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# Effects of ambient air particles on mortality in Seoul: Have the effects changed over time?

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ABSTRACT

*Background:* Several studies have shown that there may be temporal variation in PM short-term effect on mortality. This temporal pattern may play an important role in evaluating air quality policies.
*Objectives:* We investigated temporal variation in the association between PM and mortality in Seoul, Korea, 1998–2011.
*Methods:* We adopted a generalized additive model and a series of time windows of five years to analyze temporal variation in associations between PM and all-cause, cardiovascular, and respiratory mortality. This time-window approach offers not only a comparison between one and the other half period but also successive variation. Time-varying associations were estimated only for days without Asian dust (dust storm blown from the Gobi desert) intrusion.
*Results:* Annual average $PM_{10}$ and $PM_{2.5}$ total mass decreased from 70.0 to 46.9 $\mu g/m^3$ and 44.4 to 23.4 $\mu g/m^3$, respectively, during 2001–2011. A 10 $\mu g/m^3$ increase in $PM_{10}$ was associated with 0.16% (95% CI = −0.03% to 0.35%) additional all-cause deaths in 2002–2006 and it increased to 0.26% (95% CI = 0.05–0.48%) in 2007–2011. For $PM_{2.5}$, the association increased from 0.35% (95% CI = −0.02% to 0.71%) to 0.48% (95% CI = 0.08–0.88%). For cardiovascular and respiratory mortality, increasing trends with stronger estimates were found.
*Conclusions:* The present study showed temporally increasing trends in associations between PM and mortality. Current policies may not be as effective to reducing health risks attributable to PM as expected. Air quality interventions should be encouraged in terms of causal factors for time-varying association between PM and mortality.



## 1. Introduction

Epidemiological research has demonstrated that acute exposure to particulate matter with an aerodynamic diameter $< 10$ μm ("$PM_{10}$") is associated with diverse health response (Pope III and Dockery, 2006). Incorporating advanced measurement technologies, researchers have since then concentrated on smaller particles, with aerodynamic diameters $< 2.5$ μm ("$PM_{2.5}$") and provided consistent evidence of a stronger association with health outcomes than that of $PM_{10}$ or $PM_{10-2.5}$ (Dong et al., 2013; Schwartz and Neas, 2000). In Seoul, the capital of South Korea, many studies have reported an association between short-term exposure to PM and an increase in risk of health outcomes (Heo et al., 2014; Lee et al., 2007; Son et al., 2012).

"Asian dust," also known as yellow dust, which originates in the Gobi Desert spread from Southern Mongolia to Northern China, is sporadically blown to Korean peninsula by westerly winds and aggravates air quality in the region. It leads to increase particulate concentrations, but especially tends to increase coarse particles with crustal components (Kim et al., 2003). In fact, such particles may be less deleterious to human health than fine particles (Pope III and Dockery, 2006). Thus, an association of particulates with mortality regardless of excluding days with Asian dust intrusion in a statistical model would possibly be underestimated in terms of PM effects for dominant non-Asian dust days (Lee et al., 2007). Accordingly, it is necessary to take this concept into account when analyzing PM effects on mortality in Korea.

According to recent studies, there may be temporal variation in short-term effects of air pollution; the relative risk is not constant over time. Studies in the U.S. and Europe found decreasing patterns in PM effects over time (Breitner et al., 2009; Dominici et al., 2007). They suggested that air quality control policies may have

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had an impact on not only reducing PM mass concentration but also on desirable changes in the constituents of PM. If there are similar trends in Korea, a time-varying effect of PM may also be expected.

Thus, we sought to analyze an association between PM and mortality in Seoul, considering the intrusion of Asian dust. Second, we investigated temporal variation in the association, and suggested possible reasons for a time-varying effect of PM on mortality. Finally, we made suggestions on future studies and ambient air quality policies.

## 2. Methods and materials

### 2.1. The scope and data

The study location was Seoul, Korea, with a population of about 10 million (Statistics Korea, 2010). Data for mortality, $PM_{10}$, $PM_{2.5}$, and meteorological factors were obtained from Statistics Korea, the National Institute of Environmental Research, Seoul Metropolitan Government Research Institute of Public Health and Environment, and the Korea Metrological Administration, respectively.

PM concentration in Seoul has been measured in national monitoring stations since 1995 for $PM_{10}$ and 2001 for $PM_{2.5}$. PM values were computed as daily (24 h) mean concentrations from hourly measurements. Valid daily mean concentration was calculated with data from at least 75% of stations (18+ out of 25) and of hourly measurements (16+ out of 24). Otherwise, we imputed an annual average from valid daily estimates. Missing values were also imputed with annual averages. Exceptions to spatial criteria were the year of 1998 for $PM_{10}$ because of only 17 monitoring stations and the period of 2001–2004 for $PM_{2.5}$ due to almost 10 of unevenly operating stations. The number of invalid daily $PM_{10}$ was 270 (5.3%) from 1998 to 2011 and that of invalid daily $PM_{2.5}$ was 563 (14.0%) from 2001 to 2011. Temperature and relative humidity were measured at a single fixed station in the Jongno district, a center of Seoul city. Daily mean temperature and relative humidity were calculated and there were no missing values for them.

We classified cause-specific mortality into all-cause except for accidental causes (International Classification of Disease, Tenth Revision [ICD-10]: A00-R99 and Ninth Revision [ICD-9]: 1-799), cardiovascular (ICD-10: I00-I99, ICD-9: 390-459), and respiratory (ICD-10: J00-J99, ICD-9: 460-519) mortality.

### 2.2. Statistical analysis

A generalized additive model (GAM) was used to analyze associations between $PM_{10}$ and $PM_{2.5}$ and mortality. Poisson distribution with over-dispersion was applied. To control potential confounders, we adjusted daily mean temperature, daily mean relative humidity, time-trend, day of the week, and holidays. Temperature, relative humidity, and time-trends were adjusted as a cubic regression spline with 5 knots and 7 knots/year. Knots were equally dispersed throughout values. In preliminary analysis, we did not detect partial autocorrelation which exceeded $|0.1|$ in the main model with aforementioned knots. Day of the week and holidays were included in the model as dummy variables.

We compared estimates of days without Asian dust intrusion (NAD, non-Asian dust days) to those from all days including days with Asian dust intrusion (NAD+AD, non-Asian dust Days plus Asian dust days). Then we conducted subsequent analyses for NAD.

To explore temporal variation in associations between PM and cause-specific mortality, we used a series of time windows, five years long. This approach has been used in our previous work (Kim et al., 2015). It enables to compare one and the other half period as many studies on temporal variation in relative risk did. It also allows to see consecutive variation with sufficient statistical power and avoids inter-annual harvesting effect (Kim et al., 2015).

For statistical analyses, the SAS 9.4 and R 3.0.2 softwares were used.

### 2.3. Sensitivity analysis

We changed the number of knots in spline function for temperature (4, 5 and 6), relative humidity (4, 5 and 6) and time (4, 5, 6 and 8) to see whether estimated association of PM with mortality was stable. As the size of population changed over the study period, annual variation of population was also adjusted as an offset in a gam model across time-windows, even though we expected that spline function for time-trend may cover the population change sufficiently and change in the size of population in a single city is relatively minimal. The annual number of population was obtained from the statistics of registered population in Korean Statistical Information Service.

We also conducted sensitivity analyses using 1-year (annual variation) and 3-years of windows. Bayesian varying coefficient regression (VCR) was used to explore time-varying association between PM and mortality: $\beta_{PM} = f(YEAR)_{PM}$ with 'BayesX' package in R software (Kneib et al., 2011). Similar approach was adapted elsewhere (Breitner et al., 2009).

In addition, multi-pollutant model needs to be taken into consideration if temporal variation in PM effect is (partially) attributed to other pollutants. We added $SO_2$, $NO_2$, or $O_3$ into the main model (so that two-pollutant model) to see if it shows different temporal patterns of PM effects.

## 3. Results

### 3.1. Descriptive statistics

Regardless of Asian dust intrusion, the average daily $PM_{10}$ concentration for the study period, 1998–2011, was 60.7 $\mu g/m^3$. For $PM_{2.5}$, it was 32.1 $\mu g/m^3$ in 2001–2011. There were a total of 159 Asian dust days. Average concentrations of $PM_{10}$ and $PM_{2.5}$ were higher during Asian dust intrusion in the corresponding periods (Table 1). Annual ambient PM concentrations have declined consistently (Fig. 1)

The average daily all-cause mortality was 93.3. Death count in those aged 65 years or older (65+) represented two-thirds of all ages (Table 1). For cause-specific deaths, the averages were 24.4 and 5.7 in cardiovascular and respiratory-related death, respectively. Daily death count increased slightly over time as the elderly population grew (Supplemental materials, Fig. S1).

### 3.2. Quantification of PM effect on mortality

Table 2 shows associations between $PM_{10}$, $PM_{2.5}$, and mortality. An increment of 10 $\mu g/m^3$ in $PM_{10}$ was associated with a 0.12% (95% CI=0.12–0.21%) increase in all-cause mortality in 1998–2011. For $PM_{2.5}$, it was associated with a 0.20 (95% CI=−0.01% to 0.41%) increase in risk of all-cause mortality in 2001–2011. When we excluded days with Asian dust intruded, both associations of $PM_{10}$ and $PM_{2.5}$ were strengthened to 0.22% (95% CI=0.10% to 0.35%) and 0.23% (95% CI=−0.01% to 0.47%), respectively, for the corresponding periods. Looking into cause-specific mortality, stronger associations of PM were found compared to risk in all-cause mortality. As with all-cause mortality, estimates for NAD were higher. To confirm this effect modification, we checked statistical significance of an interaction between PM and the occurrence of