Pol. J. Environ. Stud. Vol. 23, No. 5 (2014), 1797-1804

Original Research

Time-Series Study on Air Pollution and Mortality

Fengying Zhang[1, 2, 3], Liping Li[4], Thomas Krafft[2, 3], Li Wang[3], Jianhui Zhang[1],
Lanyu Lin[1], Qian Li[1], Yu Shi[1], Wuyi Wang[2]*

[1]China National Environmental Monitoring Centre, Beijing 100012, China
[2]Institute of Geographic Sciences and Natural Resources Research,
Chinese Academy of Sciences, Beijing 100101, China
[3]Department of International Health, Faculty of Health, Medicine and Life Sciences,
Maastricht University, the Netherlands
[4]Injury Prevention Research Center, Shantou University Medical College,
Shantou 515041, Guangdong, China

Received: 28 October 2013
Accepted: 17 February 2014

Abstract

This paper studies the association between concentration of ambient air pollutants and daily mortality number in an urban area of Beijing. Different age and gender groups were taken into consideration. The results showed that, for all the groups, the average daily mortality number showed an increasing trend from June to January of next year, and a decreasing trend from February to June. When the concentration of air pollutants increased, the health risk also increased. In multi-pollutants models, the pollutants had a decreasing order NO_2, PM_{10}, SO_2 for the different gender groups when the concentration of pollutants increased, and had a decreasing order NO_2, PM_{10}, SO_2 for different age groups when the levels of pollutants increased. Lag effects of air pollutants and seasonal differences also were found. The results of our study could serve to strengthen the local evidence base for air pollution-related health effects that is imminently needed for better air quality management, and also adds valuable information from Beijing.

Keywords: ambient air pollutants, daily mortality, Chaoyang District, Beijing

Introduction

Ambient air pollution has been found to be associated with a wide range of effects on human health, including increased mortality, increased hospital admission rates and emergency department visits, exacerbation of chronic respiratory conditions, and decreased lung function[1-3]. Urban air pollution results in an annual loss of 800,000 human lives and decreases life expectancy for another 4.6 million lives across the world (WHO, 2002).

The relationship between outdoor air pollution and daily mortality/morbidity has been examined in several large Chinese cities, including Beijing [4, 5], Tianjin [6], Chongqing [7], Shanghai [8, 9], Wuhan [10], Shenyang [11], and so on [2, 12, 13]. Most studies have focused on larger areas, but a few study focus on a district inside a city, such as Beijing, the district level data provide further evidence on the actual health burden of the urban population by focusing on the inner city and excluding rural Beijing [14]. Studies from districts of a city are scarce, possibly due to lack of assessment of individual exposure to air pollutants and their relationship to mortality [14].

To investigate the relationship between mortality in different age and gender groups and the concentration level of air pollutants, and to compare the results with others in Beijing, we performed a time-series study relating concentrations of air pollutants and daily mortality in the Chaoyang District of Beijing (one of the biggest areas in Beijing), from

---

*e-mail: wangwy@igsnrr.ac.cn

2003 through 2008. Chaoyang District was chosen since it is representative for the urban core of Beijing and because of the availability of mortality data for its permanent residents. These results should provide further epidemiological and scientific evidence for informed decisions on air pollution control measures and related polices and provide information to environmental health research.

Materials and Methods

Study Area

The Chaoyang District lies in the east and north east of urban Beijing, comprising an area of 470.8 km^2. The district's population was 1.818 million in 2008 [15].

Data Source

All mortality data for the calendar years 2003 to 2008 were obtained from death certificates recorded at Centers for Disease Control (CDC) of Chaoyang District. In this study, all deaths from all causes, different age groups and different gender groups were identified. Daily ambient air concentrations of PM_{10}, SO_2, and NO_2 were provided by the Beijing Municipal Environmental Monitoring Center, and these data were opened to all the public. The monitoring data reflect the general background urban air pollution level in our study area, for the location of these monitoring stations must not be in the direct vicinity of traffic intersections or of major industrial polluters and should also have sufficient distance to any other emitting sources. Meteorological data (daily average temperature, relative humidity and air/barometric pressure) was obtained from the Beijing Meteorological Office.

Data Analysis

The objective of the data analysis was to quantify the association between daily mortality and daily mean air pollutant concentrations, while adjusting for weather and temporal factors in the multivariable modeling. Because the daily number of deaths was small and typically followed a Poisson distribution [16-19], the core analysis was a GAM with log link and Poisson error that accounted for fluctuations in daily numbers of deaths. Consistent with other time-series studies [20, 21], we used the generalized additive model (GAM) with penalized splines to analyze the daily counts of mortality, air pollution, and covariates (meteorological factors, time trend, and day of the week).

$$\log[E(Y_t)] = \alpha + \sum_{i=1}^{q} \beta_i(X_i) + \sum_{j=1}^{p} f_j(Z_j, df) + W_t(week)$$

...where $E(Y_t)$ represents the expected number of deaths at day t; β represents the log-relative rate of mortality associated with a unit increase of air pollutants; X_i indicates the concentrations of pollutants at day t; $W_t(week)$ is the dummy variable for day of the week. $\sum_{j=1}^{p} f_j(Z_j, df)$ is the non-parametric spline function of calendar time, temperature, and humidity.

Further, we examined the effect of air pollutants with different lag (L) structures of single day lag (distributed lag; from L0 to L2) and multi-day lag (moving average lag; L01 and L02). Here a lag of 0 days (L0) corresponds to the current-day pollution, and a lag of 1 day refers to the previous-day concentration. In multi-day lag models, L02 corresponds to 3-day moving average of pollutant concentration of the current and previous 2 days [8]. Here, the meteorological factors used in the lag models (distributed lag model, moving average model) were the current day data.

Seasonality was differentiated on the basis of heating and no-heating periods between the warm season from April to September and October to March as cold season of Beijing with additional pollution from heating sources [22]. Our seasonal analysis followed the method introduced in Peng et al. [16].

All statistical analyses were conducted in R 3.0.1 using the MGCV package (R Development Core Team, 2013). The results obtained were expressed as the relative risk ($RR = e^{\beta x \Delta C}$, where ΔC is the increased amount of air pollutants, in this study we used 10 $\mu g/m^3$ for comparisons with similar studies conducted for other places of China) of mortality per 10 $\mu g/m^3$ increase in air pollutant concentrations.

Results

Describe Information

During the study period, there were 50,032 mortalities in the Chaoyang District; 37,095 were over 65 years old; 22,009 were younger than 65 years old. 28,023 were males, 22,009 were females, the descriptive statistics for mortality on different age groups and different genders are shown in Table 1.

The seasonal number distribution of daily mortality shows that cold season had a larger amount of mortality than that of warm season.

There was no obvious regularity for daily concentration of PM_{10} and NO_2. The average concentration of PM_{10} and NO_2 showed only small variations between the cold season and the warm season. SO_2 showed an obvious seasonal variability (Fig. 1), with peaks in the cold or heating season (October to March). It was also five times higher in the cold than in the warm season, because sulfur-rich coal was the major energy source for heating in winter.

The details of descriptive statistics for air pollutants and weather conditions has been described in another paper of our team [14].

Table 1. Description on daily mortality numbers.

	Mean	Warm Season	Cold Season	SD	Percentage				
					Min	25%	Median	75%	Max
Total	22.82	21.08	24.57	7.22	6	18	22	27	54
Male	12.78	12.15	13.86	4.93	2	9	12	16	31
Female	10.04	9.57	10.71	3.84	1	7	10	12	30
D	16.92	16.01	18.39	6.06	3	13	16	21	42
X	5.9	5.70	6.18	2.71	0	4	6	8	18

D denotes more than 65 years old; X denotes younger than 65 years.

Time Trend on Daily Mortality Number

We analyzed daily average mortality numbers of the groups in different months. The results are shown in Fig. 2.

Though there were differences among the groups, some common points also could be found. For all the groups, the average daily mortality number showed an increasing trend from June to January of the next year, and a decreasing trend from February to June.

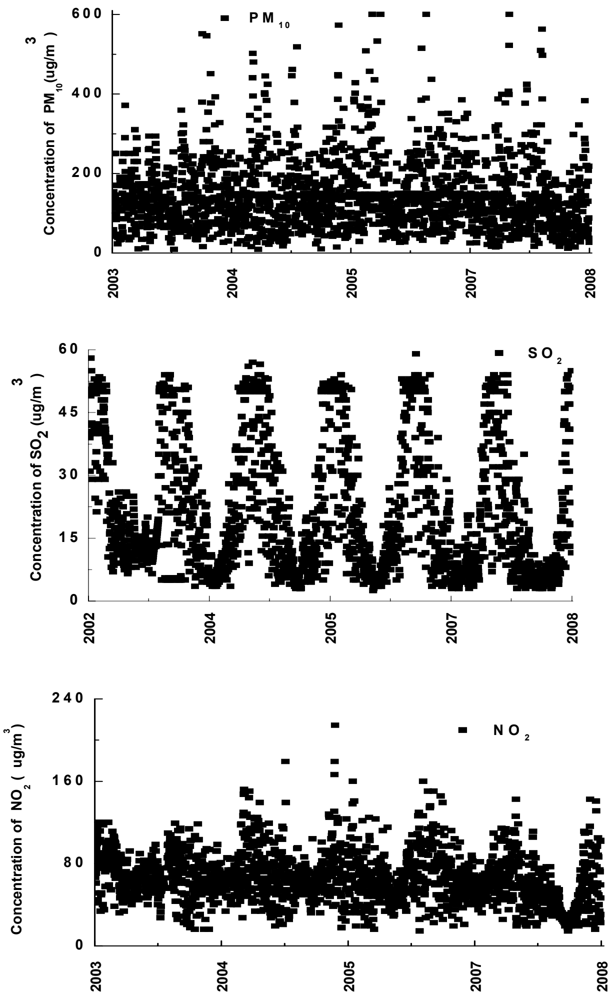

Fig. 1. Daily concentrations of air pollutants in Beijing.

Single-Pollutant RRs and Lag Effects

In the one pollutant model, we also took the lag-effect of air pollutants into consideration. Fig. 3 showed results from the single-lag day for the RR increase in mortality per 10 μg/m^3 increase in air pollutants. An increase of 10 μg/m^3 of PM_{10} corresponded to 1.00159, 1.00110, 1.00221, 1.00132, and 1.00237 for total group, male group, female group, over-65-year age group and less-than-65-year age group, respectively. An increase of 10 μg/m^3 of SO_2 corresponded to 1.00027, 1.00006, 1.00055, 1.00032, and 1.00013 for total group, male group, female group, over-65-year-age group and less-than-65-year age group, respectively. An increase of 10 μg/m^3 of NO_2 corresponded to 1.00580, 1.00570, 1.00593, 1.00502, and 1.00809 for total group, male group, female group, over-65-yearage group and less-than-65-year age group, respectively.

Effects of the three air pollutants on mortality of total cause were getting weaker over the days. The biggest decrease was found in the second day for SO_2. For NO_2, the risk in L01 was larger than that in the current day (L0). The risks in lag0 were larger than L01 for SO_2 and PM_{10}.

For the male gender group, the one-day moving average (L01) risks of the three air pollutants were higher than that of the current day (L0); and the risks were decreasing with the increasing of day time for both PM_{10} and NO_2; the risks for SO_2 were no obvious time trend.

For the female gender group, the one-day moving average (L01) risks of the three air pollutants were lower than that of the current day (L0); and the strongest risk found on lag0 for all three pollutants. The risks were decreasing with the increasing of lag day for both PM_{10} and SO_2; the risks for NO_2 saw no obvious time trend. The results show that the RRs for the female gender group were higher than that for the male gender group.

For the over-65-year age group, the largest effect was found in the current day, the effects decreased by time, and the moving average effects were lower than current day effects.

The lag effects for the younger group (less than 65 years) of all the air pollutants showed a decreasing trend by time. The risk on lag01 was larger than that of the current day (L0) for PM_{10}; and the risks of current day were larger than the moving average risks for SO_2 and NO_2.

The results show that, when the concentration of air pollutants increased, the RRs for the younger age group were higher than that of the older age group for PM_{10} and NO_2, but lower for SO_2.

Multi-Pollutants RR

It was an ideal condition that only one pollutant exists in the atmosphere. Actually, in real conditions, the above three air pollutants existed in ambient air simultaneously, and the three air pollutants may have an interactive influence on human health. So we considered the multi-pollutants risks. A multiple-pollutant model was more realistic than a single pollutant model since we were able to estimate the net effect of each of the pollutants when controlling for other pollutants. Table 2 summarized the results for fitting the multiple-pollutant model for AR.

In the PM_{10}-NO_2 multi-pollutants models, PM_{10} had a higher risk on female than male; NO_2 had a lower risk on female than male. In the PM_{10}-SO_2 multi-pollutants models, PM_{10} had higher risks than SO_2 on both female and male groups. In the SO_2-NO_2 multi-pollutants models, NO_2 had higher risks than SO_2 on both groups. In multi-pollutant models, the three pollutants had a decreasing order NO_2, PM_{10}, SO_2 for the two gender groups when the concentrations increased by 10 μg/m^3.

In the PM_{10}-NO_2 multi-pollutants models, PM_{10} had a higher risk on the younger group than the older one; NO_2 had a lower risk on younger group than the older one; NO_2 had higher risks than PM_{10} on both age groups. In the PM_{10}-SO_2 multi-pollutants models, PM_{10} had higher risks on younger group than the older one; SO_2 has a lower risk on the younger group than the older one. PM_{10} has higher risks than SO_2 in both age groups. In the SO_2-NO_2 multi-pollutant models, NO_2 had higher risks on the younger group than the older one; SO_2 has a lower risk on the younger group than the older one. NO_2 has higher risks than SO_2 in both age groups. In multi-pollutant models, the three pollutants had a decreasing order NO_2, PM_{10}, SO_2 for the two age groups when the concentrations increased by 10 μg/m^3.

Seasonal Specific Analysis

Air pollutants had different human health effects in different seasons [16, 22, 23]. According to the average monthly temperature of Beijing, we divided the season into the warm season from April to September, and the cool season from October to the next March (the latter is the heating season of Beijing, reflected in higher concentrations of some air pollutants).

The seasonal analysis results (Table 3) showed higher mortality risks related to PM_{10} during the cold season on total mortality, different age groups, and female group; and shows small differences on the male group. For SO_2, the RRs with 10 μg/m^3 concentration increasing were higher during the warm season than in cold season in all the study

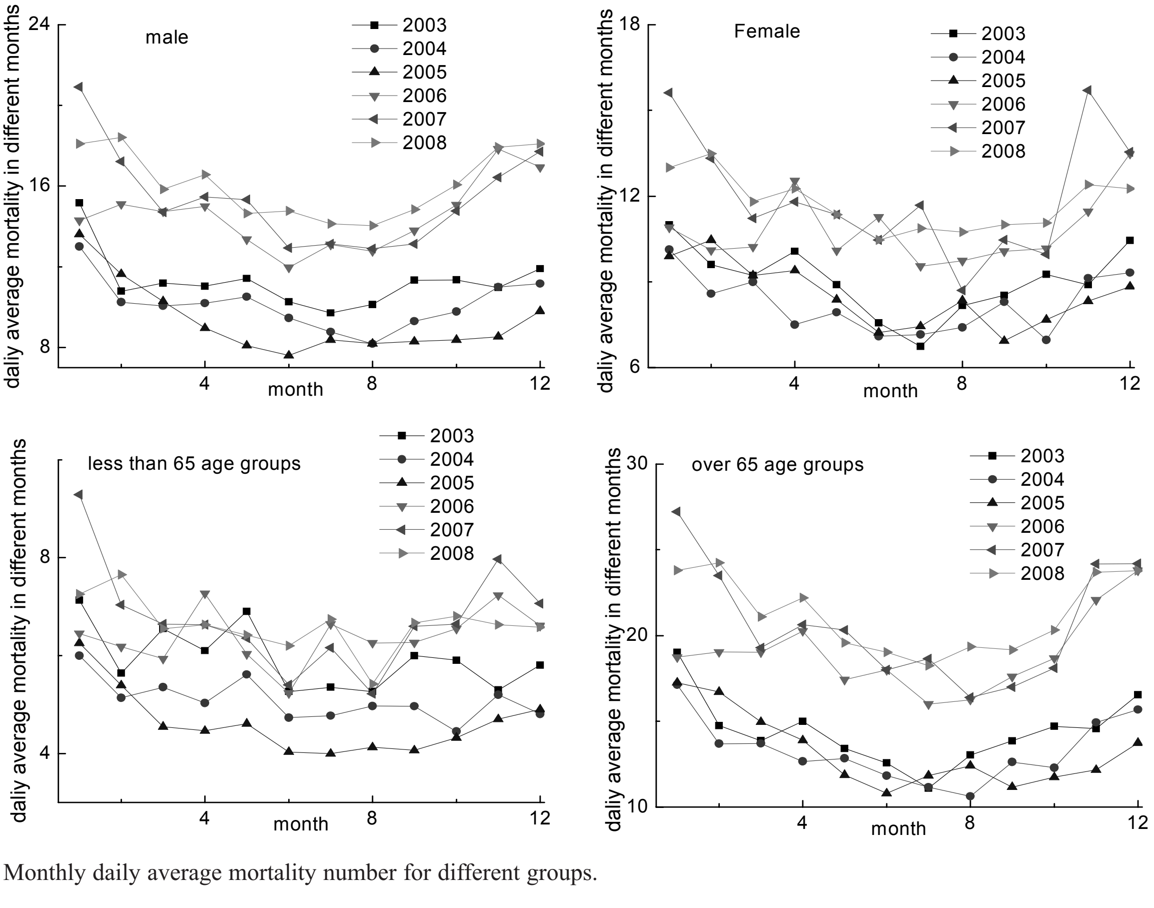

Fig. 2. Monthly daily average mortality number for different groups.

Table 2. The RRs of multi-pollutant models.

Models	Total RR (CI)	Male RR (CI)	Female RR (CI)	D RR (CI)	X RR (CI)
PM_{10}	1.00119 (1.00102-1.00136)	1.00052 (1.00030-1.00074)	1.00203 (1.00179-1.00228)	1.00096 (1.00077-1.00115)	1.00189 (1.00157-1.00221)
NO_2	1.00310 (1.00240-1.00381)	1.00451 (1.00358-1.00543)	1.00137 (1.00034-1.00239)	1.00284 (1.00203-1.00365)	1.00381 (1.00246-1.00516)
PM_{10}	1.00137 (1.00122-1.00152)	1.00115 (1.00095-1.00134)	1.00166 (1.00144-1.00188)	1.00099 (1.00082-1.00117)	1.00247 (1.00218-1.00275)
SO_2	1.00016 (1.00012-1.00020)	0.99996 (0.99992-1.00001)	1.00041 (1.00036-1.00047)	1.00024 (1.00020-1.00029)	0.99993 (0.99975-1.00010)
NO_2	1.00471 (1.00407-1.00536)	1.00624 (1.00540-1.00709)	1.00277 (1.00183-1.00371)	1.00338 (1.00263-1.00412)	1.00848 (1.00725-1.00972)
SO_2	1.00017 (1.00013-1.00021)	0.99992 (0.99987-1.00098)	1.00049 (1.00043-1.00054)	1.00025 (1.00020-1.00029)	0.99994 (0.99976-1.00011)
PM_{10}	1.00110 (1.00093-1.00127)	1.00060 (1.00037-1.00082)	1.00174 (1.00149-1.00198)	1.00080 (1.00061-1.00100)	1.00198 (1.00166-1.00231)
NO_2	1.00248 (1.00175-1.00321)	1.00502 (1.00406-1.00598)	0.99929 (0.99823-1.00035)	1.00175 (1.00091-1.00259)	1.00444 (1.00304-1.00584)
SO_2	1.00013 (1.00009-1.00017)	0.99990 (0.99836-1.00045)	1.00042 (1.00037-1.00048)	1.00022 (1.00017-1.00026)	0.99987 (0.99967-1.00008)

D denote over-65-year age group, X denote less-than-65-year age group.

groups. Higher mortality risks related to NO_2 during warm season than cold season for the younger group, and a lower mortality risk related to NO_2 during the warm season than the cold season on the other study groups.

Discussion

The air pollutant exposure-response is a hot research area in epidemiology and environmental health recently [24-26]. A lot of time-series studies showed that short-time variations on concentration of air pollutants was related to the changes on daily number of mortality, especially for mortality on respiratory disease and cardiovascular disease [8, 26-28]. A time-series study conducted in Tianjin showed that air pollutants was more strongly associated with coronary heart disease mortality, and by single GAM analysis, a 10 μg/m^3 increase in SO_2, PM_{10}, and NO_2, which accounted for a 1.25%, 0.65%, and 1.04% increase in daily mortality [6]. In our study, an urban district of Beijing was selected as our study research area, daily number of mortality from different age groups and gender groups, and daily

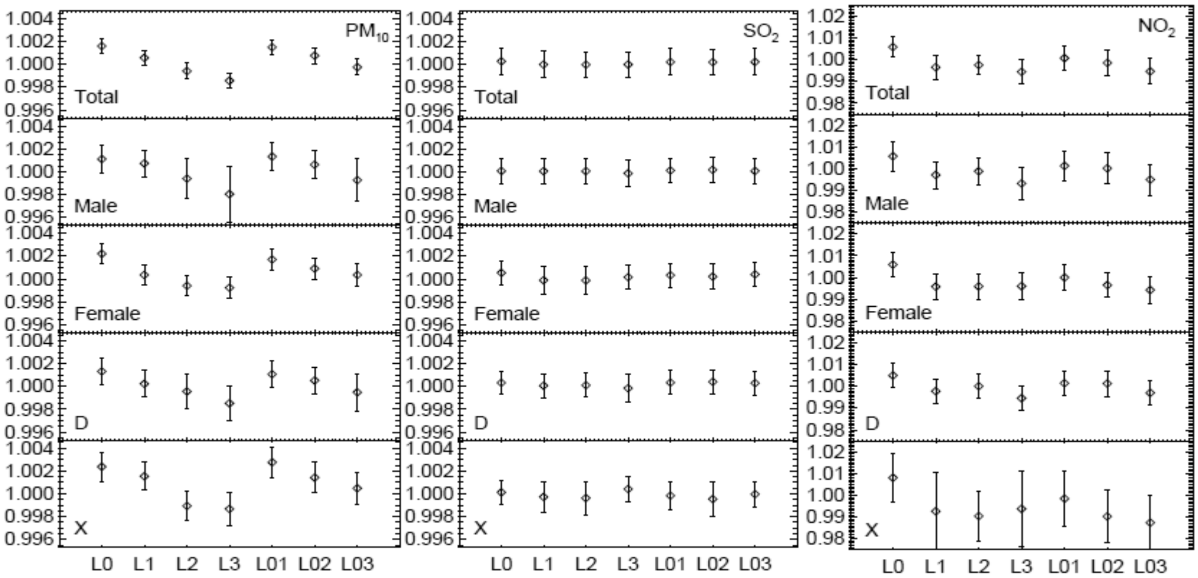

Fig. 3. Distribution of RRs across lags of different pollutants.
D denotes over-65-year age group, X denote younger-than-65-year age group.

Table 3. The RRs for a 10 μg/m^3 increase in pollutant levels in seasonal specified analysis.

	Season	PM_{10} RR (CI)	SO_2 RR (CI)	NO_2 RR (CI)
Total	warm	1.00069 (1.00047-1.00091)	1.01542 (1.01393-1.01692)	1.00809 (1.00699-1.00919)
	cold	1.00218 (1.00199-1.00237)	1.00029 (1.00025-1.00032)	1.00666 (1.00592-1.00739)
Male	warm	1.00082 (1.00054-1.00111)	1.01370 (1.01173-1.01568)	1.01789 (1.01644-1.01935)
	cold	1.00079 (1.00054-1.00104)	1.00009 (1.00004-1.00014)	1.00144 (1.00048-1.00239)
Female	warm	1.00051 (1.00019-1.00083)	1.01755 (1.01537-1.01973)	0.99600 (0.99100-1.00101)
	cold	1.00398 (1.00371-1.00425)	1.00054 (1.00049-1.00059)	1.01339 (1.01234-1.01444)
D	warm	1.00072 (1.00046-1.00097)	1.01426 (1.01249-1.01603)	1.00463 (1.00331-1.00594)
	cold	1.00188 (1.00167-1.00209)	1.00031 (1.00027-1.00035)	1.00705 (1.00623-1.00786)
X	warm	1.00062 (1.00019-1.00105)	1.01876 (1.01587-1.02165)	1.01765 (1.01553-1.01978)
	cold	1.00308 (1.00273-1.00344)	1.00022 (1.00015-1.00029)	1.00548 (1.00410-1.00687)

D denote over 65 year age group, X denote less than 65 year age group

concentrations of three air pollutants were used to find the possible association between mortality and air pollutants. We found that when the concentration of air pollutants increased, the health risk also increased. A 10 μg/m^3 increase of PM_{10} corresponded to 1.00159, 1.00110, 1.00221, 1.00132, and 1.00237 of RRs for the total group, male group, female group, over-65-year age group and less-than-65-year age group, respectively. A 10 μg/m^3 increase of SO_2 corresponded to 1.00027, 1.00006, 1.00055, 1.00032, and 1.00013 of RRs for total group, male group, female group, the older group and the younger group, respectively. A 10 μg/m^3 increase of NO_2 corresponded to 1.00580, 1.00570, 1.00593, 1.00502, and 1.00809 of RRs for total group, male group, female group, the older group and the younger group, respectively.

Short-term adverse health response may occur within minutes or may be lagged by several hours, even up to several days. Using the lag selection of exposure measure was a sensitive method to evaluate the air pollution effect [28]. In our study we also found the lag effects of air pollutants, and different groups/air pollutants had different lag days. Effects of the three air pollutants on mortality of total cause were getting weaker over the days. A declining trend in the short-term risk estimates was evidence that the day-to-day association between pollutants and mortality is getting weaker over time, possibly as a result of the changes in the composition and toxicity of the pollutants (especially particulate matter) from the air quality control programs or of nonlinearity between daily particulate matter concentration and the associated risk.

For the male group, the risks were decreasing with the increase of daytime for both PM_{10} and NO_2; the risks of SO_2 show no obvious time trend. For the female group, risks were decreasing with increasing days for both PM_{10} and SO_2; the risks for NO_2 show no obvious time trend. The results show that the RRs for the female gender group were higher than that for the male gender group. For the older group and the younger group, the effects decreased by time, and the moving average effects were lower than current day effects.

The seasonal analysis results show higher mortality risks related to PM_{10} and during cold season on total mortality, different age groups, and the female group; and show tiny differences on the male group. For SO_2, the RRs with 10 μg/m^3 concentration increases were higher during warm season that in cold season in all the study groups. Higher mortality risks related to NO_2 during warm season than cold season on the younger age group, and lower mortality risks related to NO_2 during warm season than cold season on the other study groups. Though the results were not significant in warm season, some interesting findings still need to be noticed.

One may assume that a higher daily pollution concentration would affect the daily mortality from air pollution and had higher RRs. A simple explanation to our finding, which contradicted the above assumption, can be that during winter there are some other risk factors effecting mortality, and their effects were stronger than the effect of SO_2 on mortality, hence the effects of SO_2 may be reduced. It should be noted that not all possible risk factors or confounders were measured and taken into consideration in this study and there is no way to eliminate these effects. The second explanation was this may indicate that the health impact associated with both air pollution and global climate change. A study conducted in eight Chinese cities showed that the effects of PM_{10} on mortality may depend on the temperature; extreme high temperature increased the associations of PM_{10} with daily mortality, while extreme low temperature didn't show any significant effect modification [29]. Another explanation to our finding was that in winter most of the windows were closed due to central heating in the room, so the exchange between outside SO_2 and indoor SO_2 was less, and the concentration of indoor SO_2 may be lower than that of outdoor.

This study also had some limitations. As in other time-series studies [6, 28], we used available outdoor monitoring data to represent the population exposure to ambient air pollutants. Although a study suggested that measurement error would generally tend to bias estimates downward, some results interpreting the effect of air pollutants were still found in this research. However, we lacked information on personal exposure to air pollutants to quantify this bias. Another limitation was that our assessment of ambient air pollutants was derived entirely from the average data of 11 state-controlled monitoring stations. And the exchange between outdoor air pollutants and indoor air pollutants was not considered during cold seasons, which may influence the results.

Conclusion

In this time-series study we found that the average daily mortality number showed an increasing trend from June to January of next year, and a decreasing trend from February to June. The evaluated concentrations of ambient air pollutants were associated with an increase in mortality for different age groups and gender groups in Chaoyang District during 2003 to 2008. The pollutants had a decreasing order NO_2, PM_{10}, SO_2 for the different gender groups when the concentration of air pollutants increased, and had a decreasing order NO_2, PM_{10}, SO_2 for different age groups when the pollutant levels increased. The lag effects and seasonal differences of air pollutants were also found.

The findings provide additional information about the health effects of air pollution, and may impact local planning, especially districted environmental protection and public health interventions, and also could add valuable information for Beijing.

Acknowledgments

The authors wish to thank all the staff members at the Chaoyang District Centre for Disease Control and Prevention for their strong support of this study. We thank the Beijing Municipal Environmental Monitoring Center and the Beijing Meteorological Office for providing data. Further appreciations are due to Professor Xiaochuan Pan and Doctor Guoxing Li, Department of Occupation and the Environment, Peking University School of Public Health, for support and advice in using statistical software.

The present study was supported by the Forestry Public Welfare Project of China (No. 201304301), the National Natural Science Foundation of China (No. 41371118), the International Science and Technology Cooperation Project (2007DFC20180), and The National Key Scientific Program of China (No. 2012CB955500). We also acknowledge support by the Chinese Academy of Sciences's Program for Visiting Professorships for Senior International Scientists (2009Z2-22).

References

1. QI J., YANG L. S., WANG W. Y. Environmental degradation and health risks in Beijing, China. Archives of Environmental & Occupational Health. **62**, 33, **2007**.
2. WONG C. M., OU C. Q., CHAN K. P., CHAU Y. K., THACH T. Q., YANG L., CHUNG R. Y. N., THOMAS G. N., PEIRIS J. S. M., WONG T. W., HEDLEY A. J., LAM T. H. The effects of air pollution on mortality in socially deprived urban areas in Hong Kong, China. Environ. Health Perspect. **116**, 1189, **2008**.
3. SAMOLI E., PENG R., RAMSAY T., PIPIKOU M., TOULOUMI G., DOMINICI F., BURNETT R., COHEN A., KREWSKI D., SAMET J., KATSOUYANNI K. Acute Effects of Ambient Particulate Matter on Mortality in Europe and North America: Results from the APHENA Study. Environ. Health Perspect. **116**, 1480, **2008**.
4. BREITNER S., CYRYS J., BRUSKE-HOHLFELD I., FRANCK U., SCHLINK U., LEITTE A., HERBARTH O., WIEDENSOHLER A., WEIMER B., ZHU T., HU M., PAN X., WICHMANN H., PETERS A. Short-Term Health Effects of Particulate Air Pollution in Beijing, China. Epidemiology. **19**, S153, **2008**.
5. DU X. A., KONG Q. A., GE W. H., ZHANG S. J., FU L. X. Characterization of personal exposure concentration of fine particles for adults and children exposed to high ambient concentrations in Beijing, China. Journal of Environmental Sciences-China. **22**, 1757, **2010**.
6. WANG D., JIANG G., ZHANG H., SONG G., ZHANG Y. Effect of air pollution on coronary heart disease mortality in Tianjin, 2001-2009: a time-series study. Zhonghua liu xing bing xue za zhi. **34**, 478, **2013**.
7. VENNERS S. A., WANG B. Y., PENG Z. G., XU Y., WANG L. H., XU X. P. Particulate matter, sulfur dioxide, and daily mortality in Chongqing, China. Environ. Health Perspect. **111**, 562, **2003**.
8. CHEN R. J., CHU C., TAN J. G., CAO J. S., SONG W. M., XU X. H., JIANG C., MA W. J., YANG C. X., CHEN B. H., GUI Y. H., KAN H. D. Ambient air pollution and hospital admission in Shanghai, China. J. Hazard. Mater. **181**, 234, **2010**.
9. ZHOU Y., FU J. S., ZHUANG G. S., LEVY J. I. Risk-Based Prioritization among Air Pollution Control Strategies in the Yangtze River Delta, China. Environ. Health Perspect. **118**, 1204, **2010**.
10. QIAN Z. M., HE Q. C., LIN H. M., KONG L. L., LIAO D. P., DAN J., BENTLEY C. M., WANG B. W. Association of daily cause-specific mortality with ambient particle air pollution in Wuhan, China. Environ. Res. **105**, 380, **2007**.
11. ZHANG P. F., DONG G. H., SUN B. J., ZHANG L. W., CHEN X., MA N. N., YU F., GUO H. M., HUANG H., LEE Y. L., TANG N. J., CHEN J. Long-Term Exposure to Ambient Air Pollution and Mortality Due to Cardiovascular Disease and Cerebrovascular Disease in Shenyang, China. PLoS One. **6**, **2011**.
12. THACH T. Q., WONG C. M., CHAN K. P., CHAU Y. K., THOMAS G. N., OU C. Q., YANG L., PEIRIS J. S. M., LAM T. H., HEDLEY A. J. Air pollutants and health outcomes: Assessment of confounding by influenza. Atmos. Environ. **44**, 1437, **2010**.
13. TSAI D. H., WANG J. L., CHUANG K. J., CHAN C. C. Traffic-related air pollution and cardiovascular mortality in central Taiwan. Sci. Total Environ. **408**, 1818, **2010**.

14. 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. International Journal of Environmental Research and Public Health. **8**, 2109, **2011**.
15. STATISTICS B. M. B. O., STATISTICS N. B. O., ORGANIZATION B. S. Regional Statistical Yearbook, Beijing. **2009**.
16. PENG R. D., DOMINICI F., PASTOR-BARRIUSO R., ZEGER S. L., SAMET J. M. Seasonal analyses of air pollution and mortality in 100 US cities. Am. J. Epidemiol. **161**, 585, **2005**.
17. DOMINICI F., MCDERMOTT A., ZEGER S. L., SAMET J. M. On the use of generalized additive models in time-series studies of air pollution and health. Am. J. Epidemiol. **156**, 193, **2002**.
18. JIANG L. L., ZHANG Y. H., SONG G. X., CHEN G. H., CHEN B. H., ZHAO N. Q., KAN H. D. A time series analysis of outdoor air pollution and preterm birth in Shanghai, China. Biomed. Environ. Sci. **20**, 426, **2007**.
19. HAJAT S., ANDERSON H., ATKINSON R., HAINES A. Effects of air pollution on general practitioner consultations for upper respiratory diseases in London. Occup. Environ. Med. **59**, 294, **2002**.
20. PENG R. D., DOMINICI F., LOUIS T. A. Model choice in time series studies of air pollution and mortality. J. Roy. Stat. Soc. A Sta. **169**, 179, **2006**.
21. HUANG W., TAN J. G., KAN H. D., ZHAO N., SONG W. M., SONG G. X., CHEN G. H., JIANG L. L., JIANG C., CHEN R. J., CHEN B. H. Visibility, air quality and daily mortality in Shanghai, China. Sci. Total Environ. **407**, 3295, **2009**.
22. ZHANG F., KRAFFT T., YE B., ZHANG F., ZHANG J., LUO H., LI M., ZHANG Y., ZHOU L., XU J., WANG W. The lag effects and seasonal differences of air pollutants on allergic rhinitis in Beijing. Sci. Total Environ. **442**, 172, **2013**.
23. KAN H. D., LONDON S. J., CHEN G. H., ZHANG Y. H., SONG G. X., ZHAO N. Q., JIANG L. L., CHEN B. H. Differentiating the effects of fine and coarse particles on daily mortality in Shanghai, China. Environ. Int. **33**, 376, **2007**.
24. KARAKATSANI A., KAPITSIMADIS F., PIPIKOU M., CHALBOT M. C., KAVOURAS I. G., ORPHANIDOU D., PAPIRIS S., KATSOUYANNI K. Ambient air pollution and respiratory health effects in mail carriers. Environ. Res. **110**, 278, **2010**.
25. KNIBBS L. D., COLE-HUNTER T., MORAWSKA L. A review of commuter exposure to ultrafine particles and its health effects. Atmos. Environ. **45**, 2611, **2011**.
26. MOOLGAVKAR S. H., MCCLELLAN R. O., DEWANJI A., TURIM J., LUEBECK E. G., EDWARDS M. Time-Series Analyses of Air Pollution and Mortality in the United States: A Subsampling Approach. Environ. Health Perspect. **121**, 73, **2013**.
27. MILLER K. A., SISCOVICK D. S., SHEPPARD L., SHEPHERD K., SULLIVAN J. H., ANDERSON G. L., KAUFMAN J. D. Long-Term Exposure to Air Pollution and Incidence of Cardiovascular Events in Women. New Engl. J. Med. **356**, 447, **2007**.
28. SHUANG W. Z., JIE C. R., RAO W. J., DONG K. H., GANG W., FANG W. X. Short-term Effects of Air Pollution on Mortality in a Heavily Polluted Chinese City. Biomed. Environ. Sci. **26**, 671, **2013**.
29. MENG X., ZHANG Y., ZHAO Z., DUAN X., XU X., KAN H. Temperature modifies the acute effect of particulate air pollution on mortality in eight Chinese cities. Sci. Total Environ. **435–436**, 215, **2012**.