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Qingnan Wang
Xi'an Jiaotong University
Zhuo Chen
University of Georgia
Wei Huang
Southern University of Science and Technology
Bo Kou (bobiekou@163.com)
Xi'an Jiaotong University Medical College First Affiliated Hospital https://orcid.org/0000-0002-5727-9124
Jingwei Li
Xi'an Jiaotong University

Research Article

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Examining the Short-term Effect of Moderate Level Air Pollution on Multi-department Outpatient Visits in Xi'an, China

Qingnan Wang[1, †], Zhuo Chen[4,5], Wei Huang [2,1], Bo Kou [3, *], Jingwei Li[6]

[1]Department of Information Management, School of Management, Xi'an Jiaotong University, Xi'an 710049, China; wqingnan1118@gmail.com

[2]College of Business, Southern University of Science and Technology, Shenzhen 518055, China; waynehw@qq.com

[3]Department of Otolaryngology, the First Affiliated Hospital of Xi'an Jiaotong University, Xi'an 710049, China; bobiekou@163.com

[4] College of Public Health, University of Georgia, Athens, GA 30602, USA; zchen1@uga.edu

[5]School of Economics, University of Nottingham Ningbo China, Ningbo 315000, China

[6]Department of Information Management, School of Management, Xi'an Jiaotong University, Xi'an 710049, China; li.jing.wei123@stu.xjtu.edu.cn

[*]Correspondence: bobiekou@163.com

[†]Current address: No.28, Xianning West Road, Xi'an, Shaanxi, 710049, P.R. China

Abstract

Objective: There is limited evidence concerning the association between air pollution and outpatient visits in moderately polluted areas. This paper investigates the effects of moderate level ambient air pollution on the number of outpatient visits associated with five categories of medical conditions.

Methods: We analyzed a total of 1,340,791 outpatient visits for five medical departments (pediatrics, respiratory, ENT, cardiovascular, and orthopedics) in Xi'an from 2016 to 2018. A distributed non-linear model was used to analyze the associations and was fitted and stratified by age and season.

Results: We found SO_2 had the largest effect on pediatrics visits (RR=1.105 (1.090, 1.121)). The relationships among $PM_{2.5}$ and O_3 and ENT were more statistically significant in a heating season than those in a non-heating season. Meanwhile, $PM_{2.5}$, PM_{10}, and SO_2 had bigger impacts on ENT visits for people under 50 years. The results showed a strong association between O_3 and cardiovascular outpatient visits in a non-heating season (RR=1.026 (1.020,1.032)). The results also showed that PM_{10} was not significantly associated with respiratory outpatient visits, and every 10 $\mu g/m^3$ increase of SO_2 reduced the number of respiratory outpatient visits by 3%. We found $PM_{2.5}$ and NO_2 were significantly related to orthopedic outpatient visits for people under 60.

Conclusion: Our findings indicated short-term exposure to air pollutants had varying associations with outpatient visits to four medical departments. We also proposed a new set of air pollution thresholds, which could help hospitals optimize outpatient resource allocation and the government determine appropriate air quality standards.

Keywords: Outpatient visits; air pollutants; moderate pollution; exposure-response effect; distributed non-linear model; cardiovascular disease; pediatric department disease.

What is already know on this subject:

Previous studies had emphasized a lot on air pollutants' impact on hospital admission for different disease, e.g., cardiovascular disease, respiratory disease, emergency room visits, and so on. Most studies conducted on heavily polluted areas, and rare findings on moderately polluted area. However, there was a growing body of evidence on the associations between low-level air pollution exposure and increased mortality, with a limited number of studies on moderate-level air pollution exposure, it is thus important to fill the research gap in this field and help the public to understand more about adverse effects of air pollutants.

What this study adds:

- The research results showed that short-term exposure to moderate-level air pollutants had various significant effects on different medical departments' outpatient visits.
- Although some previous studies analyzed air pollution and respiratory diseases, this study provided new findings that O_3 had a stronger association with respiratory outpatient visits in moderately polluted areas than in heavily polluted areas.
- This paper found that although most of the pollutants were not relevant to orthopedic outpatient visits, $PM_{2.5}$ and NO_2 were significantly associated with increased orthopedic outpatient visits for people aged under 60.
- This study provided suggestions on air pollution thresholds according to the exposure-response curves. The new pollution thresholds could help hospital to optimize outpatient resource allocation and government to reconsider the air pollution standards.

1. Introduction

Climate change and air pollution are associated with increased mortalities and hospital admissions worldwide. Particulate matters have adverse effects including more hospital admissions(Tao, Mi, Zhou, Wang, & Xie, 2014), higher disease incidence(Z. Zhang et al., 2019), and stressed hospital management such as emergency ambulance dispatches(Michikawa et al., 2015). Understanding the associations between air pollution and the incidence of diseases could help vulnerable groups take preventive measures in their daily lives and governments allocate environmental protection resources.

Studies on the adverse effects of air pollution on health were primarily conducted in heavily polluted megacities such as Beijing(Tian et al., 2017), Shanghai(L. Liu et al., 2020), New York(Hsu, Hwang, Kinney, & Lin, 2017). However, few studies in the research literature focused on areas or cities with moderate pollution levels, which may be more common in developing countries like China. We conducted a brife literature review in the PubMed database using 'air pollution,' 'outpatient visits,' and 'low/moderate pollution' as keywords. We found that only 1,113 papers on low-level/moderate-level air pollution from January 2016 to April 2021. Because there is a growing body of evidence on the associations between low-level air pollution exposure and increased mortality(Brauer et al., 2019; Christidis et al., 2019), with a limited number of studies on moderate-level air pollution exposure, it is important to fill the research gap in this field.

This study collected outpatient visits data in a large hospital to assess the associations between daily hospital visits and moderate air pollution exposure. Our findings could help hospital managers to optimize clinic resource allocation according to different air quality and provide additional evidence for the government to determine air quality standards.

2. Methods

2.1. Study area

Xi'an city locates in northwestern China, with a total land area of 10,752 square kilometers and a total resident population of more than 10.20 million in 2019. $PM_{2.5}$ and PM_{10} are primary pollutants in Xi'an, while NO_2 and O_3 has risen sharply in recent years(Di & Li, 2019). The daily AQI of Xi'an exhibits a seasonal shift, high in Winter and Spring and low in Summer and Autumn (Fig.1a). Quarterly AQI data showed that about 50% to 60% of the days in each quarter of Xi'an are classified as moderately polluted according to China and U.S. AQI standards(Gao, 2013; Hu, Ying, Wang, & Zhang, 2015) (Fig.1b), an appropriate moderate-polluted area for this study.

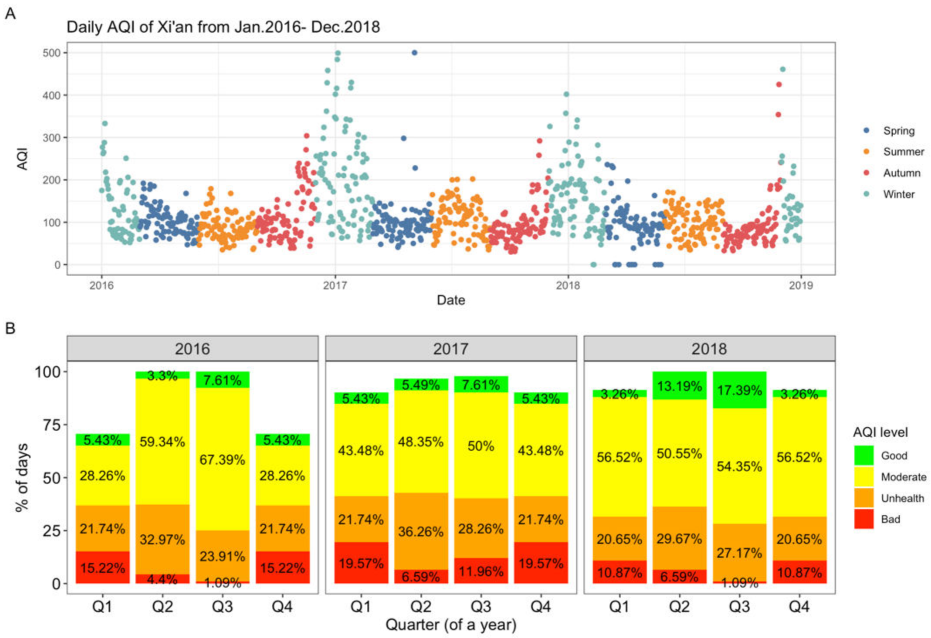

Fig.1 Time trend of Air Quality Index (AQI) and quarterly AQI in Xi'an from Jan.2016 to Dec.2018.

2.2. Hospital outpatient visits

Epidemiological studies commonly used mortality and morbidity to analyze the effects of air pollutants on health(Anderson, 2009), and there were concerns with using outpatient visits to estimate the acute effects of air pollution in developed countries because hospitalizations were usually scheduled by appointment, and patients were used to visiting local clinics rather than hospitals(L. Liu et al., 2021; H. Zhang et al., 2018). However, most hospitals in developing countries like China are usually appointment-free and first-come first-served(Zhao, Li, & Liu, 2020). Therefore, outpatient visits may track actual morbidity more reliably than other measures.

The outpatient visits data (from January 2016 to December 2018) were collected from a large hospital in Xi'an. The target hospital is one of the largest hospitals in Northwestern China, with 3.26 million outpatients and emergency visits in 2019, accounting for nearly 10% of the total number of general hospital outpatients in Xi'an.

Existing studies have found respiratory diseases, cardiovascular diseases, children are vulnerable to air pollution, so we chose the following departments: Pediatrics, ENT (ear-nose-throat), Cardiovascular Diseases, Respiratory Diseases, and Orthopedics. Orthopedics as the control group. The ethics committee of the hospital approved the protocol of this study and the access to hospital outpatient data (approval number: XJTU1AF2021LSK-2021-115).

2.3. Air pollution and meteorological data

Air pollution data were collected through thirteen environmental monitoring stations in Xi'an (Fig.2), established by the Xi'an Environmental Protection Administration. Air pollutants included $PM_{2.5}$ ($\mu g/m^3$), PM_{10} ($\mu g/m^3$), SO_2 ($\mu g/m^3$), NO_2 ($\mu g/m^3$), CO (mg/m^3), and O_3 ($\mu g/m^3$). Daily 24-h concentrations were calculated by averaging air pollutant concentrations over 24 hours per day for all five pollutants except O_3, which was calculated as 8-h maximum values (from 10 a.m. to 6 p.m.). Missing data were imputed by linear interpolation. Daily meteorological data, including mean temperature (℃), minimum temperature (℃), maximal temperature (℃), and relative humidity (%), were collected from the Xi'an Meteorological Administration.

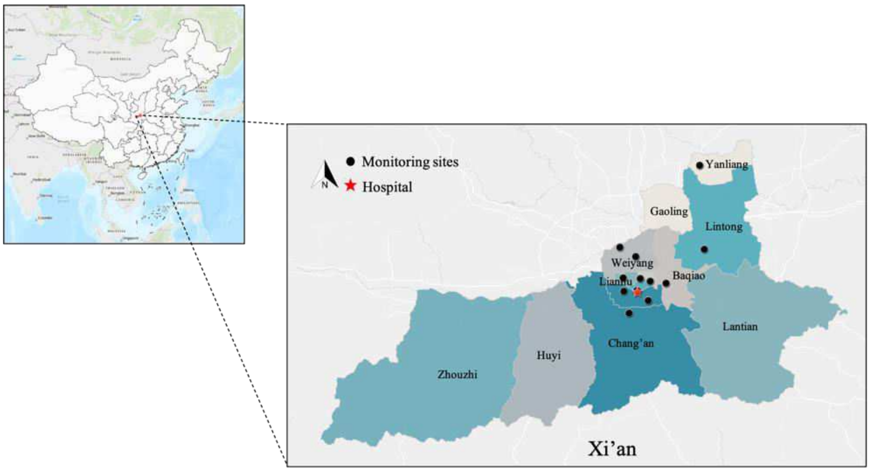

Fig.2 Locations of monitoring stations in Xi'an.

2.4. Statistical analysis

A generalized additive model (GAM) combined with a distributed non-linear lag model (DLNM) was built to illustrate the association between air pollution and outpatient visits. DLNM can analyze the non-linear exposure-response relationship and capture the cumulative health risks for different lag days of air pollution exposure than single lag days or moving averages(Armstrong, 2006). Previous studies shown that PM_{10} has a 3-5 days lag effect on respiratory disease admission, SO_2 had a 1-3 days lag effect on CVD mortality, and NO_2 had a 1-4 days lag effect on respiratory disease admission. Therefore, we chose a maximum lag of 5 days in the DLNM for all air pollutants as a priori in the main analyses(Peng, Dominici, & Louis, 2006).

A natural cubic spline cross-basis function was built to account for daily mean temperature's potentially lagged and non-linear effects, and the maximum lag days was 14 days (2 weeks)(Yin et al., 2017). A natural cubic spline function for calendar date was used to control seasonality or long-term trends, with a degree of freedom (df) of 7 per year.

Dummy variables for day of the week (DOW) and public holidays were used to control short-term time effects. A natural cubic spline function with 3 df was used to control for the relative humidity. The basic model was as follows:

$$\log[E(Y_t)] = \alpha + \beta PLNM(X_t, df = 5) + DLNM(temperature, df = 5) + ns(Calender\ Date, df = 7 * year) + ns(RH, df = 3) + factor(DOW) + factor(Holiday) + \quad [1]$$

where $E(Y_t)$ indicates the expected number of outpatient visits at day t; α is the intercept, β represents the log-relative rate of outpatient visits associated with a unit increase in each pollutant concentration; $PLNM(X_t)$ is the PLNM for each air pollutant; $DLNM(temperature)$ is the DLNM function for daily temperature; ns is the natural cubic spline function; DOW is a dummy variable representing the day of the week (Monday to Sunday); Holiday is a dummy variable representing public holidays to control for short-term fluctuations, and ε represents the residual error.

The relative risks (RRs) associated with per 10-unit increase for pollutants were calculated. Single-pollutant models were built to estimate each pollutant's exposure-response relationship. Two-pollutant models were built by adding one pollutant at a time to test the robustness of each air pollutant's effect on daily outpatient visits. Exposure-response curves also fitted for the associations between air pollutants and outpatient visits.

Sensitivity analyses were conducted to test the robustness of the findings. DLNM controlled for longer effects of temperature, including maximum lags of 7, 14, and 21 days. Alternative dfs (4, 8, and 12 dfs per year) were adjusted for long-term trends.

All statistical tests were performed using R software (Version 3.6.4) with the "dlnm" package for the DLNM model and the "mgcv" package for the GAM model(Gasparrini, 2011; Wood, 2001). Statistical tests were two-sided with the significance level set at p-value < 0.05.

3. Results

3.1. Descriptive analysis and correlation analysis

The time series of concentrations of each air pollutant showed seasonal trends (Fig.3 left). Concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO increased from November to May, then decreased from June to October, while O_3 had opposite trend due to its formation mechanism. The number of days in which the concentration exceeded China's new National Meteorological Air Quality Standard Level II (NAAQS) (GB3095-2012) (Gao, 2013) were 298 days (27.2%), 282 days (25.7%), 0 days, 133 days (12.1%), 9 days (0.8%) and 156 days (14.23%) for $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3, respectively. For meteorological factors, the average daily humidity and temperature during the study period were 66.12 ± 17.03% and 15.59 ±10.18 ℃.

During the study period, the total number of outpatient visits were 1,340,791, and daily average outpatient visits were 1,223, of which pediatrics outpatients, ENT outpatients, cardiovascular outpatients, respiratory outpatients, orthopedics outpatients accounted for 24.50%, 17.18%, 19.27%, 19.54%, and 19.51%, respectively. Time-series plots of total outpatient visits showed apparent seasonal trends in the number of outpatient visits for all departments except orthopedics (Fig.3 right).

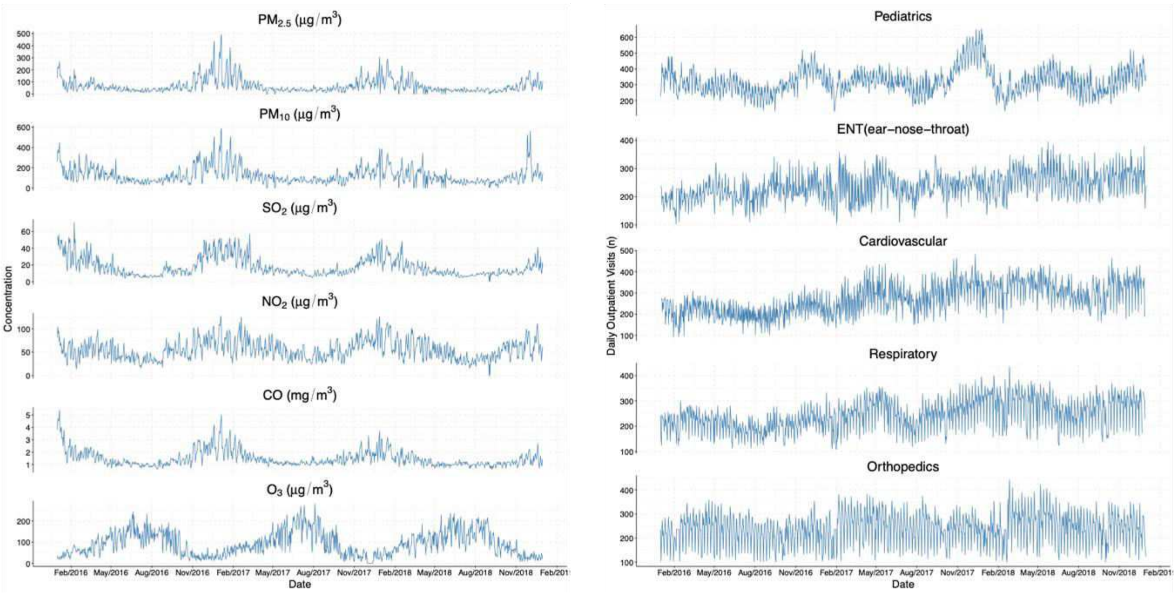

Fig.3 Time series of air pollutants and outpatient visits in Xi’an from Jan.2016 to Dec.2018.

Table 1 summarized descriptive results of air pollutants and meteorological conditions. Strong correlations were found between pollutants, with Spearman’s correlation coefficients running from 0.71 to 0.93 (Table S1). All pollutants except for O_3 were negatively correlated with average temperature and RH, because O_3 was more sensitive to high temperatures.

3.2. Exposure-effect analysis

Table 2 showed RRs of air pollutants on daily outpatient visits for each department, stratified by season and age. Overall, a 10-unit increase in the concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3 was associated with RRs of total visits of 1.088 (95% CI: 0.881, 1.277), 1.035 (95% CI: 0.945, 1.126), 1.381 (95% CI: 0.795, 1.966), 1.137 (95% CI: 0.201, 2.047), 1.114 (95% CI: 0.877, 1.352), and 1.152 (95% CI: 0.958, 1.345), respectively.

The orthopedics department was least affected by air pollution among the five departments. As for pediatrics, a 10-unit increase in concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO increased the risk of pediatrics visits, with RRs of 1.032 (95% CI: 0.998, 1.064), 1.047 (95% CI: 1.028, 1.067), 1.371 (95% CI: 1.272, 1.471), 1.105 (95% CI: 1.090, 1.121), and 1.044 (95% CI: 1.025, 1.064), respectively. Whereas no positive association was observed for changes in O_3. There were significantly stronger associations in the heating season for $PM_{2.5}$, SO_2, NO_2, and CO. For different population groups, significant associations were observed for patients above 6 years with $PM_{2.5}$ and SO_2, and for patients under 6 years with PM_{10} and CO. NO_2 had significant associations on both age groups but had a higher impact on patients above 6 years than those under 6 years.

As for ENT, a10-$\mu g/m^3$ increase in the concentrations of $PM_{2.5}$, PM_{10}, SO_2, and O_3 increased the risk of pediatrics visits, with RRs of 1.074 (95% CI: 1.053, 1.096), 1.136 (95% CI: 1.114, 1.159), 1.061 (95% CI: 1.021, 1.102), and 1.011 (95% CI: 1.007, 1.015), respectively. For different seasons, $PM_{2.5}$ and O_3 had a significantly strong association in the heating season than the non-heating season. For different population groups, significant associations were observed for patients under 50 years with $PM_{2.5}$, PM_{10}, and SO_2, and for patients above 50 years with PM_{10}, NO_2 and CO.

As for cardiovascular outpatient visits, an increase of 10-unit concentrations of $PM_{2.5}$, PM_{10}, and CO were associated with significantly increased risks of cardiovascular visits, with RRs of 1.101 (95% CI: 1.090, 1.113), 1.061 (95% CI: 1.053, 1.069), and 1.187 (95% CI: 1.212, 1.350), respectively. The estimates of $PM_{2.5}$ were significant for in the non-heating season. There were significant associations in the heating season for PM_{10} and SO_2, while for CO and O_3 only had adverse effects in the non-heating season. After stratified for age groups, $PM_{2.5}$, NO_2, and CO had significant associations with outpatient visits for patients under 60 years.

As for respiratory department visits, an increase of 10-unit in the concentrations of $PM_{2.5}$, SO_2, NO_2, CO, and O_3 was associated with increased risks of outpatient visits,, with RRs of 1.169 (95% CI: 1.152, 1.186), 0.970 (95% CI: 0.961, 0.981), 1.030 (95% CI: 1.024, 1.035), 1.101 (95% CI: 1.031, 1.171), and 1.074 (95% CI: 1.059, 1.089) respectively. For seasons, $PM_{2.5}$ had significant associations in both seasons, while NO_2 and CO had stronger associations in the heating season than the non-heating season. For different age groups, NO_2 were significantly associated with patients of all ages. SO_2 and CO were significantly associated with patients under 60 years and O_3 were significantly associated with patients above 60 years.

As for orthopedics visits, an increase of 10 $\mu g/m^3$ in the concentrations of $PM_{2.5}$ and NO_2 was associated with an increased risk of orthopedics visits, with RRs of 1.063 (95% CI:

1.032, 1.095), and 1.055 (95% CI: 1.011, 1.101), respectively. For NO_2, estimated RRs were significant for both seasons and slightly stronger in the non-heating season, but the difference was not significant. Significant associations were observed for patients under 60 years with $PM_{2.5}$ and NO_2, and for patients above 60 years with O_3 and CO.

Generally speaking, $PM_{2.5}$ had the strongest association with outpatient visits for the orthopedics department, followed by the respiratory department and the ENT department, and had the weakest association with the pediatrics department. PM_{10} was most strongly associated with ENT outpatient visits, followed by the cardiovascular department and the pediatrics department, and was not significantly associated with the respiratory department and the orthopedics department. The association between SO_2 and pediatric visits was the strongest, followed by ENT outpatient visits. The association between SO_2 and respiratory visits, although statistically significant, was the weakest, and SO_2 was not significantly related to cardiovascular and orthopedic visits. NO_2 had similar associations with pediatrics and respiratory visits. CO has significant effects on outpatient visits for pediatrics, cardiovascular, and respiratory department, with the most significant association on the cardiovascular department and the least significant association on the pediatrics department. O_3 had stronger associations with the respiratory department than that with ENT.

Figure 4 showed the associations between air pollutants and outpatient visits in two-pollutant models. Since there were strong correlations between particulate matters, only uncorrelated pollutants (R^2 < 0.7 in Table S2) were selected for analysis. The associations of $PM_{2.5}$ and pediatrics visits, cardiovascular visits, and respiratory visits remained significant after controlling for all other pollutants, whereas the associations between CO and pediatrics visits became insignificant after incorporating another pollutant. The associations of NO_2 and pediatrics visits decreased but remained significant after controlling for $PM_{2.5}$ or CO, and became insignificant after adding PM_{10} or SO_2.

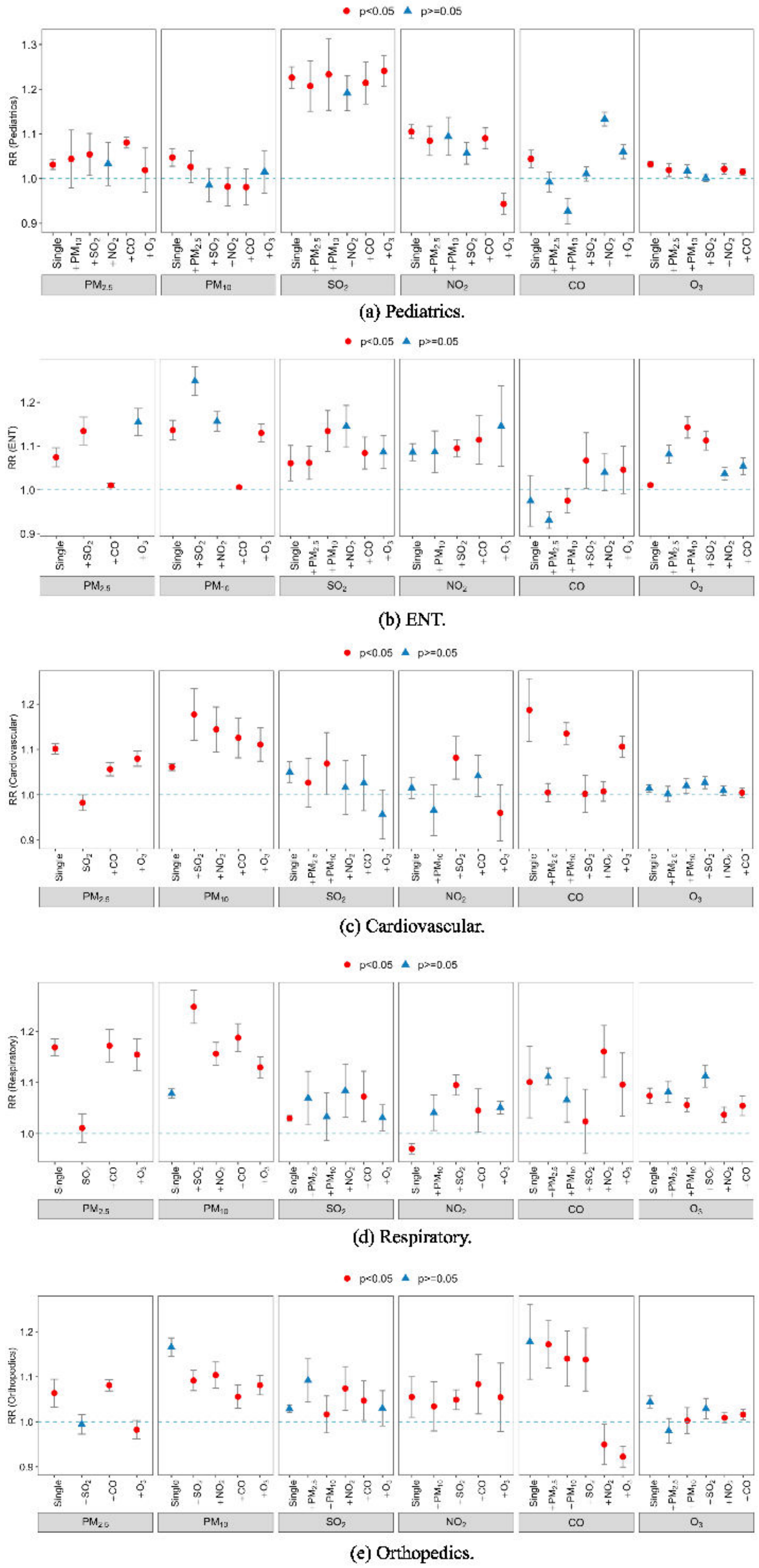

Fig.4 Relative risks of outpatient visits for four medical departments with a 10-unit increase in air pollutant concentrations (cumulative lags from 0 to 3 days) in single- and two-pollutant models.

For outpatient visits to cardiovascular, respiratory, and orthopedic departments, PM_{10} remained significant after controlling for other pollutants, while the associations between PM_{10} and pediatrics visits and ENT visits became insignificant after adding SO_2. The associations between SO_2 and pediatrics, ENT, cardiovascular and respiratory visits became insignificant after including NO_2, whereas the including of PM_{10} significantly enhanced the effect of SO_2 on ENT visits.

The associations between NO_2 and orthopedics visits remained robust after controlling for other pollutants, while the associations between NO_2 and other department visits became insignificant after including PM_{10}. The effect of CO on pediatrics visits became insignificant after controlling for other pollutants,, while the effect on orthopedics remained significant. O_3 have no significant associations with all departments' visits after controlling for $PM_{2.5}$ or SO_2. Table S3 provided a more detailed comparison between one-pollutant models and two-pollutants models.

Sensitivity analysis showed that the associations between air pollutant concentrations and outpatient visits for each department were not sensitive to alternative temperature lags (Fig.S1), and not sensitive to the use of different df in adjusting for long-term time trends (Fig.S2).

4. Discussion

This study provided evidence on the adverse effect of air pollutants on daily outpatient visits to different diseases departments in a moderately polluted city. The results highlighted the adverse effect of SO_2 on pediatric outpatient visits, likely because 37.12% of pediatric visits in the dataset were due to respiratory diseases. Our research showed that when the concentration of SO_2 in the atmosphere exceeds 10 mg/m^3, the incidence of respiratory diseases increased, and the condition of patients with chronic diseases deteriorated rapidly.

The effects of air pollution on outpatient visits were different after stratified by age and season. Single-pollutant models showed that $PM_{2.5}$, SO_2, NO_2 and CO had significant associations with respiratory outpatient visits for children over 6 years old, which was consistent with a study in Yichang(Y. Liu et al., 2017). These prior studies speculate that exposure to $PM_{2.5}$, PM_{10}, NO_2, and CO (without lag) may be responsible for increased pediatric outpatient visits for respiratory diseases, but they found no seasonal differences(Y. Liu et al., 2017). Our research results found a significant seasonal difference in the associations between air pollutants and pediatrics outpatient visits. While pediatrics outpatient visits were found to be significantly sensitive to all pollutants except O_3, $PM_{2.5}$

and PM_{10} had higher significant associations on pediatric outpatient visits during a heating season than during a non-heating season. $NO_2$and CO were significantly associated with pediatric outpatients only during a heating season. These seasonal differences may be due to that the concentration of each pollutant was higher in a heating season due to the combustion of fossil fuels, and $PM_{2.5}$ and PM_{10} were highly harmful after being inhaled.

This study was one of few studies that empirically analyzed the relationships between air pollution and ENT outpatient visits. In our dataset, pharyngitis and rhinitis accounted for the main ENT visits (50%), followed by thyroid diseases (38%). Zhao et al. found that PM_{10} and SO_2 were significantly related to outpatient visits for chronic pharyngitis and people aged 15-65 were more likely to be affected than people over 65(X. Zhao et al., 2020). Our results showed that $PM_{2.5}$, PM_{10}, SO_2, and O_3 were significantly related to ENT visits, with SO_2 and NO_2 being more relevant for ENT outpatients for people under 60. Compared with Zhao's study, our findings suggested that the newly retired population should reduce outdoor activities during working days' commuting time and heating seasons to reduce health risks and alleviate hospital systems' burden.

Our findings indicated air pollutants had similar associations on respiratory visits and ENT visits. The respiratory department has similar patient groups with the ENT department, and there were prior studies about the associations between air pollution and respiratory outpatient visits. It is generally recognized that short-term exposure to air pollutants may increase respiratory diseases(Z. Zhang et al., 2019). Inhalation of air pollutants can damage the airway, increase susceptibility, and cause respiratory infections. Our findings illustrated that $PM_{2.5}$, NO_2, SO_2 , CO, and O_3 were all related to the respiratory outpatient visits. Mo et al. found that NO_2 and SO_2 were closely related to the respiratory mortality and diagnosis rate in Hangzhou, and O_3 had a greater impact on respiratory mortality and outpatient visits in areas with low air pollution than areas with high air pollution(Mo et al., 2018). COPD, lung infections, and other pulmonary diseases were major outpatient diseases in our data. Our research results reported that $PM_{2.5}$ and NO_2 had higher associations with reparatory outpatient visits, given that they had adverse effects on COPD and lung infections. For example, Chang et al. conducted a study in the Northeastern China and showed that $PM_{2.5}$ increased COPD incidence, and NO_2 had an adverse effect on lung infections, asthma, and COPD(Chang, Zhang, & Zhao, 2020). On the other hand, our results showed that PM_{10} was not significant related to respiratory outpatient visits, this may be because the smaller the diameter of the particulate matter, the deeper it enters the respiratory tract. Compared with

PM_{10}, $PM_{2.5}$ was more likely to accumulate in the lower respiratory tract(Goldizen, Sly, & Knibbs, 2016). Our results were also consistent with new research findings on COVID-19. COVID-19 is a type of severe acute respiratory syndrome that spreads through the air. Zhu et al. found that $PM_{2.5}$, PM_{10}, CO, NO_2, and O_3 were significantly positively correlated with COVID-19 after studying confirmed cases in 120 cities in China, while an increase in the concentration of SO_2 reduced the diagnosis rate of COVID-19 (7.79% decrease)(Zhu, Xie, Huang, & Cao, 2020). Our results indicated that an increase in SO_2 reduced respiratory outpatient visits (3% decrease), which was in line with Zhu's research, showing the importance of air pollution research to health issues related to COVID-19. These findings indicated that patients with respiratory diseases should pay more attention to the concentration of gaseous pollutants than particulate matters.

Existing studies on the associations between cardiovascular outpatient visits and air pollution were inconsistent. Su et al. (2016) found that $PM_{2.5}$ was associated with an overall RR of 1.022 (95% CI: 0.990–1.057) in emergency department visits for cardiovascular diseases in Beijing(Su et al., 2016). Our results showed that $PM_{2.5}$ has a significant impact on cardiovascular department visits with RR of 1.101 (95% CI: 1.090, 1.113), but PM_{10} and CO were also attributed to the cardiovascular department visits. Existing studies were not consistent on the seasonal effects. Prior studies found evidence of stronger association of particulate matters in a cold season (October to March) (Hsu et al., 2017; Y. Zhang et al., 2020). Samoli et al. proposed that PM in a warm season (April to September) was more likely to affect cardiovascular visits(Samoli et al., 2016). Our study found that $PM_{2.5}$ in a non-heating season (March to November) had a higher significant association on cardiovascular visits than that of a heating season (December to February). The difference was significant, consistent with the findings of Liu et al. who found that during a non-heating period, the impact of air pollution on CVD mortality was 2.8 times greater, and the impact of gaseous pollutants was more significant than that of particulate matter in a heavily polluted city(M. Liu et al., 2019). We found similar patterns in a moderately polluted city. During a non-heating season, SO_2, CO, and O_3 had significant effects on cardiovascular visits, and the effect of SO_2 was greater than that of $PM_{2.5}$. The different effects of SO_2 and $PM_{2.5}$ may be due to gaseous pollutants' physical form, which may be more likely to be inhaled into the respiratory tract and enter blood circulation, leading to dyspnea and hypoxia symptoms of CVD patients. We also found that O_3 had a substantial impact on CVD during a non-heating season, consistent with prior studies that a strong positive relationship existed between O_3

and increased cardiovascular outpatients(C. Zhang et al., 2017). There was a reasonable explanation for the seasonal correlation of ozone because ozone is the main pollutant in Xi 'an in summer(Day et al., 2017).

In this paper, the orthopedics department was used as the control group for other departments. Currently, few studies focused on orthopedics diseases, and this paper found that although most of the pollutants were not relevant to orthopedic outpatient visits, $PM_{2.5}$ and NO_2 were significantly associated with increased orthopedic outpatient visits for people aged under 60. This may be because of the characteristic of orthopedics diseases. Cervical and lumbar pain accounted for the main reason for medical consultation in our study (74%), and they are related to improper working and living habits. One way to relieve the pain is through daily exercise. One possible reason for $PM_{2.5}$ to increase orthopedic outpatients for people under 60 was that young people have less time to exercise. On the contrary, older people may have more time to do regular morning or evening exercises and thus less likely to experience discomfort. However, the impact of air pollution on orthopedic outpatients needs to be further studied in the future.

This paper also proposed new suggestions for pollutant concentration thresholds according to the exposure-response curves of various department outpatients and air pollutants (Figure S3). Since the pollutant exposure-response relationships were geographically different, it necessary to set various standards for different areas. The threshold of $PM_{2.5}$ in pediatrics (61 $\mu g/m^3$ and cardiovascular (65 $\mu g/m^3$) were lower than the current daily air quality standards (150$\mu g/m^3$) in China (CNNAQ II), and the threshold of NO_2 was lower than the standard (80 $\mu g/m^3$) in cardiovascular (70 $\mu g/m^3$) and respiratory (40 $\mu g/m^3$), and the threshold of CO was lower than the standard (4 mg/m^3) in pediatrics (2.8 mg/m^3) (as shown in Table 3).

The present study had several limitations. First, we used outpatient visits data from only one hospital. Although the hospital carried a large portion of the medical visits in Xi'an, the results are not necessarily representative. Second, we took an average of the air pollutant concentrations from thirteen fixed monitoring sites, which might lead to underestimating the associations.

Overall, our findings proved that the effects of air pollutants on various departments' outpatient visits were different. One possible advantage of this study was the inclusion of outpatient visits from various medical departments instead of prior studies focusing on one specific disease, which provided a more comprehensive general analysis of the effects of air pollutants. The new thresholds provided important policy implications to the health department of a city's public services. Carrying out daily work duties under the current national air quality standards would harm the health of more than 10 million Xi'an residents. Therefore, authorities in Xi'an should take immediate action to update the existing air quality standards given our research findings. If 10% of the city population had respiratory problems, up to 1 million people of the city whose health and lives in the next ten or more years could be protected and affected, not to mention the whole country's population of 1.4 billion.

This study also provided evidence to help hospital managers make better workload allocation decisions of different outpatient departments under different air pollution conditions. For example, during a heating season, when PM_{10} levels exceed the standard, the number of respiratory and ENT clinics can be kept the same, and more pediatric and cardiovascular clinics can be offered.

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Tables

Table 1. Descriptive results for data on outpatient visits, air pollutants, and meteorological conditions.

Variables		Mean±SD	Min	Q1	Median	Q3	Max	Skewness	Kurtosis
Daily outpatient visits									
Pediatrics		320±13.89	130	261	312	372	654	0.71	0.94
ENT		239±5.4	102	203	239	273	396	0.12	-0.23
Cardiovascular		269±17.4	93	214	263	329	482	0.16	-0.71
Respiratory		246±6	108	201	245	291	434	0.02	-0.70
Orthopedics		239±6.35	100	205	242	283	443	-0.18	-0.28
Daily outpatient visits (by season)[1]									
	Non-heating	297±65	132	251	296	341	495	0.15	-0.27
	Heating	236±53	102	198	232	277	379	0.05	-0.56
ENT	Non-heating	241±48.43	110	206	241	272	396	0.20	0.01
	Heating	275±74.3	93	216	268	342	482	0.01	-0.83
Cardiovascular	Non-heating	266±73.76	102	211	260	320	464	0.26	-0.58
	Heating	257±60.63	108	215	257	302	434	-0.06	-0.57
Respiratory	Non-heating	238±59.2	113	193	237	283	379	0.06	-0.80
	Heating	238±62.2	100	205	240	278	443	-0.15	-0.11
Orthopedics	Non-	241±64.42	100	204	240	278	443	-0.21	-0.39

	heating								
Daily outpatient visits (by age)[1]									
Pediatrics	<6	224±60	102	182	218	260	460	0.68	0.56
	>=6	86±34.99	22	61	78	108	225	0.86	0.61
ENT	<50	157±44	10	139	160	181	259	-1.31	3.49
	>=50	73±28.54	1	52	74	94	153	-0.06	-0.40
Cardiovascular	<60	144±64.76	6	90	153	196	294	-0.33	-0.82
	>=60	75±51.95	13	32	61	121	219	0.50	-0.92
Respiratory	<60	169±67.46	8	144	188	215	278	-1.34	1.18
	>=60	54±32.54	10	30	46	82	130	0.22	-1.03
Orthopedics	<50	126±62.3	10	96	143	170	265	-0.81	-0.24
	>=50	82±43.57	6	48	91	113	206	-0.45	-0.73
Air pollutants (24-hour average)									
$PM_{2.5}$ ($\mu g/m^3$)		68.22±60.17	9	31	47	82	493	2.54	9.09
PM_{10} ($\mu g/m^3$)		125.9±38.92	16	68	100	156	589	1.79	4.18
SO_2 ($\mu g/m^3$)		17.58±11.35	4	9	13	22	71	1.35	1.29
NO_2 ($\mu g/m^3$)		54.97±20.91	14	39	52	68	127	0.63	-0.01
CO (mg/m^3)		1.48±0.66	0.6	1	1.3	1.7	5.4	1.98	5.25
O_3 ($\mu g/m^3$, 8-hour average)		93.13±57.26	6	47	80	136	280	0.59	-0.52
Weather condition (24-hour average)									
Temperature (°C)		15.66±9.92	-6	6.5	16.5	24.5	34	-0.08	-1.22
RH[2] (%)		66.12±17.03	18.25	54.51	64.67	79.97	100	0.08	-0.78

[1]Heating season: from November to March; Non-heating season: from April to October.

[2]RH: relative humidity; Q1, 25th percentile; Q3, 75th percentile; SD, standard deviation; Min, minimum; Max, maximum.

Table 2. Relative risks of outpatient visits with a 10-unit increase in daily air pollutant concentrations (cumulative lags from 0 to 3 days).

	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
All						
Entire period	1.088 (0.881, 1.277)**	1.035 (0.945, 1.126)**	1.381 (0.795, 1.966)**	1.381 (0.795, 1.966)**	1.114 (0.876, 1.352)**	1.152 (0.958, 1.345)**
Heating	1.047 (0.890, 1.204)**	1.077 (0.918, 1.236)**	1.219 (1.018, 1.421)**	0.930 (0.740, 1.119)**	1.156 (0.634, 1.678)**	1.018 (0.816, 0.816)**
Non-heating	0.996 (0.828, 1.164)*	0.992 (0.980, 1.004)**	1.250 (1.182, 1.318)*	0.784 (0.699, 0.868)	1.202 (1.025, 1.379)	0.954 (0.943, 0.965)*
p-value	0.002	0.401	0.583	0.188	0.014	0.046
Pediatrics						
Entire period	1.032 (0.998, 1.064)**	1.047 (1.028, 1.067)**	1.236 (1.201, 1.250)**	1.105 (1.090, 1.121)**	1.044 (1.025, 1.064)*	1.032 (1.026, 1.039)
Heating	1.067 (1.035, 1.098)**	1.009 (1.006, 1.013)*	1.266 (1.236, 1.296)**	1.006 (0.974, 1.038)**	1.139 (1.053, 1.224)*	1.098 (0.943, 1.253)
Non-heating	1.008 (0.975, 1.040)**	0.959 (0.943, 0.975)*	0.995 (0.936, 1.055)	1.130 (1.047, 1.214)	0.843 (0.801, 0.886)	0.979 (0.970, 0.988)
p-value	0.134	0.001	<0.001	<0.001	<0.001	0.856
Age<6	1.078 (0.972, 1.185)	1.038 (0.991, 1.084)*	1.218 (1.049, 1.388)	1.024 (0.76, 1.289)*	0.983 (0.833, 1.132)*	1.077 (0.902, 1.251)
Age>=6	1.01 (1.002, 1.018)*	1.005 (0.978, 1.033)	1.196 (0.903, 1.489)*	1.057 (1.006, 1.108)*	1.083 (0.867, 1.299)*	0.995 (0.861, 1.129)

p-value	0.425	0.944	0.0002	<0.01	0.0005	0.134
ENT						
Entire period	1.074	1.136	1.061	1.086	0.975	1.011
	(1.053,	(1.114,	(1.021,	(1.067,	(0.9170,	(1.007,
	1.096)*	1.159)**	1.102)**	1.106)	1.032)	1.015)**
Heating	1.010	1.063	0.916	1.129	1.051	1.185
	(0.993,	(1.034,	(0.890,	(1.094,	(1.014,	(1.144,
	1.082)*	1.091)	0.941)	1.164)	1.088)	1.226)*
Non-heating	0.841	1.029	1.118	1.104	1.050	1.020
	(0.709,	(1.001,	(0.949,	(0.898,	(0.815,	(0.999,
	0.973)*	1.057)**	1.287)**	1.310)	1.285)	1.042)**
p-value	<0.001	0.066	0.103	0.337	0.570	<0.001
Age<50	1.085	1.006	1.105	1.02	0.916	1.036
	(1.067,	(0.998,	(0.810,	(0.794,	(0.574,	(0.871,
	1.102)*	1.014)*	1.412)*	1.245)	1.259)	1.201)
Age>=50	1.003	1.162	0.927	1.011	0.989	0.963
	(0.967,	(1.065,	(0.687,	(0.808,	(0.668,	(0.836,
	1.04)	1.259)**	1.166)	1.213)*	1.309)*	1.090)
p-value	0.274	0.003	0.007	0.031	0.121	0.133
Cardiovascular						
Entire period	1.101	1.061	1.050	1.015	1.187	1.014
	(1.090,	(1.053,	(1.027,	(0.974,	(1.212,	(1.006,
	1.113)**	1.069)*	1.073)	1.022)	1.350)**	1.022)
Heating	0.991	0.967	1.339	0.946	1.012	1.273
	(0.977,	(0.946,	(1.289,	(0.905,	(0.999,	(1.189,
	1.006)*	0.988)**	1.389)**	0.987)	1.026)	1.358)
Non-heating	1.138	1.014	1.306	0.931	1.053	1.026
	(0.888,	(1.006,	(1.097,	(0.879,	(0.487,	(1.020,
	1.388)**	1.023)	1.515)*	0.984)	1.62)**	1.032)*
p-value	0.001	<0.001	0.095	0.565	0.008	<0.001
Age<60	1.134	1.046	1.027	1.068	1.111	1.051
	(1.023,	(0.991,	(0.935,	(1.029,	(0.843,	(0.964,
	1.245)*	1.101)**	1.119)	1.107)*	1.379)*	1.137)

Age>=60	1.126 (0.996, 1.256)	1.149 (1.071, 1.229)*	1.184 (1.062, 1.307)	1.023 (0.901, 1.144)	0.971 (0.912, 1.029)	1.017 (0.964, 1.071)
p-value	0.062	0.342	<0.001	0.07	<0.001	0.003
Respiratory						
Entire period	1.169 (1.152, 1.186)**	1.078 (1.069, 1.088)	0.970 (0.961, 0.981)*	1.030 (1.024, 1.035)*	1.101 (1.031, 1.171)*	1.074 (1.059, 1.089)*
Heating	1.022 (1.007, 1.037)**	1.037 (1.018, 1.056)	0.993 (0.966, 1.020)	1.026 (1.011, 1.042)**	1.151 (1.044, 1.258)*	1.112 (0.942, 1.281)
Non-heating	1.143 (1.085, 1.201)**	1.030 1.007, 1.054)**	0.992 (0.954, 1.041)*	1.081 (1.029, 1.133)	1.078 (1.040, 1.116)	1.015 (1.005, 1.024)
p-value	<0.001	0.488	0.087	<0.001	<0.001	0.604
Age<60	1.019 (0.789, 1.249)	1.028 (0.862, 1.195)	1.012 (0.794, 1.231)*	1.077 (0.933, 1.211)*	1.170 (1.161, 1.182)*	1.101 (0.962, 1.242)
Age>=60	0.994 (0.949, 1.039)	1.060 (0.995, 1.083)	0.914 (0.724, 1.104)	1.086 (0.979, 1.193)	1.098 (1.087, 1.109)	1.011 (0.858, 1.163)*
p-value	0.181	0.039	0.155	<0.01	0.101	0.045
Orthopedics						
Entire period	1.063 (1.032, 1.095)**	1.166 (1.145, 1.186)	1.029 (1.021, 1.038)	1.055 (1.011, 1.101)**	1.178 (1.095, 1.262)	1.044 (1.031, 1.058)
Heating	0.985 (0.976, 0.993)	1.035 (1.006, 1.064)	0.935 (0.902, 0.967)	1.123 (1.029, 1.218)*	1.064 (1.044, 1.085)	1.106 (1.009, 1.203)
Non-heating	0.987 (0.828, 1.146)	1.008 (0.995, 1.020)	1.057 (1.030, 1.083)*	1.207 (1.076, 1.338)*	1.176 (0.818, 1.533)	1.034 (1.020, 1.049)
p-value	0.938	0.025	<0.001	0.275	0.238	0.938

Age<60	1.056 (1.036, 1.076)*	1.122 (1.107, 1.137)	0.996 (0.841, 1.150)	1.039 (0.973, 1.104)*	0.990 (0.761, 1.219)	0.974 (0.875, 1.073)
Age>=60	1.038 (1.005, 1.070)	1.096 (1.085, 1.107)	1.012 (0.843, 1.180)	1.112 (1.013, 1.212)	1.142 (0.881, 1.405)*	1.001 (0.898, 1.104)*
p-value	0.286	0.779	0.051	0.009	0.689	0.764

**: p-value<0.001; *: p-value<0.05.

Table 3. Threshold concentrations of air pollutants for different departments.

Pollutant	Pediatrics	ENT	Cardiovascular	Respiratory	Orthopedics	Class II
$PM_{2.5}$ $(\mu g/m^3)$	61	80	65	125	100	75
PM_{10} $(\mu g/m^3)$	106	45	125	100	125	150
SO_2 $(\mu g/m^3)$	51	34	40	36	39	150
NO_2 $(\mu g/m^3)$	101	95	70	45	95	80
CO (mg/m^3)	2.8	4.6	3.7	4	3.9	4
O_3 $(\mu g/m^3)$	110	105	95	130	155	160

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