



Seasonal analysis of the short-term effects of air pollution on daily mortality in Northeast Asia



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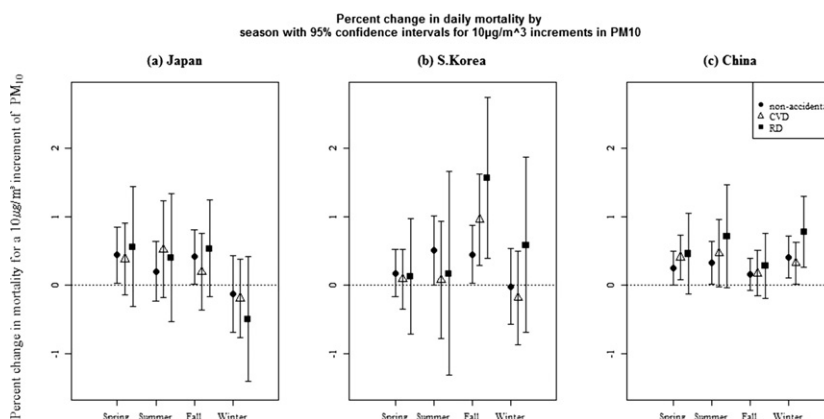
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HIGHLIGHTS

- Studies regarding the seasonality of PM on mortality are inconsistent.
- We estimated seasonal PM₁₀ effects on mortality in 3 northeast Asian countries.
- The seasonal mortality effect of PM₁₀ varied considerably by cause of death and location.

GRAPHICAL ABSTRACT



This graphical abstract indicates the percent changes in cause-specific mortality per season in 10 µg/m³ increments of PM₁₀. The effect was first quantified within each season and at each location using a time-series model, after which city-specific estimates were pooled using a hierarchical Bayesian model.

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ABSTRACT

The constituents and concentrations of pollutants, individual exposures, and biologic responses to air pollution may vary by season and meteorological conditions. However, evidence regarding seasonality of the acute effects of air pollution on mortality is limited and inconsistent. Herein, we examined seasonal patterns in the short-term associations of particulate matter (PM) smaller than 10 µm (PM₁₀) with daily mortality in 29 cities of three north-east Asian countries. Stratified time-series models were used to determine whether season altered the effect of PM₁₀ on mortality. This effect was first quantified within each season and at each location using a time-series model, after which city-specific estimates were pooled using a hierarchical Bayesian model. In all data sets, 3,675,348 non-accidental deaths were registered from 1993 to 2009. In Japan, a 10 µg/m³ increase in PM₁₀ was

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significantly associated with increases in non-accidental mortality of 0.44% (95% confidence interval [CI]: 0.03%, 0.8%) in spring and 0.42% (0.02%, 0.82%) in fall. In South Korea, a 10 $\mu\text{g}/\text{m}^3$ increase in PM_{10} was significantly associated with increases in non-accidental mortality of 0.51% (0.01%, 1.01%) in summer and 0.45% (0.03%, 0.87%) in fall, in cardiovascular disease mortality of 0.96% (0.29%, 1.63%) in fall, and in respiratory disease mortality of 1.57% (0.40%, 2.75%) in fall. In China, a 10 $\mu\text{g}/\text{m}^3$ increase in PM_{10} was associated with increases in non-accidental mortality of 0.33% (0.01%, 0.66%) in summer and 0.41% (0.09%, 0.73%) in winter, in cardiovascular disease mortality of 0.41% (0.08%, 0.74%) in spring and 0.33% (0.02%, 0.64%) in winter, and in respiratory diseases mortality of 0.78% (0.27%, 1.30%) in winter. Our analyses suggest that the acute effect of particulate air pollution could vary seasonally and geographically.

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1. Introduction

Several time series studies of air pollution and daily mortality have typically assumed that the effects of air pollution on mortality remained constant over the study period. However, the short-term effects of air pollution on mortality might vary seasonally. Annual variations in meteorological conditions and sources of air pollution could lead to variations in the mixtures and concentrations of air pollution components; in addition, seasonal exposure patterns have been observed. Human behavior patterns also differ from season to season, and could lead to seasonal differences in personal exposure. Therefore, season should be considered an important modifying factor when investigating the acute health effects of air pollution. Hence, it is conceivable that the short-term associations of air pollution with daily mortality might differ from season to season (Peng et al., 2005). The particulate matter (PM) composition also varies by geographic region, suggesting that seasonal patterns should be examined according to location. For example, in China, coal is a greater source of PM in the summer and winter seasons, during which more energy is used than in the spring and fall seasons. In South Korea, the PM mixture during spring contains a large proportion of wind-blown dust from Asian dust storms that are less hazardous to health than combustion-related particles. A few multi- and single-city studies have provided evidence of seasonality with respect to the short-term health effects of PM, although this evidence has been inconsistent (Peng et al., 2005; Pope and Dockery, 2006; Qian et al., 2010; Kan et al., 2008; Bell et al., 2008). Therefore, a multi-city study conducted using common methodology is needed to clarify the effect of seasonality on the health impacts of air pollution. To address this need, this study examined the seasonal significance of the acute effect of air pollution on cause-specific mortality in northeast Asia, including 29 cities in Japan, South Korea, and China since these three countries are located in proximity to each other and are similar in many socioeconomic and cultural aspects, but are exposed to different air pollution conditions.

2. Materials and methods

2.1. Data collection

The collected data included meteorological variables, air pollution values, and daily information about health outcomes in six Japanese cities (1993–2008), Sapporo, Sendai, Tokyo, Nagoya, Osaka, and Kitakyushu; seven South Korean cities (2000–2009): Seoul, Incheon, Daejeon, Daegu, Gwangju, Busan, and Ulsan; and sixteen Chinese cities (study period for each city can be found in Table 1): Anshan, Beijing, Fuzhou, Guangzhou, Hangzhou, Hong Kong, Lanzhou, Shanghai, Shenyang, Suzhou, Taiyuan, Tangshan, Tianjin, Wuhan, Urumqi, and Xian (Fig. 1). Lanzhou was excluded from the cardiovascular diseases (CVD) and respiratory diseases (RD) analysis because of a lack of available data. Daily mortality counts were obtained from the Ministry of Health and Welfare of Japan, the Korea National Statistics Office, and the Center for Disease Prevention and Control of China. All diseases were classified according to the International Classification of Diseases, version 10 (WHO, 1996). For analysis, deaths due to injuries or accidents were

not considered because these were not thought to associate with air pollution; therefore, we examined non-accidental, cardiovascular, and respiratory mortality (codes A00–R99 for total non-accidental mortality, I00–I99 CVD, and J00–J99 for RD).

Information about weather variables was supplied by the Japan Meteorological Agency, the Korea Meteorological Office, and the China Meteorological Data Sharing Service System; these included data on daily mean temperature ($^{\circ}\text{C}$), daily mean relative humidity (%), and daily mean atmospheric pressure (hPa; Japan and S. Korea only). For air pollution, we collected data on PM with an aerodynamic diameter $<10 \mu\text{m}$ (PM_{10}). We calculated the daily representative concentration value of PM_{10} for each metropolitan city by averaging the hourly values of all monitoring stations per metropolitan city to yield 24-h average PM_{10} concentrations. PM_{10} data were provided by the Japan National Institute for Environmental Studies, the Korea Research Institute of Public Health, and the Environmental Monitoring Center of China.

2.2. Statistical analysis

We applied two-stage Bayesian hierarchical statistical models to estimate the average associations of PM_{10} with daily mortality (Bell et al., 2008). In the first stage, we obtained city-specific estimates; in the second stage, we combined these estimates to generate national average estimates and account for their statistical uncertainty.

We investigated the potential patterns of interactions between PM_{10} and season on daily mortality while adjusting for other covariates. The shape of the dose-response relationship between PM air pollution and mortality is critical to this assessment; therefore, a smoothing spline function was adopted to capture the shape of the PM–mortality association. City-specific plots are presented in the supplementary material (Fig. S1). It was concluded that the relationship could be described using a linear model. Therefore, a linear model was used to assess the effect of PM_{10} on daily mortality.

We applied stratified time-series models to the data sets to examine whether the effects of PM_{10} on mortality were modified by the four seasons: spring, summer, fall, and winter. The effect of PM_{10} on daily mortality was first quantified within each season and at each location using a time-series model. We stratified the effect of PM_{10} on mortality according to the four seasons in each city. This approach allowed us to examine heterogeneity of the effects of PM_{10} across the season strata and provided a simple, quantitative comparison of the effect of mortality on PM_{10} in the different season strata. To analyze the effects of PM_{10} in these different season strata, we used a Poisson log-linear model and included the season strata for which it was assumed that the effect of PM_{10} on mortality was purely additive. Model (1) is described as follows:

$$\ln(E(Y_t^c)) = \alpha_c + \text{factor}(\text{season}_{t-i}^c) + \text{PM}_{10,t-i}^c : \text{factor}(\text{season}_{t-i}^c) + s(\text{temp}_{t-i}^c \text{df}) + s(\text{time}_t \text{df}) + \text{factor}(\text{DOW}_t) + s(\text{humid}_{t-i}^c) + s(\text{press}_{t-i}^c) \quad (1)$$

where t refers to the day of the observation; c is the city; i is the lag, $E(Y_t^c)$ is the estimated daily case counts on day t in city c ; $s()$ is the

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