Letter to the Editor

Short-term Effects of Air Pollution on Mortality in a Heavily Polluted Chinese City*

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Since the London fog in 1952, numerous epidemiological studies have revealed that both short-term and long-term exposure to air pollutants is associated with the development of diseases[1]. Up to date, the assessment of air quality on health and air quality standard establishment in developing countries were mainly relied on extrapolation based on the results from long-term cohort studies conducted in Europe and North America[2]. And this raises a number of uncertainties. For example, the air pollution levels, human health conditions, demographic and economic characteristics in Chinese residents are significantly different from those in Europe or North America. We believe that the shape of exposure-response relationships is crucial for public health assessment and there were growing demand for providing the relevant curves[3]. However, little information on air pollution exposure-health relationship at high level of air pollution was available. This study was aim to study the association between short-term exposure to air pollution and daily mortality in Urumqi, China, one of the most serious polluted cities in the world. As the capital city of Xinjiang Uygur Autonomous Region, Urumqi is located in the north of Taklimakan desert and in the south of Guerbantonggute Desert. The urban area of the city is surrounded by Tianshan Mountain on its eastern, southern, and western sides and the dust can be therefore carried to the urban area of the city by wind on its north side. This study focused on the central urban areas of Urumqi (Tianshan District and Shayibake District) with a registered population of almost 1.2 million from 2006 to 2007.

Daily mortality records were obtained from Urumqi Municipal Center for Disease Control and Prevention, and were classified according to the International Classification of Diseases, Tenth Revision (ICD-10). The air pollution data including particulate matter with an aerodynamic diameter less than 10 microns (PM_{10}), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) were collected from three fixed monitoring stations, located in Tianshan District and Shayibake District, conducted by the Urumqi Environmental Monitoring Center. The over-dispersed generalized additive models (GAMs) and polynomial distributed lag models (PDLMs) (empirical maximum lag of 7 days) were used to estimate the cumulative effects of air pollutants on human health over the current days and the previous week[4]. Factors as time, season, day of the week, mean temperature and relative humidity were controlled as potential confounders in the models[5].

Table 1 shows the descriptive statistics result of daily mortality, air quality, and weather conditions. From January 1, 2006 to December 31, 2007, there was a daily average of 9 non-accidental deaths in the central urban areas of Urumqi. Among them, there were 2 deaths due to cardiovascular disease and 1 death due to respiratory disease, which were associated with high-level air pollution, where the air pollution was much higher than the international health-based air quality standard, as well as the reported levels in developed countries.

Table 2 summarizes the effects of PM_{10}, SO_2, and NO_2 on daily mortality using a single-pollutant model. A total mortality percent increases of 0.98% (95% CI: 0.33%-1.63%), 2.68% (95% CI: 1.25%-4.11%), and 5.65% (95% CI: 1.92%-9.38%) at lags 0-7 days was responded to a 10 μg/m^3 increase in PM_{10}, SO_2, and NO_2 respectively. We once conducted a similar study and we failed to find a significant association between air pollution and daily mortality in Urumqi[5]. And the reason is possibly due to that the previous analysis covered all city areas. The hazard degree of PM_{10} and SO_2 were similar as those reported in other heavily-polluted cities in developing countries[6] and also in developed countries[1]. Data from the first-wave Public Health

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and Air Pollution Study in Asia (PAPA), which covered 3 cities in China (Shanghai, Wuhan and Hong Kong), showed that 0.37% and 0.98% increase of total mortality in response to per 10 μg/m^3 PM_{10} or SO_2 increase[3]. Data from the second PAPA study showed the similar result in two Indian cities (Chennai and Delhi). Another APHENA (Air Pollution and Health: A Combined European and North American Approach) study revealed that a total mortality increase in percent in response to per 10 μg/m^3 PM_{10} increase were 0.84% in Canada, 0.33% in Europe and 0.29% in the United States[7]. Stieb et al. reported that the total mortality increase in percent was 0.64% per 10 μg/m^3 PM_{10} increase based on a meta-analysis from 21 studies worldwide, most of which were conducted in Europe and North America[8]. The consistent results were further proved that the association between air pollution and mortality is existed and not likely to be affected by factors such as geography, climate, population and publication bias. Interestingly, the effect of per 10 μg/m^3 NO_2 increase was 4.7 times higher than per 10 μg/m^3 PM_{10} increase. And the possible reason is that the daily variation range for NO_2 was much smaller than PM_{10}, and thus the corresponding effect per an interquartile range of NO_2 turned out to be only 0.6 times higher than PM_{10}. Further studies are therefore needed to proof this. Additionally, the hazard effect of NO_2 in current study was stronger than those from the previous findings and it might due to the use of DLM analysis which may tend to generate a stronger effect than the effects obtained from previous studies using one day or two-day moving lag days.

Table 1. Descriptive Statistics of Daily Mortality, Pollutant Levels, Weather Conditions from 2006 to 2007 in the Central Urban Areas of Urumqi, China

	Mean	**SD**	**Percentiles**				
			Min	25th	50th	75th	Max
Deaths							
Non-accidental	9	3	1	6	8	11	18
Cardiovascular	2	2	0	1	2	3	8
Respiratory	1	1	0	0	1	3	6
Pollutants (μg/m^3)							
PM_{10}	144	135	23	59	90	174	882
SO_2	100	104	4	26	49	148	405
NO_2	65	24	24	48	62	80	155
Weather conditions							
Temperature (°C)	9	13	-24	-4	10	21	33
Humidity (%)	55	21	8	37	57	73	95

Note. SD: standard deviation; PM_{10}: particulate matter with aerodynamic diameter less than 10 microns. SO_2: sulfur dioxide. NO_2: nitrogen dioxide.

Table 2. Percentage Increase (Mean and 95% Confidence Intervals) in Daily Total Mortality Associated with the Increase of a 10 μg/m^3 PM_{10}, SO_2, and NO_2 using different Lag Structures.

Mortality	**Pollutants**	**Lag 0**[a]	**Lag 01**[b]	**DLM for lag 0-3**[c]	**DLM for lag 0-7**[d]
Total	PM_{10}	0.34 (0.05, 0.63)	0.42 (0.08, 0.75)	0.57 (0.11, 1.03)	0.98 (0.33, 1.63)
	SO_2	0.70 (0.13, 1.26)	0.78 (0.14, 1.42)	1.58 (0.61, 2.56)	2.68 (1.25, 4.11)
	NO_2	2.74 (0.84, 4.65)	3.05 (0.89, 5.21)	4.64 (1.90, 7.39)	5.65 (1.92, 9.38)
Cardiovascular	PM_{10}	0.28 (-0.27, 0.83)	0.27 (-0.38, 0.92)	0.62 (-0.26, 1.51)	0.36 (-0.90, 1.61)
	SO_2	-0.10 (-1.23, 1.02)	0.16 (-1.12, 1.43)	1.36 (-0.59, 3.30)	0.84 (-2.02, 3.70)
	NO_2	2.01 (-1.73, 5.75)	0.45 (-3.80, 4.70)	4.11 (-1.23, 9.45)	1.63 (-5.59, 8.85)
Respiratory	PM_{10}	0.38 (-0.23, 0.98)	0.41 (-0.30, 1.11)	0.11 (-0.89, 1.11)	0.84 (-0.59, 2.27)
	SO_2	0.89 (-0.33, 2.12)	0.82 (-0.56, 2.20)	0.48 (-1.64, 2.60)	2.37 (-1.17, 5.91)
	NO_2	4.53 (0.37, 8.68)	4.15 (-0.57, 8.86)	4.24 (-1.79, 10.27)	6.73 (-1.97, 8.70)

Note. [a]corresponds to the concurrent day's concentration; [b]corresponds to two-day moving average lag; [c]corresponds to polynomial distributed lag model for a maximum lag of 3 days; [d]corresponds to polynomial distributed lag model for a maximum lag of 7 days. PM_{10}: particulate matter with aerodynamic diameter less than 10 microns; SO_2: sulfur dioxide; NO_2: nitrogen dioxide.

As shown in Table 2, the three pollutants were all significantly associated with total mortality, but not with cardiovascular and respiratory disease mortality. The reasons are not clear. Small number of daily cardiovascular (2 per day on average) and respiratory deaths (1 per day on average) during our study period might reduce the statistical power, especially when a few of zero values were included in the time-series dataset. More importantly, before this study started, the mortality registry system was not well established in Urumqi and this influences the code quality of cause-of-death according to ICD-10. In addition, the potential error or omissive diagnosis of diseases might lower the quality of mortality data in Urumqi.

Table 2 also shows that the effects of air pollution on human health could extend a few days in Urumqi, and the single-day lag and multiple-day average model could generate a smaller result than expected. Air pollution was not significantly associated with cardiovascular and respiratory mortality using the alternative lag model, except the NO_2-respiratory mortality in the lag 0 model. The measure index of air pollution exposure used in previous studies is the typical single-or multiday moving average concentration. Our results demonstrated that the temporary effects of air pollution on daily mortality could extend multiple days. And we believe that it is a sensitive method to evaluate the air pollution effect using the lag selection of exposure measure , and the lag 0 model and lag 01 model could substantially underestimate the effects of air pollution. The polynomial distributed lag models (PDLMs) allows the effects of different air pollutants to extend multiple days, avoiding the problem of proper selection of an average period for the air pollution exposure. A similar study reported that PDLMs was a more robust estimate method to estimate the temporary effects of air pollution on daily mortality, avoiding the potential negative bias as compared with the single-or multi-day moving average exposure measure[9]. Increasing studies have adopted the PDLMs to investigate the effects of air pollution on human health, and suggested that the PDLMs was better than the single- or multi-day moving average exposure measures.

Figure 1 shows the positive linear relations between air pollutants (PM_{10}, SO_2, and NO_2) and total mortality using the PDLMs with a maximum lag of 7 days. The log-relative risk curve for the SO_2-mortality relationship tends to be flatter at the high level and we did not find the low limit concentration that PM_{10}, SO_2, and NO_2 had no effects on total mortality in this study.

In the two-pollutant models (data not shown), we found that the relationship of SO_2 and NO_2 to daily mortality remained statistically significant after control PM_{10}. This result suggested that SO_2 and NO_2 were two important components of the air pollutants in Urumqi. Furthermore, they might be the independent risk factors to human health, although it is well-known that SO_2/NO_2 contributes to particle formation[10]. In contrast, PM_{10} turned to be not significantly associated with daily mortality after control SO_2 and/or NO_2. This might be due to that sand dust constitutes the major source of PM_{10} in Urumqi, and thus it was not as hazardous as PM_{10} in other cities. Additionally and up to date, the main pathogenic pollutant/pollutants was/were not found because the concentration of air pollutants generally interacted with each other continuously. Therefore,it is hard to inform a policy guidance about air pollution control in this heavily-polluted city and further work is needed to investigate the most hazardous air pollutants (or its components).

Findings from our present study may have important value for air pollution control, health assessment and air quality standard formulation. However, air pollution epidemiological study, especially the long-term cohort study, is limited in China. Therefore, it is unreasonable to directly use the data from the long-term cohort study on air pollution effect estimation of American Cancer Society. Our study revealed that the temporary effect levels of air pollution was similar to those in

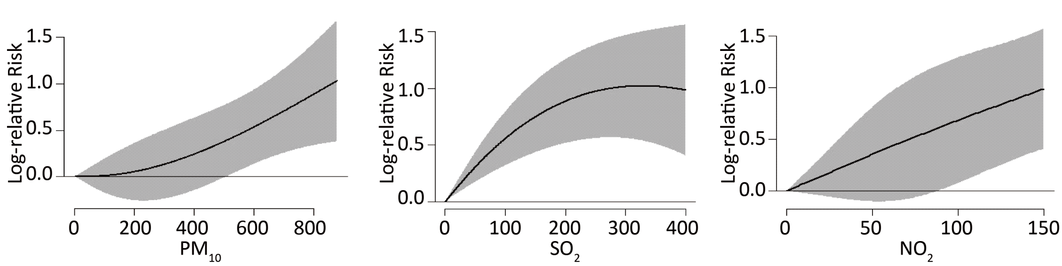

Figure 1. The overall effects of PM_{10}, SO_2, and NO_2 on daily total mortality from 2006 to 2007 in the central urban areas of Urumqi, China, using polynomial distributed lag model with a maximum lag of 7 days. The black line represents the mean effect estimate, and the grey area represents its 95% confidence interval. PM_{10}: particulate matter with aerodynamic diameter less than 10 microns; SO_2: sulfur dioxide; NO_2: nitrogen dioxide.

developed countries, and also there is a linear air pollution exposure-effect relationship in developed countries, even at the high air pollution levels. Therefore, our findings support the continue use of data from long-term cohort studies conducted in developed countries for the reference, e.g., use the published data in developed countries to estimate the disease burden caused by air pollution in China.

In summary, this study found that short-term exposure to air pollution significantly associated with the daily mortality in Urumqi, and this association was linear in term of exposure-effect relationship. The temporary effects of air pollution on daily mortality could extend for several days, and the single-day lag model and multi-day average lag model could substantially underestimate the effects. The results from the present study can therefore provide scientific evidence to evaluate the temporary effects of air pollution in other severely-polluted cities in China. In addition, our findings may have an important reference value for air pollution control, health assessment and air quality standard formulation in China.

Conflict of interest statement: None of the authors has any conflict of interest to this paper.

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REFERENCE

1. Pope CA, 3rd, Dockery DW. Health effects of fine particulate air pollution: lines that connect. J Air Waste Manag Assoc, 2006; 56, 709-42.
2. Pope CA, 3rd, Burnett RT, Thun MJ, et al. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA, 2002; 287, 1132-41.
3. Wong CM, Vichit-Vadakan N, Kan H, et al. Public Health and Air Pollution in Asia (PAPA): a multicity study of short-term effects of air pollution on mortality. Environ Health Perspect, 2008; 116, 1195-202.
4. Gasparrini A. Distributed Lag Linear and Non-Linear Models in R: The Package dlnm. J Stat Softw, 2011; 43, 1-20.
5. Chen R, Kan H, Chen B, et al. Association of particulate air pollution with daily mortality: the China Air Pollution and Health Effects Study. Am J Epidemiol, 2012; 175, 1173-81.
6. Shang Y, Sun Z, Cao J, et al. Systematic review of Chinese studies of short-term exposure to air pollution and daily mortality. Environ Int, 2013; 54, 100-11.
7. Samoli E, Peng R, Ramsay T, et al. Acute effects of ambient particulate matter on mortality in Europe and North America: results from the APHENA study. Environ Health Perspect, 2008; 116,1480-6.
8. Stieb DM, Judek S, Burnett RT. Meta-analysis of time-series studies of air pollution and mortality: effects of gases and particles and the influence of cause of death, age, and season. J Air Waste Manag Assoc, 2002; 52, 470-84.
9. Roberts S. An investigation of distributed lag models in the context of air pollution and mortality time series analysis. J Air Waste Manag Assoc, 2005; 55, 273-82.
10. Cao J, Xu H, Xu Q, et al. Fine Particulate Matter Constituents and Cardiopulmonary Mortality in a Heavily Polluted Chinese City. Environ Health Perspect, 2012; 120, 373-8.