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The Impact of Air Pollution on Human Health in Suwon City

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ABSTRACT

Scientific evidence shows that ambient air quality is one of the major environmental issues related to human health. The aim of this paper was to provide quantitative data on the short-term impact of air pollution on the mortality and morbidity of people living in Suwon city. There are some studies that have conducted health impacts of the air pollution in Seoul, Korea. However, there are few studies of the health effects on air pollution conducted in satellite cities of the Seoul Metropolitan area. For this reason, we investigated the health effects of air pollution in Suwon city, one of the highly populated satellite cities of Seoul. In order to estimate the short-term mortality impact of air pollution, this study applied the approach suggested by the World Health Organization (WHO), using AirQ2.2.3 software. Daily concentrations of PM_{10}, O_3, NO_2, and SO_2 were used to assess human exposure and health effects, in terms of attributable proportion of the health outcome, annual number of excess cases of mortality for all causes, and cardiovascular and respiratory diseases. Among the four considered air pollutants, PM_{10} had the highest health impact on the 1,118,000 inhabitants of Suwon city, causing an excess of total mortality of 105 out of 4,254 in a year. Sulfur dioxide had the least health impact. Ozone and nitrogen dioxide each caused 42.7 and 81.3 excess cases of total mortality in a year. The results are also in line with those of other international studies that apply AirQ software.

Key words: Ambient air pollution, Health impact, Mortality, AirQ software, Suwon city

1. INTRODUCTION

Air pollution levels in many Asian cities, including Korea, remain well above WHO guideline values. In Korea, the annual mean PM_{10} should not exceed 50 $\mu g/m^3$ (limit values set in 2005), and it is requested to reduce $PM_{2.5}$ exposure in urban areas below 25 $\mu g/m^3$ by 2015 (legally binding value). These values still offer exposure to concentrations exceeding the WHO recommendations.

Many researchers have studied the impact of air pollution on human health, and have demonstrated links between air pollution and mortality (HEI, 2010; Pope and Dockery, 2006). According to a World Health Organization (WHO, 2006) assessment of the burden of disease due to air pollution, more than two million premature deaths each year can be attributed to the effects of urban outdoor air pollution and indoor air pollution. WHO estimated that urban particulate air pollution contributed to approximately 800,000 deaths and 6.4 million lost life years worldwide in 2000, with two-thirds of these losses occurring in Asia (Atkinson *et al.*, 2012). Several epidemiological studies also have reported associations between an increase in daily levels of ozone and particulate matter, and an increase of the mortality and hospital admissions predominantly related to respiratory and cardiovascular diseases (Pacel *et al.*, 2013).

There are some studies that have conducted health impacts of the air pollution in Seoul, Korea (Lee *et al.*, 2011; Yi *et al.*, 2010; Bae and Park, 2009; Lee *et al.*, 2007; Kim *et al.*, 2004). Kim *et al.* (2004) studied the threshold effect of ozone on daily mortality in Seoul. Lee *et al.* (2007) investigated the relative risk of mortality associated with Asian dust events in Seoul. Bae and Park (2009) investigated the short-term association between air pollution and mortality, and assessed the impact of improved air quality on mortality in a rapidly aging city, Seoul. Yi *et al.* (2010) examined the associations between PM_{10} concentrations, mortality and hospital admissions in Seoul for the periods 2000-2006 and 2001-2006. Lee *et al.* (2011) performed a health risk assessment based on an exposure response function, and evaluated the prospective damage costs of $PM_{2.5}$ inhalation in Seoul metropolitan city.

The Seoul metropolitan area is composed of many satellite cities, which have high population and vehicle densities. However, there are few studies of the health effects on air pollution conducted in satellite cities of the Seoul Metropolitan area. For this reason, we investigated the health effects of air pollution in Suwon city, one of the highly populated satellite cities of Seoul.

The Air Quality Health Impact Assessment Tool (AirQ) software was developed by the WHO European Centre for Environment Health, Bilthoven Division. The AirQ is specialized software that enables the user to assess the potential impact on human health of exposure to a given air pollution in a defined urban area during a certain time period, and has been applied in some recent studies (e.g. Naddafl *et al.*, 2012; Fattore *et al.*, 2011). According to the Health and Air Pollution in Asia (PAPA) study, although the social and environmental conditions may be quite different, it is reasonable to apply estimates derived from the previous health effect of air pollution studies in the West, to Asia in public (Wong *et al.*, 2008). So, in order to estimate the health effects of air pollution in Suwon city, AirQ software was used in this study.

2. MATERIALS AND METHODS

2. 1 Site Characterization and Air pollution Data

Suwon city is located about 40 km from the south of Seoul, and has a total area of about 121 km^2 (i.e. about 12 km × 12 km). Within the Metropolitan regions of Seoul, Suwon city presents the highest population, of about 1.18 million people, with about 9,589 hab km^{-2} of population density in 2011. From 1981 to 2010, the annual average temperature was around 12°C (with minima of about 7.5°C and maxima of about 17.2 °C) and the difference between warmer and colder months was around 28.5°C. The climate is considered continental climate with cold. Annual air humidity is about 69% with insignificant variations during the year, and the total annual precipitation is about 1312 mm, with more intensity in summer months. The prevailing wind is WNW during almost all of the year, and the mean wind velocity is around 1.7 m s^{-1} (Korea Meteorological Administration, 2011).

The Korean Ministry of Environment (MOE) sets National Ambient Air quality Standards (NAAQS) for seven common "criteria" pollutants (PM_{10}, O_3, Pb, CO, NO_2, Benzene and SO_2) at levels adequate to protect public health and the environment. A national network of air quality monitors measures the ambient levels of each pollutant, to determine if a community meets each of the seven NAAQS. Observations from this national network are also used to characterize trends in the daily and annual changes of these pollutants.

Suwon city has six fixed-site monitoring sites, which are controlled by the National Monitoring Network.

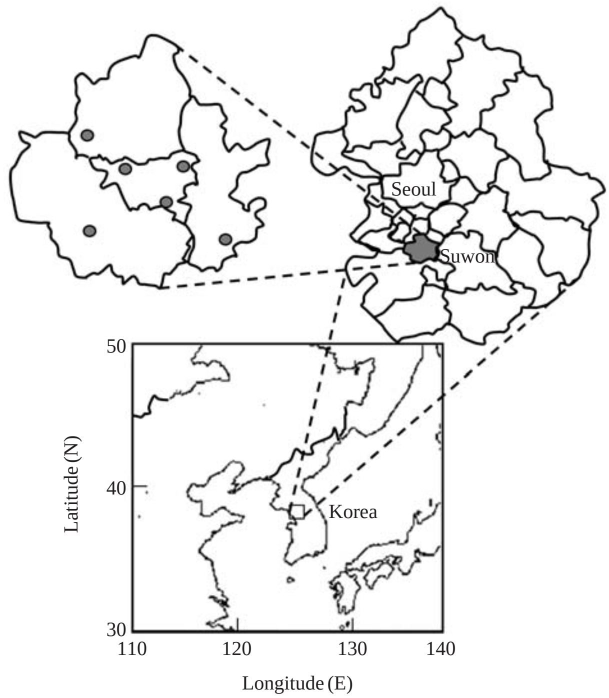

Fig. 1. Location of Suwon city (circles reveal fixed sampling positions of Suwon city).

The locations of the sampling sites in Suwon city are shown in Fig. 1. In this study, hourly air pollution data between January and December 2011 were obtained from six fixed monitoring sites, and used to evaluate the health effects on air pollution.

2. 2 AirQ Software

The Air Quality Health Impact Assessment Tool (AirQ) was developed by the WHO European Centre for Environment Health, Bilthoven Division, and proposed by the World Health Organization. The AirQ is specialized software that enables the user to assess the potential impact on human health of exposure to a given air pollutant in a defined urban area, during a certain time period. The assessment is based on the attributable proportion (AP), defined as the fraction of the health outcome in a certain population attributable to exposure to given atmospheric pollutant, assuming a proven causal relation between exposure and health outcome, and no major confounding effects in that association. According to the WHO (2006), the AP can be easily calculated by the following general formula:

$$AP = \sum \{[RR(c) - 1] \times \frac{p(c)}{\sum [RR(c) \times p(c)]} \tag{1}$$

Where, AP is the attributable proportion of the health

Table 1. Relative risk (RR) with 95% confidence intervals (95% CI), and corresponding reference, implemented in AirQ 2.2.3 software and used for the health effect estimates in this study.

Outcome	Health endpoint	Incidence[a]	Relative Risk (95% CI) per 10 μg/m^3			
			PM_{10} (Daily average)	O_3 (8 hr average)	NO_2 (1 hr average)	SO_2 (Daily average)
Mortality	Total ICM-9-CM[b] < 800	380.5	1.006 (1.004-1.008) (Anderson *et al.*, 2004)	1.003 (1.002-1.005) (Gryparis *et al.*, 2004)	1.003 (1.002-1.004) (Samoli *et al.*, 2006)	1.004 (1.003-1.0048) (WHO, 1999)
	Cardiovascular ICM-9-CM 390 -459	84.5	1.009 (1.005-1.013) (Anderson *et al.*, 2004)	1.005 (1.002-1.007) (Gryparis *et al.*, 2004)	1.004 (1.003-1.005) (Samoli *et al.*, 2006)	1.008 (1.002-1.012) (Burret & Doles, 1997)
	Respiratory ICM-9-CM 460 -519	28.8	1.013 (1.005-1.02) (Anderson *et al.*, 2004)	1.013 (1.007-1.015) (Gryparis *et al.*, 2004)		1.01 (1.006-1.014) (Burret & Doles, 1997)
Morbidity	HA[e] Respiratory Disease	1260	1.008 (1.0048-1.0112) (WHO, 2000)			
	HA Cardiovascular Disease	436	1.009 (1.006-1.013) (Touloumi *et al.*, 1996)			
	HA COPD[d]	101.4		1.0086 (1.0044-1.013) (Spix, 1997)	1.0026 (1.0006-1.0044) (Samoli *et al.*, 2006)	1.044 (1.0-1.011) (Spix, 1997)
	Acute myocardial infraction	132			1.0036[c] (1.0015-1.0084) (Anderson & Leon, 1996)	1.0064 (1.0026-1.0101) (Anderson & Leon, 1996)

[a]Crude rate per 100,000 inhabitants
[b]International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM).
[c]Daily average
[d]Chronic obstructive pulmonary disease
[e]Hospital Admission

outcome, RR is the relative risk for a given health outcome, in category "c" of exposure, obtained from the exposure-response functions derived from epidemiological studies, and p(c) is the proportion of the population in category "c" of exposure. If the baseline frequency of the health outcome in the population under investigation is known, the rate attributable to the exposure can be calculated as

$$IE = I \times AP \quad (2)$$

Where, IE is the rate of the health outcome attributable to the exposure, and I is the baseline frequency of the health outcome in the population under investigation. Finally, knowing the size of the population, the number of cases attributable to the exposure can be estimated as follows:

$$NE = IE \times N \quad (3)$$

Where, NE is the number of cases attributed to the exposure and N is the size of the population investigated.

RR gives the increase in probability of adverse effect associated with a given change in the exposure levels, and comes from time-series studies, where day-to-day changes in air pollutants over long periods were related to daily mortality, hospital admissions and other public health indicators (Fattore *et al.*, 2011).

RR values used in this study are shown in Table 1, and are based on the default WHO values in AirQ software. The RR values used for PM_{10} were summary estimates derived from a quantitative meta-analysis of peer-reviewed studies that focused on European in-

Table 2. Summary of concentrations of air pollutants, Suwon city (2011).

Pollutant	Average	Maximum	Minimum	98%	No. of data
PM_{10}, Annual 24 hr (μg/m^3)	52	278	5	149	365
O_3, Annual 8 hr (μg/m^3)	43	191	2	120	1096
NO_2, Annual 24 hr (μg/m^3)	75	169	12	146	365
SO_2, Annual 24 hr (μg/m^3)	15	44	3	32	365

vestigations (Anderson *et al.*, 2004). For O_3, SO_2 and NO_2, the RR values came directly from published studies on short-term effects within the APHEA project (Samoli *et al.*, 2006; Gryparis *et al.*, 2004). The baseline rates of the health outcomes were based on statistics available on-line from Statistic Korea (http://kostat.go.kr).

2. 3 Exposure Assessment

Air concentrations of PM_{10}, O_3, NO_2, and SO_2 were measured by six fixed-site monitoring sites, which are controlled by the National Monitoring Network in Suwon city. In this study, air pollutants data from January 2011 to December 2011 from the six stations were used. Exposure was estimated considering the city of Suwon as single agglomerate, with a residential population of 1,118,000 people.

For all the pollutants, the parameters required by the AirQ software (annual and seasonal maximum and annual 98th percentiles) were obtained, and concentrations were divided into 10 μg/m^3 categories, corresponding to equivalent exposure categories. For O_3, data were expressed as a 1 h average, and an 8 h moving average. For NO_2, data were expressed as both 1h and daily average concentrations, and PM_{10} and SO_2 as daily averages.

The software assumes that measured concentrations are representative of the average exposure of the people. For example, if 5% of sampling day concentrations were between 10 and 20 μg/m^3, it was assumed that people were exposed to the corresponding concentration for 5% of their time (Fattore *et al.*, 2011).

3. RESULTS AND DISCUSSION

Table 2 shows a summary of the statistics of pollutant data in Suwon city. The highest PM_{10} concentration was detected in the winter period, with a maximum value of 278 μg/m^3. The obtained results reveal that the daily average of PM_{10} in Suwon city was similar to the guideline values prescribed by the air quality guideline (50 μg/m^3) of WHO (2006). For O_3, the maximum 8 h average concentration was 191 μg/m^3, detected as expected in summer; this value was 1.9 times larger than the guideline value of WHO prescribed by the daily maximum 8-hour mean 100 μg/m^3 (WHO, 2006). The daily average NO_2 and SO_2 concentrations, respectively, were 75 (this value is larger than the WHO guideline of 40 μg/m^3) and 15 μg/m^3 (this value is smaller than the WHO guideline of 20 μg/m^3) were detected in the winter period.

Fig. 2 (a)-(d) illustrate the concentrations of various pollutants intervals, and the percentage of days in which people were exposed to these concentrations. These data were used to estimate the short-term effects.

The short-term health impacts of exposure to PM_{10}, O_3, NO_2 and SO_2 above a reference value of 10 μg/m^3 are shown in Tables 3 (PM_{10} and O_3), and 4 (NO_2 and SO_2). These impacts were estimated as the increase in all causes of cardiovascular and respiratory mortality for short-term exposure. For O_3, the numbers of excess cases over total mortality, cardiovascular and respiratory mortality (Table 3) were based on the RR values from the APHEA-2 project (Samoli *et al.*, 2006), which investigated the health effects of ambient O_3 in 23 European cities/areas for at least three years (Gryparis *et al.*, 2004). For NO_2, the estimated short-term effects (Table 4) are based on the pooled estimates for the increase in mortality associated with an increase of 10 μg/m^3 in 30 European cities participating in the APHEA-2 project (Samoli *et al.*, 2006).

In this study, PM_{10} had the greatest health impact on the 1,118,000 inhabitants of Suwon city, causing an excess of total mortality of 105.5 out of 4,254 people in a year. Recently, the AirQ software has been used by other investigators to assess the human health impact of PM_{10} (Naddafl *et al.*, 2012; Fattore *et al.*, 2011). Fattore *et al.* (2011) estimated the human health risk in relation to air quality in two municipalities in an industrialized area of Northern Italy, where the authors found that PM_{10} had a health impact on the 24,000 inhabitants of the two small towns, causing an excess of total mortality of 4.4 out of 177 in a year. Naddafl *et al.* (2012) provided a quantification of the short-term health effect of air pollutants for people living in Tehran, by using the WHO approach. They suggested PM_{10} had the greatest health impact on the 8,700,000 inhabitants of Tehran city, causing an excess of total mortality of 2,194 out of 47, 284 people in a year. These other results, if normalized to the population in Suwon city (1,118,000 inhabitants), would be shown to be

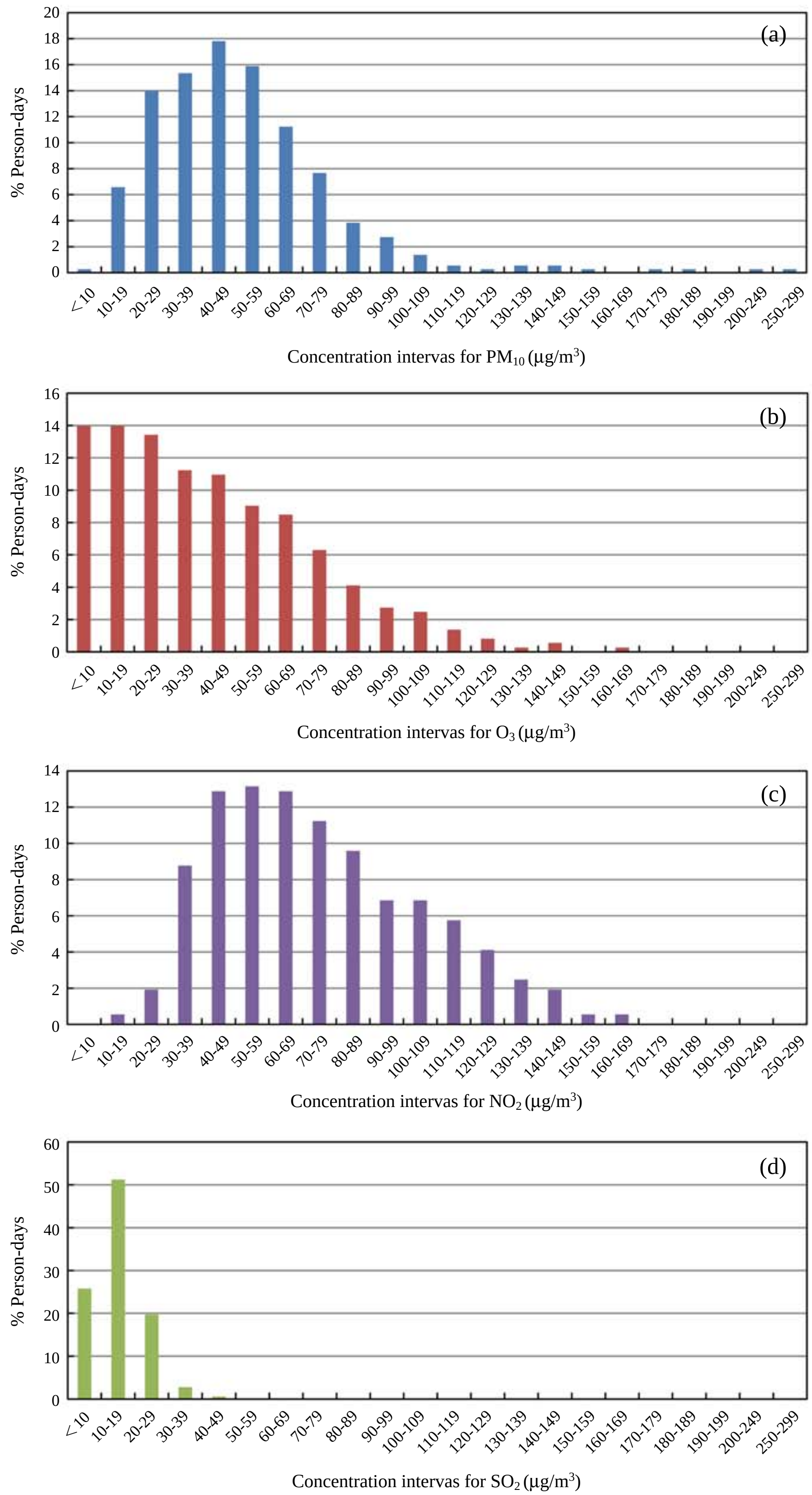

Fig. 2. Percentage of days on which people in Suwon city are exposed to different concentrations of (a) PM_{10}, (b) O_3, (c) NO_2, (d) SO_2.

Table 3. Estimated attributable proportion (AP) expressed as percentage and number of excess cases in a year due to short-term exposure above 10 μg/m^3 for PM_{10} and O_3.

Air pollution	PM_{10}		O_3	
Health end points	Attributable proportion (uncertainty range)	No. of excess case (uncertainty range)	Attributable proportion (uncertainty range)	No. of excess case (uncertainty range)
Total mortality	2.5 (1.67-3.28)	105.5 (70.9-139.5)	1.0 (0.67-1.66)	42.7 (28.6-70.8)
Cardiovascular mortality	3.7 (2.06-5.22)	34.7 (19.6-49.3)	1.7 (0.67-2.31)	15.7 (6.3-21.9)
Respiratory mortality	5.2 (2.06-7.81)	16.8 (6.7-25.2)	4.2 (2.31-4.83)	13.6 (7.4-15.6)
HA Res. Disease	3.3 (1.99-4.53)	462.0 (280.9-634.8)		
HA Car. Disease	3.7 (2.48-5.22)	179.1 (120.9-254.6)		
HA COPD			2.3 (1.47-4.21)	32.1 (16.6-47.8)
Acute Myocardial infraction				

Table 4. Estimated attributable proportion (AP) expressed as percentage and number of excess cases in a year due to short-term exposure above 10 μg/m^3 for NO_2 and SO_2.

Air pollution	NO_2		SO_2	
Health end points	Attributable proportion (uncertainty range)	No. of excess case (uncertainty range)	Attributable proportion (uncertainty range)	No. of excess case (uncertainty range)
Total mortality	1.9 (1.28-2.53)	81.3 (54.5-107.7)	0.3 (0.19-0.31)	10.9 (8.1-13.0)
Cardiovascular mortality	2.5 (1.91-3.14)	23.9 (18.0-29.7)	0.5 (0.13-0.76)	4.8 (1.2-7.2)
Respiratory mortality			0.6 (0.38-0.89)	2.0 (1.2-2.9)
HA Res. Disease				
HA Car. Disease				
HA COPD	1.75 (0.39-2.78)	18.8 (4.4-31.5)	2.8 (1.48-4.21)	32.1 (16.6-47.8)
Acute Myocardial infraction	2.3 (0.96-5.17)	33.7 (14.2-76.3)	0.4 (0.17-0.62)	6.0 (2.5-9.5)

1.7-1.8 times higher than those reported for PM_{10} in this study (Table 3). As other studies did, PM_{10} is the pollutant with the biggest health effects in the present study.

The effect of O_3 and NO_2 on total mortality was an excess of about 42.7, and 81.3 cases, respectively, in a year in Suwon city (about 1,180,000 inhabitants). In the Italian study, O_3 and NO_2 caused about 2.6 and 3.1 excess cases of total mortality (about 24,000 inhabitants), respectively; and the Tehran study (of about 8,700,000 inhabitants) showed 819 and 1,050 excess cases of total mortality for O_3, and NO_2, respectively. The O_3 impact on human health of Suwon city, if normalized to Suwon city, would result in about 0.67 and 0.59 times lower mortality than the two municipalities in industrialized northern Italy and Tehran, respectively. For NO_2, Suwon city was very similar to those reported in the northern Italian and Tehran study.

Although the results of this study are in line with those of other studies that apply AirQ software, this study has some limitations. One of the limitations of this study is that the health impact focuses on individual air pollutants, without considering the simultaneous exposure to several compounds, which is what actually occurs. The second limitation is that this study assumes that concentrations measured in fixed sampling points are representative of the average exposure suffered by people living in Suwon city. A further limitation is due to the RR estimates derived in studies of different populations, in comparison to the one under investigation. In particular, for PM_{10}, O_3, NO_2 and SO_2, the RRs were mainly based on studies on the European population.

4. CONCLUSIONS

This study illustrates a study case using the WHO approach to assess the impact of atmospheric pollution on human health for people living in Suwon city. The AirQ software and the approach proposed by the WHO provide quantitative data on the impact of PM_{10}, SO_2, NO_2 and O_3 on the health of people living in a certain area.

In spite of some limitations, the results of this study are generally consistent with those of other health impact studies that used AirQ software. Therefore, the results of this study are comparable to other city studies. Even though the magnitude of the health impact estimated for the city of Suwon is lower than for the two municipalities in an industrialized area of Northern Italy, and the capital city of Iran, the impact of air pollution on human health for people living in Suwon city reveals considerable amount in this study, there still remains the need for action to reduce the health burden of air pollution.

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