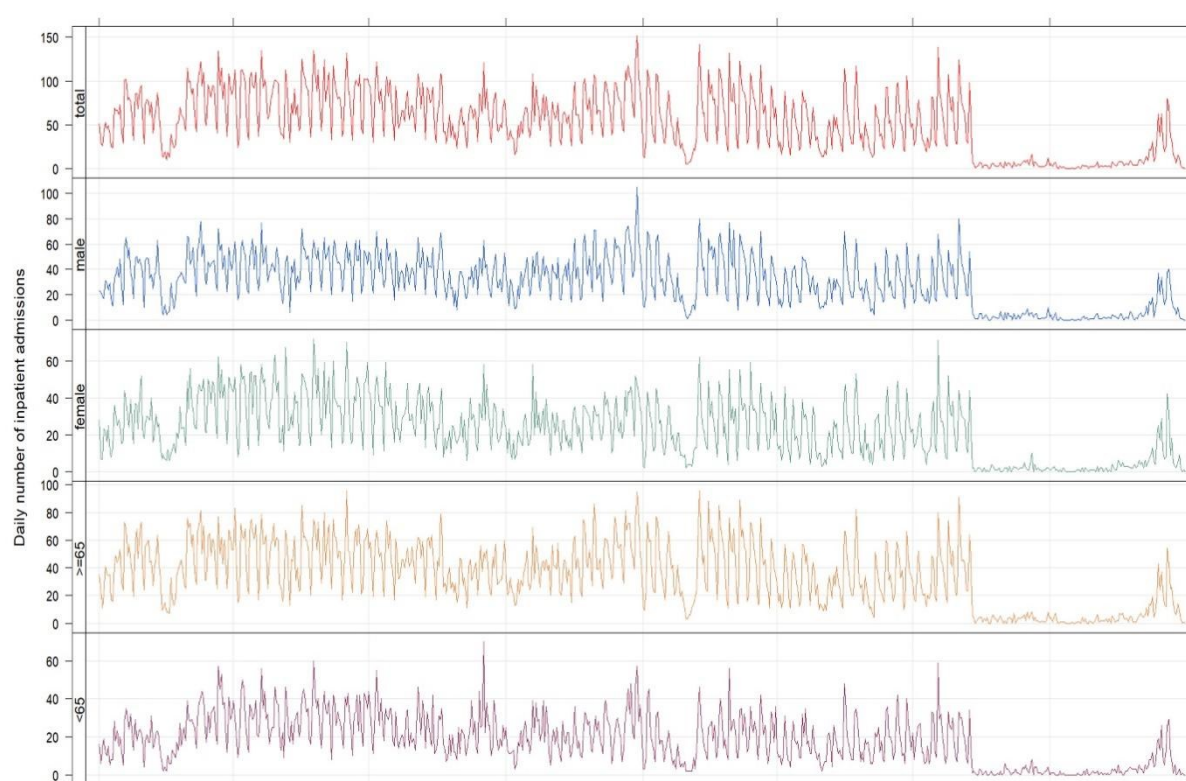


Figure 1. Distribution time series of daily inpatients with T2DM.

3.2. Correlation analysis

Spearman correlation analysis showed that PM_{2.5} positively correlated with PM₁₀, NO₂, and CO among air pollutants, and the correlation coefficients were 0.86, 0.84, and 0.86 ($P < 0.05$). CO was negatively correlated with O₃ and temperature, and the correlation coefficients were -0.77 and -0.78 ($P < 0.05$), as shown in **Figure 2**.



Figure 2. Heat map of correlation analysis between air pollutants and meteorological factors.

3.3. Analysis of the exposure-hystere-effect relationship

In the exposure-lag-effect analysis of air pollutants and the daily hospitalization volume of T2DM conducted in this article, the period of epidemic lockdown was excluded. During the whole day, the daily hospitalization of T2DM showed a lag effect under the influence of PM_{2.5}. With the increase of the lag days, the RR value gradually increased and reached the peak value at lag5 days, but there was no statistical difference. PM₁₀ showed an immediate effect, and with the increase of the lag days, the RR gradually decreased and reached its peak at lag0 days, but there was no statistical difference. NO₂ and CO showed an obvious cumulative lag effect, and the RR values peaked at 1.21 (95% CI: 1.11, 1.31) and 1.36 (95% CI: 1.21, 1.53) at lag6 and lag5 days, respectively, with a statistical difference. SO₂ and O₃ showed a trend of first decreasing, then increasing, and then decreasing, and the RR values peaked at 1.69 (95% CI: 1.43, 1.99) and 1.23 (95% CI: 1.14, 1.34) at lag1 and lag2 days, respectively, with statistical differences (**Figure 4**).

In the period 9–21, PM_{2.5} and PM₁₀ had the same effects on the daily hospitalization of T2DM as the results of the whole day, showing both lagged and immediate effects. RR values of SO₂, O₃, and CO showed the same change trend as RR values for the entire day, but the lag days all changed, reaching a peak at lag2, lag1, and lag4 days, respectively. NO₂ first increased, decreased, and then increased, reaching the peak value at lag0 day, with a statistical difference (**Figure 5**).

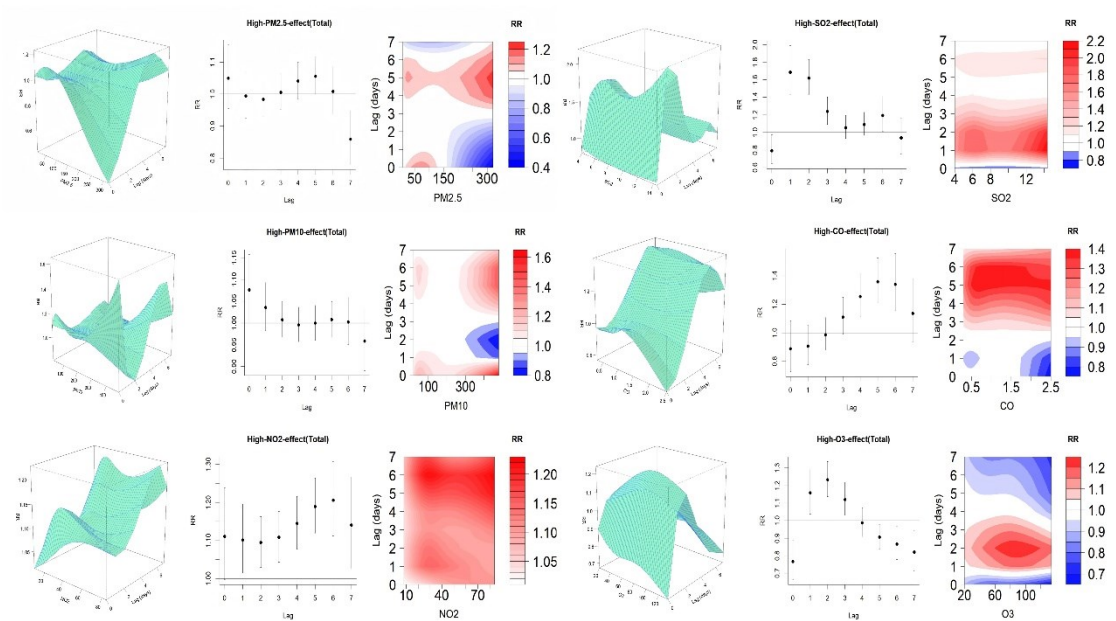


Figure 3. Expose-delay-effect relationship between air pollutants and daily hospitalizations in T2DM patients (all-day period).

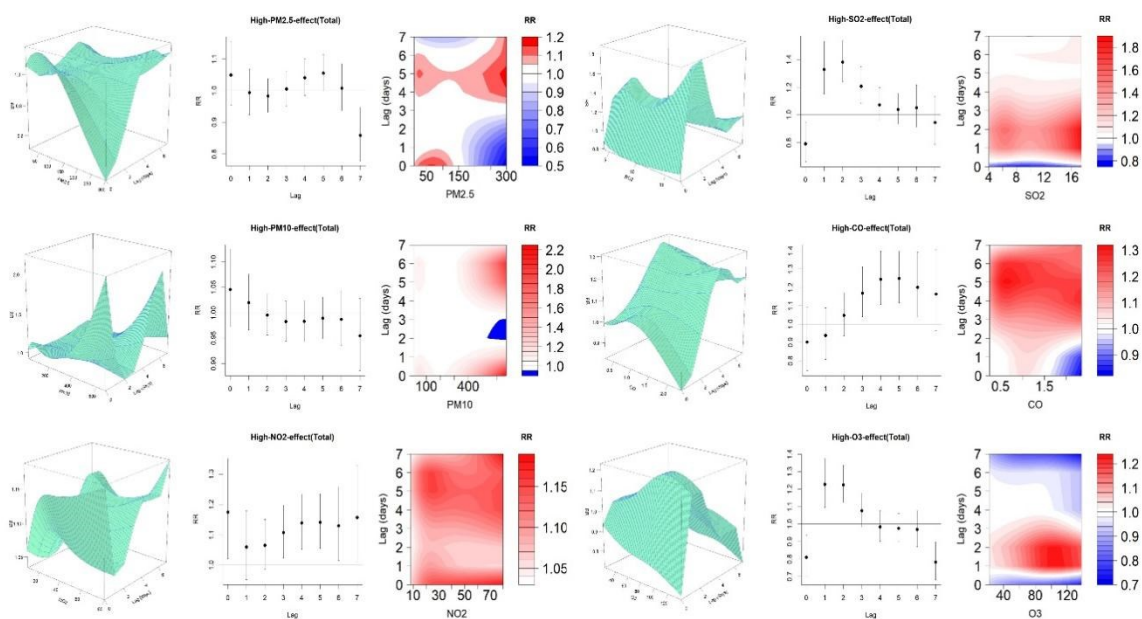


Figure 4. Expose-delay-effect relationship between air pollutants and daily hospitalizations of T2DM patients (period 9–21).

3.4. Subgroup analysis

3.4.1. Effects of air pollutants on daily hospitalization of T2DM patients of different genders and ages

All-day period

As shown in **Table 4**, there was no statistical significance in the one-day lag effect of daily hospitalization of PM_{2.5} in lag0–lag7 for all subgroups during the all-day period. PM₁₀ only had an immediate impact on the daily hospitalization of males, reaching a peak value of 1.16 (95% CI: 1.05, 1.28) at lag0 day, which was

statistically significant. The single-day lag effect of NO₂ in males and age groups less than 65 years old showed a trend of decreasing first and then increasing, and the peak RR values at lag6 days were 1.22 (95% CI: 1.09, 1.35) and 1.19 (95% CI: 1.08, 1.32), respectively, and were statistically significant. There was a trend of first increasing, then decreasing, and then increasing in females older than 65 years old, and the peak RR values at lag1 and lag6 days were 1.26 (95% CI: 1.11, 1.44) and 1.23 (95% CI: 1.07, 1.41), respectively, and were statistically significant.

The daily hospitalizations of SO₂ and O₃ in all subgroups of T2DM patients showed a trend of increasing and then decreasing, and the peaks of SO₂ and O₃ were in the range of lag1–lag3. In contrast, the RR values in the range of lag4–lag7 were not statistically significant. The single-day lag effect of CO in males and the age group less than 65 years old showed a trend of first decreasing, then increasing, and then decreasing. In females and the age group greater than 65 years old, it showed a trend of first increasing and then decreasing, and the peak value of CO in the range of lag4–lag6 was statistically significant.

Period of 9–21.

As shown in **Table 5**, in the period of 9–21, the changing trend in the influence of pollutants PM_{2.5}, PM₁₀, SO₂, O₃, and CO on the daily hospitalization of T2DM patients in each subgroup was the same as that of the whole day. The peak value of the single-day lag effect of NO₂ appeared earlier in males, age groups with ages lower than 65 years old and greater than 65 years old. RR values at lag5, lag0, and lag1 days were 1.19 (95% CI: 1.07, 1.32), 1.23 (95% CI: 1.04, 1.47), and 1.18 (95% CI: 0.98, 1.41), respectively, and were statistically significant. In the female subgroup, the variation trend of the lag effect changed, showing a trend of decreasing first and then increasing, and the peak RR value at lag0 day was 1.22 (95% CI: 0.99, 1.51).

Table 4. The relative risk of daily hospitalization and 95% CI of diabetes patients in different subgroups (all-day period).

Days of lag		PM _{2.5} (μg/m ³)	PM ₁₀ (μg/m ³)	NO ₂ (μg/m ³)	SO ₂ (μg/m ³)	O ₃ - 8 h (μg/m ³)	CO (μg/m ³)
Sex							
Male	lag0	1.06 (0.91, 1.24)	1.16 (1.05, 1.28)	1.06 (0.92, 1.22)	0.84 (0.64, 1.11)	0.69 (0.57, 0.84)	0.92 (0.71, 1.20)
	lag1	1.01 (0.91, 1.13)	1.03 (0.96, 1.10)	0.99 (0.89, 1.11)	1.79 (1.44, 2.24)	1.08 (0.94, 1.25)	0.83 (0.67, 1.01)
	lag2	0.98 (0.91, 1.07)	0.99 (0.94, 1.05)	1.00 (0.92, 1.08)	1.70 (1.44, 1.99)	1.25 (1.12, 1.39)	0.87 (0.74, 1.01)
	lag3	1.01 (0.92, 1.08)	1.00 (0.95, 1.05)	1.05 (0.97, 1.14)	1.28 (1.08, 1.51)	1.18 (1.06, 1.31)	1.01 (0.87, 1.18)
	lag4	1.04 (0.96, 1.12)	1.01 (0.96, 1.07)	1.13 (1.04, 1.22)	1.08 (0.92, 1.28)	1.01 (0.90, 1.12)	1.23 (1.05, 1.44)
	lag5	1.08 (1.00, 1.17)	1.02 (0.97, 1.07)	1.20 (1.11, 1.30)	1.15 (0.98, 1.35)	0.86 (0.77, 0.95)	1.42 (1.22, 1.65)
	lag6	1.04 (0.94, 1.16)	1.00 (0.93, 1.07)	1.22 (1.09, 1.35)	1.35 (1.08, 1.68)	0.80 (0.69, 0.92)	1.41 (1.15, 1.72)
	lag7	0.85 (0.74, 0.98)	0.96 (0.87, 1.06)	1.13 (0.99, 1.30)	1.20 (0.90, 1.60)	0.89 (0.74, 1.07)	1.07 (0.83, 1.39)
female	lag0	0.99 (0.85, 1.15)	0.97 (0.87, 1.09)	1.19 (1.01, 1.40)	0.72 (0.53, 0.99)	0.88 (0.70, 1.11)	0.85 (0.63, 1.15)
	lag1	0.99 (0.89, 1.12)	1.05 (0.97, 1.14)	1.26 (1.11, 1.44)	1.55 (1.20, 1.99)	1.28 (1.08, 1.52)	1.02 (0.80, 1.28)
	lag2	0.99 (0.91, 1.08)	1.03 (0.97, 1.09)	1.24 (1.13, 1.36)	1.52 (1.26, 1.83)	1.22 (1.07, 1.38)	1.16 (0.97, 1.38)
	lag3	1.01 (0.93, 1.1)	0.99 (0.93, 1.05)	1.19 (1.09, 1.31)	1.19 (0.98, 1.43)	1.04 (0.92, 1.19)	1.25 (1.05, 1.50)
	lag4	1.03 (0.95, 1.13)	0.98 (0.92, 1.04)	1.17 (1.06, 1.28)	1.01 (0.84, 1.22)	0.96 (0.85, 1.10)	1.29 (1.08, 1.55)

Table 4. (Continued).

Days of lag	PM _{2.5} (µg/m ³)	PM ₁₀ (µg/m ³)	NO ₂ (µg/m ³)	SO ₂ (µg/m ³)	O ₃ - 8 h (µg/m ³)	CO (µg/m ³)
lag5	1.05 (0.96, 1.14)	0.99 (0.93, 1.06)	1.18 (1.07, 1.29)	1.02 (0.85, 1.22)	0.98 (0.87, 1.11)	1.28 (1.08, 1.53)
lag6	1.01 (0.9, 1.14)	1.01 (0.93, 1.09)	1.19 (1.05, 1.35)	1.02 (0.79, 1.31)	0.98 (0.82, 1.16)	1.25 (1.00, 1.57)
lag7	0.87 (0.74, 1.02)	0.95 (0.85, 1.06)	1.14 (0.97, 1.34)	0.68 (0.49, 0.94)	0.73 (0.58, 0.90)	1.23 (0.91, 1.66)
Age						
≤65 lag0	0.94 (0.81, 1.09)	1.08 (0.99, 1.18)	1.17 (1.03, 1.34)	0.87 (0.67, 1.12)	0.79 (0.66, 0.94)	0.94 (0.74, 1.21)
lag1	0.98 (0.89, 1.09)	1.02 (0.95, 1.09)	1.07 (0.96, 1.18)	1.83 (1.49, 2.25)	1.09 (0.95, 1.24)	0.83 (0.68, 1.01)
lag2	1.01 (0.93, 1.08)	1.01 (0.96, 1.06)	1.06 (0.98, 1.14)	1.67 (1.44, 1.95)	1.22 (1.10, 1.34)	0.91 (0.79, 1.05)
lag3	1.02 (0.94, 1.10)	1.02 (0.97, 1.07)	1.11 (1.02, 1.19)	1.23 (1.05, 1.43)	1.17 (1.06, 1.29)	1.09 (0.94, 1.26)
lag4	1.05 (0.97, 1.13)	1.03 (0.98, 1.08)	1.16 (1.07, 1.25)	1.03 (0.89, 1.20)	1.03 (0.93, 1.14)	1.28 (1.11, 1.49)
lag5	1.06 (0.99, 1.15)	1.03 (0.98, 1.08)	1.18 (1.11, 1.28)	1.10 (0.95, 1.28)	0.89 (0.81, 0.98)	1.39 (1.20, 1.61)
lag6	1.02 (0.93, 1.13)	1.02 (0.95, 1.09)	1.19 (1.08, 1.32)	1.27 (1.03, 1.56)	0.81 (0.71, 0.93)	1.35 (1.12, 1.63)
lag7	0.86 (0.75, 0.99)	0.99 (0.90, 1.08)	1.15 (1.01, 1.31)	1.02 (0.78, 1.33)	0.84 (0.71, 1.00)	1.19 (0.93, 1.52)
>65 lag0	1.06 (0.89, 1.26)	1.06 (0.94, 1.20)	1.01 (0.83, 1.20)	0.66 (0.46, 0.94)	0.73 (0.56, 0.94)	0.78 (0.56, 1.10)
lag1	1.02 (0.90, 1.16)	1.07 (0.98, 1.17)	1.17 (1.02, 1.35)	1.44 (1.08, 1.90)	1.32 (1.09, 1.60)	1.07 (0.83, 1.39)
lag2	0.96 (0.87, 1.06)	1.01 (0.94, 1.08)	1.16 (1.05, 1.29)	1.51 (1.23, 1.86)	1.27 (1.10, 1.46)	1.14 (0.94, 1.39)
lag3	0.95 (0.86, 1.04)	0.96 (0.90, 1.03)	1.12 (1.01, 1.24)	1.25 (1.01, 1.55)	1.03 (0.89, 1.19)	1.15 (0.94, 1.40)
lag4	0.98 (0.89, 1.08)	0.95 (0.88, 1.01)	1.12 (1.01, 1.24)	1.08 (0.88, 1.34)	0.91 (0.78, 1.05)	1.20 (0.99, 1.47)
lag5	1.04 (0.95, 1.15)	0.97 (0.90, 1.03)	1.18 (1.06, 1.31)	1.07 (0.87, 1.31)	0.94 (0.82, 1.08)	1.30 (1.07, 1.58)
lag6	1.03 (0.90, 1.17)	0.98 (0.90, 1.07)	1.23 (1.07, 1.41)	1.07 (0.81, 1.41)	0.99 (0.82, 1.20)	1.33 (1.03, 1.71)
lag7	0.83 (0.69, 0.98)	0.91 (0.81, 1.03)	1.11 (0.93, 1.33)	0.80 (0.56, 1.15)	0.76 (0.60, 0.97)	1.05 (0.75, 1.46)

Table 5. The relative risk of daily hospitalization and 95% CI of diabetes patients in different subgroups (period 9–21).

Lag days	PM _{2.5} (µg/m ³)	PM ₁₀ (µg/m ³)	NO ₂ (µg/m ³)	SO ₂ (µg/m ³)	O ₃ - 8 h (µg/m ³)	CO (µg/m ³)
Sex						
Male lag0	1.03 (0.89, 1.19)	1.13 (1.02, 1.24)	1.14 (0.95, 1.37)	0.81 (0.64, 1.02)	0.75 (0.62, 0.91)	0.85 (0.66, 1.09)
lag1	1.02 (0.92, 1.14)	1.01 (0.95, 1.09)	0.96 (0.83, 1.10)	1.53 (1.26, 1.85)	1.16 (1.01, 1.35)	0.92 (0.75, 1.12)
lag2	1.01 (0.92, 1.08)	0.98 (0.93, 1.04)	0.98 (0.89, 1.09)	1.48 (1.29, 1.70)	1.22 (1.09, 1.37)	0.98 (0.85, 1.14)
lag3	0.99 (0.92, 1.08)	0.99 (0.94, 1.04)	1.08 (0.97, 1.19)	1.19 (1.03, 1.38)	1.10 (0.98, 1.23)	1.07 (0.92, 1.25)
lag4	1.02 (0.95, 1.11)	1.01 (0.95, 1.06)	1.16 (1.05, 1.29)	1.06 (0.92, 1.23)	0.97 (0.87, 1.09)	1.20 (1.02, 1.40)
lag5	1.06 (0.98, 1.14)	1.01 (0.95, 1.06)	1.19 (1.07, 1.32)	1.14 (0.99, 1.31)	0.91 (0.82, 1.01)	1.31 (1.12, 1.52)
lag6	1.03 (0.93, 1.14)	0.99 (0.92, 1.06)	1.15 (1.01, 1.32)	1.29 (1.06, 1.57)	0.90 (0.78, 1.03)	1.29 (1.06, 1.57)
lag7	0.84 (0.73, 0.96)	0.96 (0.87, 1.06)	1.11 (0.92, 1.33)	1.13 (0.88, 1.44)	0.85 (0.71, 1.02)	1.02 (0.80, 1.32)
female lag0	1.05 (0.91, 1.22)	0.95 (0.85, 1.06)	1.22 (0.99, 1.51)	0.77 (0.59, 1.01)	0.90 (0.72, 1.13)	0.98 (0.73, 1.32)
lag1	0.97 (0.87, 1.08)	1.03 (0.95, 1.11)	1.21 (1.03, 1.43)	1.10 (0.89, 1.37)	1.33 (1.11, 1.59)	0.96 (0.76, 1.20)
lag2	0.98 (0.90, 1.07)	1.01 (0.95, 1.07)	1.19 (1.06, 1.34)	1.26 (1.07, 1.47)	1.23 (1.07, 1.40)	1.14 (0.96, 1.35)
lag3	1.02 (0.94, 1.11)	0.97 (0.91, 1.03)	1.15 (1.02, 1.30)	1.22 (1.03, 1.44)	1.05 (0.92, 1.20)	1.31 (1.10, 1.56)
lag4	1.05 (0.97, 1.14)	0.96 (0.90, 1.02)	1.11 (0.98, 1.25)	1.08 (0.92, 1.28)	1.02 (0.87, 1.15)	1.31 (1.10, 1.57)
lag5	1.04 (0.96, 1.13)	0.97 (0.91, 1.03)	1.08 (0.96, 1.22)	0.93 (0.79, 1.09)	1.08 (0.95, 1.23)	1.18 (0.99, 1.39)
lag6	0.99 (0.88, 1.11)	0.99 (0.91, 1.07)	1.10 (0.94, 1.30)	0.81 (0.65, 1.01)	1.08 (0.92, 1.28)	1.09 (0.87, 1.36)
lag7	0.92 (0.79, 1.07)	0.95 (0.85, 1.06)	1.21 (0.98, 1.50)	0.75 (0.57, 0.99)	0.70 (0.56, 0.86)	1.38 (1.04, 1.84)

Table 5. (Continued).

Lag days	PM _{2.5} (μg/m ³)	PM ₁₀ (μg/m ³)	NO ₂ (μg/m ³)	SO ₂ (μg/m ³)	O ₃ – 8 h (μg/m ³)	CO (μg/m ³)
Age						
≤65 lag0	0.97 (0.85, 1.12)	1.07 (0.98, 1.17)	1.23 (1.04, 1.47)	0.83 (0.67, 1.04)	0.84 (0.71, 1.02)	0.96 (0.76, 1.22)
lag1	0.97 (0.88, 1.08)	1.00 (0.94, 1.07)	1.00 (0.88, 1.14)	1.45 (1.21, 1.73)	1.13 (0.99, 1.30)	0.87 (0.73, 1.05)
lag2	1.00 (0.92, 1.07)	0.99 (0.94, 1.04)	1.02 (0.93, 1.12)	1.44 (1.26, 1.64)	1.19 (1.07, 1.32)	0.97 (0.85, 1.12)
lag3	1.02 (0.95, 1.10)	1.00 (0.96, 1.06)	1.11 (1.01, 1.22)	1.21 (1.05, 1.38)	1.12 (1.01, 1.25)	1.13 (0.98, 1.30)
lag4	1.04 (0.97, 1.12)	1.01 (0.96, 1.07)	1.17 (1.06, 1.28)	1.07 (0.93, 1.22)	1.04 (0.93, 1.16)	1.24 (1.07, 1.43)
lag5	1.03 (0.96, 1.11)	1.01 (0.96, 1.06)	1.16 (1.05, 1.27)	1.07 (0.94, 1.22)	0.98 (0.88, 1.08)	1.25 (1.09, 1.44)
lag6	0.97 (0.88, 1.07)	0.99 (0.93, 1.06)	1.13 (0.99, 1.29)	1.12 (0.94, 1.34)	0.91 (0.80, 1.04)	1.21 (1.01, 1.45)
lag7	0.86 (0.76, 0.98)	0.98 (0.89, 1.07)	1.20 (1.01, 1.43)	0.95 (0.76, 1.20)	0.79 (0.67, 0.94)	1.25 (0.99, 1.58)
>65 lag0	1.05 (0.89, 1.24)	1.00 (0.88, 1.13)	1.06 (0.84, 1.35)	0.71 (0.53, 0.97)	0.76 (0.59, 0.97)	0.79 (0.58, 1.1)
lag1	1.02 (0.90, 1.16)	1.06 (0.97, 1.16)	1.18 (0.98, 1.41)	1.12 (0.88, 1.43)	1.45 (1.19, 1.77)	1.07 (0.83, 1.37)
lag2	0.97 (0.89, 1.07)	1.01 (0.94, 1.07)	1.16 (1.02, 1.32)	1.27 (1.06, 1.52)	1.30 (1.12, 1.51)	1.20 (0.99, 1.45)
lag3	0.96 (0.87, 1.05)	0.94 (0.88, 1.01)	1.11 (0.97, 1.27)	1.20 (1.01, 1.45)	0.99 (0.85, 1.15)	1.24 (1.02, 1.51)
lag4	0.99 (0.91, 1.09)	0.93 (0.87, 0.99)	1.09 (0.95, 1.24)	1.08 (0.90, 1.30)	0.88 (0.76, 1.03)	1.25 (1.03, 1.52)
lag5	1.05 (0.96, 1.15)	0.96 (0.89, 1.02)	1.11 (0.97, 1.26)	0.98 (0.82, 1.17)	0.98 (0.85, 1.13)	1.25 (1.03, 1.51)
lag6	1.04 (0.92, 1.18)	0.98 (0.90, 1.08)	1.13 (0.94, 1.35)	0.94 (0.74, 1.19)	1.10 (0.91, 1.32)	1.19 (0.93, 1.52)
lag7	0.85 (0.72, 1.01)	0.91 (0.81, 1.03)	1.08 (0.86, 1.37)	0.93 (0.68, 1.26)	0.76 (0.60, 0.97)	1.02 (0.74, 1.40)

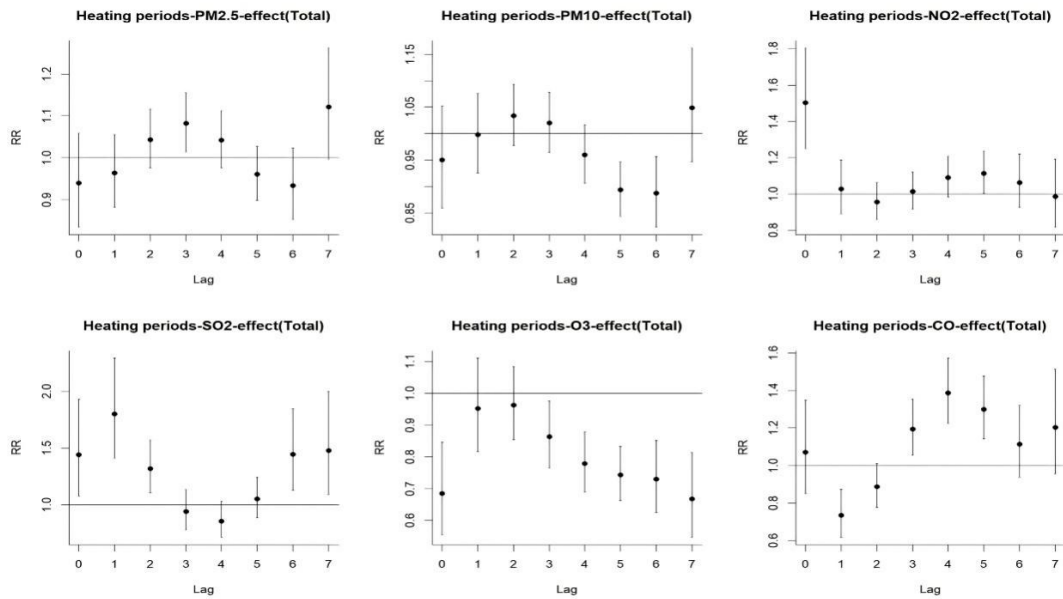


Figure 5. Effect of pollutants on daily hospitalizations of T2DM patients during the heating season (all-day period).

3.4.2. Effect of pollutants in the heating season and non-heating season on daily hospitalization of T2DM patients

All-day period

In the all-day heating season, PM_{2.5}, PM₁₀, and O₃ had no statistical significance on T2DM daily admissions in lag0–lag7 days of each lag. NO₂ and SO₂ showed an immediate effect and peaked at lag0 and lag1 with statistical significance. In contrast, RR values decreased with an increase in time. CO showed a hysteresis

effect and peaked at lag4 days with statistical significance (**Figure 6**). In the non-heating season, all the pollutants showed a lag effect, and the peaks of PM_{2.5}, PM₁₀, and CO were statistically significant between lag5 and lag7. NO₂, SO₂, and O₃ showed their peaks between lag2 and lag4 and were statistically significant (**Figure 7**).

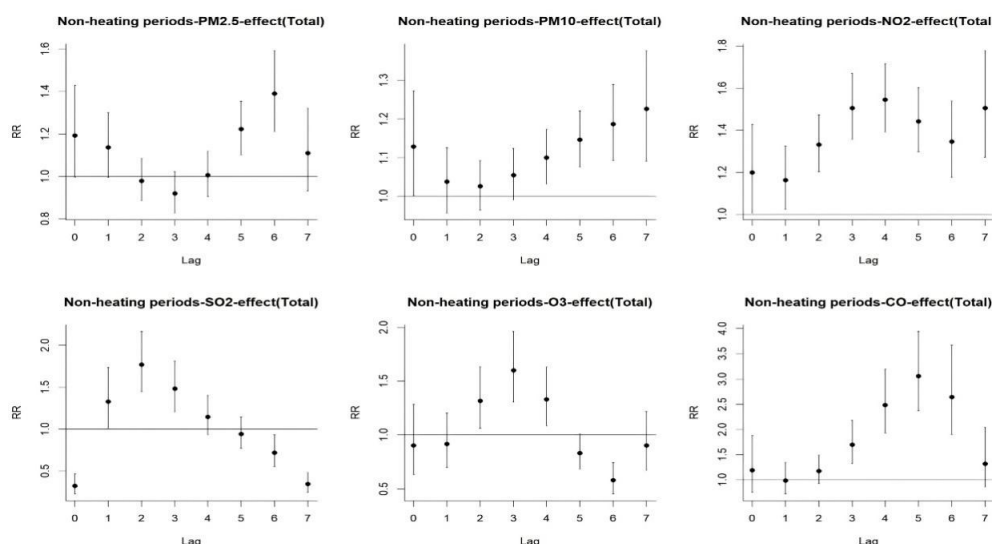


Figure 6. Effect of pollutants on daily hospitalization of T2DM patients in non-heating season (all-day period).

Period of 9–21

The effects of six air pollutants, PM_{2.5}, PM₁₀, NO₂, SO₂, O₃, and CO, on the lagging impact of daily admissions of T2DM patients during the heating season from 9 to 21 were the same as those during the whole day (**Figure 8**). In the non-heating season, PM_{2.5}, PM₁₀, SO₂, O₃, and CO pollutants all showed a lag effect, and the influence on the lag effect of the daily admissions of T2DM patients was the same as that of the whole day. Only NO₂ showed an immediate impact from the entire day, reaching a peak value at lag1 day on the same day and then showing a trend of decreasing at first and then increasing slowly (**Figure 9**).

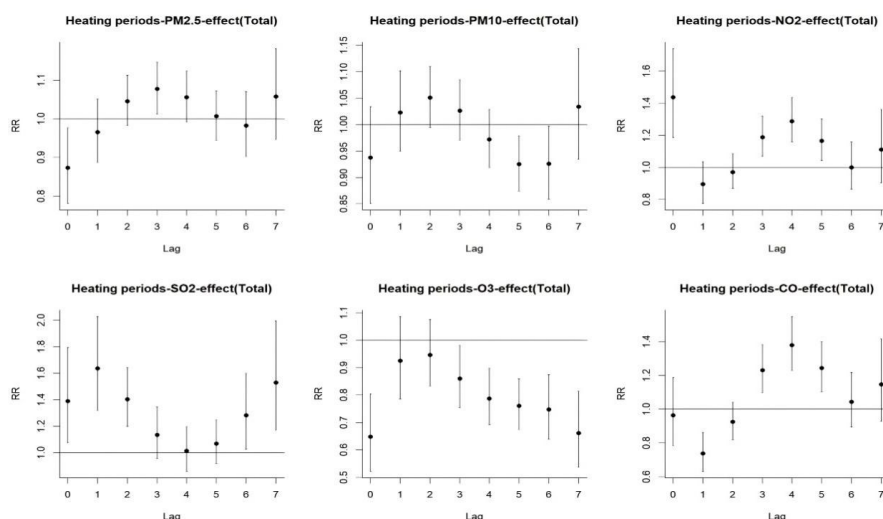


Figure 7. Effect of pollutants in heating season on daily hospitalization of T2DM patient (period 9–21).

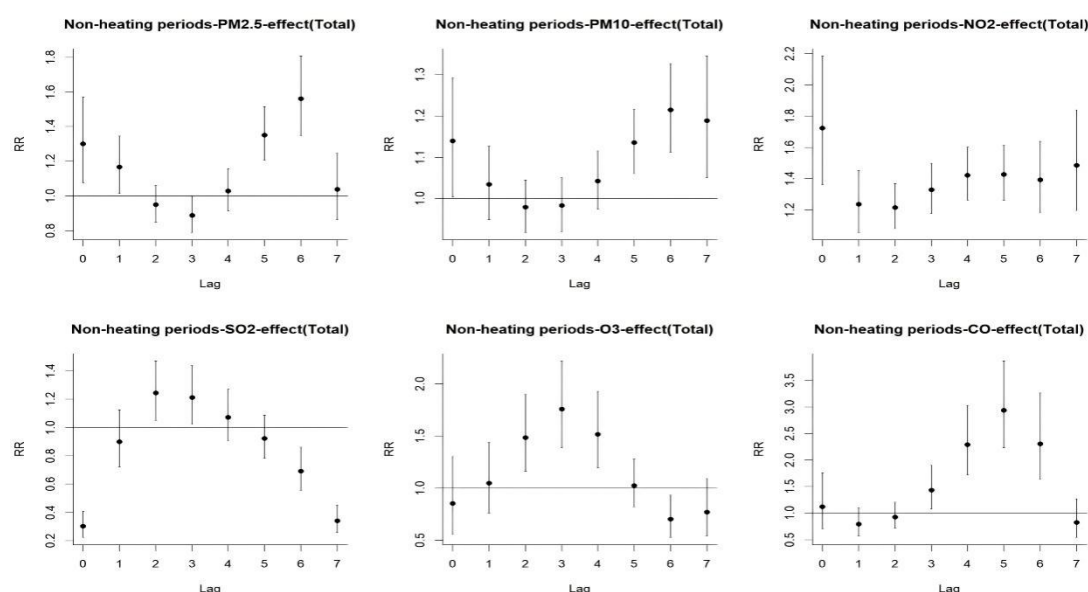


Figure 8. Effect of pollutants in non-heating season on the daily hospitalization of T2DM patients (period 9–21).

4. Discussion

With rapid economic development, a city in Xinjiang has formed a fast-growing industrial cluster, and the impact of industrial industries on air pollution is becoming increasingly apparent. In recent years, some researchers have gradually found that air pollution has an important effect on developing chronic noncommunicable diseases [20]. Diabetes is one of the major chronic noncommunicable diseases, and the impact of air pollutants on it has been paid attention by scholars at home and abroad. Air pollutants and meteorological factors are closely related to damage to vascular endothelial function, atherosclerosis development, and the abnormal mechanism of blood coagulation. These factors are associated with insulin resistance and dysfunction of islet beta cells, thus increasing the risk of cardiovascular and cerebrovascular diseases and diabetes [21]. As a city in Xinjiang entered a period of isolation due to the novel coronavirus epidemic in August 2022, the number of hospitalized patients with diabetes dropped sharply. Therefore, the specific data analysis period was from 1 January 2021, to 10 August 2022, to explore the delayed impact of air pollutants on the daily hospitalization of diabetes to provide a basis for the early warning of air pollution-related diseases.

4.1. The effects of different air pollutants on the daily hospitalization of T2DM patients

In this study, no significant difference was found between short-term exposure to PM_{2.5} and PM₁₀ on the daily hospitalizations of T2DM patients. Although PM_{2.5} and PM₁₀ showed delayed effects and immediate effects on daily hospitalizations of T2DM patients and reached the peak RR value at lag5 and lag0, respectively, the difference was not statistically significant ($P > 0.05$). Cross-sectional studies [22] from India are consistent with the results of this study, and no significant association between PM_{2.5} and T2DM has been found. Another study that [23] recruited four ethnic groups (e.g., black, white, Chinese, and Hispanic) for nine years found no

association between PM_{2.5} and T2DM, which is consistent with this study. However, several studies have reported an association between PM_{2.5} and T2DM. A Danish cohort study showed [24] an 11% increase in the incidence of T2DM for every additional quartile of PM_{2.5}. Additionally, a study from Japan found that the extent of the association between PM_{2.5} and T2DM became stronger with prolonged exposure [25].

NO₂, SO₂, O₃, and CO all showed a significant cumulative lag effect, reaching the peak RR values at lag6, lag5, lag1, and lag2 days, respectively, and showed significant differences in the daily hospitalization of T2DM patients. Consistent with the results of this study, many studies have confirmed a correlation between NO exposure and T2DM. A cohort study [26] in the United Kingdom found a positive association between NO and the incidence of diabetes (HR = 1.13, 95% CI: 1.05%–1.22%). A study [27] from Lanzhou, Gansu Province, also found a positive correlation between NO₂ and daily hospitalizations for T2DM, and exposure to NO₂ was associated with an increased risk of hospitalization for T2DM.

4.2. Subgroup analysis

In the subgroup stratification analysis, PM_{2.5} still did not produce a statistically significant difference in the daily hospitalization of each subgroup; PM₁₀ only had an immediate effect on the daily hospitalization of males, reaching a peak value of 1.16 (95% CI: 1.05, 1.28) at lag0 day, which was statistically significant but was not significant in other subgroups. This result suggests that men are more susceptible to PM₁₀ exposure and have an increased risk of hospitalization compared with women. Previous studies have shown [28,29] that the association between particulate pollutants and T2DM was more significant in patients aged 65 years and older, men with lower education, higher BMI, current smokers, use of unclean heating energy, or living in rural areas. This result may be explained by the fact that men engage in more outdoor occupations and activities in their daily lives and thus have more opportunities to be exposed to air pollution.

Regarding NO₂ and CO, males and the younger age group showed the same lagging trend, as did females and the older age group. The exposure risk of females and the older age group was higher than that of males and young individuals. These results suggest that women and people over 65 are more vulnerable to air pollution, especially exposure to NO₂ and CO, which is consistent with the results of previous studies [30,31].

After stratification of the heating and non-heating seasons, all pollutants in the non-heating season showed a lag effect, and the influence on the daily hospitalization of T2DM was statistically significant. In the heating season, only NO₂, SO₂, and CO had statistically significant effects on the daily hospitalization of T2DM patients. This study speculated that this might be because the temperature is too low in the cold season in Xinjiang, and residents are more likely to reduce outdoor activities and close Windows, which is related to reduced air exposure compared with the non-heating season. Additionally, relevant studies have shown [32] that heat exposure is more likely to increase the risk of diabetes-related hospitalization than cold exposure. T2DM patients are more likely to experience this phenomenon due to

increased heat exposure during non-heating periods.

4.3. Effects of whole-day and 9–21 periods on daily hospitalizations in T2DM patients

According to previous studies [17,18], there are significant differences in the variation of atmospheric pollutant concentrations between day and night, and the concentration of pollutants at night is high. This is the same as the result of the descriptive analysis of air pollutant characteristics in this study, and the concentration of pollutants during the whole day was higher than that from 9 to 21 (daytime).

Compared with the all-day period, the effects of PM_{2.5} and PM₁₀ in the 9–21 period on the daily hospitalization of T2DM patients were the same as those in the all-day period. The effects of SO₂, O₃, and CO on the daily hospitalization of T2DM patients were only slightly different, and the changing trend of the lag effect was the same. Only the lag days and RR values changed. NO₂ in the female subgroup and the non-heating seasonal subgroup showed a completely different change trend in the lag effect during the whole day, and the other subgroups also showed changes in the lag days and RR values. These results suggest that T2DM patients may be more susceptible to NO₂ exposure, women and non-heating season are more affected by NO₂ exposure, and the risk of hospital admission is higher, consistent with the subgroup analysis results in this paper. Most sources of NO₂ were from industrial production and traffic exhaust, and exposure to traffic-related pollutants was associated with an increased risk of diabetes [33].

In the female and non-heating subgroups, NO₂ in the period 9–21 showed a different immediate effect than that in the whole day, peaking at lag0 days on the same day. Given the high sensitivity of the two subgroups to NO₂ exposure, the immediate effect of RR decreasing gradually with the increase in lag days is more likely to occur in the above two subgroups. Therefore, this study suggests that the 9–21 period may be a more suitable analysis period.

4.4. Innovation and limitations

This study sets a comparison and analysis between the all-day period and the 9–21 period (daytime) to more reasonably and accurately quantify the impact of environmental factors on population health.

The limitation of this study lies in the fact that the epidemic has a significant impact on hospitalization. Even after excluding the epidemic control period, there was still a lag effect between air pollutants and the daily hospitalization rate of T2DM in other periods. At the same time, diabetes is susceptible to many factors, and the extrapolation of the results needs to further expand the sample size.

5. Conclusion

1) Both air pollutant concentration and meteorological factors have seasonal and regular fluctuations, showing positive U-shaped or inverted U-shaped changes, especially in heating and non-heating seasons.

2) Exposure to NO₂, SO₂, O₃, and CO increases the risk of hospitalization for

diabetes mellitus.

3) Women and people with diabetes over 65 years of age are more susceptible to exposure to NO₂ and CO, leading to an increased risk of hospitalization.

4) The trend change of NO₂ on the daily hospitalization of diabetic patients was the biggest difference between the whole day and the 9–21 period. At the same time, the other pollutants showed no significant change trend.

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Data availability statement: All data used in this study are publicly available and sourced from A System of Health Accounts 2011 edition. All data used are publicly available and do not require approval from the ethics committee.

Conflict of interest: The authors declare no conflict of interest.

References

1. Chen Z, Zhao Z, et al. Association between Air Pollution and Type 2 Diabetes Mellitus in Developing Countries: A Systematic Review and Meta-Analysis. *Chinese Medical Sciences Journal*. 2022; 37(3): 218–227. doi: 10.24920/004065
2. Murray, Christopher JL. GBD 2019 Risk Factor Collaborators, Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet*. 2020; 396(10258): 1224–1249.
3. Cesaroni G, Forastiere F, Stafoggia M, et al. Long term exposure to ambient air pollution and incidence of acute coronary events: Prospective cohort study and meta-analysis in 11 European cohorts from the escape project. *BMJ*. 2014; 348: f7412.
4. Beelen R, Raaschou-Nielsen O, Stafoggia M, et al. Effects of long-term exposure to air pollution on natural-cause mortality: An analysis of 22 European cohorts within the multicentre escape project. *Lancet*. 2014; 383 (9919): 785–95.
5. Yu H, Feng L, Hou C et al. A prospective cohort study on the relationship between improved air quality and the onset of type 2 diabetes mellitus. *Public Health & Preventive Medicine*. 2019; 31(01): 11–15.
6. Ruiz D, Becerra M, Jagai JS, et al. Disparities in Environmental Exposures to Endocrine-Disrupting Chemicals and Diabetes Risk in Vulnerable Populations. *Diabetes Care*. 2017; 41(1): 193–205. doi: 10.2337/dc16-2765
7. International Diabetes Federation. IDF Diabetes Atlas 10th edition 2021 [EB/OL] (2021-12-06) [2024-03-01]. Available online: <https://diabetesatlas.org/> (accessed on 6 January 2025).
8. International Diabetes Federation. IDF Diabetes Atlas, 9th edn. Brussels, Belgium: 2019. [EB/OL]. Available online: <http://www.diabetesatlas.org> (accessed on 6 January 2025).
9. Xu Y. Prevalence and Control of Diabetes in Chinese Adults. *JAMA*. 2013; 310(9): 948. doi: 10.1001/jama.2013.168118
10. China CDC. Chinese Cause-of-death Surveillance dataset 2016. Beijing Science and Technology Press of China; 2017.
11. Park SK, Adar SD, O'Neill MS, et al. Long-Term Exposure to Air Pollution and Type 2 Diabetes Mellitus in a Multiethnic Cohort. *American Journal of Epidemiology*. 2015; 181(5): 327–336. doi: 10.1093/aje/kwu280
12. Renzi M, Cerza F, Gariazzo C, et al. Air pollution and occurrence of type 2 diabetes in a large cohort study. *Environment International*. 2018; 112: 68–76. doi: 10.1016/j.envint.2017.12.007
13. Puett RC, Hart JE, Schwartz J, et al. Are Particulate Matter Exposures Associated with Risk of Type 2 Diabetes? *Environmental Health Perspectives*. 2011; 119(3): 384–389. doi: 10.1289/ehp.1002344
14. Chen W, Liu G, Jiang Q, et al. Health economics. Beijing: People's Medical Publishing House; 2017.

15. Bergen S, Sheppard L, Kaufman JD, et al. Multipollutant Measurement Error in Air Pollution Epidemiology Studies Arising from Predicting Exposures with Penalized Regression Splines. *Journal of the Royal Statistical Society Series C: Applied Statistics*. 2016; 65(5): 731-753. doi: 10.1111/rssc.12144
16. Guxens M, Lubczyńska MJ, Muetzel RL, et al. Air Pollution Exposure During Fetal Life, Brain Morphology, and Cognitive Function in School-Age Children. *Biological Psychiatry*. 2018; 84(4): 295-303. doi: 10.1016/j.biopsych.2018.01.016
17. Liu J, Gu Y, Ma S, et al. Diurnal variation and source analysis of inorganic components in PM (2.5) in Changzhou during summer and winter. *Environmental Science*. 2018; 39(03): 980-989.
18. Qiu CC, Yu XN, Ding C, et al. Diurnal variation of chemical components of PM (2.5) in Jiangbei New Area of Nanjing in winter and their source analysis. *Environmental Science*. 2019; 41(02): 529-536.
19. Wang H, Wang H, Lu X, et al. Increased night-time oxidation over China despite widespread decrease across the globe. *Nature Geoscience*, In Chinese. 2023; 16(3): 217-223.
20. Hvidtfeldt UA, Sørensen M, Geels C, et al. Long-term residential exposure to PM2.5, PM10, black carbon, NO2, and ozone and mortality in a Danish cohort. *Environment International*. 2019; 123: 265-272. doi: 10.1016/j.envint.2018.12.010
21. Mi X. Relationship between exposure to ultra-fine particulate matter and nitrogen dioxide and incidence of hypertension and diabetes. *Chinese Journal of Preventive Medicine*. 2019; 53(1): 9-9.
22. Curto A, Ranzani O, Mila C, et al. Lack of association between particulate air pollution and blood glucose levels and diabetic status in peri-urban India. *Environment international*. 2019; 131: 105033.
23. Park SK, Adar SD, O'Neill MS, et al. Long-Term Exposure to Air Pollution and Type 2 Diabetes Mellitus in a Multiethnic Cohort. *American Journal of Epidemiology*. 2015; 181(5): 327-336. doi: 10.1093/aje/kwu280
24. Hansen AB, Ravnskjaer L, Loft S, et al. Long-term exposure to fine particulate matter and incidence of diabetes in the Danish Nurse Cohort. *Environment International*. 2016; 91: 243-250. doi: 10.1016/j.envint.2016.02.036
25. Lee M, Ohde S. PM2.5 and Diabetes in the Japanese Population. *International Journal of Environmental Research and Public Health*. 2021; 18(12): 6653. doi: 10.3390/ijerph18126653
26. Li R, Cai M, Qian Z (Min), et al. Ambient air pollution, lifestyle, and genetic predisposition associated with type 2 diabetes: findings from a national prospective cohort study. *Science of The Total Environment*. 2022; 849: 157838. doi: 10.1016/j.scitotenv.2022.157838
27. Zhang W, Ling J, Zhang R, et al. Effect of short-term NO2 exposure on daily inpatients with type 2 diabetes mellitus in Lanzhou. *Modern Preventive Medicine*. 2019; 50(22): 4071-4076.
28. Liu C, Yang C, Zhao Y, et al. Associations between long-term exposure to ambient particulate air pollution and type 2 diabetes prevalence, blood glucose and glycosylated hemoglobin levels in China. *Environment International*. 2016; 92-93: 416-421. doi: 10.1016/j.envint.2016.03.028
29. Liu F, Guo Y, Liu Y, et al. Associations of long-term exposure to PM1, PM2.5, NO2 with type 2 diabetes mellitus prevalence and fasting blood glucose levels in Chinese rural populations. *Environment International*. 2019; 133: 105213. doi: 10.1016/j.envint.2019.105213
30. Wu C, Yan Y, Chen X, et al. Short-term exposure to ambient air pollution and type 2 diabetes mortality: A population-based time series study. *Environmental Pollution*. 2021; 289: 117886. doi: 10.1016/j.envpol.2021.117886
31. Du N, Ji AL, Liu XL, et al. Association between short-term ambient nitrogen dioxide and type 2 diabetes outpatient visits: A large hospital-based study. *Environmental Research*. 2022; 215: 114395. doi: 10.1016/j.envres.2022.114395
32. Xu R, Zhao Q, Coelho MSZS, et al. Association between Heat Exposure and Hospitalization for Diabetes in Brazil during 2000–2015: A Nationwide Case-Crossover Study. *Environmental Health Perspectives*. 2019; 127(11). doi: 10.1289/ehp5688
33. Weinmayr G, Hennig F, et al. Long-term exposure to fine particulate matter and incidence of type 2 diabetes mellitus in a cohort study: effects of total and traffic-specific air pollution. *Environmental Health*. 2015; 14(1). doi: 10.1186/s12940-015-0031-x