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Air quality management policy and reduced mortality rates in Seoul Metropolitan Area: A quasi-experimental study

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ABSTRACT

Background: The air quality management policy was introduced in Seoul and Incheon metropolitan cities in the Republic of Korea, from 2005 to 2014. Despite particulate matter concentrations decreasing after policy implementation, the consequent health benefits have not been evaluated. Therefore, we evaluated the effects of the air quality management policy on cause-specific mortality rates in Seoul and Incheon.
Methods: Using interrupted time series analysis with a generalized Poisson regression model, we compared daily average mortality rates before (baseline, 2004–2005) and after (2006–2007, 2008–2009, 2010–2011, 2012–2013) the policy implementation. To account for the long term mortality trends, we weighted daily mortality rate of Seoul and Incheon with daily mortality rate of Daejeon (another metropolitan city with no air quality management policy implemented during the same period).
Results: Decline in the particulate matter concentration was greater in Seoul and Incheon than in Daejeon. After adjusting for potential confounders, there were 8% decrease in cardiovascular disease mortality rates and 10% decrease in cerebrovascular disease mortality rates in Seoul in 2012–2013 compared to the baseline period. In Incheon, an 8% reduction in cerebrovascular disease mortality rates in 2012–2013 was calculated. There was no change in mortality rates due to external causes or respiratory disease after policy implementation.
Conclusions: Our study suggests that the air quality management policy was effective in reducing cardiovascular and cerebrovascular mortality rates in Seoul and cerebrovascular mortality rates in Incheon.

1. Introduction

Air pollution is one of the major environmental health risk factors. The World Health Organization estimated that globally about 3 million deaths were attributable to ambient particulate matter less than 2.5 µm in diameter ($PM_{2.5}$) in 2012 (World Health Organization, 2016). Recent publication from Global Burden of Disease Group estimated that about 4.2 million deaths were attributable to ambient $PM_{2.5}$ in 2015 (Cohen et al., 2017). Therefore, many countries are implementing air pollution control and management plans as well as forecasting and warning systems to protect the public from air pollution (Clancy et al., 2002; Dockery et al., 2013; Han et al., 2018; Johnston et al., 2013; Medley et al., 2002; Yorifuji et al., 2016).

In 2002, annual particulate matter less than 10 µm in diameter (PM_{10}) and nitrogen dioxide (NO_2) concentrations in Seoul were higher than that of any other major cities in the Organization for Economic Co-operation and Development (OECD) countries (Korea Ministry of Environment (KMOE), 2005). Therefore, the government of the Republic of Korea legislated a special act named "Improvement of Air Quality in Seoul Metropolitan Areas (SMA, areas including Seoul and Incheon metropolitan cities, Gyeonggi province)" in December 2003 to improve air quality in SMA (Chae, 2010). The main focus of the first phase of air quality improvement plan for SMA (from 2005 to 2014) was to regulate the total amount of emissions in the workplace, to supply low-emission vehicles, and to strengthen gas emission management regulations (Korea Ministry of Environment (KMOE), 2005).

Following the special act, the Ministry of Environment announced basic plans for the first phase of the air quality improvement for SMA in November 2005 and established the annual PM_{10} and NO_2 concentration targets as 40 µg/m^3 and 22 ppb till 2014, respectively (Korea Ministry of Environment (KMOE), 2005). To follow the basic plan of the Ministry, each local government in Seoul and Incheon metropolitan

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cities and Gyeonggi province developed and implemented specific action plans to reduce PM_{10}, nitrogen oxides (NOx), sulfur oxides (SO_X), and volatile organic compounds (VOC_S) concentrations.

After the implementation of the first phase of air quality improvement plan, annual concentration of PM_{10} decreased to 45 μg/m^3 in Seoul (from 60 μg/m^3 in 2004) and 51 μg/m^3 in Incheon (from 61 μg/m^3 in 2004) in 2013. However, NO_2 concentrations remained similar in both cities (Seoul: 36 ppb in 2004 and 33 ppb in 2013; Incheon: 28 ppb in 2004 and 28 ppb in 2013), far from the initial target concentration (Hong, 2016). Based on the evaluation of prior policy measures of the first phase, the government adopted the second phase of the air quality improvement plan (from 2015 to 2024) for SMA (Korea Ministry of Environment (KMOE), 2013).

Although the Korean government announced the effectiveness of the first phase of air quality management plan based on the absolute reduction values of PM_{10} concentrations during the policy period, potential health benefits of the policy have never been evaluated. Therefore, using interrupted time series analysis with a control city without policy implementation, we evaluated the health effects of the first phase of the air quality improvement plan in Seoul and Incheon metropolitan cities by comparing mortality rates before and after policy implementation.

2. Materials and methods

2.1. Study design and study area

The air quality management policy was implemented in Seoul and Incheon metropolitan cities and several sub-regions of the Gyeonggi province. We selected Seoul and Incheon metropolitan cities as the intervention region for this study (Fig. 1) and evaluated the changes in cause-specific mortality rates before and after the implementation of the policy measures. Even though the special act was effective since January 1, 2005, the detailed measures and action plans were developed by the local government at the end of 2006. Therefore, we selected 2004–2005 as our baseline period and estimated the changes in mortality rate in 2-year intervals (2006–2007, 2008–2009, 2010–2011, 2012–2013) until 2013.

Interrupted time series design is a useful method in evaluating the effectiveness of an intervention or policy at the population level (Bernal et al., 2017). However, if there are other factors changing simultaneously with an intervention (e.g. other policies or changes in regional-level factors related to the study exposure and outcome), study results can be confounded. In addition, we cannot rule out the possibilities that the observed changes in outcome are from other national-level policies or from long-term trends in study outcome. Therefore, to minimize these problems and strengthen causal inferences, we added several features to the interrupted time series analysis. First, we selected a control city, Daejeon metropolitan city, where air quality management policy was not implemented during the study period. We hypothesized that the same relative changes in mortality rates observed in Daejeon would have occurred in Seoul and Incheon if there was no air quality management policy implementation. Therefore, additional relative changes in mortality rates in Seoul and Incheon compared to Daejeon represents the effectiveness of the air quality improvement plan for the SMA on the mortality rates. Second, we used secondary data to show that diverse factors associated with mortality showed similar patterns in both intervention and control cities throughout the study periods to minimize the possibilities of other regional factors which might affect mortality rate. Third, we selected deaths from external causes as reference outcome mortality with expectations that there might be no changes in mortality rates due to external causes after policy implementation. Lastly, we selected 2002 as an additional baseline period and estimated the changes in mortality rate in 1-year intervals (2003, 2004, 2005, and 2006) until the air quality management policy implementation, to show that there were no additional relative changes in mortality rates in Seoul and Incheon compared to Daejeon before the policy implementation.

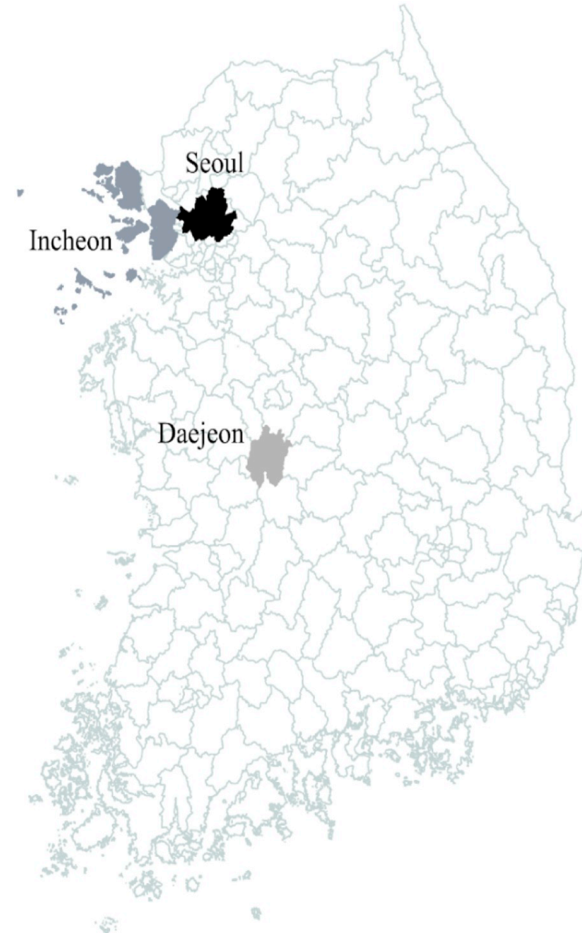

Fig. 1. Map of the study area including Seoul, Incheon, and Daejeon metropolitan cities.

Daejeon is one of the top five metropolitan cities of the Republic of Korea and is located closest to the cities of Seoul and Incheon. We selected the metropolitan city geographically nearest to Seoul and Incheon to increase the comparability because cities that are geographically near will be similarly affected by external factors of air quality, such as transboundary air pollution from neighboring countries. According to the National Statistical Office of the Republic of Korea, 9,631,482; 2,632,035; and 1,490,158 residents lived in Seoul, Incheon, and Daejeon cities in 2010, respectively (Statistics Korea, 2017b). Geographic locations and other basic characteristics of Seoul, Incheon, and Daejeon cities are shown in Fig. 1 and summarized at Supplemental Table S1 (see Table S1).

The institutional review board of the Seoul National University Hospital, the Republic of Korea, exempted this study from review because we used publicly available population and air pollution concentration data from the Korean Statistical Information Service and National Institute of Environmental Research, the Republic of Korea, respectively (IRB no. E-1801-001-909).

2.2. Mortality and population data

The mortality data of Seoul, Incheon, and Daejeon cities were obtained from the deaths registration database of Korean Statistical Information Service (Statistics Korea, 2017a). We obtained the information of date and primary cause of deaths to calculate the daily number of deaths due to the following eight mortality categories