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Visibility, air quality and daily mortality in Shanghai, China

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ABSTRACT

This study was designed to assess the association between visibility and air quality, and to determine whether the variations in daily mortality were associated with fluctuations in visibility levels in Shanghai, China. Mortality data were extracted from the death certificates, provided by Shanghai Municipal Center of Disease Control and Prevention, and visibility data were obtained from Shanghai Municipal Bureau of Meteorology. Air quality data (PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$, SO_2, NO_2 and O_3) were obtained from Shanghai Environmental Monitoring Center. Generalized additive model (GAM) with penalized splines was used to analyze the mortality, visibility, air pollution, and covariate data. Among various pollutants, $PM_{2.5}$ showed strongest correlation with visibility. Visibility, together with humidity, was found appropriate in predicting $PM_{2.5}$ (*R*-squared: 0.64) and PM_{10} (*R*-squared: 0.62). Decreased visibility was significantly associated with elevated death rates from all causes and from cardiovascular disease in Shanghai; one inter-quartile range (8 km) decrease in visibility corresponded to 2.17% (95%CI: 0.46%, 3.85%), 3.36% (95%CI: 0.96%, 5.70%), and 3.02% (95%CI: −1.32%, 7.17%) increase of total, cardiovascular and respiratory mortality, respectively. The effect estimates using predicted $PM_{2.5}$ and PM_{10} concentrations were similar to those assessed using actual concentrations. This is the first study in Mainland China assessing the association between visibility and adverse health outcomes. Our findings suggest the possibility of using visibility as a surrogate of air quality in health research in developing countries where air pollution data might be scarce and not routinely monitored.

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1. Introduction

Outdoor air pollution has been found to be associated with a wide range of adverse health outcomes, including increased mortality, increased rates of hospital admissions and emergency department visits, exacerbation of chronic respiratory conditions (e.g., asthma), and decreased lung function (Samet and Krewski, 2007). However, most of these studies were conducted in developed countries, and only a small number of studies have been conducted in developing countries. A common problem in conducting air pollution health research in developing countries is the scarcity or nonexistence of air monitoring data. Identifying appropriate air quality proxy that can be commonly available in developing countries would potentially benefit the conduct of health studies.

Environmental studies have found that particulate matter (PM) and gaseous pollutants in the air can scatter or absorb light, therefore reduce the visibility. For example, fine particles ($PM_{2.5}$, particulate matter with aerodynamic diameter less than 2.5 μm) can be effective light scatters because the wavelength of visible light falls in this range (Sisler and Malm, 1994). Visibility data are routinely collected at airports or meteorology stations throughout the world, and thus available for interpolation of missing pollutant measurements in developing countries. It is reasonable to hypothesize that visibility can be used as a surrogate of air pollution level assessing the health effects in places where routine air monitoring is not available (Abbey et al., 1995; Schwartz, 1991; Vajanapoom et al., 2002).

As the largest developing country in the world, China has achieved rapid development in the recent two decades. However, levels of outdoor air pollution in China are among the highest in the world (Chen et al., 2004). Although the relationship between outdoor air pollution and daily mortality/morbidity has been examined in several

Abbreviations: μg/m^3, micrograms per cubic meter; 95% CI, 95% confidence interval; *df*, degree of freedom; DOW, day of the week; GAM, generalized additive model; ICD-10, the 10th revision of International Classification of Diseases; NO_2, nitrogen dioxide; O_3, ozone; $PM_{2.5}$, particulate matter less than 2.5 μm in aerodynamic diameter; PM_{10}, particulate matter less than 10 μm in diameter; $PM_{10-2.5}$ particulate matter between 10 and 2.5 μm in aerodynamic diameter, SMCDCP Shanghai Municipal Center of Disease Control and Prevention; SO_2, sulfur dioxide.

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large Chinese cities, such as Beijing (Xu et al., 1995, 1994), Chongqing (Venners et al., 2003), Shanghai (Kan and Chen, 2003a,b; Zhang et al., 2006; Kan et al., 2007), Wuhan (Qian et al., 2007a,b), and Shenyang (Xu et al., 2000), no study has ever assessed the relationships between visibility, air quality and health outcomes, as well as the feasibility of using visibility as a surrogate assessing the air pollution health effects. In this study, we made the first attempt to assess the possibility of using visibility decrease as an exposure proxy to interpret its association with air quality and with daily deaths in Shanghai, China.

2. Materials and methods

2.1. Data

Daily mortality data (excluding accidents and injuries) of residents living in the nine urban districts of Shanghai between March 4, 2004 and December 31, 2005 (668 calendar days) were collected from the central database of Shanghai Municipal Center of Disease Control and Prevention (SMCDCP). The death report system in Shanghai was implemented in 1951, and has become computerized since 1990. For both in-home and in-hospital deaths, physicians are responsible for completing the death certificate cards. Information on the cards is then sent to SMCDCP through internal computer network. Causes of deaths were coded according to the International Classification of Diseases, Revision 10 (ICD 10), and classified into deaths due to total non-accidental causes (A00–R99), cardiovascular diseases (I00–I99), and respiratory diseases (J00–J98).

Daily visibility data were measured at a fixed-site monitoring station in Baoshan District of Shanghai. The digital photo visibility system (DPVS) was installed about 3 m above ground, monitoring the real time atmospheric visibility.

Daily air pollution data, including PM_{10} (particulate matter with aerodynamic diameter less than 10 μm), $PM_{2.5}$, $PM_{10-2.5}$ (particulate matter with aerodynamic diameter between 10 and 2.5 μm), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3), were obtained from Shanghai Environmental Monitoring Center (SEMC), a government agency responsible for air pollution data collection in Shanghai. The monitoring system in Shanghai is part of National Environmental Monitoring Quality Control Management Network, and has been certified by China Ministry of Environmental Protection. Daily concentrations for each pollutant were collected from a fixed-site station located in Putuo District which is within the National Environmental Monitoring Quality Control Management Network. $PM_{10-2.5}$ concentrations were estimated by subtracting $PM_{2.5}$ from PM_{10} measurements. We extracted 24-hour average concentrations for PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$, SO_2 and NO_2; and an 8-hour (from 10 AM to 6 PM) average concentration for O_3. For the calculation of 24-hour average pollutant concentrations, at least 75% of the hourly values on that particular day have to be valid. For the 8-hour average of O_3, at least six hourly values from 10 AM to 6 PM have to be valid.

To allow adjustment for meteorologic effect on mortality, daily mean temperature and humidity data were obtained from the Shanghai Meteorological Bureau. Daily weather data were measured at a fixed-site station located in Xuhui District of Shanghai.

2.2. Statistical methods

We calculated the Spearman correlation coefficients of visibility with both particulate matter ($PM_{2.5}$, $PM_{2.5-10}$ and PM_{10}) and gaseous pollutants (SO_2, NO_2 and O_3). Visibility and meteorological parameters (humidity, temperature, wind speed and season) were used to predict $PM_{2.5}$ and PM_{10} concentrations. *R*-squared (R^2) was used to measure how well the prediction model fit the data; and higher R^2 values indicated the preferred model.

We used the generalized additive model (GAM) with penalized splines to analyze the mortality, visibility, air pollution, and covariate data. Because counts of daily mortality counts typically follow a Poisson distribution, the core analysis used a GAM with log link and Poisson error that accounted for smooth fluctuations in daily mortality. Consistent with several latest other time-series studies (Ostro et al., 2006; Peng et al., 2006; Samoli et al., 2006), we used penalized splines in the GAM.

We first built basic models for various mortality outcomes excluding visibility and air pollution variables. We incorporated smoothed spline functions of time, which can accommodate nonlinear and non-monotonic patterns between mortality and time, offering a flexible modeling tool (Hastie and Tibshirani, 1990). Day of the week (DOW) was also included as dummy variable in the basic models. In our analysis, partial autocorrelation function (PACF) was used to guide the selection of degrees of freedom (*df*) for time trend until the absolute values of sum of PACF of residuals for lags up to 30 reach minimal (Katsouyanni et al., 2001; Peng et al., 2006; Touloumi et al., 2004, 2006). Peng et al. (2006) found that the *df*, which minimizes absolute value of sum of PACF of the residuals, corresponds closely with the *df* that leads a test for white noise failing to reject the null hypothesis. Residuals of the basic models were also examined to check whether there were discernable patterns and autocorrelation by means of residual plots and PACF plots.

After basic models were established, we introduced the visibility or pollutant concentrations (both actual and predicted) in the regression models, and analyzed their associations with mortality outcomes. Based on published literature (Bell et al., 2004; Dominici et al., 2006), 3 *df* (whole period of study) for mean temperature and relative humidity could control well for meteorologic effects on mortality, and it thus was chosen to be used in our models. Additionally, because the underlying assumption of linear relationship between death risk and visibility may not hold, we used smoothing function to graphically analyze their relationship (Daniels et al., 2004).

In summary, we fit the following log-linear generalized additive model to obtain the estimated log-relative rate β of visibility in Shanghai:

$$logE(Y_t) = \beta Z_t + \mathrm{DOW} + \mathrm{ps}(\mathrm{time}, df) + \mathrm{ps}(\mathrm{temperature}, 3) + \mathrm{ps}(\mathrm{humidity}, 3) + \mathrm{intercept}$$

Here $E(Y_t)$ means the expected number of deaths at day *t*; β represents the log-relative rate of mortality associated with a unit increase of visibility or pollutant concentrations; Z_t indicates the visibility or pollutant concentrations at day *t*; DOW is day of the week effect; ps(time,*df*) is the penalized spline function of calendar time;

Table 1
Summary statistics of daily deaths, air pollutant concentrations and weather conditions in Shanghai (Mar. 4, 2004–Dec. 30, 2005).

	No.	Mean ± S.E.	Min	P(25)	Median	P(75)	Max
Daily death counts							
Total (non-accident)	668	119.1 ± 0.87	54.0	104.0	115.0	131.0	191.0
Cardiovascular	668	45.7 ± 0.45	22.0	37.0	44.0	52.0	82.0
Respiratory	668	13.1 ± 0.21	3.0	9.0	12.0	16.0	35.0
Visibility (km)	666	17.1 ± 0.18	4.0	13.0	17.0	21.0	30.0
Air pollutants concentrations[a]							
PM_{10} (μg/m^3)	668	107.9 ± 2.39	22.0	63.0	93.5	135.8	403.0
$PM_{2.5}$ (μg/m^3)	661	56.4 ± 1.34	8.3	32.5	49.0	72.4	235.0
$PM_{10-2.5}$ (μg/m^3)	661	52.3 ± 1.57	2.0	28.5	42.0	66.0	330.3
SO_2 (μg/m^3)	668	57.7 ± 1.10	12.0	35.0	52.0	74.0	156.5
NO_2 (μg/m^3)	668	61.8 ± 0.97	14.4	43.2	59.2	75.2	171.2
O_3 (μg/m^3)	668	77.0 ± 2.89	5.6	36.7	58.3	84.6	253.1
Meteorologic measures							
Mean temperature (°C)	668	18.8 ± 0.34	−2.8	12.3	19.8	26.2	35.0
Relative humility (%)	668	69.2 ± 0.46	33.0	61.5	70.0	76.8	94.8

[a] 24-hr average for PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$, SO_2 and NO_2; 8-hr (10 AM to 6 PM) average for O_3.

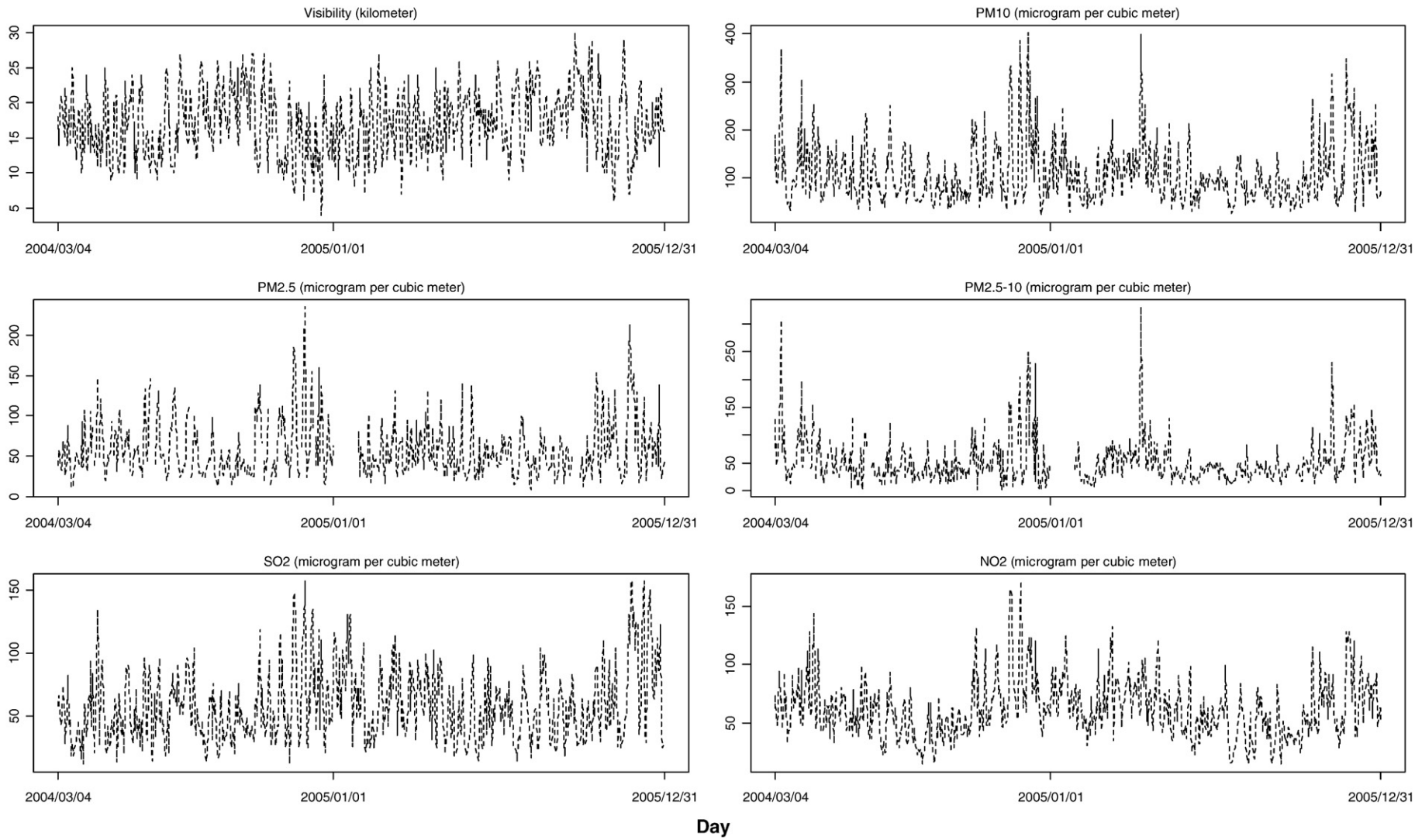

Fig. 1. Daily visibility and air pollutant concentrations in Shanghai (Mar. 4, 2004–Dec. 30, 2005).

and ps(temperature/humidity,3) is the penalized spline function for current-day temperature/humidity with 3 *df*.

All analyses were conducted in R 2.6.1 using the MGCV package (R Development Core Team, 2007). To facilitate the comparison with previous studies (Kan et al., 2007, 2008), the results are presented as the percent change in daily mortality per inter-quartile range (IQR) increase of visibility, and per 10 μg/m^3 increase of $PM_{2.5}$ or PM_{10}.

3. Results

3.1. Data description

From March 4, 2004 to December 31, 2005, a total of 79,530 deaths (41,857 males and 37,673 females) were recorded in this study population. The percentages of total deaths by age group were 0.2% for 0–4, 2.4% for 5–44, 13.9% for 45–64 and 83.4% for 65+, respectively. On average, there were 119 non-accidental deaths per day, including 46 deaths from cardiovascular diseases, and 13 deaths from respiratory diseases (Table 1). Approximately, cardiopulmonary disease accounted for 49.4% of total non-accidental deaths.

Daily visibility and air pollutant concentrations during our research period were described in Fig. 1 ($n=668$ days). During the study period, the mean visibility was 17.1 km in distance. Generally, visibility was strongly, negatively correlated with both $PM_{2.5}$ (correlation coefficient, $r=-0.68$), PM_{10} ($r=-0.63$), and moderately correlated with $PM_{2.5-10}$ ($r=-0.41$), SO_2 ($r=-0.44$) and NO_2 ($r=-0.58$), but not with O_3 ($r=-0.04$) (Table 2).

Fig. 2 describes the relations of visibility with $PM_{2.5}$ and PM_{10}. In various models, visibility, together with humidity, was found appropriate in predicting $PM_{2.5}$ ($R^2=0.64$) and PM_{10} ($R^2=0.62$). Further inclusion of temperature, wind speed or season did not significantly increase the R^2 values.

3.2. Regression results

Table 3 summarizes the associations of visibility with total and cause-specific mortality after controlling for long-term and seasonal trend of mortality, DOW, and weather conditions. Significant associations were found between visibility and daily deaths from all and cardiovascular causes. One inter-quartile range (8 km) decrease in visibility corresponded to 2.17% [95% confidence interval (95%CI): 0.46%, 3.85%] increase of total mortality, 3.36% (95%CI: 0.96%, 5.70%) increase of cardiovascular mortality, and 3.02% (95%CI: −1.32%, 7.17%) increase of respiratory mortality.

Fig. 3 graphically presents exposure–response relationships between visibility and mortality outcomes. For total and cardiovascular mortality (Fig. 3a and b), though the death risks do not decrease monotonically with increased visibility, the exposure–response curves present negative, linear relationships (chi-square test for linearity, p value>0.05). For respiratory mortality (Fig. 3c), a nonlinear relationship was observed for most visibility levels represented in our data (chi-square test for linearity, p value<0.05).

The effect estimates using actual and visibility-based predicated particle concentrations were further assessed (Table 4). For total and cardiovascular mortality, significant associations were found with both actual PM_{10} and actual $PM_{2.5}$; for respiratory mortality, the association was significant only with actual $PM_{2.5}$, but not with actual PM_{10}. The effect estimates using predicted concentrations were similar to those assessed using actual concentrations.

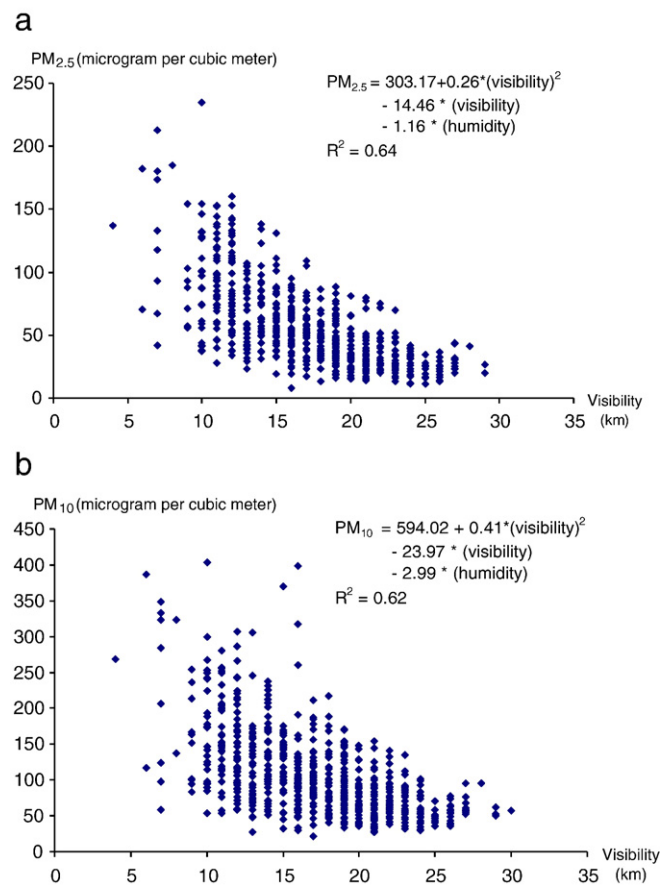

Fig. 2. Relationship of visibility with $PM_{2.5}$ (a) and PM_{10} (b) in Shanghai (Mar. 4, 2004–Dec. 30, 2005).

4. Discussion

Consistent with several prior studies (Abbey et al., 1995; Schwartz, 1991; Vajanapoom et al., 2002), decreased visibility was significantly associated with elevated death rates from all causes and from cardiovascular disease in Shanghai. To our knowledge, this is the first study in Mainland China assessing the association between visibility and adverse health outcomes. In addition, the magnitudes of our estimates for $PM_{2.5}$ and PM_{10} are comparable with previous analyses in Shanghai (Kan et al., 2007, 2008). Mortality outcomes showed associations, at similar magnitude, with actual and visibility-based predicted particle concentrations. Our findings support the use of visibility as a surrogate of air quality in health research in developing countries whereas visibility data are collected routinely at nearby airports.

In China, published data on the correlations between visibility and air quality is quite limited. Among measured pollutants, we found

Table 2
Correlation coefficients between visibility and air pollutant concentrations in Metropolitan Shanghai (Mar. 4, 2004–Dec. 30, 2005).

	$PM_{2.5}$	$PM_{2.5-10}$	PM_{10}	SO_2	NO_2	O_3
Visibility	−0.68	−0.41	−0.63	−0.44	−0.58	−0.04
$PM_{2.5}$	1	0.42	0.80	0.80	0.79	0.31
$PM_{2.5-10}$		1	0.87	0.42	0.51	0.07
PM_{10}			1	0.70	0.75	0.21
SO_2				1	0.75	0.32
NO_2					1	0.23

Table 3
Percent change of mortality outcomes of Shanghai residents per inter-quartile range (IQR) decrease of visibility.

	%	95% CI
Total mortality	2.17	0.46, 3.85
Cardiovascular mortality	3.36	0.96, 5.70
Respiratory mortality	3.02	−1.32, 7.17

Current day temperature and relative humidity (lag = 0), and current-day visibility (lag = 0) were used; 3 *df* were applied to temperature and relative humidity respectively.

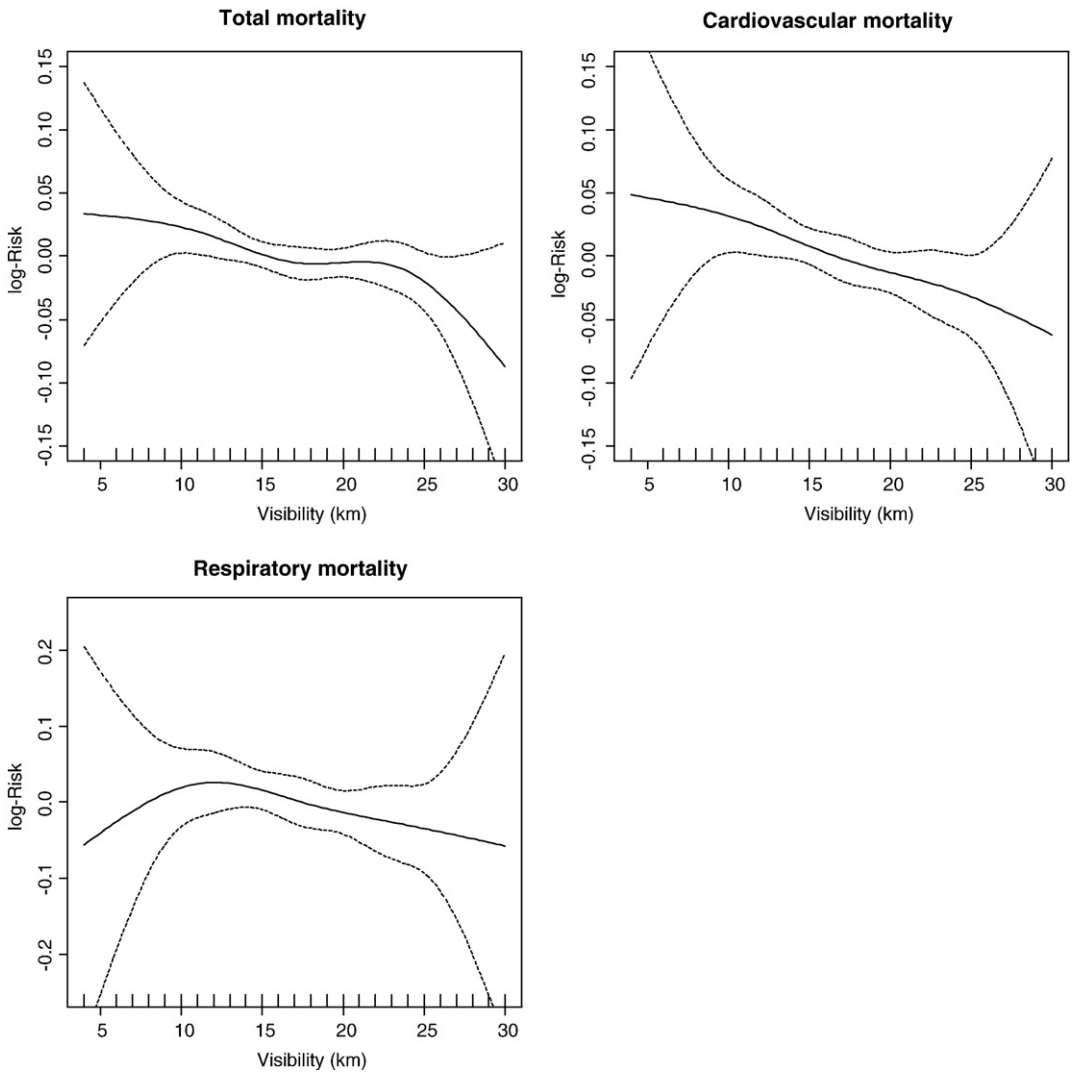

Fig. 3. Smoothing plots of visibility against mortality risk ($df = 3$). X-axis is the current-day visibility (km). The estimated mean percentage of change in daily mortality is shown by the solid line, and the dotted lines represent twice the point-wise standard error (current-day temperature and relative humidity (lag = 0) were used; 3 df were applied to temperature and relative humidity respectively).

strongest correlation of visibility with $PM_{2.5}$, which is consistent with prior studies showing that visibility had higher correlation with smaller particles (Ozkaynak et al., 1985). In addition, our regression model of visibility and $PM_{2.5}$ (Fig. 2), with R^2 of 0.64, were comparable to or even better than those reported in other studies. For example, Ozkaynak et al reported a mean of R^2 of 0.43 in their 12 large U.S. city regression models estimating $PM_{2.5}$ from visibility (Ozkaynak et al., 1985). Our analyses suggest that visibility measurement may provide relatively accurate predicted $PM_{2.5}$, and thus to be used as an exposure proxy assessing the health effects of $PM_{2.5}$.

Consistent with most prior air pollution studies (Englert, 2004), we found significant effects of visibility on both total and cardiovascular mortality. Of additional interest is the magnitude of the association of visibility with cardiovascular mortality relative to that for total mortality. In our study, visibility was more strongly associated with cardiovascular mortality than with all-cause mortality risk (Table 3). Many recent studies have addressed potential mechanisms linking air pollutants (e.g. $PM_{2.5}$) and cardiovascular diseases (Brook et al., 2004). For example, ambient particles have been associated with increased plasma viscosity (Peters et al., 1997), sequestration of red cells in the circulation (Seaton et al., 1999), and indicators of cardiac autonomic dysfunction including increased heart rate, decreased heart rate variability, and increased cardiac arrhythmias (Dockery, 2001). These findings provide evidence on possible pathways by which visibility, a surrogate of air pollutants, is associated with cardiovascular mortality.

Table 4
Percent change (95% CI) of mortality outcomes of Shanghai residents per 10 μg/m^3 increase of $PM_{2.5}$ and PM_{10}.

	$PM_{2.5}$		PM_{10}	
	Actual	Predicted	Actual	Predicted
Total mortality	0.30 (0.06, 0.54)	0.34 (0.01, 0.67)	0.14 (0.02, 0.26)	0.10 (−0.03, 0.23)
Cardiovascular mortality	0.39 (0.12, 0.66)	0.30 (−0.01, 0.61)	0.24 (0.08, 0.40)	0.22 (0.01, 0.43)
Respiratory mortality	0.71 (0.05, 1.37)	0.63 (0.02, 1.24)	0.22 (−0.08, 0.52)	0.11 (−0.04, 0.26)

Current day temperature and relative humidity (lag = 0), and current-day visibility (lag = 0) were used; 3 df were applied to temperature and relative humidity respectively.

The limitations of our study should be noted. First of all, the chemical composition is hypothesized to affect the role of $PM_{2.5}$ in atmospheric visibility (Wu et al., 2005). Our analysis did not involve chemical composition assessment of particles in Shanghai, which may be critical in interpreting the correlation between visibility and particles, and therefore in explaining the uncertainties of using visibility as a surrogate of air pollution in health research. Secondly, as in other time-series studies (Samet et al., 2000), we used routinely collected outdoor monitoring data to represent the population exposure to air pollution. The potential exposure misclassification may have implications for interpreting the effect of air pollutants (Zeger et al., 2000). However, we lack information on personal exposure to air pollution to quantity this bias. Third, we did not consider the exposure from indoor sources. In Shanghai, little or no indoor air monitoring data is available. However, some studies suggested that the daily population average concentrations of pollutants derived from indoor sources are approximately independent of ambient levels (Wilson and Suh, 1997). When this is true, failure to measure indoor sources will not introduce further bias in the estimated effects of ambient pollutants (Zeger et al., 2000). Finally, our assessment of visibility and air pollution was derived entirely from one monitoring station. Compared with studies in Europe and North America, data collected in this study were limited by virtue of the single city and limited monitoring time period. This may have limited our power to detect significant associations with respiratory mortality.

On health research perspectives, Shanghai dataset offers advantages in investigating the visibility–air pollution–mortality relationship. Our study area, nine urban districts of Shanghai, is extremely densely populated. More than six-million permanent residents reside within 279 km^2. In addition, compared with the residents in North America, a lower proportion of Shanghai residents have access to or use air conditioning. Thus, the monitored air pollution data from the summer months may be more closely associated with average population exposures in Shanghai than in cities in North America.

In summary, our analyses provide statistically significant evidence on the association between daily mortality and visibility in general population of Shanghai. Given that the availability of routinely collected air pollution monitoring data is much lower in developing countries, our results provide important implications that routinely-collected visibility data can be used as a surrogate for air quality in health studies conducted in developing world, and likely to make the findings comparable to those observed in developed countries.

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References

Abbey DE, et al. Chronic respiratory symptoms associated with estimated long-term ambient concentrations of fine particulates less than 2.5 microns in aerodynamic diameter (PM2.5) and other air pollutants. J. Expo. Anal. Environ. Epidemiol. 1995;5:137–59.
Bell ML, et al. Ozone and short-term mortality in 95 US urban communities, 1987–2000. JAMA 2004;292:2372–8.
Brook RD, Franklin B, Cascio W, Hong Y, Howard G, Lipsett M, et al. Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. Circulation 2004;109(21):2655–71.
Chen B, et al. Exposures and health outcomes from outdoor air pollutants in China. Toxicology 2004;198:291–300.
Daniels MJ, et al. The National Morbidity, Mortality, and Air Pollution Study. Part III: PM10 concentration–response curves and thresholds for the 20 largest US cities. Res. Rep. Health Eff. Inst. 2004:1-21 discussion 23–30.
Dockery DW. Epidemiologic evidence of cardiovascular effects of particulate air pollution. Environ. Health Perspect. 2001;109(Suppl 4):483–6.
Dominici F, et al. Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. JAMA 2006;295:1127–34.
Englert N. Fine particles and human health—a review of epidemiological studies. Toxicol. Lett. 2004;149(1–3):235–42.
Hastie TJ, Tibshirani RJ. Generalized additive models. London: Chapman and Hall; 1990.
Kan H, Chen B. A case-crossover analysis of air pollution and daily mortality in Shanghai. J. Occup. Health 2003a;45:119–24.
Kan H, Chen B. Air pollution and daily mortality in Shanghai: a time-series study. Arch. Environ. Health 2003b;58:360–7.
Kan H, et al. Differentiating the effects of fine and coarse particles on daily mortality in Shanghai, China. Environ. Int. 2007;33:376–84.
Kan H, et al. Season, sex, age, and education as modifiers of the effects of outdoor air pollution on daily mortality in Shanghai, China: the Public Health and Air Pollution in Asia (PAPA) study. Environ. Health Perspect. 2008;116:1183–8.
Katsouyanni K, et al. Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 project. Epidemiology 2001;12:521–31.
Ostro B, et al. Fine particulate air pollution and mortality in nine California counties: results from CALFINE. Environ. Health. Perspect. 2006;114(1):29–33.
Ozkaynak H, et al. Relationship between aerosol extinction coefficients derived from airport visual range observations and alternative measures of airborne particle mass. JAPCA. 1985;35:1176–85.
Peng RD, et al. Model choice in time series studies of air pollution and mortality. J. R. Stat. Soc., Series A 2006;169:179–203.
Peters A, Doring A, Wichmann HE, Koenig W. Increased plasma viscosity during an air pollution episode: a link to mortality? Lancet 1997;349(9065):1582–7.
Qian Z, et al. Association of daily cause-specific mortality with ambient particle air pollution in Wuhan, China. Environ. Res. 2007a;105:380–9.
Qian Z, et al. Short-term effects of gaseous pollutants on cause-specific mortality in Wuhan, China. J. Air. Waste Manag. Assoc. 2007b;57:785–93.
R Development Core Team. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2007.
Samet J, Krewski D. Health effects associated with exposure to ambient air pollution. J. Toxicol. Environ. Health, Part A 2007;70:227–42.
Samet JM, et al. The National Morbidity, Mortality, and Air Pollution Study. Part I: methods and methodologic issues. Res. Rep. Health Eff. Inst. 2000:5-14 discussion 75–84.
Samoli E, et al. Short-term effects of nitrogen dioxide on mortality: an analysis within the APHEA project. Eur. Respir. J. 2006;27:1129–38.
Schwartz J. Particulate air pollution and daily mortality in Detroit. Environ. Res. 1991;56: 204–13.
Seaton A, Soutar A, Crawford V, Elton R, McNerlan S, Cherrie J, et al. Particulate air pollution and the blood. Thorax 1999;54(11):1027–32.
Sisler JF, Malm WC. The relative importance of soluble aerosols to spatial and seasonal trends of impaired visibility in the United States. Atmos Environ. 1994;28:851–62.
Touloumi G, et al. Analysis of health outcome time series data in epidemiological studies. Environmetrics 2004;15:101–17.
Touloumi G, et al. Seasonal confounding in air pollution and health time-series studies: effect on air pollution effect estimates. Stat. Med. 2006;25:4164–78.
Vajanapoom N, et al. Associations of particulate matter and daily mortality in Bangkok, Thailand. Southeast Asian J. Trop. Med. Public Health 2002;33:389–99.
Venners SA, et al. Particulate matter, sulfur dioxide, and daily mortality in Chongqing, China. Environ. Health Perspect. 2003;111:562–7.
Wilson WE, Suh HH. Fine particles and coarse particles: concentration relationships relevant to epidemiologic studies. J. Air. Waste. Manag. Assoc. 1997;47:1238–49.
Wu D, et al. An extremely low visibility event over the Guangzhou region: a case study. Atmos. Environ. 2005;39:6568–77.
Xu X, et al. Air pollution and daily mortality in residential areas of Beijing, China. Arch. Environ. Health 1994;49:216–22.
Xu X, et al. Association of air pollution with hospital outpatient visits in Beijing. Arch. Environ. Health 1995;50:214–20.
Xu Z, et al. Air pollution and daily mortality in Shenyang, China. Arch. Environ. Health 2000;55:115–20.
Zeger SL, et al. Exposure measurement error in time-series studies of air pollution: concepts and consequences. Environ. Health Perspect. 2000;108:419–26.
Zhang Y, et al. Ozone and daily mortality in Shanghai, China. Environ. Health Perspect. 2006;114:1227–32.