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...
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 policies 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 km². 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).

$$\log[E(Y_t)] = \alpha + \sum_{j=1}^{4} \beta_j(X_j) + \sum_{j=1}^{8} f_j(Z_{j}, df) + W_{j}(\text{week})$$...

where $E(Y_t)$ represents the expected number of deaths at day $t$; $\beta$ represents the log-relative rate of mortality associated with a unit increase of air pollutants; $\chi$ indicates the concentrations of pollutants at day $t$; $W(\text{week})$ is the dummy variable for day of the week. $\sum_{j=1}^{8} f_j(Z_{j}, df)$ 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 ($RR = e^{\Delta C}$, where $\Delta C$ is the increased amount of air pollutants, in this study we used 10 µg/m$^3$ for comparisons with similar studies conducted for other places of China) of mortality per 10 µg/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 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 season.

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

Table 1. Description on daily mortality numbers.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Warm Season</th>
<th>Cold Season</th>
<th>SD</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>25%</td>
<td>Median</td>
<td>75%</td>
<td>Max</td>
</tr>
<tr>
<td>Total</td>
<td>22.82</td>
<td>21.08</td>
<td>24.57</td>
<td>7.22</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>12.78</td>
<td>12.15</td>
<td>13.86</td>
<td>4.93</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>10.04</td>
<td>9.57</td>
<td>10.71</td>
<td>3.84</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>16.92</td>
<td>16.01</td>
<td>18.39</td>
<td>6.06</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>5.9</td>
<td>5.70</td>
<td>6.18</td>
<td>2.71</td>
<td></td>
</tr>
</tbody>
</table>

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

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/m³ increase in air pollutants. An increase of 10 µg/m³ 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/m³ of SO₂ 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/m³ of NO₂ corresponded to 1.00580, 1.00570, 1.00593, 1.00502, and 1.00809 for total group, male group, female group, over-65-year age 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 SO₂. For NO₂, the risk in L01 was larger than that in the current day (L0). The risks in lag0 were larger than L01 for PM_{10} 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 NO₂; the risks for SO₂ 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 NO₂; the risks for SO₂ 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 SO₂ and NO₂.

Fig. 1. Daily concentrations of air pollutants in Beijing.
The results show that, when the concentration of air pollutants increased, the RR 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 RR 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.
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

<table>
<thead>
<tr>
<th>Models</th>
<th>Total RR (CI)</th>
<th>Male RR (CI)</th>
<th>Female RR (CI)</th>
<th>D RR (CI)</th>
<th>X RR (CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{10}$</td>
<td>1.00119 (1.00012-1.00136)</td>
<td>1.00052 (1.00030-1.00074)</td>
<td>1.00203 (1.00179-1.00228)</td>
<td>1.00096 (1.00077-1.00115)</td>
<td>1.00189 (1.00157-1.00221)</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>1.00310 (1.00240-1.00381)</td>
<td>1.00451 (1.00358-1.00543)</td>
<td>1.00137 (1.00034-1.00239)</td>
<td>1.00284 (1.00203-1.00365)</td>
<td>1.00381 (1.00246-1.00516)</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>1.00137 (1.00122-1.00152)</td>
<td>1.00115 (1.00095-1.00134)</td>
<td>1.00166 (1.00144-1.00188)</td>
<td>1.00099 (1.00082-1.00117)</td>
<td>1.00247 (1.00182-1.00275)</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>1.00016 (1.00012-1.00020)</td>
<td>0.99996 (0.99992-1.00001)</td>
<td>1.00041 (1.00036-1.00047)</td>
<td>1.00024 (1.00020-1.00029)</td>
<td>0.99999 (0.99975-1.00001)</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>1.00471 (1.00407-1.00536)</td>
<td>1.00624 (1.00540-1.00709)</td>
<td>1.00277 (1.00183-1.00371)</td>
<td>1.00338 (1.00263-1.00412)</td>
<td>1.00848 (1.00725-1.00972)</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>1.00017 (1.00013-1.00021)</td>
<td>0.99992 (0.99987-1.00009)</td>
<td>1.00049 (1.00043-1.00054)</td>
<td>1.00025 (1.00020-1.00029)</td>
<td>0.99994 (0.99976-1.00011)</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>1.00110 (1.00093-1.00127)</td>
<td>1.00060 (1.00037-1.00082)</td>
<td>1.00174 (1.00149-1.00198)</td>
<td>1.00080 (1.00061-1.00100)</td>
<td>1.00198 (1.00166-1.00231)</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>1.00248 (1.00175-1.00321)</td>
<td>1.00502 (1.00406-1.00598)</td>
<td>0.99929 (0.99823-1.00035)</td>
<td>1.00175 (1.00091-1.00259)</td>
<td>1.00444 (1.00304-1.00584)</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>1.00013 (1.00009-1.00017)</td>
<td>0.99990 (0.99836-1.00045)</td>
<td>1.00042 (1.00037-1.00048)</td>
<td>1.00022 (1.00017-1.00026)</td>
<td>0.99987 (0.99967-1.00008)</td>
</tr>
</tbody>
</table>

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

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.
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/m³ increase of PM₁₀ 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/m³ increase of SO₂ 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/m³ increase of NO₂ corresponded to 1.000580, 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 PM₁₀ and NO₂; the risks of SO₂ show no obvious time trend. For the female group, risks were decreasing with increasing days for both PM₁₀ and SO₂; the risks for NO₂ 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 PM₁₀ and during cold season on total mortality, different age groups, and the female group; and show tiny differences on the male group. For SO₂, the RRs with 10 µg/m³ concentration increases were higher during warm season that in cold season in all the study groups. Higher mortality risks related to NO₂ during warm season than cold season on the younger age group, and lower mortality risks related to NO₂ 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 SO₂ on mortality, hence the effects of SO₂ 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 PM₁₀ on mortality may depend on the temperature; extreme high temperature increased the associations of PM₁₀ 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 SO₂ and indoor SO₂ was less, and the concentration of indoor SO₂ may be lower than that of outdoor.

### Table 3. The RRs for a 10 µg/m³ increase in pollutant levels in seasonal specified analysis.

<table>
<thead>
<tr>
<th>Season</th>
<th>PM₁₀ RR (CI)</th>
<th>SO₂ RR (CI)</th>
<th>NO₂ RR (CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>warm</td>
<td>1.00069 (1.00047-1.00091)</td>
<td>1.01542 (1.01393-1.01692)</td>
</tr>
<tr>
<td></td>
<td>cold</td>
<td>1.00218 (1.00199-1.00237)</td>
<td>1.00029 (1.00025-1.00032)</td>
</tr>
<tr>
<td>Male</td>
<td>warm</td>
<td>1.00082 (1.00054-1.00111)</td>
<td>1.01370 (1.01173-1.01568)</td>
</tr>
<tr>
<td></td>
<td>cold</td>
<td>1.00079 (1.00054-1.00104)</td>
<td>1.00009 (1.00004-1.00014)</td>
</tr>
<tr>
<td>Female</td>
<td>warm</td>
<td>1.00051 (1.00019-1.00083)</td>
<td>1.01755 (1.01537-1.01973)</td>
</tr>
<tr>
<td></td>
<td>cold</td>
<td>1.00398 (1.00371-1.00425)</td>
<td>1.00054 (1.00049-1.00059)</td>
</tr>
<tr>
<td>D</td>
<td>warm</td>
<td>1.00072 (1.00046-1.00097)</td>
<td>1.01426 (1.01249-1.01603)</td>
</tr>
<tr>
<td></td>
<td>cold</td>
<td>1.00188 (1.00167-1.00209)</td>
<td>1.00031 (1.00027-1.00035)</td>
</tr>
<tr>
<td>X</td>
<td>warm</td>
<td>1.00062 (1.00019-1.00105)</td>
<td>1.01876 (1.01587-1.02165)</td>
</tr>
<tr>
<td></td>
<td>cold</td>
<td>1.00308 (1.00273-1.00344)</td>
<td>1.00022 (1.00015-1.00029)</td>
</tr>
</tbody>
</table>

D denote over 65 year age group, X denote less than 65 year age group.
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 NO2, PM10, SO2 for the different gender groups when the concentration of air pollutants increased, and had a decreasing order NO2, PM10, SO2 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’ Program for Visiting Professorships for Senior International Scientists (2009Z2-22).

References

11. ZHANG P. F., DONG G. H., SUN B. J., ZHANG L. W., CHEN X., MA N. Y., 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. Environ. & Occupational Health. 6, 2011.


