

Vital Surveillances

A Time-Series Analysis on the Association Between Fine Particulate Matter and Daily Mortality — Shijiazhuang City, Hebei Province, China, 2015–2020

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ABSTRACT

Introduction: Shijiazhuang is one of the most polluted cities in China, but few studies have investigated the acute impact of fine particulate matter (PM_{2.5}) on mortality in this city. We assessed associations between PM_{2.5} and cause-specific mortality during 2015 to 2020.

Methods: We obtained air quality data from Shijiazhuang Ecology and Environment Bureau, meteorological data from Shijiazhuang Meteorological Bureau, and mortality data from Shijiazhuang CDC's Cause of Death Reporting System for our analyses. We used a quasi-Poisson regression generalized additive model to assess excess risk of death for a single time-lag and for moving average time-lags of 0–7 days, stratifying by year, sex, age, and education.

Results: There were 76,859 non-accidental deaths recorded in Shijiazhuang during the study period. The daily concentration of PM_{2.5} ranged from 6.3 µg/m³ to 625.3 µg/m³, and the annual mean concentration was 77.6 µg/m³. Regression analysis showed that an increment of PM_{2.5} of 10 µg/m³ in a two-day average concentration (lag01) was associated with 0.47% [95% Confidence Interval (CI): 0.24%, 0.70%], 0.49% (95% CI: 0.19%, 0.79%), and 0.72% (95% CI: 0.22%, 1.23%) increases in non-accidental deaths, cardiovascular disease deaths, and respiratory disease deaths, respectively. With reduction of PM_{2.5} concentration, impact of PM_{2.5} on respiratory disease deaths decreased, but the impact of PM_{2.5} on total non-accidental deaths and circulatory disease deaths did not change significantly.

Conclusion: Although PM_{2.5} has been greatly reduced in recent years, PM_{2.5} pollution is still serious in Shijiazhuang. PM_{2.5} was significantly associated with non-accidental death, cardiovascular disease death, and respiratory disease death. As PM_{2.5} concentrations decreased, risk of death from respiratory diseases also decreased.

Air pollution is a major environmental risk factor affecting health worldwide. According to the World Health Organization, more than 4 million people die prematurely every year due to outdoor air pollution (1). The relationship between fine particulate matter (PM_{2.5}) and mortality has been evaluated worldwide, in China, and in multiple-city studies (2–4). Evidence is accumulating showing regional differences in health response to air pollution. For example, the impact of PM_{2.5} on mortality varies greatly by country, region, and climate characteristics. Hebei Province's capital, Shijiazhuang, is situated in the heart of the North China Plain and the Beijing-Tianjin-Hebei regional city cluster, and is one of the most polluted cities in China (5). We analyzed the most recent and longest time series data available, spanning the years 2015 to 2020, to explore the relation between PM_{2.5} and cause-specific mortality and to identify PM_{2.5}-related sensitive illnesses and vulnerable populations. We determined the shapes of PM_{2.5} exposure-response curves and explore how PM_{2.5} and its health risks have changed in recent years in Shijiazhuang through environmental pollution control measures such as the “Blue Sky Protection Campaign,” improvements in energy, heating, transportation and land use, and improvements in polluting small enterprises.

METHODS

The study obtained daily mortality data from January 1, 2015, to December 31, 2020 from Shijiazhuang CDC's Cause of Death Reporting System. Causes of death were classified according to the International Classification of Diseases, 10th revision (ICD-10) (6), including total non-accidental causes (“ALL”, codes A00-R99), cardiovascular disease (“CVD”, codes I00-I99), and respiratory diseases (“RESP”, codes J00-J99). We categorized non-accidental deaths into strata by sex, age group (5–64 years and 65 years or older), and education level (low:

less than or equal to 9 years of education; high: more than 9 years of education). Deaths of children five years and under were too few to analyze and were excluded. Meteorological factors (daily average temperature and relative humidity) and air pollution data [daily 24-hour average concentration of PM_{2.5}, particulate matter with particle size below 10 microns (PM₁₀), SO₂, and NO₂, and maximum eight-hour mean concentration of O₃] were obtained from Shijiazhuang Meteorological Bureau and Shijiazhuang Ecology and Environment Bureau, respectively.

We examined associations between PM_{2.5} and cause-specific mortality using generalized additive models (GAM) (7) with a quasi-Poisson link function to account for over-dispersion of daily cause-specific deaths. We controlled for seasonal patterns, long-term trends, temperature, and relative humidity using natural cubic regression smoothing. Our analyses allowed 7 degrees of freedom (*df*) per year for time long-term trends, 6 *df* for daily mean temperature, and 3 *df* for daily mean relative humidity, to minimize the Akaike's Information Criterion (AIC) value of GAM. We stratified analyses by year (2015–2017 and 2018–2020).

The description of the model, methods and results for analyses of different periods (2015–2017 and 2018–2020) as shown in Supplementary Table S1 (available in <http://weekly.chinacdc.cn/>), Spearman's correlation coefficients as shown in Supplementary Table S2 (available in <http://weekly.chinacdc.cn/>), sensitivity analyses as shown in Supplementary Table S3 (available in <http://weekly.chinacdc.cn/>), two-pollutant models as shown in Supplementary Table S4 (available in <http://weekly.chinacdc.cn/>), and stratification analyses were presented in the

Supplementary materials. Analyses were conducted using the packages “mgcv” in R statistical software (version 3.5.1; The R Foundation for Statistical Computing, Vienna, Austria). We used two-tailed tests; *P* values less than 0.05 were considered statistically significant.

RESULTS

Table 1 showed mortality, PM_{2.5}, and meteorological data and daily average counts of non-accidental (ALL), cardiovascular (CVD), and respiratory (RESP) deaths. During the study period, there were averages of 35 ALL, 19 CVD, and 5 RESP deaths per day. Among the 76,859 ALL deaths, there were 41,473 (54.0%) CVD deaths and 9,955 (13.0%) RESP deaths. Daily concentration of PM_{2.5} ranged from 6.3 µg/m³ to 625.3 µg/m³, and the annual-mean concentration was 77.6 µg/m³. There were 767 days (35% of the study period days) in which PM_{2.5} concentration was over 75 µg/m³, the national second ambient air quality standard in China. As shown in Supplementary Table S1, PM_{2.5} pollution was lower during 2018 to 2020 compared with 2015 to 2017, as the PM_{2.5} average concentration decreased from 91.1 µg/m³ to 64.1 µg/m³, while the maximum concentration decreased from 625.3 µg/m³ to 355.0 µg/m³ and the number of days exceeding the national standard decreased from 480 to 287 days.

As shown in Figure 1, the delayed effects of PM_{2.5} on ALL mortality were statistically significant for lag1, lag2, lag01, lag02, lag03, and lag04; the largest delayed effects estimates were for lag01, in which a 10 µg/m³ increase in PM_{2.5} was associated with an increment in ALL deaths of 0.47% (95% CI: 0.24%, 0.70%). For

TABLE 1. Daily mortality, PM_{2.5}, and meteorological data in Shijiazhuang, 2015–2020.

Variable	Mean (SD)	Min	P ₂₅	P ₅₀	P ₇₅	Max
Daily mortality						
ALL	35 (10)	12	28	34	41	107
CVD	19 (7)	4	14	18	23	67
RESP	5 (3)	0	3	4	6	31
Air pollutant (µg/m ³)						
PM _{2.5}	77.6 (67.9)	6.3	35.0	56.0	94.5	625.3
Weather conditions						
Average temperature (°C)	14.8 (10.8)	-10.2	4.6	16.0	24.6	33.7
Relative humidity (%)	55.5 (20.3)	7	39	55	72	100

Abbreviations: ALL=total non-accidental mortality from all causes; CVD=cardiovascular disease; RESP=respiratory disease; PM_{2.5}=particulate matter with an aerodynamic diameter less than or equal to 2.5 µm; SD=standard deviation; Min=Minimum; P₂₅=the 25th percentile; P₅₀=the median; P₇₅=the 75th percentile; Max=Maximum.

CVD mortality, the delayed effects of PM_{2.5} were statistically significantly for lag1, lag2, lag01, lag02, lag03, lag04, and lag05; the largest delayed effects estimates were also for lag01, with a 10 µg/m³ increase in PM_{2.5} corresponding to a 0.49% (95% CI: 0.19%, 0.79%) increment in death. For RESP mortality, in single-day lag models, significant associations were limited to the first day after PM_{2.5} exposure, with a 10 µg/m³ increase in PM_{2.5} corresponding to a 0.78% (95% CI: 0.33%, 1.23%) increment in death. When PM_{2.5} exposures were lagged over multiple days, the associations were strongest for exposures during lag01 (Estimates: 0.72%, 95% CI: 0.22%, 1.23%).

For Figure 2A and 2B, the exposure-response curves for ALL and CVD showed increasing trends. When PM_{2.5} concentrations were lower than 120 µg/m³ or higher than 300 µg/m³, slopes of curves showed marked increases. When PM_{2.5} concentrations were between 120 µg/m³ and 300 µg/m³, slope was flat. In

Figure 2C, the exposure-response curve for respiratory mortality was nearly linear and positive. When PM_{2.5} concentration was over 300 µg/m³, confidence intervals were wider than when PM_{2.5} concentration was less than 300 µg/m³.

As shown in Table 2, compared with 2015–2017, during 2018–2020, the effect of PM_{2.5} on ALL mortality was larger, and the estimated effect value changed from 0.50% to 0.63%, but the difference was not statistically significant. The effect on CVD mortality was slightly less and not statistically significantly different. The effect of PM_{2.5} on RESP mortality was significantly less and was statistically significantly different. The association between PM_{2.5} and total mortality varied by demographic characteristics. Throughout the 2015–2020 study period, an increase in PM_{2.5} of 10 µg/m³ corresponded to a 0.53% increment in deaths of males and a 0.39% increment in deaths of females. The

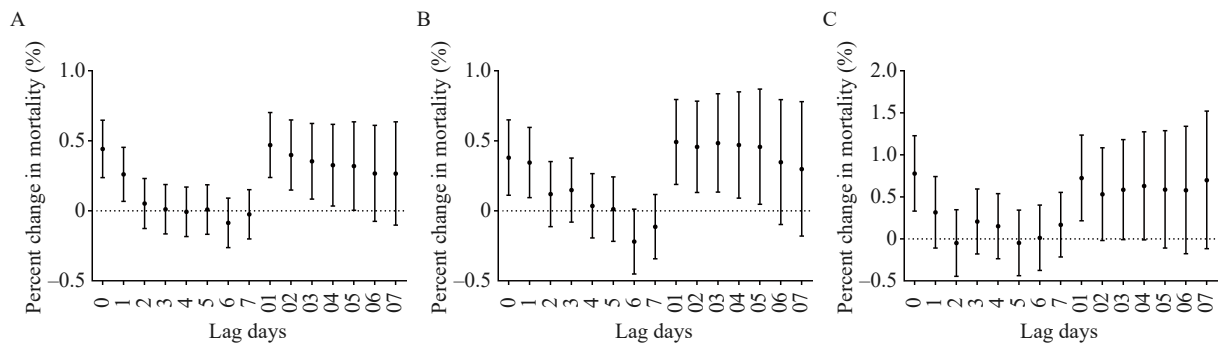


FIGURE 1. Percent changes (95% CI) in daily cause-specific mortality per 10 µg/m³ increase in PM_{2.5} concentrations using different lag days; (A) ALL mortality, (B) CVD mortality, (C) RESP mortality.

Abbreviations: ALL=total non-accidental death; CVD=cardiovascular disease; RESP=respiratory disease; PM_{2.5}=particulate matter with an aerodynamic diameter less than or equal to 2.5 µm.

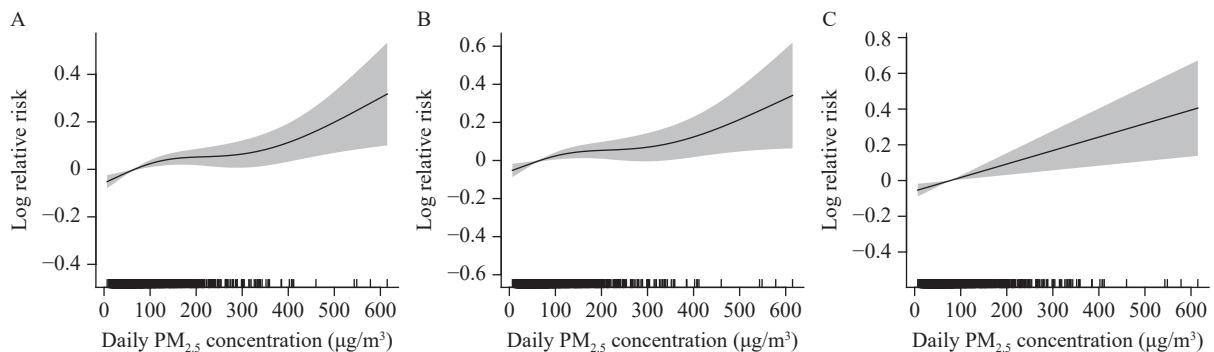


FIGURE 2. Exposure-response curves for associations of daily PM_{2.5} concentrations (lag 01) with (A) ALL mortality, (B) CVD mortality, and (C) RESP mortality.

Notes: The y-axis can be interpreted as the relative change from the mean effect of PM_{2.5} on mortality. The solid lines represent mean estimates, and the shaded areas represent 95% confidence intervals.

Abbreviations: ALL=total non-accidental death; CVD=cardiovascular disease; RESP=respiratory disease; PM_{2.5}=particulate matter with an aerodynamic diameter less than or equal to 2.5 µm.

TABLE 2. Percent change (95% CI) in daily cause-specific mortality and total non-accidental mortality stratified by sex, age, and educational level per 10 $\mu\text{g}/\text{m}^3$ increase in concentration of $\text{PM}_{2.5}$ in different time periods.

Different groups	2015–2020 (Lag01)	2015–2017 (Lag01)	2018–2020 (Lag0)
Cause-Specific mortality			
ALL	0.47 (0.24, 0.70)	0.50 (0.23, 0.78)	0.63 (0.26, 1.01)
CVD	0.49 (0.19, 0.79)	0.65 (0.28, 1.01)	0.60 (0.12, 1.08)
RESP	0.72 (0.22, 1.23)	0.94 (0.32, 1.56)	-0.15 (-0.99, 0.70)*
Sex			
Man	0.53 (0.25, 0.81)	0.58 (0.25, 0.91)	0.60 (0.12, 1.08)
Woman	0.39 (0.07, 0.70)	0.39 (0.01, 0.78)	0.69 (0.18, 1.20)
Age (years)			
5–64	0.51 (0.09, 0.93)	0.63 (0.13, 1.14)	0.54 (-0.16, 1.25)
≥ 65	0.47 (0.22, 0.72)	0.47 (0.17, 0.78)	0.67 (0.27, 1.07)
Education level			
Low	0.51 (0.25, 0.78)	0.57 (0.25, 0.89)	0.67 (0.23, 1.10)
High	0.37 (0.02, 0.72)	0.37 (-0.07, 0.81)	0.56 (-0.01, 1.12)

Notes: Educational level: low, ≤ 9 years of education; high, >9 years of education.

Abbreviations: ALL=total non-accidental mortality from all causes; CVD=cardiovascular disease; RESP=respiratory disease.

* $P < 0.05$ vs. 2015–2017.

5–64-year-old group and ≥ 65 -year-old-group had similar mortality associations. The association between $\text{PM}_{2.5}$ and total mortality was a 0.51% increment for people with lower educational achievement and a 0.37% increment for those with higher educational achievement. There were no statistically significant differences among sex, age, and education in stratified analyses.

DISCUSSION

During the study period, $\text{PM}_{2.5}$ pollution in Shijiazhuang improved compared with previous years (8), but pollution was still serious. Our general additive model results showed that ALL mortality, CVD mortality, and RESP mortality were related to $\text{PM}_{2.5}$ concentration. Sensitivity analysis and 2 pollutant models indicated that $\text{PM}_{2.5}$ had an independent health effect on ALL mortality, CVD mortality, and RESP mortality.

Whether improvement of $\text{PM}_{2.5}$ can reduce mortality is still controversial. During the study periods of 2015–2017 and 2018–2020, after the concentration of $\text{PM}_{2.5}$ was reduced, the most direct manifestation of the reduction was a significant decrease in RESP mortality. The respiratory system is a target organ of $\text{PM}_{2.5}$ direct action, and $\text{PM}_{2.5}$ concentration is directly related to the occurrence and development of respiratory diseases. With improvement of people's health awareness, residents

wear masks and use air purifiers on polluted days. No significant change was observed for ALL mortality and CVD mortality. Due to its small particle size, $\text{PM}_{2.5}$ can enter the blood circulation through the gas-blood barrier, thus affecting the circulation system, in which the composition of $\text{PM}_{2.5}$ plays a major role. $\text{PM}_{2.5}$ components should be further analyzed in the future to find harmful components and take targeted control measures.

ALL mortality in our study consisted mainly of circulatory system diseases, tumors, respiratory system diseases, endocrine and metabolic diseases, and digestive system diseases. In addition to circulatory system diseases and respiratory system diseases, the connection between other system diseases and $\text{PM}_{2.5}$ needs to be explored in future studies.

The effect values we observed differed slightly from those observed in previous studies. There is significant spatial heterogeneity between $\text{PM}_{2.5}$ concentration and daily mortality in different countries and regions (2,9). Our study found that every 10 $\mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ concentration was associated with a 0.47% increase in ALL mortality — a value that was higher than results of a recent study of 272 cities in China (0.22%) (3). Many factors may be responsible for the difference, including different $\text{PM}_{2.5}$ components, long-term air pollution levels, and population susceptibility. The larger effect estimates observed in our study may also be due to higher $\text{PM}_{2.5}$ concentrations.

The shape of the exposure-response curves was linear without discernible thresholds, which was consistent with findings from previous studies (10). As shown in our study and a previous multisite study of 272 representative cities in China, there was a marked increase in E-R values at lower PM_{2.5} levels and a leveling off at relatively high concentrations (3). The stability observed at higher concentrations may be the result of a “harvesting effect,” since susceptible populations may die before air pollutant concentrations reach very high levels (11). When PM_{2.5} concentrations were above 300 µg/m³, slopes of the curves markedly increased. Therefore, reducing outdoor activity on heavily polluted days may reduce risk of death. Associations of PM_{2.5} on RESP mortality for PM_{2.5} concentrations over 300 µg/m³ were characterized by wider confidence intervals, implying that the mortality risk has greater uncertainty.

When stratified by sex, age, and educational attainment, we found higher association in males, 5–64-year-olds, and individuals with lower educational achievement, but differences between sex, age group, and education were not statistically significant in stratified analyses. These findings may be due to occupational factors, as young men with low education levels may engage in more outdoor work, resulting in exposure to higher concentrations of air pollution. Lin et al. (12) found that older people may be more susceptible to PM_{2.5} in 6 cities of the Pearl River Delta region. Lee et al. (13) found that the most vulnerable population in three southeastern states was people with low educational achievement. A study in Shenzhen showed a high effect of PM_{2.5} on males and the elderly (14), whereas an analysis from 160 communities of China showed females, older individuals, and widows appeared to be more vulnerable to PM_{2.5} (9). There were differences in lifestyle, physiological factors, immunity, housing, and medical conditions by sex, age, and education, all of which can lead to different research results. Identification of potentially susceptible populations is crucial to public health and to the development of targeted intervention strategies.

This study was subject to some limitations. First, we used pollutant concentration data from urban environmental monitoring stations instead of population exposure concentrations. People spend much of their time indoors, and there is a significant difference between indoor and outdoor pollution (15). Therefore, there will be differences between our results and the real effects of PM_{2.5}. Second, the primary causes of death were categorized into circulatory and

respiratory diseases. Categorization should be further refined to screen out sensitive diseases. Finally, our research only analyzed Shijiazhuang, which has relatively high pollution levels, thus, caution should be exercised when generalizing these findings to other locations.

Our findings showed an effect of air pollution on mortality in Shijiazhuang and emphasized the necessity of further controlling PM_{2.5} and continuing the significant achievements in PM_{2.5} control that have been made in Shijiazhuang. Further studies on associations of components of PM_{2.5} with cause-specific mortality are still needed to guide environmental health policies to improve population health.

Conflicts of Interest: No conflicts of interest.

doi: 10.46234/ccdcw2022.052

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Submitted: October 21, 2021; Accepted: November 26, 2021

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Supplementary Material

Overall Summary Descriptive

During the study period of 2015–2017 and 2018–2020, the total number of non-accidental deaths increased from 31 to 39, with an increase of 8 in total deaths, including an increase of 6 deaths from circulatory diseases (from 16 to 22) and an increase of one death from circulatory diseases (from 4 to 5) (Supplementary Table S1). The annual average concentration of fine particulate matter (PM_{2.5}) decreased from 91.1 µg/m³ to 64.1 µg/m³, a decrease of 29.64%, but still exceeded the annual average concentration limit (the secondary limit of 35 µg/m³ in China and 10 µg/m³ in WHO). Temperature and humidity remained stable.

Spearman's Correlation Coefficients

As show in Supplementary Table S2, the relationship between PM_{2.5} and four pollutants or two meteorological

SUPPLEMENTARY TABLE S1. Overall summary descriptive statistics of daily mortality, PM_{2.5} and meteorological data in Shijiazhuang for two periods (2015–2017 and 2018–2020).

Variable	Period	Mean (SD)	Min	P ₂₅	P ₅₀	P ₇₅	Max
Daily mortality							
ALL	2015–2017	31 (8)	12	25	30	36	69
ALL	2018–2020	39 (10)	17	32	38	44	107
CVD	2015–2017	16 (5)	4	12	16	19	43
CVD	2018–2020	22 (7)	6	17	21	25	67
RESP	2015–2017	4 (2)	0	3	4	6	31
RESP	2018–2020	5 (3)	0	3	5	6	16
Air pollutant (µg/m ³)							
PM _{2.5}	2015–2017	91.1 (79.4)	6.3	40.3	66.2	112.0	625.3
PM _{2.5}	2018–2020	64.1 (50.5)	9.0	31.6	47.4	78.0	355.0
Weather conditions							
Temp (°C)	2015–2017	14.8 (10.6)	-10.2	4.6	16.1	24.4	33.2
Temp (°C)	2018–2020	14.8 (11.0)	-7.4	4.6	15.9	25.0	33.7
RH (%)	2015–2017	55.9 (20.8)	13	39	55	73	98
RH (%)	2018–2020	55.2 (19.9)	7	40	55	70	100

Abbreviations: ALL=total non-accidental mortality from all causes; CVD=cardiovascular disease; RESP=respiratory disease; PM_{2.5}=particulate matter with an aerodynamic diameter less than or equal to 2.5 µm; Temp=average temperature; RH=relative humidity; SD=standard deviation; Min=minimum; P₂₅=the 25th percentile; P₅₀=the median; P₇₅=the 75th percentile; Max=maximum.

SUPPLEMENTARY TABLE S2. Spearman correlations between air pollutants and weather conditions in Shijiazhuang from 2015 to 2020.

Variables*	PM ₁₀	SO ₂	NO ₂	O ₃	Temperature	Humidity
PM _{2.5}	0.92*	0.58*	0.65*	-0.33*	-0.43*	0.23*
PM ₁₀		0.64*	0.72*	-0.27*	-0.38*	0.02
SO ₂			0.69*	-0.23*	-0.40*	-0.35*
NO ₂				-0.44*	-0.49*	-0.07*
O ₃					0.80*	-0.09*
Temperature						0.13*

Abbreviations: PM_{2.5}=particulate matter with an aerodynamic diameter less than or equal to 2.5 µm; PM₁₀=particulate matter with particle size below 10 microns.

* P<0.01.

conditions is illustrated. Spearman's correlation coefficients between PM_{2.5} and particulate matter with particle size below 10 microns (PM₁₀), SO₂, NO₂ were all positive. In contrast, the relationship between PM_{2.5} and O₃ was negatively correlated. Temperature and humidity were both important factors for PM_{2.5}. Coefficients of -0.43 and 0.23 were observed between PM_{2.5} and temperature and relative humidity, respectively.

Model Description

We controlled for the day of the week and holidays using factor variables. The model can be described as follows: $\log E(Y_t) = \beta Z_t + ns(\text{time}, df = 7/\text{year}) + ns(\text{temperature}, df = 6) + ns(\text{humidity}, df = 3) + as.factor(DOW) + as.factor(Holiday) + intercept$, where “ $E(Y_t)$ ” is the expected cause-specific death numbers on day t , “ β ” represents the logrelated rate of cause-specific mortality associated with a unit increase of PM_{2.5}, “ df ” represents degree of freedom, “ DOW ” is a dummy variable for the day of the week, “ $Holiday$ ” is a binary dummy variable for the public holiday, and “ ns ” indicates natural cubic regression smooth function. We examined the associations with different lag structures from lag0 (current day) up to lag7, as well as moving averages for the current day and the previous one to seven days: from lag01 to lag07. The exposure-response relationship curves between PM_{2.5} and cause-specific mortality also were plotted.

Sensitivity Analyses and Two-Pollutant Models

We performed sensitivity analyses to assess the robustness of our estimates for the associations between PM_{2.5} and cause-specific mortality. First, we changed the degrees of freedom (df) in the smoothness of time from 5 to 9 df/year . In addition, we fit two-pollutant models with adjustment for concomitant exposure to O₃.

Supplementary Table S3 summarizes the association between PM_{2.5} and total non-accidental (ALL), cardiovascular (CVD), and respiratory (RESP) mortality after adjusting temporal trends by alternative degrees of freedom (5–9/year). Furthermore, although the estimates for association were changed marginally, they still remained statistically significant.

Supplementary Table S4 compared the results of the two pollutant models, after adjusting for O₃, with the results of the single pollutant models. The estimated effects of PM_{2.5} on ALL, CVD, and RESP mortality remained

SUPPLEMENTARY TABLE S3. Percent change (95% CI) in ALL, CVD, and RESP mortality per 10 $\mu\text{g}/\text{m}^3$ increase in 2-day moving average concentrations of PM_{2.5} (lag01) using different degrees of freedom per year.

<i>df</i> /year	ER (%)		
	ALL (95% CI)	CVD (95% CI)	RESP (95% CI)
5	0.52 (0.29, 0.75)*	0.53(0.23, 0.83)*	0.81(0.31, 1.32)*
6	0.54 (0.31, 0.78)*	0.56 (0.25, 0.86)*	0.82 (0.31, 1.33)*
7	0.47 (0.24, 0.70)*	0.49 (0.19, 0.79)*	0.72 (0.22, 1.23)*
8	0.46 (0.23, 0.69)*	0.47 (0.17, 0.77)*	0.74 (0.23, 1.25)*
9	0.47 (0.25, 0.70)*	0.50 (0.20, 0.80)*	0.73 (0.22, 1.24)*

Abbreviations: ALL=total non-accidental death; CVD=cardiovascular disease; RESP=respiratory disease; PM_{2.5}=particulate matter with an aerodynamic diameter less than or equal to 2.5 μm ; df =degree of freedom; ER=excess risk; CI=confidence interval.

* $P < 0.05$.

SUPPLEMENTARY TABLE S4. Percent change (95% CI) in ALL, CVD, and RESP mortality per 10 $\mu\text{g}/\text{m}^3$ increase in 2-day moving average concentrations of PM_{2.5} (lag01) in two-pollutant models.

Models	ER (%)		
	ALL (95% CI)	CVD (95% CI)	RESP (95% CI)
PM _{2.5}	0.47 (0.24, 0.70)*	0.49 (0.19, 0.79)*	0.72 (0.22, 1.23)*
PM _{2.5} + O ₃	0.48 (0.24, 0.71)*	0.50 (0.19, 0.80)*	0.73 (0.22, 1.24)*

Abbreviations: ALL=total non-accidental death; CVD=cardiovascular disease; RESP=respiratory disease; PM_{2.5}=particulate matter with an aerodynamic diameter less than or equal to 2.5 μm ; df =degree of freedom; ER=Excess Risk; CI=confidence Interval.

* $P < 0.05$.

statistically significant.

Stratification Analyses

We stratified analyses by demographic factors, sex, age, and education; we tested for statistical significance of differences between effect estimates of the strata of a potential effect modifier by calculating the 95 percent confidence interval (95% CI) as $(\hat{Q}_1 - \hat{Q}_2) \pm 1.96\sqrt{(\hat{SE}_1)^2 + (\hat{SE}_2)^2}$, where \hat{Q}_1 and \hat{Q}_2 are the estimates for the two categories, \hat{SE}_1 and \hat{SE}_2 are their respective standard errors.