Temporal cross-correlations between air pollutants and outpatient visits for respiratory and circulatory system diseases in Fuzhou, China

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Abstract

Background: Previous studies have suggested that there is an association between air pollutants and circulatory and respiratory diseases, but relatively few have analyzed the association between air pollutants and outpatient visits considering mortality, hospitalization rates, etc., especially areas with relatively good air quality. Therefore, we conducted this study to research the association between air pollutants and outpatient visits in Fuzhou, China.

Methods: We used a generalized linear Poisson model to study the association between air pollution and outpatient visits for respiratory and circulatory diseases during 2016-2018 in Fuzhou, China.

Results: In the single pollutant model, nitrogen dioxide (NO_2) had a significant effect. For lag day 0 to lag day 5, the effect decreased with every 10 μg/L increase in NO_2. Daily maximum 8-h mean ozone (8-h O_3) and upper respiratory outpatient visits were positively associated during the cold period [lag2, excess risk (ER) (95% confidence interval (CI)): 1.68% (0.44%-2.94%)], while 8-h O_3 and respiratory disease were positively associated during the warm period [lag5, ER (95% CI): 1.10% (0.11%-2.10%) and lag4, ER (95% CI): 1.02% (0.032%-2.02%)]. Similarly, particulate matter (PM) with an average aerodynamic diameter of less than 10 μm (PM_{10}) and lower respiratory diseases were positively associated during the warm period [lag0, ER (95% CI): 1.68% (0.44%-2.94%)]. When the concentration of 8-h O_3 was higher than 100 μg/L, there was a positive effect on circulatory [lag5, ER (95% CI): 2.83% (0.65%-5.06%)], respiratory [lag5, ER (95% CI): 2.47% (0.85%-4.11%)] and upper respiratory [lag5, ER (95% CI): 3.06% (1.38%-4.77%)] outpatient visits. The variation in 8-h O_3 changed slightly when we adjusted for the other air pollutants, and after adjusting for 8-h O_3, the ERs of the other air pollutants changed slightly. After adjusting for PM with an average aerodynamic diameter of less than 2.5 μm ($PM_{2.5}$), the ERs of the other air pollutants increased, and after adjusting for NO_2, the ER of PM decreased.

Conclusion: Exposure to ambient NO_2, O_3, $PM_{2.5}$ and PM_{10} was associated with an increase in respiratory and circulatory system-related outpatient visits in Fuzhou, China.

Background

Ambient air pollution is on the rise, with the most marked increases in rapidly developing and industrializing low-income and middle-income countries [1]. As the largest developing country, China has developed increasingly serious air quality problems, and air pollution issues are increasingly prominent. However, few Chinese cities have established citywide morbidity reporting systems, and there are few studies of China's coastal area [2, 3]. Data revealing the association between air pollution and human health are limited in China, and the lack of fine particulate matter ($PM_{2.5}$) and ozone (O_3) data from most Chinese cities further hinders the value of such studies [2]. According to the World Health Organization's (WHO's) air quality standards, the acceptable daily average concentrations of $PM_{2.5}$ and PM_{10} are 25 μg/m³ and 50 μg/m³, respectively, and the 8-hour average concentration of O_3 is 100 μg/m³[4]. In China, even areas with relatively good air quality may not meet the WHO's air quality standard.

Previous studies have shown that air pollution and outpatient visits are likely associated with respiratory and circulatory diseases [5, 6]. High pollutant concentrations can even increase the daily cardiovascular/respiratory death rates [7]. For example, NO_2 may cause lung cancer [8], particulate matter (PM) has been associated with increased blood pressure (BP), and a certain concentration of ozone has been associated with decreased BP [9]. There is an association between $PM_{2.5}$ and inflammation [10]. $PM_{2.5}$ can also increase the incidence of various respiratory and circulatory diseases [11, 12]. Even low air pollution concentrations can increase the risk of emergency department visits [13]. One study in an area with a low level of air pollution found that interquartile range (IQR) increases in $PM_{2.5}$, PM_{10}, NO_2 and O_3 were related to increases in outpatient visits for respiratory conditions [5]. A study that lasted approximately seven years and considered over 4 million emergency department visits in 31 hospitals showed an association between cardiovascular disease and levels of ambient pollutants [14]. Another study conducted over 17 years in Canada reported that ozone is highly associated with circulatory hospitalizations [15]. Some studies have suggested that low-level PM exposure could cause an increased excess risk (ER) of circulatory outpatient visits [11, 16]. Overall, even if the air quality is good in some regions, the effects of air pollution cannot be ignored.

Similar studies may obtain different outcomes because of differences in pollution concentrations and components and different population age structures and sensitivities among different regions [3]. In particular, regarding the concentration of air pollutants, the association between air pollution and health effects in areas with poor air quality was lower than that in areas with good air quality [2, 17]. It is inaccurate to describe the effects of air pollutants by comparisons with analyzes of data from other regions. Thus, research on the association between air pollutants and outpatient visits is necessary to understand the effects of local air pollution.

Modeling is particularly important in such studies. A single air pollutant model is not sufficient; comprehensive air pollutant models that consider synergistic effects are essential for studying the association between air pollutants and outpatient visits [18]. We conducted this study to analyze the associations between air pollutants and outpatient visits in Fuzhou with a comprehensive air pollutant model that considered the synergistic effects of different air pollutants; a total single air pollutant model, a seasonal model (examining the cold season and warm season) and a double pollutant model were constructed.

Methods

Data collection

Our daily air pollution monitoring data were based on 3-year data collection from 1 January 2016 to 31 December 2018 from seven air pollution monitoring stations of the Fuzhou Environmental Monitoring

Center Station, and daily meteorological monitoring data were collected through daily monitoring by the Fuzhou Meteorological Bureau, which is part of the nationwide network of monitoring stations and strictly implements relevant national technical requirements. The indicators of air pollution included nitrogen dioxide (NO_2), daily maximum 8-h mean ozone (8-h O_3), PM with a particle size less than 10 microns (PM_{10}) and fine PM ($PM_{2.5}$). The meteorological indicators included air pressure (AP), relative humidity (RH) and temperature (T). Values of 8-h O_3, PM_{10} and $PM_{2.5}$ were evaluated on the basis of the WHO air quality standard (100, 50 and 25 μg/m^3, respectively), and NO_2 was evaluated on the basis of the China class I air quality standard (80 μg/m^3). The daily outpatient visits of Jianxin Hospital and Kongjun Hospital were collected by the Fuzhou Center for Disease Control and Prevention, which has been part of the Fuzhou health monitoring network for 3 consecutive years and was subject to strict quality control according to requirements. We identified diseases according to their International Classification of Diseases, 10th edition (ICD-10) codes (J00-J99 for respiratory diseases and I00-I99 for circulatory diseases). Among the J00-J99 codes, J00-J06 and J30-J39 represent upper respiratory diseases, and J20-J22, J40-J47, and J85-J86 represent lower respiratory diseases.

In the analysis of the association between outpatient visits and air pollutants, there were meteorological factors and natural fluctuations in daily events over the course of a week that we needed to account for. Ethics approval and consent to participate were not needed for the present study since no individual-level data were used (the study only used publicly available secondary data).

Statistical analysis

In this study, a generalized linear model (GLM) was used to analyze the association between outpatient visits and the studied air pollutants. The GLM with a time-series regression analysis was based on a Poisson distribution. We introduced meteorological parameters, including T (℃) and RH (%). Because the relationship between meteorology and health is generally nonlinear, we used a natural smoothing spline function to control for this nonlinear hybrid effect. We used 3 degrees of freedom for T and RH [18-20]. The natural spline (ns) function of date was also used in the GLM to address nonlinear trends, sequence correlations and the number of events per day on the time axis. The day of the week (DOW) was considered in this model to control for the natural fluctuation trends over a week. The degrees of freedom (df) for date were 7 df per year[21, 22]{Li, 2015 #64;Chai, 2019 #66;Bhaskaran, 2013 #67}. The model is as follows [23, 24]:

See formula 1 in the supplementary files.

where E (Yt) is the expected value of the number of outpatient visits on day t; Zt is the pollutant concentration on day t; β is the exposure-response coefficient; ns () is the natural smoothing spline function; df is the degrees of freedom; time is the calendar time variation; DOW is the weekly variation; and Xt is the meteorological factor.

The study analyzed the ER of outpatient visits associated with air pollutants and included a total single air pollutant model, seasonal model (cold period and warm season) and exceeding 100 μg/m^3 of ozone mode, double pollutant model. The double air pollutant model considered data from lag0. The seasonal model was divided into a cool period and warm period according to the monthly mean temperature. The months in which the monthly mean temperature exceeded 20°C were considered the warm period (April-October). Otherwise, the months were considered the cool period (November-March of the following year). The ozone model exceeding 100 μg/m^3 did not introduce the ns function of date and DOW because of discontinuity. The model is as follows:

See formula 2 in the supplementary files.

where E (Yt) is the expected value of the number of outpatient visits on day t; Zt is the pollutant concentration on day t; β is the exposure-response coefficient; ns () is the natural smoothing spline function; and df is the degrees of freedom. We also conducted a Wilcoxon paired test to find the significance of the relationship in different seasons. The mgcv package of R 3.5.1 statistical software was used for calculating and painting.

Results

Descriptive analyses

Table 1 shows that during the study, the mean pollutant concentrations were 27.38 μg/m^3 for NO_2, 89.60 μg/m^3 for daily 8-h O_3, 26.07 μg/m^3 for $PM_{2.5}$, and 49.68 μg/m^3 for PM_{10}. During the study, the 8-h O_3 concentration exceeded 100 μg/m^3 for a total of 390 days, the NO_2 concentration exceeded 80 μg/m^3 for a total of 0 days, the $PM_{2.5}$ concentration exceeded 25 μg/m^3 for a total of 509 days, and the PM_{10} concentration exceeded 50 μg/m^3 for a total of 478 days. The mean daily average T, RH and AP were 21.54 ℃, 72% and 1010 hpa, respectively.

Association between air pollution and meteorological factors

Fig. 1A shows that except for temperature and PM_{10}, meteorological factors were significantly correlated with air pollutants. RH was positively correlated with NO_2 and negatively correlated with 8-h O_3, $PM_{2.5}$ and PM_{10}. T was positively correlated with 8-h O_3 and negatively correlated with NO_2, $PM_{2.5}$ and PM_{10}. AP was positively correlated with PM_{10}, NO_2 and $PM_{2.5}$ and negatively correlated with 8-h O_3.

Time series distribution of air pollutants and outpatient visits

Fig. 2A shows that NO_2, PM_{10} and $PM_{2.5}$ had higher concentrations during the cold season than during the warm season, but 8-h O_3 had a higher concentration during the warm season than during the cold season. Fig. 2B shows that respiratory diseases, including upper and lower respiratory diseases, resulted in more outpatient visits during the cold season than during the warm season.

Association between air pollutants and outpatient visits

In Fig. 3A, the single air pollutant model shows that NO_2 had a significant effect on the ER of total respiratory, lower respiratory, upper respiratory and circulatory diseases. There was a single-day lag effect that was most obvious at lag0 and increased by 5.11% (95% CI: 3.31%-6.95%) for total respiratory visits, 6.04% (95% CI: 3.91%-8.21%) for upper respiratory visits, 3.23% (95% CI: 0.46%-6.08%) for lower respiratory visits, and 4.75% (95% CI: 6.81%-2.73%) for circulatory outpatient visits. The cumulative lag effect was the most obvious at lag0-5, increasing by 9.43% (95% CI: 6.31%-12.65%) for total respiratory disease, 10.96% (95% CI: 7.22%-14.84%) for upper respiratory disease, 7.69% (95% CI: 2.96%-12.64%) for lower respiratory disease, and 8.14% (95% CI: 4.74%-11.65%) for circulatory diseases.

As shown in Fig. 3B, after adjusting for the three other air pollutants, the ER of 8-h O_3 did not obviously change. NO_2, after adjusting for $PM_{2.5}$ and PM_{10}, increased greatly. Because of the possible collinearity of PM_{10} and $PM_{2.5}$, we did not introduce them into our model, but after adjusting for NO_2, the ERs of PM_{10} and $PM_{2.5}$ decreased.

Fig. 4A shows the association between the different air pollutants and outpatient visits during the cold and warm seasons. During the cold season, NO_2 appeared to have an obvious effect, but its effect was less than that during the warm season. Eight-hour O_3 had a significant impact on outpatient visits for upper respiratory diseases at lag2 during the cold season; the ER was 1.68% (2.94%-0.44%).

Fig. 5 shows that when the concentration of 8-h O_3 was higher than 100 μg/L, there was a positive effect on circulatory [lag5, ER (95% CI): 2.83% (0.65%-5.06%)], respiratory [lag5, ER (95% CI): 2.47% (0.85%-4.11%)] and upper respiratory [lag5, ER (95% CI): 3.06% (1.38%-4.77%)] outpatient visits.

Discussion

In this study, NO_2 presented a more obvious effect than the other three air pollutants in Fuzhou. We explored the relationship between air pollutants and outpatient visits for different diseases and in different seasons. During the cold season, there were more outpatient visits for respiratory, upper respiratory and circulatory diseases in association with the effects of 8-h O_3, $PM_{2.5}$ and PM_{10} than during the warm season, but during the warm season, there were more outpatient visits for lower respiratory diseases in association with those three air pollutants than there were during the cold season. In the double pollutant model, after adjusting for NO_2, the effects of the other three air pollutants decreased. After adjusting for $PM_{2.5}$, PM_{10} showed a significant effect. After adjusting for the other three air pollutants, the ER of 8-h O_3 changed only slightly. Different air pollutants presented different effects because of different conditions.

Our study showed the association between meteorological factors and the air pollutants NO_2, 8-h O_3, PM_{10} and $PM_{2.5}$. We found that the action of AP, RH and T caused high concentrations of air pollutants. Other studies showed that meteorological factors had an effect on the concentrations of air pollutants, similar to the findings of our study [25, 26]. RH is known to increase haze, possibly because RH is positively correlated with NO_2, which converts from the gas phase of NO_x to the particulate phase in relatively low-visibility conditions [27]. We did not find a positive association between PM and RH in the Spearman correlation model, but in the contour plot, the correlation between RH and PM_{10} and $PM_{2.5}$ first increased and then decreased at a certain AP and T. The joint action of meteorological factors had seemingly obvious effects on PM. O_3 had a positive association with T and a negative association with RH because sunshine might be the main promoter of O_3, as O_3 is enhanced by photochemical factors, and RH can affect sunshine duration [28]. Meteorological factors can influence air pollution, thus impacting health. Therefore, meteorological factors were introduced into the GLM. The time series diagram shows that during the cold season, all the air pollutants except ozone had higher concentrations than during the warm season. This discrepancy is due to the negative association between T and air pollutants and the positive association between AP and air pollutants other than ozone. In addition to meteorological factors, emissions also increase pollutant concentrations [29]. During the cold season, people in Fuzhou do not keep warm with coal but usually light fires, leading to increased PM emissions. The time series diagram also shows that there were more outpatient visits for respiratory diseases, including upper and lower respiratory diseases, during the cold season than during the warm season, which may be different from the findings for other regions; for example, the spring dust storm season in Lanzhou may increase emergency room visits for respiratory diseases [30].

The GLM reflected different aspects, including the total situation, different seasons and double air pollutant model. Because of the significant effects of the different air pollutants, we conducted a comprehensive study to evaluate the ERs of NO_2, O_3, $PM_{2.5}$ and PM_{10} [31, 32]. In the overall model, we found that NO_2 had a more obvious effect than the other three air pollutants on the ER of outpatient visits, especially considering the cumulative lag effect. Some studies also found that NO_2 was strongly associated with hospital admissions for both respiratory and cardiovascular diseases [33, 34]. In China, the Sixth National Population Census showed that coastal areas had become old-age societies, and a systematic review and meta-analysis reported that the effect of NO_2 exhibited regional differences because of differences in the proportions of elderly people with increased susceptibility to NO_2, which may be the cause of the high ER associated with NO_2 [35]. Even when air quality is not poor, the elderly may still be susceptible to air pollutants.

However, when we examined the results according to seasons, the effect of NO_2 was less significant than that of the total situation, and the ER of NO_2 was lower during the warm season than during the cold season; more specifically, it lost all significance during the warm season. In addition to T, the concentrations of air pollutants differed between the cold season and the warm season. During the cold season, the concentration of NO_2 was 33.11 μg/m^3, while during the warm season, it was 23.32 μg/m^3. There is a dose-dependent relationship between pulmonary injuries and ambient NO_2 [36], but for circulatory injuries, there is a lack of research. Interestingly, NO_2, O_3, $PM_{2.5}$ and PM_{10} had similar results in terms of their influences on outpatient visits for upper and lower respiratory diseases. Generally, PM_{10}

has a greater impact on the upper respiratory tract than on the lower respiratory tract, while $PM_{2.5}$ and O_3 exhibit the opposite effect. During the cold season, the increase in outpatient visits for upper respiratory disease was greater than that during the warm season, while the opposite results were observed for lower respiratory disease-related visits, except in the case of NO_2. Nitrogen dioxide, ozone and $PM_{2.5}$ caused more ERs for upper respiratory-related outpatient visits than for lower respiratory-related outpatient visits during the cold period, but nitrogen dioxide, ozone, $PM_{2.5}$ and PM_{10} caused more ERs for lower respiratory-related outpatient visits during the warm season. T and AP were 14.66 °C and 1016.65 hPa, respectively, during the cold season and 26.40°C and 1004.66 hPa, respectively, during the warm season. Some studies reported that low AP and warm Ts increased susceptibility to respiratory-related diseases [37, 38]. A study pointed out that a greater diurnal temperature range caused more outpatient visits for the common cold [39]. Similarly, greater temperature change affects the number of hospital admissions for chronic obstructive pulmonary disease [40]. Fuzhou often experiences a high diurnal temperature range during cold periods. However, PM and O_3 had greater effects on upper respiratory-related outpatient visits during the cold season and greater effects on lower respiratory-related outpatient visits during the warm season, possibly because the depths of the respiratory tract that pollutants are able to reach are impacted by T and AP; however, this theory needs further study. Regarding circulatory diseases, in our study, we found that during the cold season, air pollutants increased the number of outpatient visits for circulatory diseases. Some studies presented similar outcomes [34, 41]. However, a study conducted over a 17-year period in Canada reported that 1-day lagged ozone had a greater association with the three examined circulatory hospitalization causes (ischemic heart disease, other heart disease and cerebrovascular disease) during the warm season than during the cold season [15]. A study in Hong Kong reported that PM and NO_2 increased emergency hospital admissions during the warm season [42]. During our study, increased concentrations of PM and NO_2 were observed during the cold season, but an increased concentration of O_3 was not. In addition to the increased concentrations of air pollutants, heat waves and other extreme high-temperature events were more likely to occur on low-temperature days, which may cause more outpatient visits for circulatory diseases [43]. We found that during the warm season of high temperatures (> 30 ℃), pollutants cause greater damage to the cardiovascular system than when temperature are less than 30 ℃. Studies have reported that under high temperature conditions, the risk of ozone-related cardiovascular death increases, and PM has a greater impact on the cardiovascular system; thus, temperature and pollutants may have a synergistic effect on cardiovascular disease [18, 46]. However, a study in low-pollution areas found that the effects of $PM_{2.5}$ were more obvious during the cool season than during the warm season[5].

We also conducted analyses of ozone concentrations exceeding 100 μg/m^3 because ozone pollution is serious. The model with ozone exceeding 100 μg/m^3 did not introduce the ns function of date and DOW because of discontinuity. Ozone exceeded 100 μg/m3 for a total of 390 days during the study period (total study period, 1096 days), and during the warm season, ozone exceeded 100 μg/m3 for a total of 315 days. The warm season model showed that high ozone levels had a significant effect on respiratory outpatient visits at lag4 and lag5. The time at which the significant effect appeared was the same in the warm period model and the model with ozone exceeding 100 μg/m3, but the predominant diseases were different. The difference may be due to the increased concentration of O_3 in the 100 μg/m3 ozone model [8-h O_3 average (standard 8-h O_3 concentration model): 126.36 ug/m^3 vs 8-h O_3 average (the warm season average): 100.48 μg/m3].

In the double model, at lag0, after adjusting for $PM_{2.5}$, NO_2 and 8-h O_3 presented increased ERs. In contrast, after adjusting for $NO_{2,}$ the three other pollutants, especially PM ($PM_{2.5}$ and PM_{10}), presented decreased ERs. There was a strong correlation between PM and NO_2. The ER of ozone did not fluctuate considerably after adjusting for the three other pollutants. The interaction between PM and NO_2 was strong, and the effect of 8-h O_3 was independent. Previous studies also found a strong correlation between PM and gaseous air pollution, with the exception of O_3, which did not change much after the other air pollutants were added to the model [6, 18]. Some mechanics studies noted that inflammation, oxidative stress, changes in systemic coagulation functioning and reduced cardiac autonomic control occurred after exposure to gaseous air pollutants and PM [44, 45], which may trigger respiratory and cardiovascular events as well as high concentrations of air pollutants, except 8-h O_3, during the same period (the cold season). These factors may cause high correlations among air pollutants. Therefore, it is difficult to evaluate the independent effects of PM or NO_2 because of their high correlations [17].

There are several limitations. In coastal areas, ozone pollution is more serious than PM and NO_2 pollution, but in this study, NO_2 increased the number of outpatient visits. Eight-hour O_3 and NO_2 are related to photochemical smog, and they promote one another; it is possible that they exhibit joint action. However, we could not find obvious interactions in the double model; therefore, further research is required. $PM_{2.5}$ increased the outpatient visit risk rate in many studies, even in areas with better air quality than Fuzhou, which may indicate that there are regional differences in the effect of $PM_{2.5}$ exposure in China [47]. In our study, we did not observe a significant effect of $PM_{2.5}$. If we stratify the results by different ages and diseases, we may obtain significant outcomes. Overall, our study comprised a comprehensive analysis of the association between air pollutants and outpatient visits. In some comprehensive studies of large cohorts in other regions, even low exposure to air pollutants can have health effects [48, 49]. However, there is a lack of studies on the association between specific respiratory and circulatory diseases and different air pollutants. The effects observed in this study were short-term effects. Studies of long-term effects still need to be conducted in coastal areas in China.

Conclusions

There was an association between air pollutants and respiratory and circulatory outpatient visits. During the cold season, the ER of NO_2 was higher than that during the warm season for both respiratory- (both upper and lower) and circulatory-related outpatient visits. However, during the cold season, 8-h O_3, NO_2 and $PM_{2.5}$ had greater ERs for upper respiratory-related outpatient visits than for lower respiratory-related outpatient visits, and during the warm season, 8-h O_3, NO_2 PM_{10} and $PM_{2.5}$ had greater ERs for lower respiratory-related outpatient visits. In the double air pollutant model, PM and NO_2 had high correlations.

Declarations

Ethics approval and consent to participate

We only collected the total number of outpatient visits, and the selection was not related to outpatients' personal privacy (i.e., not including personal name, gender, ethnicity, body weight, etc.), and the data belong to de-identification.

Consent to publish

Not applicable.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

All authors declare that they have no competing interests.

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Authors' Contributions: YJ, CW, XZ and BL: study concept and design; YJ, XL, QZ, SJ, XZ: data collection and supervision; JC and YJ: drafting of the manuscript; JC, CW and SY: analysis and interpretation of data; XZ and BL: critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Abbreviations

AP: air pressure; DOW: day of the week; 8-h O_3: daily maximum 8-h mean ozone; ERs: excess risks; df: degrees of freedom; GLM: generalized linear model; ICD-10: 10th edition of the International Classification of Diseases; NO_2: nitrogen dioxide; ns: natural spline; PM_{10}: particulate matter with an aerodynamic diameter less than 10 μg^{-3}; $PM_{2.5}$: particulate matter with an aerodynamic diameter less than 2.5 μg^{-3}; RH: relative humidity; T: temperature

References

1. Landrigan PJ, Fuller R, Acosta NJ, Adeyi O, et al. The Lancet Commission on pollution and health. Lancet. 2018;391(10119):462-512.
2. Kan H, Chen R, Tong S. Ambient air pollution, climate change, and population health in China. Environ Int. 2012;42:10-19.
3. Lu F, Xu D, Cheng Y, Dong S, Guo C, Jiang X, Zheng X. Systematic review and meta-analysis of the adverse health effects of ambient PM2.5 and PM10 pollution in the Chinese population. Environ Res. 2015;136:196-204.
4. Organization WHO. Air quality guidelines: global update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide. World Health Organization. 2006.

5. Liu C, Liu Y, Zhou Y, Feng A, Wang C, Shi T. Short-term effect of relatively low level air pollution on outpatient visit in Shennongjia, China. Environ Pollut. 2019; 245:419-426.
6. Wang Y, Zu Y, Huang L, Zhang H, Wang C, Hu J. Associations between daily outpatient visits for respiratory diseases and ambient fine particulate matter and ozone levels in Shanghai, China. Environ Pollut. 2018;240:754-763.
7. Zhang F, Li L, Krafft T, Lv J, Wang W,Pei D, Study on the association between ambient air pollution and daily cardiovascular and respiratory mortality in an urban district of Beijing. Inter J Env Res Pub Heal, 2011; 8(6):2109-2123.
8. Lamichhane DK, Kim HC, Choi CM, Shin MH, et al. Lung cancer risk and residential exposure to air pollution: a Korean population-based case-control study. Yonsei Med J. 2017; 58(6):1111-1118.
9. Hoffmann B, Luttmann-Gibson H, Cohen A, Zanobetti A, de Souza C, et al. Opposing effects of particle pollution, ozone, and ambient temperature on arterial blood pressure. Environ Health Persp. 2011;120(2):241-246.
10. Wang C, Chen R, Shi M, Cai J, et al. Possible mediation by methylation in acute inflammation following personal exposure to fine particulate air pollution. Am J Epidemiol. 2017;187(3):484-493.
11. Huang C, Moran AE, Coxson PG, Yang X, et al. Potential cardiovascular and total mortality benefits of air pollution control in urban China. Circulation. 2017; 136(17):1575-1584.
12. Lin Y, Zou J, Yang W, Li CQ. A review of recent advances in research on PM2.5 in China. Int J Environ Res Public Health. 2018; 15(3):E438.
13. Szyszkowicz M, Rowe BH, Brook RD. Even low levels of ambient air pollutants are associated with increased emergency department visits for hypertension. Can J Cardiol. 2012; 28(3):360-366.
14. Peel JL. Metzger KB, Klein M, Flanders WD, et al. Ambient air pollution and cardiovascular emergency department visits in potentially sensitive groups. Am J Epidemiol. 2006, 165(6):625-633.
15. Shin H, Burr W, Stieb D, Haque L, Kalayci H, Jovic B, Smith-Doiron M. Air Health Trend Indicator: Association between Short-Term Exposure to Ground Ozone and Circulatory Hospitalizations in Canada for 17 Years, 1996–2012. Int J Environ Res Public Health. 2018; 15(8):E1566.
16. Crouse DL, Peters PA, van Donkelaar A, Goldberg MS, et al. Risk of nonaccidental and cardiovascular mortality in relation to long-term exposure to low concentrations of fine particulate matter: a Canadian national-level cohort study. Environ Health Perspect. 2012; 120(5):708-714.
17. Zhang S, Li G, Tian L, Guo Q, Pan X. Short-term exposure to air pollution and morbidity of COPD and asthma in East Asian area: A systematic review and meta-analysis. Environ Res. 2016; 148:15-23.
18. Wang C, Feng L, Chen K. The impact of ambient particulate matter on hospital outpatient visits for respiratory and circulatory system disease in an urban Chinese population. Sci Total Environ. 2019; 666:672-679.
19. Zhang F, Li L, Krafft T, Lv J, Wang W,Pei D, Study on the association between ambient air pollution and daily cardiovascular and respiratory mortality in an urban district of Beijing. Inter J Env Res Pub Heal, 2011; 8(6):2109-2123.

20. Chai G, He H, Sha Y, Zhai G, Zong S. Effect of PM2. 5 on daily outpatient visits for respiratory diseases in Lanzhou, China. Sci Total Environ. 2019; 649: 1563-1572.
21. Bhaskaran K, Gasparrini A, Hajat S, Smeeth L, Armstrong B. Time series regression studies in environmental epidemiology. Int J Epidemiol. 2013; 42(4):1187-1195.
22. Li L, Lin GZ, Liu HZ, Guo Y, Ou CQ, Chen PY. Can the Air Pollution Index be used to communicate the health risks of air pollution? Environ Pollut. 2015; 205: 153-160.
23. Gasparrini A. Distributed lag linear and non-linear models in R: the package dlnm. J Stat Softw, 2011; 43(8):1-20.
24. Gasparrini A, Armstrong B, Kenward MG. Distributed lag non-linear models. Stat Med. 2010; 29(21):2224-2234.
25. Zhang H, Wang Y, Hu J, Ying Q, Hu XM. Relationships between meteorological parameters and criteria air pollutants in three megacities in China. Environ Res. 2015; 140:242-254.
26. Li R, Wang Z, Cui L, Fu H, et al. Air pollution characteristics in China during 2015–2016: Spatiotemporal variations and key meteorological factors. Sci Total Environ. 2019;648: 902-915.
27. Quan J, Tie X, Zhang Q, Liu Q, et al. Characteristics of heavy aerosol pollution during the 2012–2013 winter in Beijing, China. Atmos Environ. 2014; 88:83-89.
28. McGregor GR, Bamzelis D. Synoptic typing and its application to the investigation of weather air pollution relationships, Birmingham, United Kingdom. Theor Appl Climatol. 1995; 51(4):223-236.
29. Duo B, Cui L, Wang Z, et al. Observations of atmospheric pollutants at Lhasa during 2014–2015: Pollution status and the influence of meteorological factors. J Environ Sci. 2018;63:28-42.
30. Ma Y, Xiao B, Liu C, Zhao Y,Zheng X, Association between ambient Air pollution and emergency room visits for respiratory diseases in spring dust storm season in Lanzhou, china. Inter J Env Res Pub Heal, 2016; 13(6):613.
31. Zhang H, Niu Y, Yao Y, Chen R, Zhou X, Kan H. The impact of ambient air pollution on daily hospital visits for various respiratory diseases and the relevant medical expenditures in Shanghai, China. Int J Environ Res Public Health. 2018; 15(3):E425.
32. Zhang P, Dong G, Sun B, et al. Long-term exposure to ambient air pollution and mortality due to cardiovascular disease and cerebrovascular disease in Shenyang, China. Plos One. 2011; 6(6):e20827.
33. Phung D, Hien TT, Linh HN, Luong LM, Morawska L, Chu C, Binh ND, Thai PK. Air pollution and risk of respiratory and cardiovascular hospitalizations in the most populous city in Vietnam. Sci Total Environ. 2016; 557:322-330.
34. Zhang Y, Wang SG, Xia Y, Shang KZ, Cheng YF, et al. Association between ambient air pollution and hospital emergency admissions for respiratory and cardiovascular diseases in Beijing: a time series study. Biomed Environ Sci. 2015; 28(5):352-363.
35. Sun J, Barnes A, He D, Wang M, Wang J. Systematic review and meta-analysis of the association between ambient nitrogen dioxide and respiratory disease in China. Int J Environ Res Public Health.

2017; 14(6):E646.

36. Perez-Lauterbach D, Nahum R, Ahmad H, Topeff JM, Dossick D, Cole JB, Arens AM. Dose-Dependent Pulmonary Injury Following Nitrogen Dioxide Inhalation From Kinepak™ Detonation. J Emerg Med. 2019; 57(2):77-180.
37. Sun S, Cao W, Mason TG, Ran J, Qiu H, et al. Increased susceptibility to heat for respiratory hospitalizations in Hong Kong. Sci Total Environ. 2019; 666:197-204.
38. Park JH, Lee SH, Yun SJ, Ryu S, Choi SW, et al. Air pollutants and atmospheric pressure increased risk of ED visit for spontaneous pneumothorax. Am J Emerg Med. 2018; 36(12):2249-2253.
39. Ma Y, Yang S, Yu Z, Jiao H, Zhang Y, Ma B,Zhou J, Effect of diurnal temperature range on outpatient visits for common cold in Shanghai, China. ENVIRON SCI POLLUT R, 2020; 27(2):1436-1448.
40. Ma Y, Jiao H, Zhang Y, Cheng B, Feng F, Yu Z,Ma B, Impact of temperature changes between neighboring days on COPD in a city in Northeast China. Environmental Science and Pollution Research, 2019:1-9.
41. Zhao A, Chen R, Kuang X, Kan H. Ambient air pollution and daily outpatient visits for cardiac arrhythmia in Shanghai, China. J Epidemiol. 2014; 24(4):321-326.
42. Yu IT, Qiu H, Wang X, Tian L, Tse LA. Synergy between particles and nitrogen dioxide on emergency hospital admissions for cardiac diseases in Hong Kong. Int J Cardiol. 2013;168(3):2831-2836.
43. Luo K, Li R, Wang Z, Zhang R, Xu Q. Effect modification of the association between temperature variability and daily cardiovascular mortality by air pollutants in three Chinese cities. Environ Pollut. 2017; 230:989-999.
44. Newby DE, Mannucci PM, Tell GS, Baccarelli AA, Brook RD, et al. Expert position paper on air pollution and cardiovascular disease. Eur J Heart Fail, 2014; 36(2):83-93.
45. Baccarelli A, Zanobetti A, Martinelli I, Grillo P, Hou L, Giacomini S, et al. Effects of exposure to air pollution on blood coagulation. J Thromb Haemost. 2007; 5(2):252-260.
46. Shi W, Sun Q, Du P, Tang S, Chen C, Sun Z, Wang J, Li T,Shi X, Modification Effects of Temperature on the Ozone–Mortality Relationship: A Nationwide Multicounty Study in China. Environmental Science & Technology, 2020; 54(5):2859-2868.
47. Li T, Zhang Y, Wang J, Xu D, et al., All-cause mortality risk associated with long-term exposure to ambient PM2·5 in China: a cohort study. The Lancet Public Health, 2018; 3(10):e470-e477.
48. 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. The Lancet, 2014; 383(9919), 785-795.
49. Cohen AJ, Brauer M, Burnett R, Anderson HR, et al., Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. The Lancet, 2017; 389(10082):1907-1918.

Table

Table 1 Statistical summary of daily air pollutants, meteorological factors and outpatient visits in Fujian, China, 2016-2018

Figures

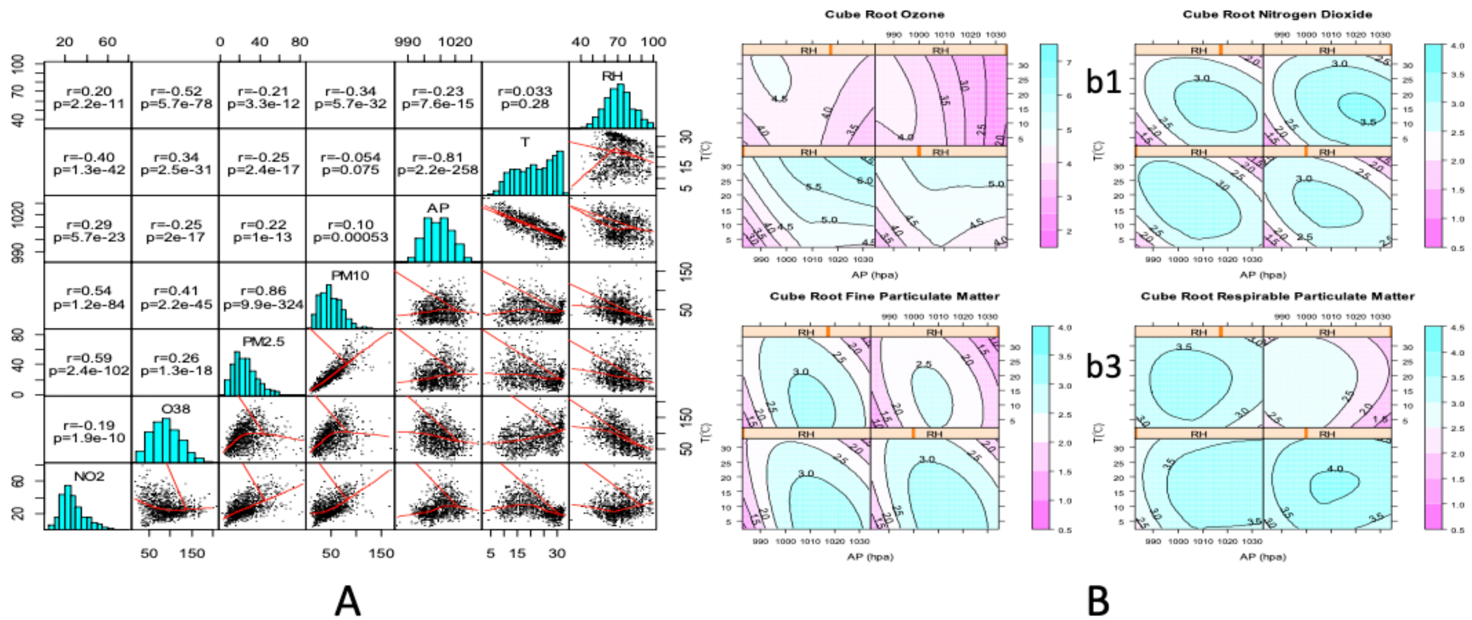

Figure 1

Spearman correlations (left) between air pollutants and meteorological factors from 2016 to 2018. (RH, relative humidity; T, temperature; AP, air pressure; PM10, respirable particulate matter; PM2.5, fine particulate matter; 8-h O3, daily maximum 8-h mean ozone; NO2, nitrogen dioxide).

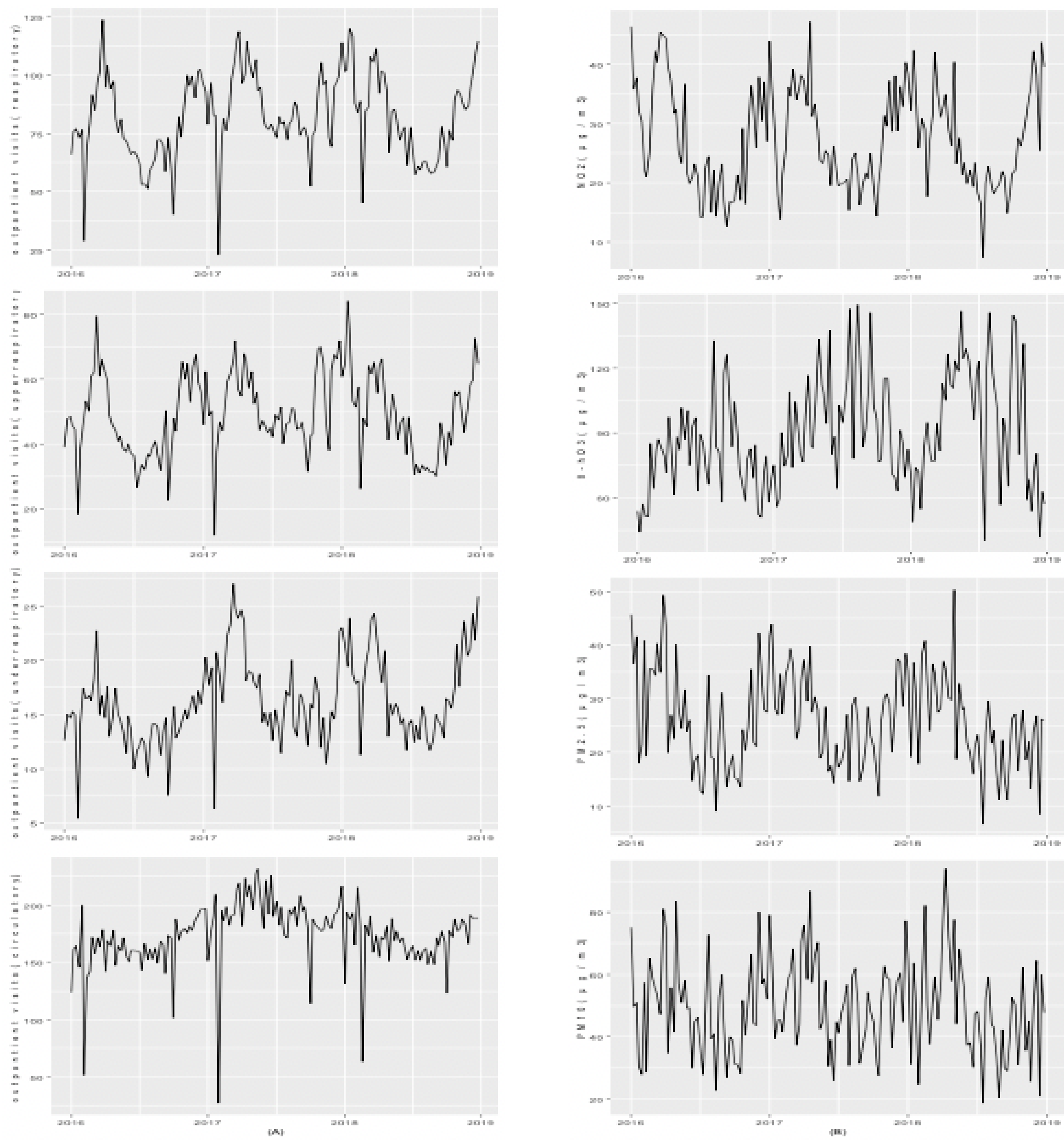

Figure 2

Time series graphs of weekly air pollutants (A) and outpatient visits (B) for respiratory and circulatory diseases

Variable	Mean ± SD	Minimum	Percentile			Maximum
			25th	50th	75th	
Total						
Respiratory disease	82±32	1	60	83	104	180
Upper respiratory disease	49±20	0	35	49	63	113
Lower respiratory disease	16±8	0	10	16	22	47
Circulatory disease	174±83	0	105	191	231	382
NO_2 ($\mu g/m^3$)	27.38±11.18	3.83	19.55	25.14	33.14	79.57
8-h O_3 ($\mu g/m^3$)	89.60±33.94	16.71	64.02	87.36	112.00	208.43
$PM_{2.5}$ ($\mu g/m^3$)	26.07±13.14	2.43	16.57	23.86	32.71	83.57
PM_{10} ($\mu g/m^3$)	49.68±22.62	7.43	33.33	46.49	63.89	167.57
Temperature (℃)	21.54±7.08	2.60	15.60	22.00	28.00	32.80
Relative humidity (%)	72±11	33	65	72	79	99
Air pressure (hpa)	1,010±8	983	1003	1009	1016	1034
Cold season						
Respiratory disease	91±34	1	70	96	114	166
Upper respiratory disease	55±22	0	43	56	70	106
Under respiratory disease	18±9	0	12	19	25	46
Circulatory disease	175±84	0	108	195	236	367
NO_2 ($\mu g/m^3$)	33.11±11.55	10.43	24.57	31.72	41.34	79.57
8-h O_3 ($\mu g/m^3$)	74.21±26.59	16.71	53.66	73.72	92.97	168.14
$PM_{2.5}$ ($\mu g/m^3$)	30.42±14.44	2.43	19.86	28.14	38.50	82.14
PM_{10} ($\mu g/m^3$)	52.28±23.48	7.43	33.72	50.79	68.54	134.14
Temperature (℃)	14.66±4.11	2.60	11.60	14.30	14.30	24.70
Relative humidity (%)	72±12	33	63	73	80	98
Air pressure (hpa)	1,017±6	1001	1013	1016	1021	1034
Warm season						
Respiratory disease	76±29	11	56	77	95	180
Upper respiratory disease	45±18	5	33	44	56	113
Under respiratory disease	15±8	0	10	15	20	47
Circulatory disease	173±81	13	103	189	229	382
	23.32±8.92	3.83	17.74	22.00	27.20	73.29

NO_2 (μg/m^3)						
8-h O_3 (μg/m^3)	100.48±34.39	30.00	75.04	99.24	124.14	208.43
$PM_{2.5}$ (μg/m^3)	22.99±11.17	4.86	15.14	21.00	28.86	83.57
PM_{10} (μg/m^3)	47.84±21.82	10.29	33.04	44.14	60.03	167.57
Temperature (℃)	26±4	14.50	23.53	27.10	27.10	32.80
Relative humidity (%)	72±11	41	65	72	79	99
Air pressure (hpa)	1,005±6	983	1001	1004	1008	1022
O_3 concentrations exceeding 100 μg/m^3						
Respiratory disease	82±30	12	61	84	102	163
Upper respiratory disease	49±19	7	36	47	62	103
Lower respiratory disease	17±8	0	11	17	23	47
Circulatory disease	181±81	18	115.5	194.5	238.75	382
NO_2 (μg/m3)	25.16±7.56	10.14	20.14	23.745	28.2825	56.14
8-h O_3 (μg/m3)	126.36±20.89	100.14	109.86	121.71	136.66	208.43
$PM_{2.5}$ (μg/m3)	29.81±10.97	6.43	21.74	27.86	35.57	70.43
PM_{10} (μg/m3)	59.81±19.55	15.29	45.895	57.43	70.86	164.14
Temperature (℃)	24.36±6.46	8.5	19.75	26	26	32.8
Relative humidity (%)	66±9	41	60	66	72	96
Air pressure (hpa)	1,007±7	992	1002	1006	1013	1031

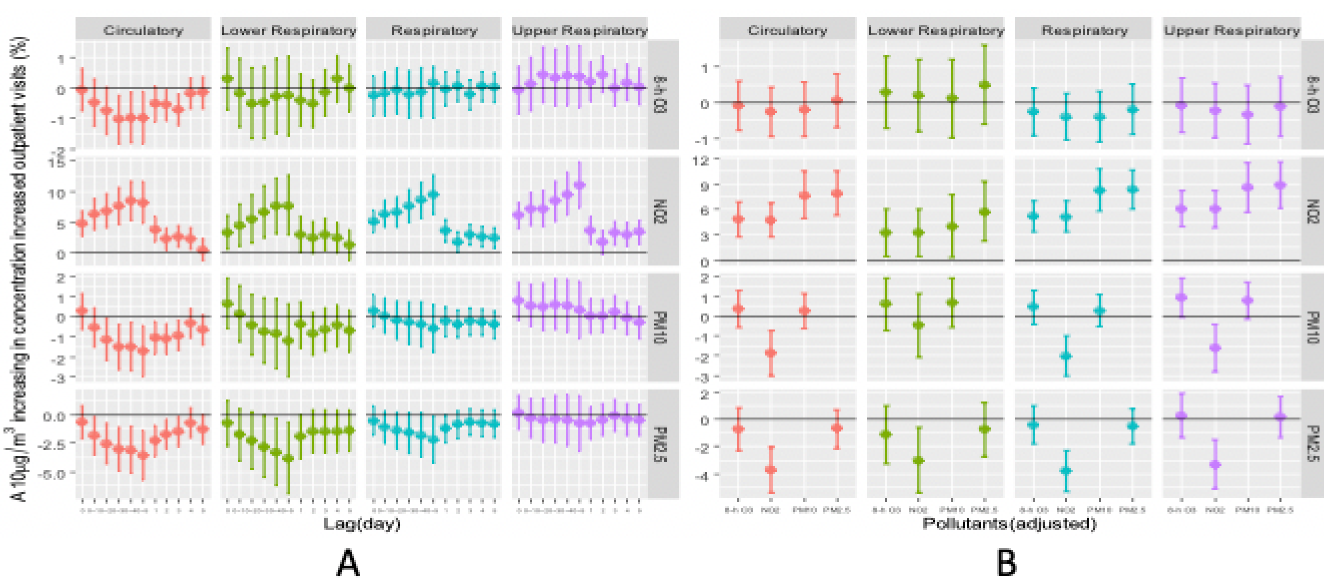

Figure 3

ERs of outpatient visits for total respiratory, lower respiratory, upper respiratory and circulatory diseases in the single air pollutant models (A) and double air pollutant models (B) (The ER (%) of the y-axis indicates that a 10 μg/m3 increase in the concentration of air pollutants increases outpatient visits; “01, 02, 03, 04, 05” represent the cumulative lag effect, same as below). See also Tables S1 and S4.

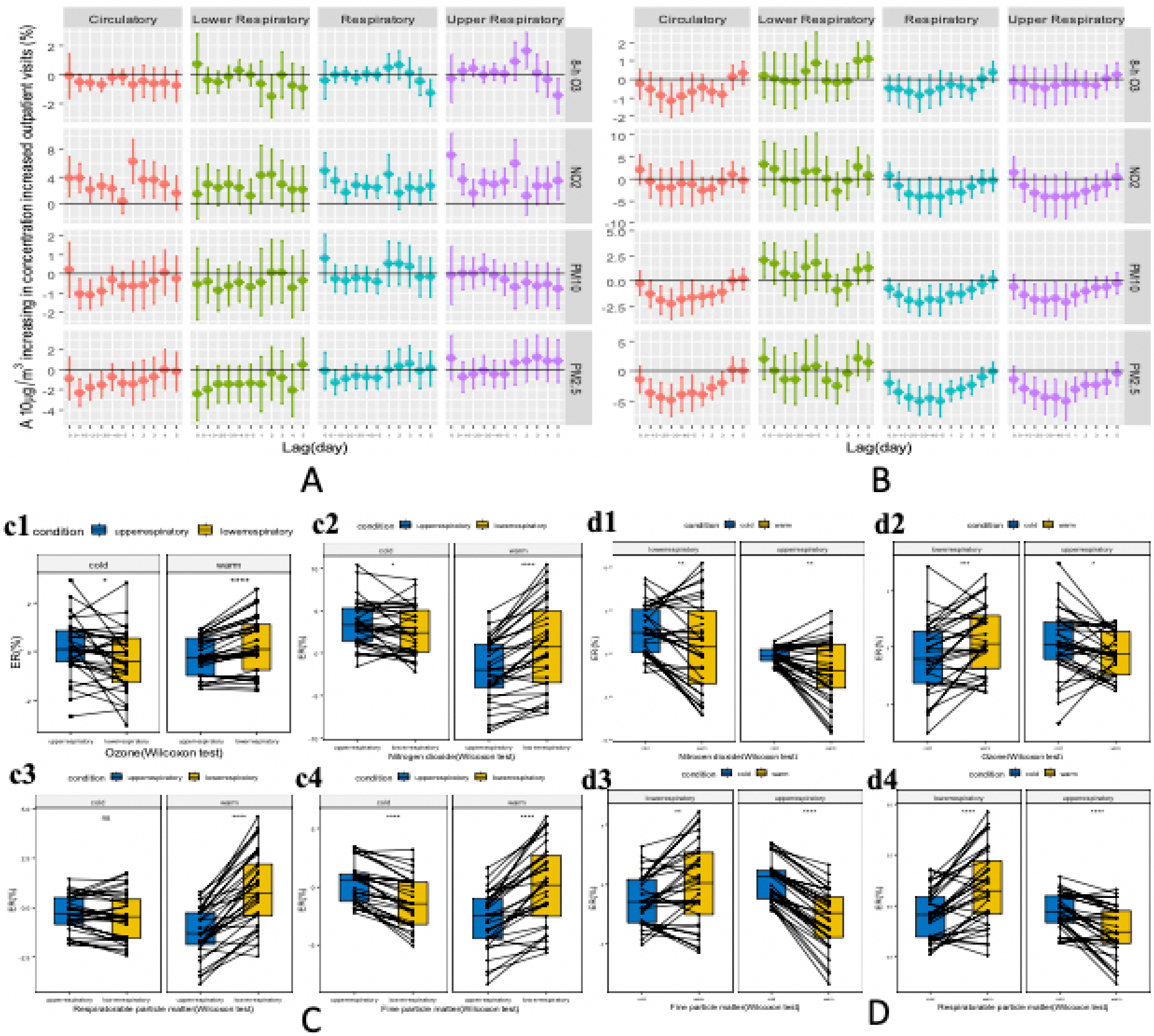

Figure 4

ERs of outpatient visits for total respiratory, lower respiratory, upper respiratory and circulatory diseases in the cold period (A) and warm period (B). See also Tables S2 and S3. The Wilcoxon paired test of ERs between the upper respiratory and lower respiratory periods in different periods and between the cold period and warm period in the upper and lower respiratory periods (C) (p>0.05: ‘ns’; 0.01<p<0.05: ‘*’; 0.001<p<0.01: ‘**’; 0.0001<p<0.001:‘***’; p<0.0001: ‘****’)

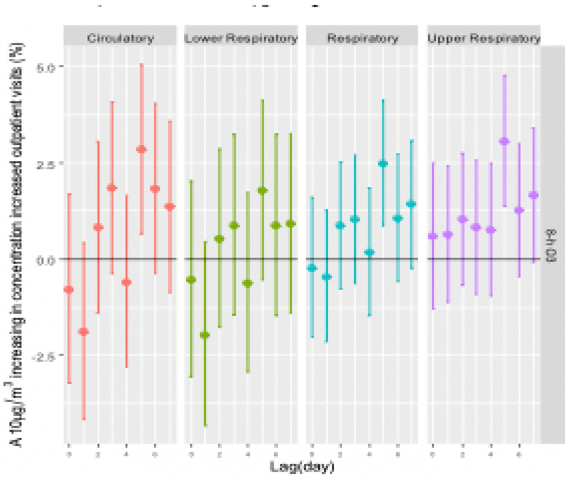

Figure 5

The ERs of outpatient visits when the ozone concentration was over 100 µg/m3. See also Table S5.

Supplementary Files

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