Association Between Ambient Air Pollution and Mortality From Chronic Obstructive Pulmonary Disease in Wuhan, China: a Population-based Time-series Study

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Research

Keywords: air pollution, short-term effects, COPD mortality, time-series

Posted Date: December 9th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-122194/v1

Abstract

Background: Previous studies have mainly focused on the associations between air pollution and total respiratory disease mortality. However, evidence on the short-term effects of air pollution on chronic obstructive pulmonary disease (COPD) mortality is still not conclusive to date. The aim of this study was to investigate the short-term effects of ambient air pollution on COPD mortality in Wuhan China.

Methods: Daily death numbers, concentrations of air pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2, and O_3) and meteorological characteristics in Wuhan between January 1, 2014 to December 31, 2019 were collected. Time-series analysis using generalized additive model was applied to evaluated the association between ambient air pollution and daily COPD mortality. Subgroup analysis by age (<65 and ≥65 year) and sex (male and female) were also conducted.

Results: During the study period, we observed a total of 16150 deaths(7.37 deaths per day) from COPD. The daily average concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3 were 59.03, 90.48, 12.91, 48.84 and 91.77 μg/m^3, respectively. In single pollutant model, for every increase of 10 μg/m^3 in PM_{10}, SO_2, NO_2 levels, COPD mortality increased by 0.581% (95CI:0.054%-1.111%), 4.316%(95CI:1.002%-7.738%) and 1.815%(95CI:0.523%-3.125%) at lag03, respectively. No significant associations were found for $PM_{2.5}$ and O_3. Subgroup analysis demonstrated that females were more susceptible to $PM_{2.5}$, PM_{10}, SO_2 and NO_2, in addition the concentrations of PM_{10}, SO_2 and NO_2 were significantly associated with COPD mortality for older adults. In two-pollutant models, the significantly positive associations between SO_2 as well as NO_2 and COPD mortality remained after adjusting for $PM_{2.5}$ or O_3.

Conclusions: Short-term exposure to PM_{10}, SO_2, and NO_2 are significantly associated with a higher risk of COPD mortality. Female or elderly are more susceptible to air pollution. Further research is required to reveal the underlying mechanisms. The implementation of the environmental protection policy has become urgent.

Background

With the rapid development of modern industry and social economy, air pollution has become a common global problem that cannot be neglected in recent years. China is a developing country and the magnitude is quite different from developed countries. Especially in several megacities, air pollution has become a major threat to public health. In 2010, air pollution is the fourth burden of disease in China, which lead to 1.234 million deaths and 250 million disability adjusted life yeas (DALY)[1]. Wuhan, as the capital city of Hubei province, has a large population of about 11.21 million. The air pollution is severe because of the drastic urbanization and industrial expansion. During 2013 to 2017, average annual limit of PM_{10}, $PM_{2.5}$, NO_2 were 1.3 ~ 1.8, 1.5 ~ 2.7 and 1.2 ~ 1.5 times higher than the annual average acceptable limit, respectively[2]. Therefore, exploring the associations between air pollution and health in Wuhan is of great importance.

Since 1990s, numerous evidences have found that short term exposure to ambient air pollution can increase the risk of adverse health effects, ranging from sub-health status to death, especially respiratory disorders[3–6]. It is accepted that air pollution can disturb the function of respiratory system. Particulate matter may exert oxidative stress on cells in the lung by presenting or by stimulating the cells to produce reactive oxygen species (ROS) and inflammatory factors, and these play important roles in lung tissue injury[7–9]. Chronic respiratory diseases represent a substantial health-care burden in China, and chronic obstructive pulmonary disease (COPD) is the third most common causes of mortality, with 910809 deaths in 2013[1]. Cohort and case crossover studies have shown that ambient air pollution has contributed to increased incidence and prevalence of COPD[10]. Among individuals with COPD, the air pollutants are associated with loss of lung function and increase respiratory symptoms[11]. So ambient air pollutants are also associated with COPD exacerbations and mortality. The World Health Organization (WHO) estimates that ambient air pollution is responsible for 3.7 million premature death worldwide in 2012 and 14% of these deaths are due to COPD or acute lower respiratory infections[12]. It is urgent to further investigate the effects of ambient air pollution exposure on COPD mortality.

Many researches have explored the health effects of air pollution with time-series methods[13–17], but few studies specific measured the association between ambient air pollution and COPD mortality. Furthermore, the characteristics of air pollution in different regions vary substantially. Hence, the aim of this study was to investigate the associations between the concentrations of ambient $PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3 and COPD mortality in Wuhan, China.

Methods

Data collection

Death counts between January 1, 2014 to December 31, 2019 were obtained from Mortality Register System in Wuhan Center for Disease Control and Prevention. For this analysis, we selected the deaths due to COPD, which were classified according to the International Statistical Classification of Disease, 10th Revision codes (ICD-10: J40-J44, I27.9). In view of the vast majority of pulmonary heart diseases (I27.9) were caused by chronic bronchitis and emphysema, few were caused by pulmonary embolism, primary pulmonary hypertension, kyphoscoliotic heart disease and so on, all pulmonary heart disease would be included in COPD. Date of death, cause of death, sex and age were collected. Because the death data were surveillance data, there was no requirement for informed consent. This study was approved by the Ethical committee of Wuhan Center for Disease Control and Prevention, and was conducted in compliance with the tenets of the Declaration of Helsinki. The results were reported according to the STORBE statement.

Wuhan is located in central China (29°58'-31°22'N, 113°41'-115°05'E), with an area of 8,569 km^2. 10 national air quality monitoring stations have been established. In this study, daily average concentrations of air pollutants including $PM_{2.5}$ (mass of particles with aerodynamic diameter < 2.5 μm), PM_{10} (mass of particles with aerodynamic diameter < 10 μm), SO_2 (sulfur dioxide), NO_2 (nitrogen dioxide) and O_3 (ground-level ozone) during January 1, 2014 to December 31, 2019 were obtained from Wuhan Ecology and Environmental Bureau.

Daily meteorological data, including daily mean temperature, atmospheric pressure and relative humidity during the same period, were obtained from Wuhan Meteorological Administration.

Statistical analysis

Daily COPD mortality, air pollutants and meteorological data were described as mean, standard deviation (SD) and quartile. Spearman's correlation was used to estimated the associations between air pollutants and meteorological factors.

For the time-series analysis, daily COPD mortality data was low, belonging to small probability event and approximately followed the Poisson distribution. Therefore, generalized additive Poisson regression with a log-link function was conducted to assess the association between daily counts of COPD mortality and air pollutants concentrations. The model is as below:

$$\log[\mathrm{E(Yt)}] = \alpha + \beta Xt + DOW + s(time, df) + s(Zt, df)$$

In this equation, t refers to the day of the observation; Yt is the observed daily death counts on day t; E(Yt) is the expected daily death count on day t; α is the intercept of the model, β represents the regression coefficient for each air pollutant; Xt is the air pollutant concentrations at day t; Zt represents meteorological data at day t; DOW is the dummy variable for day of the week; s is the smoothing spline function for the nonlinear variables such as temperature, humidity, atmospheric pressure and calendar time. We used the value of Akaike information criterion (AIC) to determine the degrees of freedom (*df*) and the smaller AIC value indicating the preferred model. Finally, we selected 7 *df* per year for the time to adjust the time trend and seasonality, and 3 *df* were used for temperature, humidity and atmospheric pressure. Regarding the concentrations of air pollutants, we estimated the associations with different lag structures using single lag from the current day up to the previous 5 days (lag0-lag5), as well as moving averages of the current and previous days (lag01-lag05). After the working model containing all control variables was built, the air pollutants were included separately. Subgroup analyses by age (< 65, ≥ 65) and sex (males, females) were also conducted. Elderly was defined as older than 65 years old. Furthermore, we used two-pollutant models for all pollutants without interactions to determine the possible role of single pollutants.

The association between air pollutants and COPD mortality was reported as excess relative risk (ERR) with 95% confidence interval (CI) for 10 μg/m^3 increase in $PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3 concentrations. All statistical analysis were performed using R (version 4.0.2) packages “mgcv” and “nlme”. Statistical significance was defined as a two-tailed $P < 0.05$.

Results

Table 1 presented the descriptive statistics for daily number of COPD death, air pollutants and meteorological data from January 1, 2014 to December 31, 2019. During the 6-year period, there were 16150 deaths (7.37 deaths per day) from COPD in Wuhan. Daily death counts were higher in males than females (4.81 vs. 2.56 deaths per day). Death among elderly (older than 65 years old) accounted for 92.28% and the daily mean was 6.80. The daily mean concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3 were 59.03, 90.48, 12.91, 48.84 and 91.77 μg/m^3, respectively. And the average of atmospheric pressure, relative humidity and daily temperature were 1013.10 kPa, 79.42% and 17.18℃.

Table 1
Descriptive statistics of daily mortality counts, air pollutants concentrations and meteorological parameters in Wuhan, China, during 2014–2019.

Variables	Mean(SD)	Min	P25	P50	P75	Max
Number of COPD deaths						
Total	7.37(3.56)	0	5	7	9	21
Males	4.81(2.57)	0	3	4	6	16
Females	2.56(1.88)	0	1	2	4	12
< 65 years	0.57(0.79)	0	0	0	1	4
≥ 65 years	6.80(3.35)	0	4	6	9	21
Air Pollutants						
$PM_{2.5}$(μg/$m^{3)}$	59.03(40.20)	5.00	31.23	48.62	75.62	300.89
PM_{10}(μg/$m^{3)}$	90.48(50.28)	7.56	53.00	81.56	117.78	532.00
SO_2(μg/$m^{3)}$	12.91 (10.23)	2.33	6.22	10.00	15.56	101.33
NO_2(μg/$m^{3)}$	48.84(20.60)	9.78	32.93	45.00	61.20	125.33
O_3(μg/$m^{3)}$	91.77(50.43)	5.33	51.00	85.33	128.00	261.50
Meteorological variables						
Air pressure (kPa)	1013.10(9.40)	993.50	1004.90	1013.10	1020.40	1043.00
Relative humidity (%)	79.42(10.27)	41.00	73.00	80.00	87.00	100.00
Temperature(℃)	17.18(9.16)	-3.80	9.10	18.15	24.90	33.90

The daily concentrations of $PM_{2.5}$, PM_{10}, SO_2 and NO_2 were strongly and positively correlated with each other, as shown in Table 2. In contrast, the daily concentrations of O_3 was moderately and negatively correlated with those of the other pollutants. In addition, air pressure was positively and temperature was negatively correlated with all air pollutants except for O_3 (r_{hpa-O3}=-0.55, $P < 0.001$; r_{tem-O3}=0.68, $P < 0.001$,). Relative humidity was negatively correlated with the five air pollutants ($P < 0.01$).

Table 2
Spearman's correlation between air pollutants and meteorological factors in Wuhan, China, during 2013–2019

	$PM_{2.5}$	PM_{10}	SO_2	NO_2	O_3	Air pressure	Relative humidity	Temperature
$PM_{2.5}$	1.00							
PM_{10}	0.84 [a]	1.00						
SO_2	0.68 [a]	0.73 [a]	1.00					
NO_2	0.70 [a]	0.77 [a]	0.72 [a]	1.00				
O_3	-0.22 [a]	-0.08 [a]	-0.03	-0.07 [b]	1.00			
Air pressure	0.49 [a]	0.29 [a]	0.41 [a]	0.38 [a]	-0.55 [a]	1.00		
Relative humidity	-0.07 [b]	-0.36 [a]	-0.37 [a]	-0.15 [a]	-0.44 [a]	-0.04	1.00	
Temperature	-0.53 [a]	-0.26 [a]	-0.37 [a]	-0.38 [a]	0.68 [a]	-0.91 [a]	-0.12 [a]	1.00

[a] $P < 0.001$, [b] $P < 0.01$

Figure 1 showed the time trends for air pollutants and all showed relatively stable seasonal trends annually. The concentrations of $PM_{2.5}$, PM_{10}, SO_2 and NO_2 had similar characteristics of periodic fluctuation, which were higher in the cold season and lower in the warm season. However, the concentrations of O_3 showed an inverses trend. The daily concentrations of $PM_{2.5}$ and SO_2 during 2017 to 2019 were lower than previous years. COPD mortality in the study period also showed a seasonal pattern with higher counts in winter and lower counts in summer.

Table 3 illustrated the EER of COPD mortality with every 10 $\mu g/m^3$ increase of air pollutant concentrations with different lag days in single pollutant models. All the five pollutants were positively associated with COPD mortality. However, for the single-day lag effects, positive significant associations were observed only for SO_2 at lag1 and lag 2, NO_2 at lag 1 and lag2, and O_3 at lag 3. The estimates of the effects of the five pollutants on COPD mortality were highest at lag0 for PM2.5 (ERR: 0.475%, 95%CI: -0.056 ~ 1.008), at lag 1 for PM_{10} (ERR: 0.384%, 95%CI: -0.002 ~ 0.772) and SO_2 (ERR: 2.962%, 95%CI:0.673 ~ 5.303), at lag 2 for NO_2 (ERR: 1.327%, 95%CI: 0.366 ~ 2.296) and at lag3 for O_3 (ERR: 0.494%, 95%CI:0.027 ~ 0.962).

Table 3
Estimated excess relative risks (ERRs) and 95% confidence intervals (95%CI) of daily death from chronic obstructive pulmonary disease for a 10 μg/m3 increase in air pollutant's concentrations with different lag days in single pollutant models.

Lag Days	$PM_{2.5}$	PM_{10}	SO_2	NO_2	O_3
Lag0	0.475(-0.056,1.008)	0.263(-0.135,0.663)	0.998(-1.339,3.391)	0.570(-0.335,1.484)	-0.119(-0.649,0.414)
Lag1	0.287(-0.239,0.817)	0.384(-0.002,0.772)	2.962(0.673,5.303) [b]	1.037(0.069,2.015) [b]	0.210(-0.298,0.720)
Lag2	0.148(-0.376,0.658)	0.319(-0.054,0.695)	2.673(0.458,4.938) [b]	1.327(0.366,2.296) [a]	0.284(-0.191,0.761)
Lag3	0.316(-0.198,0.832)	0.228(-0.140,0.596)	1.469(-0.705,3.690)	0.847(-0.074,1.776)	0.494(0.027,0.962) [b]
Lag4	-0.259(-0.769,0.254)	-0.134(-0.496,0.230)	-0.849(-2.965,1.313)	-0.165(-1.058,0.736)	-0.143(-0.604,0.320)
Lag5	-0.481(-0.997,0.037)	-0.105(-0.467,0.258)	-0.858(-2.972,1.302)	0.164(-0.724,1.061)	-0.035(-0.497,0.428)
Lag01	0.469(-0.139,1.081)	0.423(-0.026,0.875)	2.770(0.048,5.572) [b]	1.011(-0.034,2.066)	0.061(-0.567,0.692)
Lag02	0.430(-0.245,1.108)	0.536(0.045,1.029) [b]	4.010(0.967,7.145) [a]	1.558(0.378,2.752) [a]	0.255(-0.424,0.939)
Lag03	0.518(-0.219,1.261)	0.581(0.054,1.111) [b]	4.316(1.002,7.738) [b]	1.815(0.523,3.125) [a]	0.485(-0.234,1.210)
Lag04	0.368(-0.426,1.168)	0.464(-0.094,1.025)	3.480(-0.034,7.118)	1.608(0.224,3.010) [b]	0.321(-0.435,1.082)
Lag05	0.154(-0.695,1.011)	0.386(-0.201,0.977)	2.865(-0.854,6.724)	1.563(0.095,3.052) [b]	0.267(-0.526,1.067)

[a] $P < 0.01$, [b] $P < 0.05$

The effects of moving average lags were higher than single lags in different period. For the moving averages, positive significant associations were observed for PM_{10} at lag02 and lag03, SO_2 at lag01-lag03, NO_2 at lag02-lag05. All pollutants showed the strongest estimates at lag03. For each increase of 10 μg/m^3 in $PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3 concentrations, COPD mortality increased by 0.518% (95%CI: -0.219 ~ 1.261), 0.581% (95%CI: 0.054 ~ 1.111), 4.316% (95%CI: 1.002 ~ 7.738), 1.815% (95%CI: 0.523 ~ 3.215) and 0.458% (95%CI: -0.234 ~ 1.210) at lag03, respectively.

The effects of the individual air pollutants on subjects by sex and age were performed in Fig. 2. SO_2 had the greatest impact on each subgroup analysis. $PM_{2.5}$, PM_{10}, SO_2, NO_2 estimates of females were higher than those for males, except for $PM_{2.5}$ at lag5, SO_2 at lag 3, and NO_2 at lag 1, lag2 as well as lag01-lag03. In contrast, the associations of O_3 was higher for males than females, except at lag2. In general, except for O_3, all pollutants estimates of < 65 year group was higher than those for older adults, but the estimates of < 65 year group were almost nonsignificant (except for $PM_{2.5}$ at lag2, SO_2 at lag2 and lag3, and NO_2 at lag3). For older adults, significant positive associations were observed for PM_{10} at lag1 and lag01-lag03, SO_2 at lag1, lag2 as well as lag01-03, and NO_2 at lag1, lag2 as well as lag02-lag04.

Figure 3 summarized the ERRs for COPD mortality associated with every 10 μg/m^3 increase of air pollutant concentrations in two pollutant models at lag03. The estimates for SO_2 and NO_2 were the most stable across all two-pollutant models. In contrast, the estimates of $PM_{2.5}$, PM_{10} and O_3 decreased after the inclusion of SO_2 or NO_2. Additionally, the estimates of $PM_{2.5}$ decreased

after the inclusion of PM_{10}. The significant positive associations between SO_2 as well as NO_2 and COPD mortality remained after adjusting for $PM_{2.5}$ or O_3.

Discussion

In our study, a population-based time-series model was used to investigate the association between short-term air pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3) exposure and COPD mortality in Wuhan, China, during January 1, 2014 to December 31, 2019. The results showed that the concentrations of PM_{10}, SO_2, and NO_2 were significantly positively associated with COPD mortality. As far as we know, this was the first time-series study assessed the adverse effects of air pollutants on COPD mortality in China.

During 2014 to 2019, the levels of ambient air pollution were relatively high in Wuhan, China. The daily mean concentrations of $PM_{2.5}$ (59.03 μg/m^3), PM_{10} (90.48 μg/m^3) and NO_2 (48.84 μg/m^3) exceeded the values of WHO Air Quality Guidelines (10, 20, 40 μg/m^3 respectively). And the daily mean concentrations of SO_2 and O_3 were 12.91 and 91.77 μg/m^3, which were within the Air Quality Guidelines values (20, 100 μg/m^3 respectively). The concentrations of air pollutants showed relatively stable trends. $PM_{2.5}$, PM_{10}, SO_2 and NO_2 peaked in winter. It was probable that coal-burning was still the important source of heat and energy in China. Furthermore, in winter, the dispersion of pollutants was poor. However, O_3 was mostly formed by the conversion of nitrogen oxides and volatile organic compounds under high temperature, sufficient sunshine and low humidity, which finally led to the peak values of O_3 in summer. By the end of 2019, the number of motor vehicles exceed 3.3 million in Wuhan, and vehicle emission also became one of the major sources of environmental air pollution.

Our results showed that ambient air pollutants were positively associated with COPD mortality in single pollutant models. The effects on COPD mortality peaked within 4 day (lag03) and the strongest association estimated were observed for SO_2. An increase of 10 μg/m^3 of PM_{10} was associated with a 0.581%(95%CI:0.054%-1.111%) increase in COPD mortality. Moogavkar et.al reported a significantly positive association between PM_{10} and the risk of COPD mortality with a increase of 2.66% (95%CI:0.12%-5.20%) in COPD mortality per 25 μg/m^3 increase in PM_{10} [18]. And a meta-analysis by Zhu et al. also concluded that a 10 μg/m^3 increase in PM_{10} was associated with a 1.1% (95%CI:0.8%-1.4%) increase in COPD mortality [19]. While, a case-crossover study in Cook city showed a lack of association between PM_{10} and the risk of mortality for COPD [20]. We did not found significantly association between the concentrations of $PM_{2.5}$ and COPD mortality, consistent with the results of a large population-based cohort study in Metropolitan Vancouver, Canada [21]. But a meta-analysis concluded that a 10 μg/m^3 increase in daily $PM_{2.5}$ was associated with a 2.5%(95%CI:1.5%-3.5%) increase in COPD mortality[22]. And in a COPD cohort, Faustini et al found that effects on respiratory mortality among COPD subjects were particularly elevated 11.6%(95%CI:2.0%-22.2%) from $PM_{2.5}$ per 11 μg/m^3 increase[23].

Interestingly, our findings demonstrated that gaseous pollutants had stronger effects on COPD mortality than particulate matter. Similarly, other studies also suggested that compared to particulate matter, gaseous pollutant had stronger effects on COPD exacerbation and daily outpatient visits of respiratory diseases[24, 25]. Our estimates showed that a 10 μg/m^3 of NO_2 was significantly associated with a 1.815%(95%CI:0.523%-3.125%) increase in COPD mortality. In a 6-year cohort study including all residents aged 51–90 years in Oslo, Norway, the results found that the concentrations of NO_2 on COPD mortality appeared to have significantly linear effects[26]. While Hart et al found positive but nonsignificant associations of COPD mortality with NO_2, $PM_{2.5}$ and SO_2 exposure in industry workers[27].

SO_2 mainly came from burning of fossil fuels, with the promotion of clean fuels in Wuhan recently, the concentration of SO_2 gradually decreased. The mean concentrations of SO_2 in Wuhan was 12.91 μg/m^3, which could be considered as low-level compared with many other Chinese cities[5, 28, 29]. But our results showed that every increase of 10 μg/m^3 of SO_2 was associated with 4.316%(95%CI:1.002%-7.738%) increase in COPD mortality, which was higher than the estimated reported in several previous studies[30]. And Zhang et al also demonstrated that SO_2 had a stronger effect on cardiovascular mortality in Hefei, China[28]. The reason for this phenomenon was still unclear, but Samoli et al found that when the concentration of SO_2 at

a lower level, the impact of SO_2 to mortality is greater than the high concentration[31], which might partially explain the effects of SO_2 in our study. Furthermore, similar with the results of a meta-analysis, we did not find significant association between the concentrations of O_3 and COPD mortality[25]. To sum up, the inconformity with our findings might due to the different chemical compositions of PM_{10} or $PM_{2.5}$ in different areas, which could result in different effects on COPD mortality. In addition, the meteorological factors might influent the effects of air pollutants, but the compositions of air pollutants and meteorological conditions varied in different regions[32]. Moreover, the age, socioeconomic status and education level and so on were able to modify the effects of air pollutants.

Although the mechanical explanation of adverse effects of ambient air pollution on COPD mortality remains unclear, identifying the associations of ambient air pollution in different exposure windows is of great importance in the estimation of health risk. In our study, we found that exposure to air pollutants at lag03 yielded the strongest estimates on COPD mortality. Another time-series study in Hefei, China also found the similar phenomenon in the associations between ambient air pollution and cardiovascular mortality[28].

Subgroup analysis showed that females seemed to suffer more risk of COPD mortality from ambient air pollution. In addition, the results showed that the air pollution estimates of < 65 year group were higher than those for older adults, though the estimates were almost nonsignificant. Only 7.2% in our study were < 65 year group, the sample size might be a strong confounder. A population based cohort study also showed that the relative risks for COPD mortality associated with a 0.78 μg/m^3 elevation in black carbon concentrations were 1.06 (95%CI:0.97–1.15) and 1.08 (95%CI:0.97–1.20) for males and females, and 1.31 (95%CI:1.07–1.60) and 1.04 (95%CI:0.97–1.12) for < 65 and ≥ 65 year groups[21] .Similar with the results from a population based UK Biobank study, it concluded that the adverse effects of $PM_{2.5}$ and NO_2 on COPD prevalence were stronger in females[33]. However, Naess et al documented that males were more susceptible to air pollution (PM_{10}, $PM_{2.5}$, SO_2) than females[26]. The reasons for our gender-specific findings were still unclear and needed further investigation. Furthermore, the concentrations of PM_{10}, SO_2 and NO_2 were significantly associated with COPD mortality for older adults, effective public health prevention policies specified for older adults should be made to reduce the burden of COPD.

Two-pollutant models were implemented in our study to explore the possible role of single pollutants. We concluded that the estimates of $PM_{2.5}$, PM_{10} and O_3 decreased after the inclusion of SO_2 or NO_2, consistent with the previous studies[29, 34]. These results revealed the relatively independent associations of SO_2 and NO_2. The associations of SO_2 and NO_2 on COPD mortality might better reflect the associations between air pollution and COPD mortality in Wuhan compared with other pollutants.

Though this study was a population-based time-series study which covered all population in Wuhan, there were some limitations. Firstly, the average of ten fixed sited monitoring data of air pollutant concentrations were used to infer exposures of individuals, which might lead to potential misclassification exposure and ignore the spatial impact of air pollution on COPD. Secondly, due to data unavailability, some factors including personal social information (such as tobacco use, body mass index and so on) that could affect the effects were not controlled. Thirdly, we could not rule out the non-relevant death records due to obesity or other reasons than air pollution.

Conclusions

The results of this study suggested that exposure to PM_{10}, SO_2, and NO_2 were significantly positively associated with a higher risk of COPD mortality in Wuhan, China. Moreover, female and elderly are more susceptible to air pollution. Our findings could provide evidence to help understand the adverse health effects of air pollution, which might have important implications for policy makers to curb and reduce ambient air pollution in Wuhan.

Declarations

Ethics approval and consent to participate:

The death data were surveillance data, there was no requirement for informed consent. This study was approved by the Ethical committee of Wuhan Center for Disease Control and Prevention

Consent for publication:

Not applicable.

Availability of data and materials:

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

Competing interests:

The authors declare that they have no competing interests.

Funding:

This research was funded by Basic Applied Research Project of Wuhan Science and Technology Bureau (grant number: 2015061701011631), Emergency Research Fund for Novel Coronavirus Pneumonia Prevention and Control of Wuhan Municipal Health Commission (grant number:EG20A04), Scientific Research Project of Hubei Provincial Health and Family Planning Commission (grant number: WJ2019F011) and Scientific Research Program of Hubei Education Department (grant number: B2020006). The funds of the study had no role in the study design, execution, analysis, data interpretation or writing of the report.

Authors' contributions:

YY: Conceptualization, Methodology, Funding acquisition. LS: Formal analysis, Writing-Original draft preparation. YG: Software, Funding acquisition. YZ: Data curation. PZ: Software. BX: Validation. JZ: Data curation. MY: Writing-Reviewing and Editing, Conceptualization, Funding acquisition. LW: Conceptualization. All authors read and approved the final manuscript.

Acknowledgements:

Not applicable.

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Figures

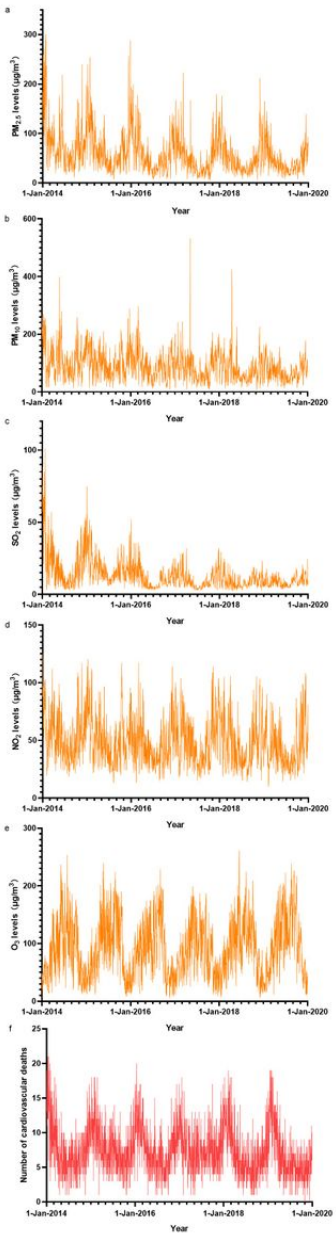

Figure 1

Time series of PM2.5 (a), PM10 (b), SO2 (c), NO2(d), O3(e) and chronic obstructive pulmonary disease mortality(f) in Wuhan, China, during 2014-2019.

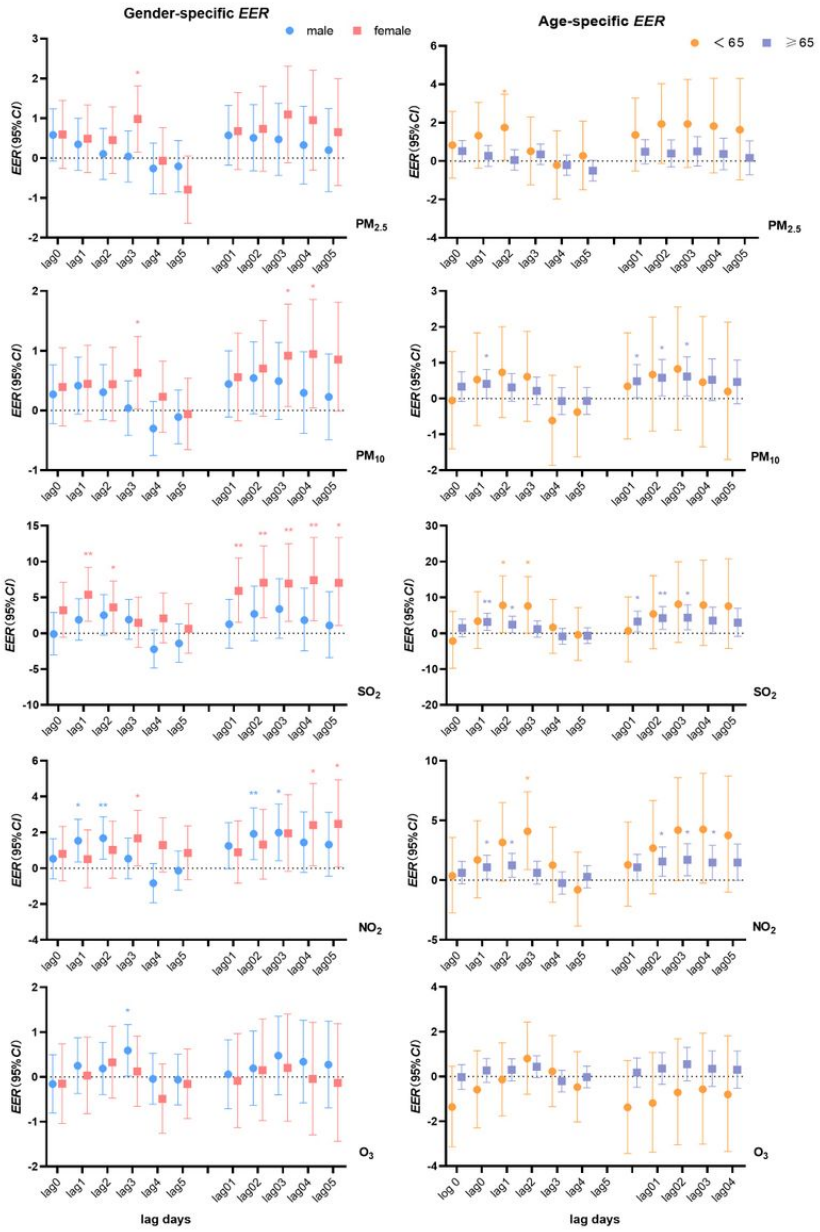

Figure 2

Age- and gender-specific estimated excess relative risks (ERRs) and 95% confidence intervals (95%CI) for daily deaths from chronic obstructive pulmonary disease with a 10μg/m3 increase in air pollutants using different lag days.

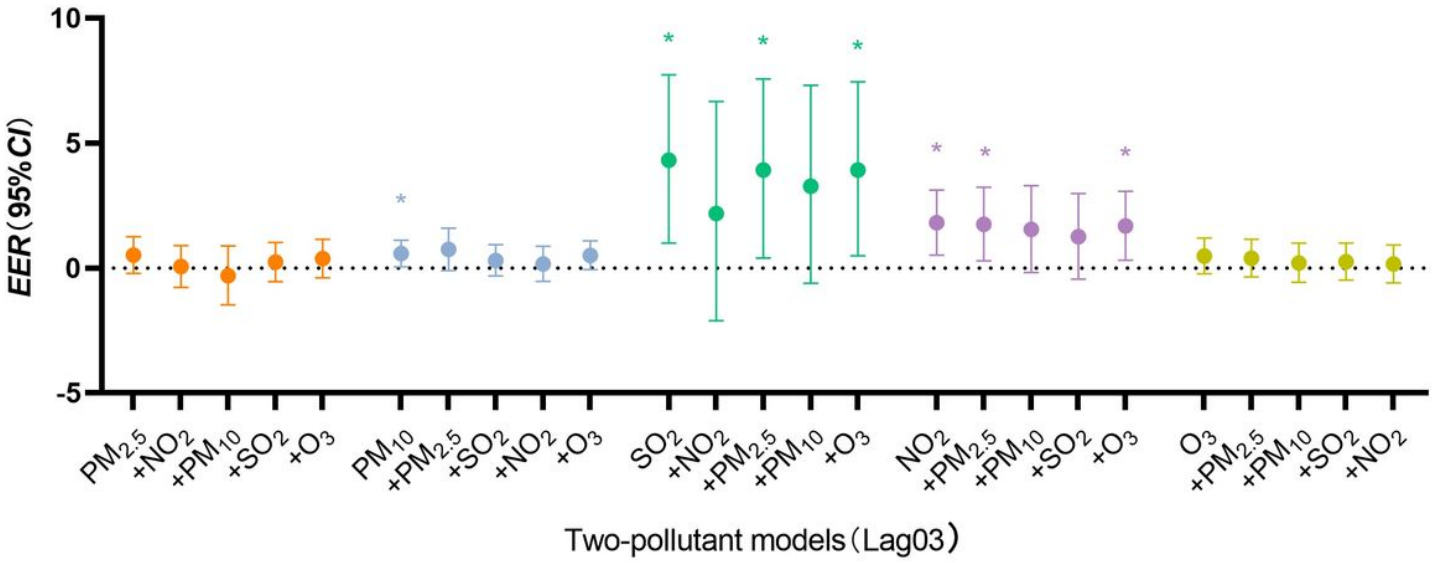

Figure 3

Estimated excess relative risks (ERRs) and 95% confidence intervals (95%CI) for daily deaths from chronic obstructive pulmonary disease with a 10μg/m3 increase in air pollutants using single- and two-pollutant models. Lag03 were used.