Air quality management policy and reduced mortality rates in Seoul Metropolitan Area

A quasi-experimental study

Han, Changwoo; Lim, Youn-Hee; Yorifuji, Takashi; Hong, Yun-Chul

Published in:
Environment International

DOI:
10.1016/j.envint.2018.09.047

Publication date:
2018

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Han, C., Lim, Y-H., Yorifuji, T., & Hong, Y-C. (2018). Air quality management policy and reduced mortality rates in Seoul Metropolitan Area: A quasi-experimental study. *Environment International*, *121*(Part 1), 600-609. https://doi.org/10.1016/j.envint.2018.09.047

Environment International 121 (2018) 600–609

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

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

Changwoo Han[a], Youn-Hee Lim[b,c], Takashi Yorifuji[d], Yun-Chul Hong[a,b,c,*]

[a] *Department of Preventive Medicine, Seoul National University College of Medicine, Seoul, Republic of Korea*
[b] *Institute of Environmental Medicine, Seoul National University Medical Research Center, Seoul, Republic of Korea*
[c] *Environmental Health Center, Seoul National University College of Medicine, Seoul, Republic of Korea*
[d] *Department of Human Ecology, Graduate School of Environmental and Life Science, Okayama University, Okayama, Japan*

ARTICLE INFO

Handling Editor: Xavier Querol

Keywords:
Air quality
Policy
Mortality
Particulate matter
Quasi-experimental study
Interrupted time series analysis

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 Cooperation 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

---

[*] Corresponding author at: Department of Preventive Medicine, Seoul National University College of Medicine, 103 Daehangno, Jongno-gu, Seoul 110-799, Republic of Korea.

E-mail address: ychong1@snu.ac.kr (Y.-C. Hong).

https://doi.org/10.1016/j.envint.2018.09.047
Received 16 July 2018; Received in revised form 12 September 2018; Accepted 25 September 2018

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.

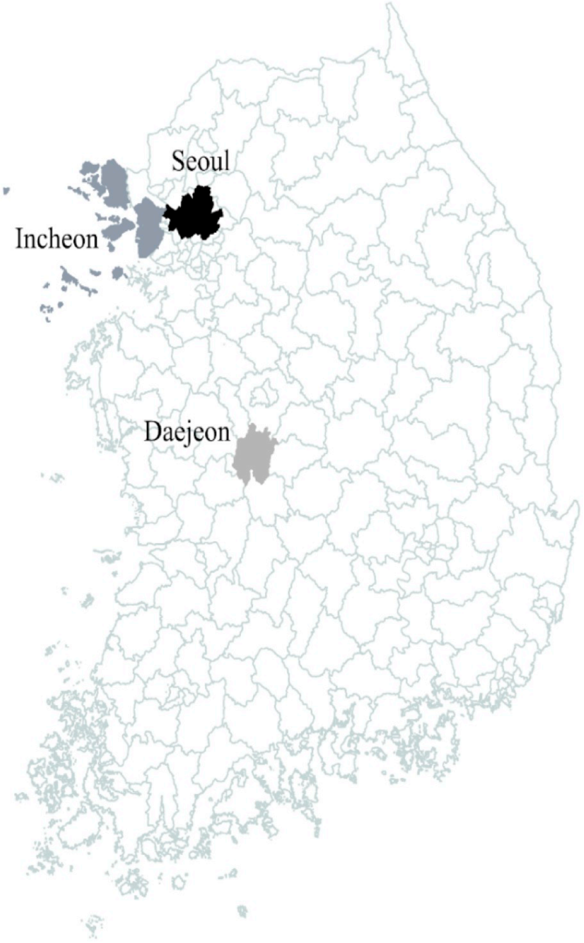

Fig. 1. Map of the study area including Seoul, Incheon, and Daejeon metropolitan cities.

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 (corresponding to *International Classification of Disease, 10th revision code*): (a) all cause (A00–A99), (b) cardiovascular disease (I10–I70), (c) ischemic heart disease (I20–I25), (d) cerebrovascular disease (I60–I69), (e) respiratory disease (J00–J99), (f) chronic obstructive pulmonary disease (J40-J44), (g) lung cancer (C33–C34), and (h) external causes (S00–T98). Categories (a) to (g) were selected based on prior studies suggesting their possible causal association between air pollution exposure and mortality (Clancy et al., 2002; Johnston et al., 2013; Medley et al., 2002; Yorifuji et al., 2016). Category (h) was selected as reference outcome because death due to external causes was hypothesized to be irrelevant to air pollutant exposure.

The annual mid-year population for different age groups (0–9, 10–19, 20–29, 30–39, 40–49, 50–59, 60–69, 70–79, and 80–) in Seoul, Incheon, and Daejeon were obtained from the resident registration data at the Korean Statistical Information Service (Statistics Korea, 2017b). We calculated daily cause-specific mortality rates for each age group by dividing the number of reported daily deaths by corresponding mid-year population. To compare mortality rates across cities and different time points, we calculated age-standardized mortality rates by summing daily mortality rates for each age group weighted by 2010 population census data of Seoul.

2.3. *Air pollution and meteorological data*

Daily average air pollution concentration levels (PM_{10}, NO_2, sulfur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3)) from 2002 to 2013 were obtained from the National Institute of Environmental Research, the Republic of Korea. Concentration of air pollutants were measured every 15 min at 27, 11, and 6 monitoring stations of Seoul, Incheon, and Daejeon, respectively (Lee et al., 2013). PM_{10} concentrations were measured using beta-ray absorption methods, while SO_2 and NO_2 were measured by pulse ultraviolet (UV) fluorescence and chemiluminescent methods, respectively. CO and O_3 were measured by UV non-dispersive infrared method and UV photometric method, respectively. Daily mean temperature (°C) and relative humidity (%) of Seoul, Incheon, and Daejeon were obtained from the Korean Meteorological Administration.

2.4. *Temporal trends of mortality related factors*

We selected Daejeon city as the control for our intervention cities (Seoul and Incheon) with the expectation that changes in the mortality rate in Daejeon may represent the changes in the mortality rate that would have occured in Seoul and Incheon if the air quality policy was not implemented. However, if other factors affecting mortality rates show different temporal trends across control and intervention cities, the internal validity of our study cannot be assured. Therefore, by using secondary data sources, we tried to prove that there were similar temporal patterns in health-related habits, obesity status, and medical service usage across the analyzed cities during our study periods.

We used results from the Korean Community Health Survey, which is the nationally representative survey conducted on 253 local districts of the Republic of Korea (Kim et al., 2012). This annual survey generates regional health-related statistics for the country since 2008. The city-specific smoking, drinking, and obesity prevalence, proportion of untreated patients, and influenza vaccination rates were assessed by self-reported questionnaire in this survey. Drinking rate refers to the proportion of individuals who had consumed any kind of alcoholic beverage during the preceding 12 months. Smoking rate refers to the proportion of individuals who had ever smoked more than 5 packs of cigarette and currently smoke very often or every day. Obesity rate refers to the proportion of individuals whose body mass index calculated by self-reported height and weight is 25 (kg/m^2) or higher. Proportions of untreated patients were calculated based on this question, "Were you unable to go to the hospital although you felt the need for medical use during the last 1 year?" Proportion of individuals with influenza vaccination was calculated by dividing the number of individuals who received influenza vaccination during the past 1 year by the total population. The city-specific smoking, drinking, and obesity prevalence, proportion of untreated patients, and influenza vaccination rates were age-standardized to compare different cities and different time points. Due to limited data availabilities, we were only able to evaluate temporal trends from 2008 to 2013. In addition, number of doctors per 1,000 population was determined from 2006 to 2013 by dividing the number of practicing physicians by resident registration population. All the data were obtained from the Statistics Korea homepage (http://kosis.kr/index/index.do).

2.5. *Statistical analysis*

We used an interrupted time series analysis with generalized Poisson regression models to evaluate health benefits of air quality management policy of SMA in Seoul and Incheon. We evaluated the changes in mortality rates in Seoul and Incheon by comparing the daily average mortality rates before (baseline period, 2004–2005) and after (2006–2007, 2008–2009, 2010–2011, 2012–2013) the air quality management policy implementation using the following equation:

$$\text{Daily Mortality Rate}_{\text{Seoul (or Incheon)}} \times (\text{Daily Mortality Rate}_{\text{Daejeon, 1 JAN,2004}}/\text{Daily Mortality Rate}_{\text{Daejeon}}) = \alpha_1\text{Period} + \delta_1(\text{Daily Humidity}_{\text{Seoul (or Incheon)}}) + \delta_2(\text{Daily Temperature}_{\text{Seoul (or Incheon)}}) + \delta_3(\text{DOW}) + \delta_4(\text{PHD}) + \varepsilon.$$

"Daily Mortality Rate" indicates cause specific age-standardized mortality rates for each region, "Daily Mortality Rate $_{\text{Daejeon, 1 JAN,2004}}$" represents age-standardized mortality rates in Daejeon at the beginning of the study period (January 1st, 2004), "Period" indicates a dummy variable for the study periods [2004–2005 (reference), 2006–2007, 2008–2009, 2010–2011, 2012–2013], "DOW" and "PHD" are dummy variables indicating the day of week and public holidays. We adjusted "Daily Humidity" and "Daily Temperature" by using smoothing function giving four knots for temperature and six knots for humidity. We could not adjust for influenza epidemics because the daily influenza data were not publicly available.

Proper adjustment for long-term background mortality trend is always challenging in interrupted time series studies. To disentangle the effects of policy implementation from other factors that affect mortality rates in Seoul and Incheon during the study period, we used mortality rates of Daejeon with the hypothesis that changes in Daejeon's daily mortality may represent changes in mortality rates that would have occurred in the intervention regions if there was no policy implementation (counterfactual scenario). However, directly adjusting for Daejeon mortality rates as a covariate in the analysis equation or smoothing Daejeon mortality rate and using it as a covariate might under- or overestimate the effect of the intervention (Dockery et al., 2013). Therefore in this study, we used weighting methods to adjust for the long-term secular trends in daily mortality rate in the control city by multiplying the daily mortality rates in Seoul and Incheon with the daily trends in age-standardized mortality rates of Daejeon (Daily Mortality $\text{Rate}_{\text{Seoul (or Incheon)}} \times (\text{Daily Mortality Rate}_{\text{Daejeon, 1 JAN,2004}}/\text{Daily Mortality Rate}_{\text{Daejeon}})$) (Yorifuji et al., 2016). In addition, because population residing in both intervention and control cities experiences same seasonal patterns of daily mortality, we may able to adjust effects of season by using weighting method. Because there were 0 values in cause-specific daily age-standardized mortality rates, we equally added a constant (2) to the age-standardized mortality rates of Seoul, Incheon, and Daejeon for our main regression analysis based on the following formula: ($\ln(a + 2) = \ln(a) \times \ln(2)$, where $\ln(2) \approx 1$).

We conducted several sensitivity analyses to show robustness of our estimates. First, we set 2004–2006 as another baseline period and evaluated the changes in mortality rate in 3-year time intervals (2007–2009, 2010–2012). Second, we adjusted long-term background mortality trends by directly adjusting age-standardized mortality rates of Daejeon as covariates or by using LOWESS smoothing of Daejeon mortality rate (windows of 90 days) as covariates in the model. Third, we selected different degrees of freedom for temperature and humidity (giving six knots for temperature and eight knots for humidity) or adding different constants (1 or 3) to the age-standardized mortality rates and repeated the same analysis. Fourth, we analyzed whether diverse factors (number of doctors per 1,000 population, smoking, drinking, obesity rates, proportion of untreated patients, and proportion of person with influenza vaccination) which may affect the mortality rates showed similar trends across Seoul, Incheon, and Daejeon metropolitan cities during the study period using secondary data sources. Last, we evaluated changes in mortality rate in 1-year intervals (2002, 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.

The level of statistical significance was set at a *p*-value of less than 0.05, and SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) and R statistical software (version 3.1.3; R Foundation for Statistical Computing, Vienna, Austria) were used for our analysis. Changes in mortality rates were presented as percent changes by multiplying 100 with rate ratio minus 1.

3. Results

Air pollution concentration trends during our study periods are shown in Fig. 2 (see Fig. S1 and Table S2). Although other pollutant showed similar patterns during the study period, PM_{10} concentration of Seoul and Incheon showed marked decreasing pattern since the 2006–2007 period compared to Daejeon. In Seoul and Incheon, PM_{10} concentration decreased by 16.33 μg/m^3 and 10.68 μg/m^3, respectively, in the 2012–2013 period compared to the 2004–2005 period (Seoul: 59.15 μg/m^3 in 2004–2005 and 42.82 μg/m^3 in 2012–2013; Incheon: 61.28 μg/m^3 in 2004–2005 and 50.60 μg/m^3 in 2012–2013). In Daejeon, PM_{10} concentration decreased by 8.10 μg/m^3 in the 2012–2013 period compared to the 2004–2005 period (Daejeon: 48.60 μg/m^3 in 2004–2005 and 40.50 μg/m^3 in 2012–2013).

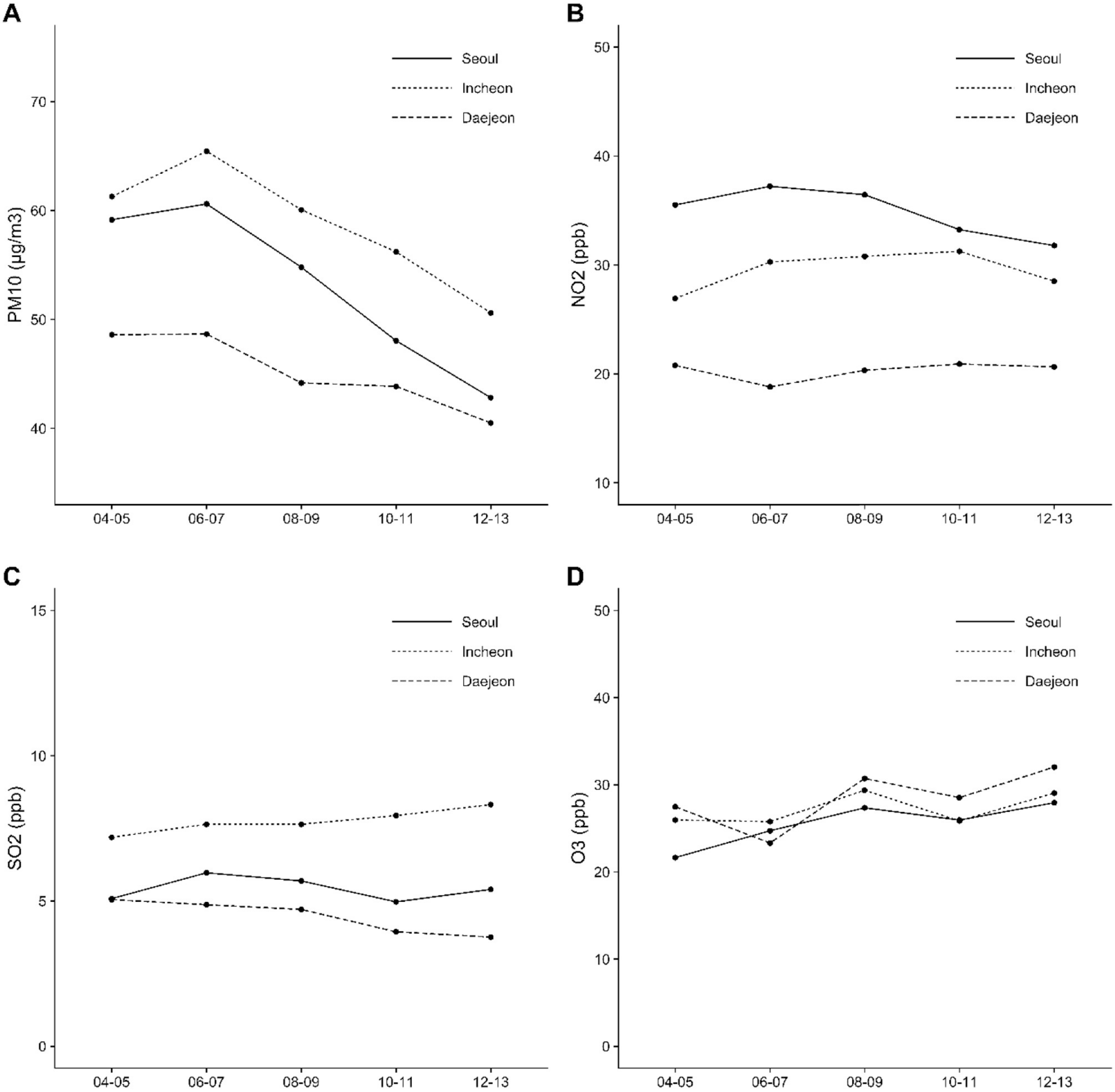

Fig. 2. Trends in air pollutant concentrations (A.PM_{10}, B. NO_2, C. SO_2, D. O_3) in Seoul, Incheon, and Daejeon metropolitan cities.

Table 1
Daily age-standardized mortality rate (per 1000,000 person) in Seoul, Incheon, and Daejeon. Study periods are separated by 2 year interval and baseline periods are between 2004 and 2005.

		Seoul		Incheon		Daejeon	
	Number of days	Daily average mortality rate (per 1,000,000 person)	Change from baseline	Daily average mortality rate (per 1,000,000 person)	Change from baseline	Daily average mortality rate (per 1,000,000 person)	Change from baseline
All cause							
2004–2005	731	11.76		13.83		12.98	
2006–2007	730	10.89	−0.87	12.68	−1.15	11.97	−1.01
2008–2009	731	9.8	−1.96	11.45	−2.38	10.98	−2.00
2010–2011	730	9.33	−2.43	11.04	−2.79	10.41	−2.57
2012–2013	731	8.96	−2.80	10.36	−3.47	9.79	−3.19
Cardiovascular disease							
2004–2005	731	3.28		3.89		3.53	
2006–2007	730	2.9	−0.38	3.66	−0.23	3.12	−0.41
2008–2009	731	2.38	−0.90	3.07	−0.82	2.80	−0.73
2010–2011	730	1.99	−1.29	2.85	−1.04	2.52	−1.01
2012–2013	731	1.8	−1.48	2.59	−1.30	2.15	−1.38
Ischemic heart disease							
2004–2005	731	0.72		0.79		0.87	
2006–2007	730	0.8	0.08	0.83	0.04	0.78	−0.09
2008–2009	731	0.6	−0.12	0.75	−0.04	0.66	−0.21
2010–2011	730	0.49	−0.23	0.83	0.04	0.58	−0.29
2012–2013	731	0.46	−0.26	0.67	−0.12	0.47	−0.40
Cerebrovascular disease							
2004–2005	731	1.95		2.45		2.07	
2006–2007	730	1.52	−0.43	2.21	−0.24	1.73	−0.34
2008–2009	731	1.18	−0.77	1.66	−0.79	1.38	−0.69
2010–2011	730	0.99	−0.96	1.35	−1.10	1.17	−0.90
2012–2013	731	0.87	−1.08	1.29	−1.16	1.07	−1.00
Respiratory disease							
2004–2005	731	0.76		0.91		1.00	
2006–2007	730	0.59	−0.17	0.76	−0.15	0.86	−0.14
2008–2009	731	0.58	−0.18	0.85	−0.06	0.89	−0.11
2010–2011	730	0.66	−0.10	0.95	0.04	0.84	−0.16
2012–2013	731	0.69	−0.07	0.89	−0.02	0.81	−0.19
Chronic obstructive pulmonary disease							
2004–2005	731	0.21		0.32		0.31	
2006–2007	730	0.18	−0.03	0.23	−0.09	0.24	−0.07
2008–2009	731	0.16	−0.05	0.24	−0.08	0.21	−0.10
2010–2011	730	0.14	−0.07	0.20	−0.12	0.18	−0.13
2012–2013	731	0.13	−0.08	0.20	−0.12	0.21	−0.10
Lung cancer							
2004–2005	731	0.72		0.91		0.81	
2006–2007	730	0.72	0.00	0.84	−0.07	0.84	0.03
2008–2009	731	0.65	−0.07	0.81	−0.10	0.74	−0.07
2010–2011	730	0.64	−0.08	0.79	−0.12	0.75	−0.06
2012–2013	731	0.66	−0.06	0.76	−0.15	0.70	−0.11
External causes							
2004–2005	731	1.36		1.76		1.79	
2006–2007	730	1.29	−0.07	1.63	−0.13	1.77	−0.02
2008–2009	731	1.31	−0.05	1.73	−0.03	1.63	−0.16
2010–2011	730	1.3	−0.06	1.62	−0.14	1.62	−0.17
2012–2013	731	1.15	−0.21	1.51	−0.25	1.47	−0.32

Table 1 shows the absolute changes in mean daily age-standardized mortality rate (per 1,000,000 population) in Seoul, Incheon, and Daejeon by 2-year intervals. There was absolute decrease in each of the mortality categories during the 10 years of study in Seoul, Incheon, and Daejeon. See Figs. S2 and S3 for the comparison in monthly trends in age-standardized mortality rates between Seoul–Daejeon and Incheon–Daejeon, respectively. Similar mortality trends were observed during the 2002–2005 period in eight mortality categories in Seoul, Incheon, and Daejeon before the air quality management policy implementation.

Table 2 shows changes in age-standardized mortality rates in Seoul and Incheon cities compared to the baseline period from 2004 to 2005. By weighting Seoul daily mortality rates with Daejeon's mortality rate and adjusting for other confounders, there were −8.3% (95% Confidence interval (CI), −12, −4.4) change in cardiovascular disease mortality rate and −9.8% (95% CI, −13.8, −5.6) change in cerebrovascular disease mortality rate in the 2012–2013 period compared to the baseline 2004–2006 periods. In Incheon, there was −7.9% (95% CI, −11.7, −3.9) change in cerebrovascular disease mortality rate in the 2012–2013 period compared to the baseline 2004–2006 periods. However, there was 6.1% (95% CI, 0.2, 12.3) increase in ischemic heart disease mortality rate in 2012–2013 period compared to the baseline period in Incheon. We did not observe any additional changes in mortality rates due to external causes or respiratory disease in Seoul and Incheon compared to Daejeon. See Fig. S4 for the monthly trends in age-standardized mortality rates of Seoul and Incheon weighted by Daejeon's mortality rate.

In the sensitivity analysis using different reference period (2004–2006), there was a −10.3% (95% CI, −13.3, −7.2) change in cardiovascular disease mortality and −7.7% (95% CI, −11.1, −4.3)

Table 2
Changes in age-standardized mortality rates in Seoul and Incheon metropolitan cities compared with the baseline period from 2004 to 2005.

	Seoul daily mortality rate	Seoul daily mortality rate weighted by Daejeon daily mortality rate and adjusted for other confounders[a]	Incheon daily mortality rate	Incheon daily mortality rate weighted by Daejeon daily mortality rate and adjusted for other confounders[a]
	% Change (95%CI)	% Change (95%CI)	% Change (95%CI)	% Change (95%CI)
All cause				
2006–2007	−6.4 (−9, −3.7)	−1.1 (−3.6, 1.4)	−7.3 (−9.7, −4.8)	−2.2 (−4.5, 0.2)
2008–2009	−14.3 (−16.7, −11.8)	−2.5 (−5, 0)	−15.1 (−17.3, −12.7)	−3.6 (−5.8, −1.2)
2010–2011	−17.7 (−20.1, −15.3)	−1.9 (−4.3, 0.7)	−17.7 (−19.9, −15.4)	−1.9 (−4.2, 0.5)
2012–2013	−20.4 (−22.7, −18)	−0.8 (−3.3, 1.8)	−22 (−24.1, −19.8)	−2.9 (−5.2, −0.6)
Cardiovascular disease				
2006–2007	−7.1 (−11.2, −2.8)	−1.5 (−5.4, 2.6)	−3.9 (−7.9, 0.3)	2.6 (−1.2, 6.5)
2008–2009	−17 (−20.8, −13)	−7.3 (−11.1, −3.5)	−13.9 (−17.6, −10.1)	−4.5 (−8.1, −0.7)
2010–2011	−24.3 (−27.9, −20.6)	−10.2 (−13.9, −6.5)	−17.7 (−21.3, −13.9)	−2.8 (−6.4, 1.1)
2012–2013	−28.1 (−31.5, −24.5)	−8.3 (−12, −4.4)	−22.1 (−25.5, −18.5)	−0.8 (−4.5, 3.1)
Ischemic heart disease				
2006–2007	2.9 (−3.3, 9.5)	4.6 (−1.2, 10.9)	1.6 (−4.5, 8)	3.3 (−2.4, 9.4)
2008–2009	−4.3 (−10.2, 1.9)	0.9 (−4.8, 7)	−1.6 (−7.4, 4.7)	4 (−1.7, 10.1)
2010–2011	−8.3 (−13.9, −2.3)	−1.9 (−7.5, 4)	1.2 (−4.8, 7.6)	8.4 (2.4, 14.7)
2012–2013	−9.5 (−15.1, −3.6)	0.2 (−5.5, 6.2)	−4.3 (−10.1, 1.8)	6.1 (0.2, 12.3)
Cerebrovascular disease				
2006–2007	−10.8 (−15.5, −6)	−4.7 (−8.8, −0.4)	−5.3 (−9.9, −0.5)	1.7 (−2.4, 6)
2008–2009	−19.4 (−23.7, −14.9)	−7.5 (−11.5, −3.2)	−17.6 (−21.7, −13.3)	−5.2 (−9.1, −1.2)
2010–2011	−24.4 (−28.5, −20)	−7.5 (−11.5, −3.3)	−24.7 (−28.5, −20.6)	−7.3 (−11.1, −3.3)
2012–2013	−27.3 (−31.2, −23.1)	−9.8 (−13.8, −5.6)	−25.9 (−29.7, −21.9)	−7.9 (−11.7, −3.9)
Respiratory disease				
2006–2007	−5.9 (−11.6, 0.2)	−2.9 (−9.7, 4.4)	−5 (−10.6, 1)	−2 (−8.7, 5.2)
2008–2009	−6.3 (−12, −0.3)	−4.5 (−11.2, 2.8)	−2.1 (−7.9, 4)	0.2 (−6.6, 7.5)
2010–2011	−3.4 (−9.3, 2.8)	−0.9 (−7.8, 6.5)	1.5 (−4.4, 7.7)	4.3 (−2.8, 11.8)
2012–2013	−2.5 (−8.4, 3.7)	0.1 (−6.9, 7.6)	−0.5 (−6.3, 5.7)	2.5 (−4.4, 9.9)
Chronic obstructive pulmonary disease				
2006–2007	−1.2 (−7.8, 5.9)	1.1 (−6, 8.7)	−3.7 (−10, 3.1)	−1.3 (−8.1, 6)
2008–2009	−2.2 (−8.7, 4.9)	0.8 (−6.3, 8.4)	−3.3 (−9.7, 3.5)	−0.3 (−7.2, 7)
2010–2011	−3.1 (−9.6, 3.9)	1 (−6.1, 8.6)	−5.3 (−11.6, 1.3)	−1.3 (−8.1, 6)
2012–2013	−3.7 (−10.2, 3.2)	−1.1 (−8.1, 6.4)	−5.3 (−11.5, 1.4)	−2.6 (−9.3, 4.6)
Lung cancer				
2006–2007	−0.3 (−6.3, 6.1)	−1.2 (−6.8, 4.7)	−2.4 (−8.1, 3.7)	−4 (−9.3, 1.6)
2008–2009	−2.7 (−8.6, 3.6)	−1.5 (−7, 4.4)	−3.5 (−9.2, 2.5)	−2.7 (−8, 2.9)
2010–2011	−3.2 (−9, 3.1)	−2.5 (−8, 3.4)	−4 (−9.7, 2)	−4 (−9.3, 1.6)
2012–2013	−2.5 (−8.4, 3.8)	−1.3 (−6.9, 4.6)	−5.2 (−10.8, 0.8)	−4.4 (−9.7, 1.1)
External causes				
2006–2007	−2.2 (−7.6, 3.4)	−1.4 (−7.5, 5)	−3.5 (−8.5, 1.8)	−3 (−8.6, 3.1)
2008–2009	−1.5 (−6.8, 4.2)	1.1 (−5.1, 7.6)	−0.8 (−5.9, 4.6)	1.8 (−4, 8.1)
2010–2011	−1.9 (−7.3, 3.7)	0.4 (−5.7, 6.9)	−3.7 (−8.8, 1.5)	−1.3 (−7, 4.8)
2012–2013	−6.2 (−11.4, −0.7)	−0.6 (−6.7, 5.9)	−6.5 (−11.4, −1.3)	−0.6 (−6.4, 5.5)

[a] Adjusted for daily temperature and humidity of Seoul (Incheon), day of week, and public holidays.

Table 3
Changes in age-standardized mortality rates in Seoul and Incheon metropolitan cities compared with the baseline period from 2004 to 2006.

	Seoul daily mortality rate	Seoul daily mortality rate weighted by Daejeon daily mortality rate and adjusted for other confounders[a]	Incheon daily mortality rate	Incheon daily mortality rate weighted by Daejeon daily mortality rate and adjusted for other confounders[a]
	% Change (95%CI)	% Change (95%CI)	% Change (95%CI)	% Change (95%CI)
All cause				
2007–2009	−10.7 (−12.7, −8.5)	−1.5 (−3.5, 0.5)	−11 (−12.9, −9)	−2.1 (−3.9, −0.1)
2010–2012	−16.9 (−18.9, −14.9)	−1 (−3, 1.1)	−17 (−18.8, −15.1)	−1.1 (−3, 0.8)
Cardiovascular disease				
2007–2009	−12.7 (−16, −9.4)	−6.7 (−9.8, −3.6)	−10.1 (−13.3, −6.9)	−4.5 (−7.4, −1.4)
2010–2012	−23.9 (−26.9, −20.9)	−10.3 (−13.3, −7.2)	−17.6 (−20.6, −14.6)	−3.4 (−6.4, −0.4)
Ischemic heart disease				
2007–2009	−3 (−7.8, 2)	−0.5 (−5.1, 4.3)	−0.9 (−5.8, 4.2)	1.5 (−3.1, 6.3)
2010–2012	−9.4 (−14, −4.6)	−3.2 (−7.7, 1.5)	−0.3 (−5.1, 4.9)	6.6 (1.8, 11.6)
Cerebrovascular disease				
2007–2009	−15.2 (−18.9, −11.4)	−6.9 (−10.2, −3.4)	−13.6 (−17.1, −9.9)	−5.1 (−8.2, −1.8)
2010–2012	−23.1 (−26.5, −19.5)	−7.7 (−11.1, −4.3)	−24.1 (−27.3, −20.8)	−8.7 (−11.8, −5.5)
Respiratory disease				
2007–2009	−4.5 (−9.3, 0.5)	−2.2 (−7.9, 3.8)	−2.2 (−7, 2.8)	0.3 (−5.4, 6.2)
2010–2012	−1.2 (−6.1, 4)	0.8 (−5, 7)	2.7 (−2.2, 7.9)	4.9 (−0.9, 11.1)
Chronic obstructive pulmonary disease				
2007–2009	−1.5 (−6.9, 4.2)	0.4 (−5.3, 6.6)	−2.2 (−7.5, 3.4)	−0.2 (−5.8, 5.8)
2010–2012	−2.6 (−8, 3.1)	0 (−5.8, 6.1)	−4.2 (−9.4, 1.3)	−1.6 (−7.2, 4.3)
Lung cancer				
2007–2009	−1.8 (−6.7, 3.4)	−1.6 (−6.2, 3.2)	−2.8 (−7.5, 2.1)	−3 (−7.4, 1.6)
2010–2012	−2.9 (−7.7, 2.2)	−2 (−6.5, 2.8)	−4.2 (−8.8, 0.7)	−3.7 (−8.1, 0.9)
External causes				
2007–2009	−0.8 (−5.3, 3.8)	1.4 (−3.7, 6.8)	−0.8 (−5, 3.6)	1.5 (−3.3, 6.6)
2010–2012	−2.5 (−6.9, 2.1)	0.5 (−4.5, 5.9)	−3.2 (−7.3, 1.2)	0.2 (−4.6, 5.2)

[a] Adjusted for daily temperature and humidity of Seoul (Incheon), day of week, and public holidays.

change in cerebrovascular disease mortality in the 2010–2012 period in Seoul. In Incheon, a −8.7% (95% CI, −11.8, −5.5) change in cerebrovascular disease mortality rate occurred in 2010–2012 compared to 2004–2006 reference period. Similar to our main analysis, we did not observe any decline in mortality rates due to external causes or respiratory disease in the analysis using the different reference period (Table 3).

By directly adjusting age-standardized mortality rates of Daejeon as covariates or by using LOWESS smoothing of Daejeon mortality rate (windows of 90 days) as covariates in the equation model, the effect estimates were higher than our main analysis (Table S3). Decline of cardiovascular and cerebrovascular mortality rate were observed in both analyses, which were similar to our main analysis. By giving different degrees of freedom to temperature and humidity or by adding diverse constants to the mortality rate, the results did not change substantially. By selecting 2002 as baseline period and estimating the changes in mortality rate in 1-year intervals (2002, 2003, 2004, 2005, and 2006) before the air quality management policy implementation, there were no additional relative change in mortality rates in Seoul and Incheon compared to Daejeon (see Table S4).

Fig. S5 shows the general trends in the regional city-specific factors which might affect mortality rates. The number of doctors per 1,000 population, obesity prevalence, and influenza vaccination rate showed similar trends throughout the study period across the intervention and control cities. There were slightly decreasing trends in the smoking rate and increase in drinking rate in Daejeon in 2011 compared with other cities. Proportion of untreated patients showed similar patterns between Seoul and Daejeon, but there was increasing trends in Incheon in 2009.

4. Discussion

In this study, we evaluated whether the implementation of air quality improvement plan of SMA was associated with decreased mortality rates in the region. There was marked decrease in annual PM_{10} concentration in Seoul and Incheon metropolitan cities during the policy period. By conducting interrupted time series analysis, we found decrease in cardiovascular and cerebrovascular diseases mortality after the air quality improvement plan implementation in Seoul. In case of Incheon, there was decrease in cerebrovascular disease mortality after policy implementation. About 960 fewer yearly cardiovascular disease deaths and 710 fewer cerebrovascular disease deaths observed in Seoul in 2012–2013 were estimated to be attributable to air quality management policy. In Incheon, about 200 fewer yearly cerebrovascular disease deaths observed in 2012–2013 were estimated to be attributable to air quality management policy.

To ensure validity of the findings, we used control city without policy implementation to evaluate the health effects of the air quality management policy. By weighting the daily mortality rate in the intervention city with the daily mortality rate in the control city, we adjusted for the long-term improvement of other factors (e.g. nationwide increase in the number of hospitals or doctors, improvement in medical quality, and application of new governmental medical policy) which might affect mortality rate other than air quality. As far as intervention and controls cities are comparable, we may have unbiased estimates regarding the health effects of air quality management policy. In addition, we used secondary data to show that diverse factors associated with mortality showed similar patterns in Seoul, Incheon, and Daejeon metropolitan cities during the study periods. In a sensitivity analysis conducted during the period before the policy implementation (from 2001 to 2006), we found no additional relative changes in mortality rates in Seoul and Incheon compared to Daejeon.

However, there are statistical concerns regarding adjustment of long-term mortality trends in time series studies. Although we used weighting methods suggested in recent study, there are no clear common strategies for adjusting background mortality trends in interrupted time series studies (Dockery et al., 2013; Yorifuji et al., 2016). Therefore, we cannot completely rule out the existence of bias, which may remain in our study results.

One of the particular findings of our study is different health benefit of policy across intervention cities. Although same air quality management policy was implemented, specific action plan was developed and implemented by each local government of Seoul and Incheon. Therefore, detailed policy measures and total amount of budget were different across Seoul and Incheon metropolitan cities, which might result in different policy effects on mortality.

Non-significant reductions in respiratory disease mortality rates after the policy implementation were unexpected. Although similar results were observed in air quality intervention study in three Israeli cities (Yinon and Thurston, 2017), direct comparison is limited because different measures were applied in our study. Rather, specific matters of Korea may explain this finding. For example, according to recent study from Korea, absolute number of deaths due to ambient $PM_{2.5}$ exposure were relatively higher in cerebrovascular disease compared to respiratory disease (year 2015, Seoul, Stroke: 847, Lung cancer: 367, COPD:60.9; Incheon, Stroke: 159.2, Lung cancer: 68.8, COPD:17.5) (Han et al., 2018). Therefore, corresponding decrease in mortality after decrease of air pollution levels may be bigger in cerebrovascular disease compared to respiratory disease.

Different degree of contribution of the emission sources on air pollution and changes in air pollution composition after the policy implementation may also explain particular findings of our study. Because city characteristics are different, contribution of industrial, area, road, and non-road sources on overall air pollution levels may be different between Seoul and Incheon. Therefore, even if identical measures were implemented, changes in air pollution levels and its composition may be differently occurred. A study suggesting an association between specific $PM_{2.5}$ components and cause-specific mortality in Seoul also supports this hypothesis (Son et al., 2012b). However, studies evaluating changes in air pollutant composition after the policy implementation and its effect on mortality are needed to confirm this hypothesis.

In addition, by analyzing air pollution and mortality data (from 2001 to 2015) of Seoul using time-series analysis, increase of PM_{10} concentration was associated with increase of all cause and cardiovascular disease mortality, but not respiratory disease mortality (Choi et al., 2018). Similar finding was observed in analysis with different time period (from 2000 to 2007) and method (case-crossover analysis) (Son et al., 2012a; Yi et al., 2010). However, these findings may results from small number of respiratory disease deaths and there are also a few studies in Korea which showed acute effect of air pollutants on diverse cause-specific mortality including respiratory disease (Hong et al., 1999; Kim et al., 2003). Therefore, non-significant reduction in mortality rates due to respiratory disease in our study needs further evaluation.

Diverse measures to improve air quality were implemented in the first phase plan of SMA (Chae, 2010; Korea Ministry of Environment (KMOE), 2005). Measures focused on the four major emission sources of air pollution: industrial, area, road, and non-road sources. Investing more than 2.7 billion US dollars within the 10-year policy period (2005–2014), Korean government aimed to decrease 39% of PM_{10}, SO_X, and VOCs; and 53% of NOx emissions of 2001 (Korea Ministry of Environment (KMOE), 2005). Major measures for industrial sources include application of total allowable emission systems in large facilities and installment of low NOx burners in small industrial sites (Korea Ministry of Environment (KMOE), 2013). For road emission sources, stringent emission control standards for new vehicles, distribution of low emission vehicles, and installment of emission reduction devices (e.g., Selective Catalyst Reduction and Diesel Particulate Filters) were conducted (Korea Ministry of Environment (KMOE), 2013). See Table S5 for the detailed air quality improvement measures and their explanations.

There was slight increase in PM_{10} concentration in Seoul and Incheon in the 2006–2007 period compared to the baseline 2004–2005 period. We believe this increase is from the delayed implementation of the policy measures. Although the first phase of air quality improvement plan was scheduled for the 2005–2014 period, a majority of measures were developed and implemented by the local governments at the end of 2006 (Seoul Metropolitan Government, 2015). For example, industrial complexes located at SMA complied with the total allowable emission system since July 1, 2007 (Gong et al., 2014). Relatively small amount of budget execution before 2007 also supports the time lag between policy legislation and actual implementation of diverse measures (Seoul Metropolitan Government, 2015).

There were relatively small but continuous decreases in PM_{10} and SO_2 concentrations in Daejeon compared to Seoul and Incheon. We believe this phenomenon is due to the national-level air quality policy measures during the study periods. For example, national level industrial emission limit values were revised every five years based on Clean Air Conservation Act during our study periods. Stricter emission controls of diesel vehicles at other metropolitan cities in Korea started from 2009, following previous management measures in SMA which was started from 2006 (Gong et al., 2014). In addition, spillover effects of improved air quality and increased cars with emission reduction devices in SMA might have affected decreasing PM_{10} and SO_2 patterns in Daejeon due to its close geographical location to SMA. Furthermore, there were overall countrywide decreasing trends in PM_{10} and SO_2 concentration throughout the study periods although the amount of decrease were smaller than for SMA (Hong, 2016). Regarding positive association between air pollution and its adverse health effects, slight decrease in PM_{10} and SO_2 levels in Daejeon metropolitan city may results in underestimation of the air quality management policy effect.

Compared to the large amount of decrease in PM_{10} concentration, there was a relatively small change in NO_2 concentration during the policy period. The Ministry of Environment suggested that limited application of NOx emission reduction technologies, and failure in application of stringent emission control standards for agricultural vehicles and traffic demand management policy were associated with relatively small decreases in NO_2 concentration during the policy period (Seoul Metropolitan Government, 2015).

There are several studies which evaluated the effectiveness of air pollution related policies or interventions for reduction of mortality rates. After banning coal sales in 1990 at Dublin, Ireland, a 35.6 $\mu g/m^3$ decrease in black smoke concentration was associated with a 15.7% decrease in respiratory disease, 10.3% decrease in cardiovascular disease, and 5.7% decrease in non-trauma mortality rates (Clancy et al., 2002). Hong Kong, by restricting sulfur contents of fuel oil in 1990, 44.7% decrease in sulfur dioxide concentration was associated with 2.1% decrease in all-cause mortality rate with 3.9% and 2.0% decrease for respiratory and cardiovascular disease mortality rates, respectively (Medley et al., 2002). From the community intervention for reducing ambient biomass smoke from domestic wood heaters in Launceston, Australia in 2001, a 5.3 $\mu g/m^3$ decrease in PM_{10} concentration was associated with a 11.4% decrease in the all-cause mortality rate, with a 17.9% and a 22.8% decrease in cardiovascular and respiratory disease mortality rates in men (Johnston et al., 2013). With diesel emission control in 2003 at Tokyo, Japan, a 8.2 $\mu g/m^3$ decrease in $PM_{2.5}$ concentration was associated with a 6.0% decrease in all-cause mortality rates, with an 11% decrease in cardiovascular disease, 10% decrease in ischemic heart disease, 6.2% decrease in cerebrovascular disease, 22% decrease in pulmonary disease, and 4.9% decrease in lung cancer mortality rates (Yorifuji et al., 2016). Air pollution control intervention regarding reduction of sulfur emission from power plants in three Israeli cities in 2002–2011 were associated with 13.3% and 19.0% decrease in cardiovascular and total mortalities (Yinon and Thurston, 2017). By summarizing both the previous study results and the findings from our study, we found that the impacts of population-level air quality policy interventions on mortality rates are considerably large. Therefore, national level policies regarding air quality management is crucial and should be adopted in both developed and developing countries to protect the public from adverse health effects of air pollution.

Several limitations should be noted for this study. First, air quality management policy was gradually implemented during our study period without clear cut points which shows abrupt decline in air pollution levels. This may result in exposure misclassification which might shift our effect estimates toward the null. However, even with such a limitation, we found significant results in our analysis. Similar problem appeared in previous study which evaluated health effects of diesel emission control in Tokyo, Japan (Yorifuji et al., 2016). Although regulation was gradually implemented in long term period (over 7 years), interrupted time series analysis with control region showed health benefit in major disease categories after the diesel emisson control.

Second, comparability issues between intervention and control cities may limit our study implication. In quasi-experimental studies, finding appropriate control city which represent counterfactual scenario (e.g., what if the outcome has changed without an intervention?) of the intervention region determines the internal validity of the study finding. Although we selected a similar urbanized metropolitan city located near Seoul and Incheon metropolitan cities and showed that several factors (number of doctors per 1,000 population, obesity prevalence, and influenza vaccination rate) which might affect the mortality outcome showed similar trends throughout the study period, there could be other factors which might have been overlooked. For example, although we reviewed major policy measures of our intervention cities to rule out the effects of other potential measures which might have changed simultaneously with the air quality management policy, there could be other regulations which might have been overlooked. In addition, the slight increase in ischemic heart disease mortality rate in Incheon after adjusting for the corresponding mortality rate in Daejeon is an unexpected result and needs further evaluation. Although similar results were not noted in the sensitivity analysis performed with different adjustment methods for long-term trends, the unexpected increases in the ischemic heart disease mortality rate in Incheon may arise from overlooked differences between intervention and control cities. Therefore, cautious interpretation is needed for our study results.

In addition, there was increasing trend in monthly alcohol drinking rate and slight decrease in smoking prevalence in Daejeon in 2011. Although we believe that the increase in alcohol drinking rate will attenuate the effect estimates of the policy, decrease in smoking prevalence of Daejeon in 2011 may lead to an overestimation of policy effects. Furthermore, due to limitations related to variables and the survey period of the Korean Community Health Survey, we were only able to evaluate trends in the possible mortality-related factors for limited variables and limited time periods (from 2008 to 2013). However, similar mortality trends in Seoul, Incheon, and Daejeon before the implementation of the policy supports the rationale for using Daejeon as control city for this analysis (see Table S4, Figs. S2 and S3).

Third, our study cannot tell with confidence that which of the policy measures were effective for reducing mortality rates. Diverse measures were implemented in the same time and we may not distinguish effects of each measure. Fourth, due to the limited monitoring data in Incheon and Daejeon, we were unable to confirm the changes in $PM_{2.5}$ levels in those metropolitan cities. Due to its small size, $PM_{2.5}$ can penetrate deep down into the small air ways and enters the bloodstream, causing significant health problems (Kim et al., 2015). Therefore, confirming the changes of $PM_{2.5}$ concentration and changes in mortality might lend support to our study findings in the future. However, we found similar trends in PM_{10} and $PM_{2.5}$ concentrations in Seoul, showing decreasing trends during the policy periods. In addition, modeled $PM_{2.5}$ concentration data (available from 2006) showed marked decrease in annual $PM_{2.5}$ concentrations in Seoul and Incheon compared to Daejeon, just as annual PM_{10} monitoring data (see Fig. S6) (Han et al., 2018). Fifth, because this study was conducted in the large urban settings in the Republic of Korea, we cannot expect to see the same amount of mortality reduction after same policy implementation in other countries or rural settings.

Lastly, we only focused on ambient air pollution and the changes in indoor air pollution were not evaluated in our study. However, our study site was highly urbanized metropolitan cities where proportion of population using solid fuels in house were extremely low (World Health Organization, 2013). In addition, household air pollution attributable deaths in Korea were 309 in year 2012, relatively lower than ambient air pollution attributable deaths (11,523) (World Health Organization, 2012a, 2012b). Therefore, we assumed that effects of indoor air pollution on mortality were very small during our study period.

5. Conclusion

Our results suggest that the air quality management policy was effective in reducing cardiovascular and cerebrovascular disease mortality in Seoul, and cerebrovascular disease mortality in Incheon. Despite of statistical concerns regarding adjustment of long-term mortality trends and comparability between Seoul, Incheon, and Daejeon, diverse sensitivity analysis in our study suggests possible association between air quality management policy and its potential health benefits.

Funding

This research was supported by the National Strategic Project-Fine particle of the National Research Foundation of Korea (NRF), funded by the Ministry of Science and ICT (MSIT), the Ministry of Environment (ME), and the Ministry of Health and Welfare (MOHW) [#2017M3D8A1092008 and #2017M3D8A1092009].

Declaration of interests

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2018.09.047.

References

Bernal, J.L., Cummins, S., Gasparrini, A., 2017. Interrupted time series regression for the evaluation of public health interventions: a tutorial. Int. J. Epidemiol. 46, 348–355.
Chae, Y., 2010. Co-benefit analysis of an air quality management plan and greenhouse gas reduction strategies in the Seoul metropolitan area. Environ. Sci. Pol. 13, 205–216.
Choi, Y., Kim, H., Lee, J.-T., 2018. Temporal variability of short term effects of PM10 on mortality in Seoul, Korea. Sci. Total Environ. 644, 122–128.
Clancy, L., Goodman, P., Sinclair, H., Dockery, D.W., 2002. Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. Lancet 360, 1210–1214.
Cohen, A.J., Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the global burden of diseases study 2015. Lancet 389, 1907–1918.
Dockery, D.W., Rich, D.Q., Goodman, P.G., Clancy, L., Ohman-Strickland, P., George, P., Kotlov, T., 2013. Effect of air pollution control on mortality and hospital admissions in Ireland. Res. Rep. Health Eff. Inst. 3–109.
Gong, S.-Y., Hong, S.-P., Ahn, G.-S., 2014. Impact of ELV Strengthening on Environmental Technology Development and Emission Reduction. Korea Environmental Institute (Research Report 2014-09).
Han, C., Kim, S., Lim, Y.-H., Bae, H.-J., Hong, Y.-C., 2018. Spatial and temporal trends of number of deaths attributable to ambient PM2.5 in the Korea. J. Korean Med. Sci. 33.
Hong, Y.D., 2016. Annual Report of Air Quality in Korea 2015. Sejong City, Ministry of environment.
Hong, Y.-C., Leem, J.-H., Ha, E.-H., Christiani, D.C., 1999. PM (10) exposure, gaseous pollutants, and daily mortality in Inchon, South Korea. Environ. Health Perspect. 107, 873.
Johnston, F.H., Hanigan, I.C., Henderson, S.B., Morgan, G.G., 2013. Evaluation of interventions to reduce air pollution from biomass smoke on mortality in Launceston, Australia: retrospective analysis of daily mortality, 1994–2007. BMJ 346, e8446.
Kim, H., Kim, Y., Hong, Y.-C., 2003. The lag-effect pattern in the relationship of particulate air pollution to daily mortality in Seoul, Korea. Int. J. Biometeorol. 48, 25–30.
Kim, Y.T., Choi, B.Y., Lee, K.O., Kim, H., Chun, J.H., Kim, S.Y., Lee, D.-H., Ghim, Y.A., Lim, D.S., Kang, Y.W., 2012. Overview of Korean community health survey. Journal of the Korean Medical Association/Taehan Uisa Hyophoe Chi 55.

Kim, K.-H., Kabir, E., Kabir, S., 2015. A review on the human health impact of airborne particulate matter. Environ. Int. 74, 136–143.

Korea Ministry of Environment (KMOE), 2005. Basic Plans for Air Quality Improvement Plan for Seoul Metropolitan Areas. Ministry of Environment.

Korea Ministry of Environment (KMOE), 2013. Basic Plans for Second Phase of Air Quality Improvement Plan for Seoul Metropolitan Areas (2015–2024). Ministry of Environment.

Lee, H., Kim, H., Honda, Y., Lim, Y.-H., Yi, S., 2013. Effect of Asian dust storms on daily mortality in seven metropolitan cities of Korea. Atmos. Environ. 79, 510–517.

Medley, A.J., Wong, C.-M., Thach, T.Q., Ma, S., Lam, T.-H., Anderson, H.R., 2002. Cardiorespiratory and all-cause mortality after restrictions on sulphur content of fuel in Hong Kong: an intervention study. Lancet 360, 1646–1652.

Seoul Metropolitan Government, 2015. Seoul Metropolitan Government Action Plan (2015–2019) to follow Second Phase of Air Quality Improvement Plan for Seoul Metropolitan Areas. Available at: http://opengovseoulgokr/public/8311812, Accessed date: 1 December 2017.

Son, J.-Y., Lee, J.-T., Kim, H., Yi, O., Bell, M.L., 2012a. Susceptibility to air pollution effects on mortality in Seoul, Korea: a case-crossover analysis of individual-level effect modifiers. Journal of Exposure Science and Environmental Epidemiology 22, 227.

Son, J.-Y., Lee, J.-T., Kim, K.-H., Jung, K., Bell, M.L., 2012b. Characterization of fine particulate matter and associations between particulate chemical constituents and mortality in Seoul, Korea. Environ. Health Perspect. 120, 872.

Statistics Korea, 2017a. MicroData Integrated Service Website. Available at: https://mdiskostatgokr/extract/extSimpleSurvSearchdo?curMenuNo=UI_POR_P1200, Accessed date: 22 October 2017.

Statistics Korea, 2017b. Statistical Database Website. Available at: http://kosiskr/statisticsList/statisticsList_01Listjsp?vwcd=MT_ZTITLE&parentId=A#SubCont, Accessed date: 22 October 2017.

World Health Organization, 2012a. Burden of Disease from Ambient Air Pollution, 2012. Global health observatory data.

World Health Organization, 2012b. Deaths from Household Air Pollution, 2012. Global health observatory data.

World Health Organization, 2013. Population Using Solid Fuels. Global health observatory data, pp. 2013.

World Health Organization, 2016. Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease. Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease.

Yi, O., Hong, Y.-C., Kim, H., 2010. Seasonal effect of PM10 concentrations on mortality and morbidity in Seoul, Korea: a temperature-matched case-crossover analysis. Environ. Res. 110, 89–95.

Yinon, L., Thurston, G., 2017. An evaluation of the health benefits achieved at the time of an air quality intervention in three Israeli cities. Environ. Int. 102, 66–73.

Yorifuji, T., Kashima, S., Doi, H., 2016. Fine-particulate air pollution from diesel emission control and mortality rates in Tokyo: a quasi-experimental study. Epidemiology 27, 769–778.