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Assessing the Health Benefits of the Seoul Air Quality Management Plan Using BenMAP

Jeongim Park† · Hyunjoo Bae
Korea Environment Institute
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Abstract: Health benefits from implementing air quality control measures were assessed using the Environmental Benefits Mapping and Analysis Program (BenMAP). BenMAP developed by US EPA is a GIS-based software tool that estimates the health impacts and associated economic values connected with changes in ambient air pollution. Once a set of BenMAP-required data was collected, the health benefits from implementing Seoul Air Quality Management Plan (SAQMP), an official AQ improvement plan for Seoul Metropolitan Area, was assessed using BenMAP. The PM10 concentrations assuming the SAQMP implemented successfully were predicted with the MM5 (Mesoscale Meteorological model version 5)/CMAQ (Community Multiscale Air Quality) model. A PM10 exposure related premature mortality function was adopted from a well-known epidemiology study. Economic valuation functions driven from benefit transfer methods were utilized. Through the SAQMP, PM10 concentrations were estimated to be lowered by 15 $\mu g/m^3$ to 75 $\mu g/m^3$ depending on air quality modeling grids. 5,569 premature deaths (95% CI 3,264~7,809 deaths) could be avoided in the Seoul Metropolitan Area. The economic value of the deaths avoided was estimated to \$13.2 billion (95% CI \$890 million~\$28.2 billion) using the benefit transfer value. BenMAP could be a useful tool for developing effective air quality improvement policy, enabling the policy makers to anticipate the effects of regulatory changes on people's health and the economy.

Keywords: health benefits, Seoul Air Quality Management Plan, BenMAP

Introduction

The deterioration of air quality from industrial activities and the soaring number of vehicles on the road is one of the most striking changes that Korea experienced during the past decades. In particular, air-related risks such as smog in major cities and serious health concerns including respiratory diseases and premature death called for immediate actions to be taken.

With a variety of air pollution reduction policies, the ambient concentrations of sulfur dioxide, carbon monoxide and lead in the Seoul Metropolitan area have steadily decreased during the last decade. However, due to the increasing vehicle and industrial activities, the ambient concentration of PM10 has not shown much improved.[1)] Many studies have reported that air pollution is strongly associated with the human health, and the adverse health effects of PM10 include an increased mortality,[2-6)] the aggravation of asthma,[7-10)] an increased number of patients with respiratory or cardiovascular diseases.[11,12)]

With clear indication that the population, vehicles, and energy consumption levels in the metropolitan area will increase continuously, existing control measures seemed insufficient to manage the air quality. To overcome such challenges, the Ministry of Environment developed the Special Measures for Seoul Metropolitan Air Quality Improvement, a landmark policy that stipulates emission standards, a total air pollution load management system, an emission trading system, the supply of low emission vehicles, and so forth. The plan has set its goal of PM10 at annual average of 40 ug/m^3 in 2014.[13)]

Benefit-cost analysis has played an important role in determining environmental policies. However, the process of analyzing benefits has a number of difficulties. One is the inherent uncertainty and variability in the approaches used in a benefit-cost analysis. Bearing the inevitable limitations, another weakness in analyzing benefits of policies is the time and resource that it takes between proposing a new policy and analyzing its benefits. To assist in the benefit-cost analyses of air pollution control policies, US EPA has developed a new Windows-

†Corresponding author : Korea Environment Institute
Tel. 82-2-380-7654, Fax. 82-2-380-7644
E-mail : jeongim@kei.re.kr

based software program. The Environmental Benefits Mapping and Analysis Program (BenMAP) is designed to provide a flexible tool for systematically analyzing the health impacts of changes in environmental quality in a timely fashion. US EPA has applied BenMAP in several recent regulatory impact analyses (RIA), including those for the proposed Clean Air Interstate Rule,[14] the final Clean Air Nonroad Diesel Rule,[15] and California's new 8-Hr Ozone standard.[16]

Recently in Korea, benefit analysis of an environmental policy has become a new consideration in the process of policy-making. Our study was designed to examine the practicability of adopting BenMAP for calculating the benefits of policy-related changes in air quality in Korea. We then presented the results of a sample analysis, Seoul Air Quality Management Plan. We limited this study to estimating and valuing the premature mortality impacts directly linked to ambient levels of PM10.

Materials and Methods

BenMAP

BenMAP developed by US EPA is a Geographic Information System (GIS)-based program that estimates the health benefits associated with air quality changes by creating population level exposure surfaces, estimating the changes in incidences of a wide range of health outcomes associated with ambient air pollution, and then placing an economic value on these reduced incidences.

Fig. 1 illustrates the major steps in BenMAP: population estimate, population exposure, adverse health effects, and economic values. BenMAP is built on data or functions placed in squares in Fig. 1. Once a set of necessary data and functions is ready, results from input data are generated as listed in circles in Fig. 1. BenMAP maps population data to air quality surfaces, which may be generated using either air quality monitoring data, modeling data, or a combination of the two. BenMAP creates air quality grids to estimate the average exposure to ambient air pollution of people living in some specified area or domain delineated by air quality models, as well as more irregular shapes such as political boundaries. It is assumed that all population in a given grid-cell is exposed to the same levels of air pollution. Typically, a BenMAP user creates both a baseline population exposure surface, reflecting current air quality conditions, and a control surface, reflecting air quality conditions after implementing a policy. The baseline and control population exposure surfaces generate changes in population exposure to ambient air pollution. These are then input to health impact functions to yield changes in incidence of health effects. Finally, the resulting health effects changes are then converted into monetary values.

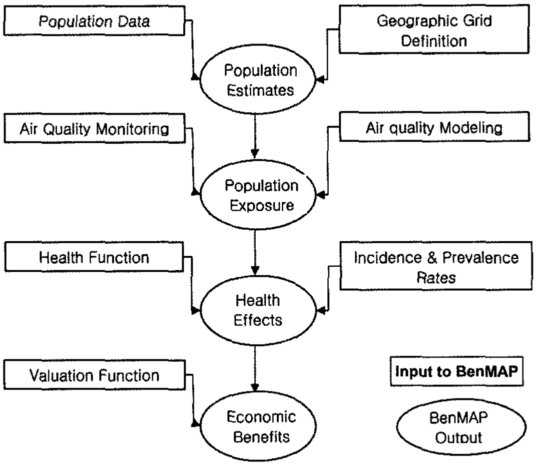

Fig. 1. BenMAP policy analysis framework.

Data Collection for Using BenMAP in Korea

US EPA's BenMAP includes large databases of population by race, gender and age, concentration-response functions and economic valuations of health impacts in US settings. In order to run BenMAP for air quality control policies in Korea, it is necessary to input relevant Korean-specific data: GIS shape files of target area, air quality monitoring or modeling data, population by political boundaries by age and gender, baseline incidence (or prevalence), concentration-response functions, and valuation functions.

Shapefiles of Seoul Metropolitan Area

Three levels of Shapefile grid were created using various political boundaries for the Seoul Metropolitan area, composed of three provinces, Seoul, Gyeonggi, and Incheon. Korea_emd Shapefile

Grid contains eup-myun-dong borders, for use with eup-myun-dong–based population data. "eup", "myun", or "dong" is the smallest administrative unit in Korea. Seoul consists of 522 "dong"s and the entire of Seoul Metropolitan area includes 1,033 units of "eup", "myun", or "dong". Korea_sgg Shapefile Grid is of "si", "gun", or "gu" that is the next level of administrative unit. Seoul has 25 "gu"s and the entire of Seoul Metropolitan area is composed of 53 units of "si", "gun", or "gu". Korea_sido Shapefile Grid contains province (Seoul, Gyeonggi, and Incheon) borders, for use in generating reports and maps with aggregated results to the province level.

Population Data

Population data of year 2001 were obtained from the National Statistical Office classified by age (5-year interval), gender, and the smallest administrative unit of eup-myun-dong.

Air Pollution Monitoring and Modeling Data

The air pollution monitoring data of year 2001 were obtained from the Korea Ministry of Environment's Air Quality System (through the National Institute of Environmental Research), a database of ambient air pollution data collected by the Ministry of Environment and local governments from >370 monitoring stations across the country. For this study, a part of the AQS data corresponding to Seoul Metropolitan area is required, which includes >60 monitoring stations. We processed the AQS data using SAS (release 8.0; SAS Institute Inc., Cary, NC) for the use in BenMAP.

PM10 concentration changes with implementing the SAQMP in 2014 were calculated with the MM5 (Mesoscale Meteorological model version 5)/CMAQ (Community Multiscale Air Quality) model, or widely accepted air quality modeling method. The MM5/CMAQ utilized CAPSS(Clean air policy support system) 2001 emission data, air quality monitoring, and meteorological data compiled in this study. The extended description on air quality modeling methodology can be found in elsewhere.[1]

Baseline Incidence and Health Impact Functions

Although US EPA's BenMAP provides an extensive list of concentration-response functions for various health end points and relating baseline incidence rates, they are not compatible for Korean population. Baseline mortality of Korean population aged over 30 was obtained from the National Statistical Office. It was applied for estimating benefits from long-term mortality changes as air quality improves.

Health impact functions measure the change in a health end point of interest, such as premature death, for a given change in PM10 and they are derived from the epidemiology studies. In this study, premature mortality from PM10 exposure was evaluated using Krewski *et al.*[17] values. Although the evidence of PM10-related health effects has been growing in Korea, most of the studies analyzed short-term effects on mortality and other health outcomes. A health impact function has four components – an effect estimate from epidemiologic studies, the estimated concentration change of pollutants, a baseline incidence rate for the health effect, and the affected population.[18,19]

$$\text{Health Impact Function} = -(\exp(-\text{Beta} \times (\text{Delta Q} \times \text{A}) - 1) \times \text{Incidence} \times \text{Pop} \quad (1)$$

Where,

Beta : 0.004625661, the effect estimate obtained from Krewski *et al.* epidemiology study that was PM2.5-related premature mortality health-impact function

Delta Q : the estimated change of PM10 concentration

A : 0.6, the Conversion factor accounting for PM2.5/PM10 ratio, NIER(2005)[20]

Incidence: 0.005054, the baseline incidence rate (mortality), Korea National Statistical Office

Pop : 11,967,690, the potentially affected population with age 30 and older, Korea National Statistical Office

Valuation Functions

Economic valuation functions driven from benefit transfer method and a CVM survey conducted in Korea were input to BenMAP. Table 1 presents Values of Statistical Life applied in this study.

Table 1. Values of Statistical Life (VSL) and function parameters used in this study (exchange rate 1$=1,000Won)

Valuation method	VSL(US $)	Distribution	Distribution parameters	
			P1	P2
Benefit transfer[21,22]	2,361,882	Weibull	1,986,877[a)]	1.509588[b)]
CVM[23]	482,3104	Normal	67,280[c)]	-

[a)]Scale parameter (α) of Weibull distribution.
[b)]Shape parameter (β) of Weibull distribution.
[c)]Standard error of normal distribution.

Results

In order to demonstrate the feasibility of adopting BenMAP in Korea, a sample application was considered. We analyzed the health benefits (limited to premature mortality) associated with PM10 by implementing the SAQMP. A set of required data, such as GIS ShapeFiles, population, baseline mortality, health impact function, and economic valuation function, was input to BenMAP as previously explained.

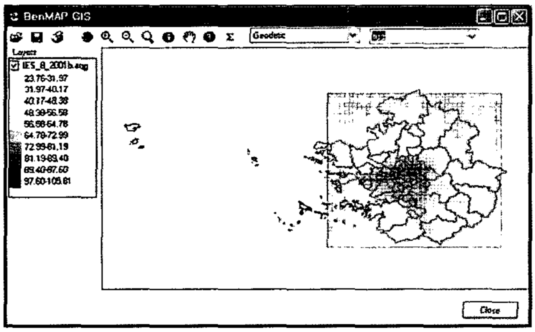

Fig. 2. Year 2001 PM10 modeling data.

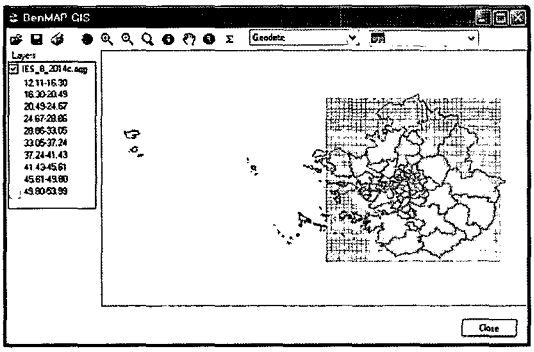

Fig. 3. PM10 modeling data from implementing the SAQMP (2014 Control).

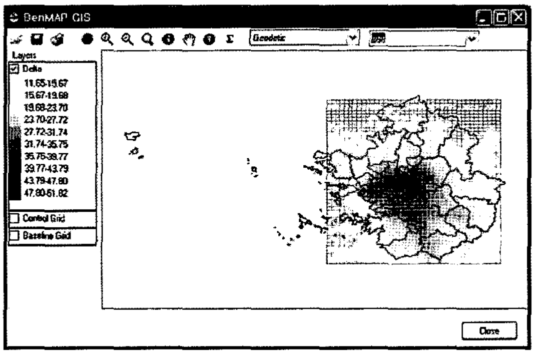

Fig. 4. PM10 concentration changes (ΔPM10) between 2014 Control and 2001.

PM10 Concentrations

To estimate PM10 exposure before and after implementing the SAQMP, this study used MM5/ CMAQ air quality modeling data, with a 3-kilometer by 3-kilometer resolution. Fig. 2, 3, and 4 display the base year (2001) modeling data, future year (2014) modeling data with implementing the SAQMP, and the resulting changes in PM10 between the base year and the future year. As a result of CMAQ modeling based on CAPSS 2001 emission data, PM10 concentrations were estimated ranged from 24 $\mu g/m^3$ to 106 $\mu g/m^3$ in the base year, 2001 (Fig. 2). The concentration levels were predicted ranged between 12 and 54 $\mu g/m^3$ in 2014 assuming the SAQMP is successfully implemented (Fig. 3). The changes in PM10 levels were between 12 and 52 $\mu g/m^3$ by grids (Fig. 4).

Reduced Premature Deaths from Implementing the SAQMP

Reduced premature deaths by grids from implementing the SAQMP were estimated from 0 to 113 lives (Fig. 5). PM10- premature mortality

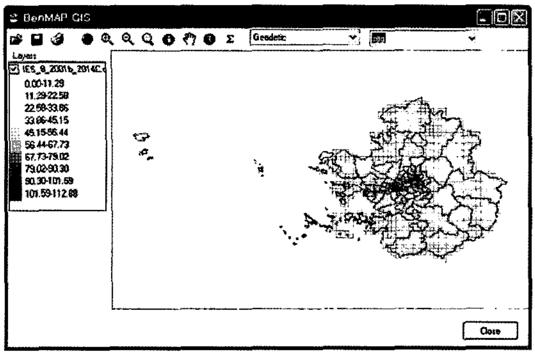

Fig. 5. Reduced premature deaths from implementing the SAQMP (2014Control-2001).

Table 2. Estimated PM10 associated annual health benefits of deaths avoided from implementing the SAQMP

Area	Lives to be saved (95% CI)	Economic values ($ million, 95% CI)	
		Benefit transfer	CVM
Seoul	2,871 (1,686~4,018)	6,802 (460~14,496)	1,389 (730~2,164)
Incheon	556 (326~782)	1,316 (89~2,819)	269 (140~421)
Gyeonggi	2,142 (1,252~3,009)	5,073 (342~10,854)	1,036 (542~1,622)
Total	5,569 (3,264~7,809)	13,191 (890~28,169)	2,694 (1,412~4,207)

relationship used in this analysis was a function derived from Krewski *et al.*'s study as explained previously. Reduced premature deaths results by air quality grids were converted to 2,871 lives in Seoul, 556 lives in Incheon, and 2,142 lives in Gyeonggi. Estimated lives to be saved were 5,569 (95% CI 3,264~7,809) as a total in Seoul Metropolitan Area by implementing the SAQMP.

Economic Benefit from Implementing the SAQMP

The economic value of the deaths avoided from implementing the SAQMP was estimated to $13.2 billion (95% CI $890 million~$28.2 billion) using the benefit transfer value. The value calculated using the VSL from the CVM study was $2.7 billion (95% CI $1.4 billion~$4.2 billion).

Discussion and Conclusion

Environment-related health effects have increasingly become a concern. Therefore, it is necessary to have tools to analyze the magnitude of the problem or the benefits that may be obtained by policies/measures to reduce the adverse effects. In recent years, US EPA's BenMAP has served as a useful tool in analyzing air policies in the US. This study was conducted to examine the applicability of BenMAP in Korean conditions. In particular, we have used it to estimate the benefits or reducing PM10 levels through the SAQMP in Seoul Metropolitan area.

Setting up BenMAP involves significant efforts and resources in the beginning, as the program requires an initial set of data such as GIS ShapeFiles, population data, baseline incidences, concentration-response functions, valuation functions, and so forth. Once it is setup, though, BenMAP offers the user with quick and flexible approaches to estimating air pollution exposure, the associated health effects, and the economic benefits of avoiding health effects. It also provides powerful mapping functions, the ability to characterize the uncertainty arising from the concentration-response functions and the valuation functions. BenMAP keeps track of the assumptions applied in the analysis, allowing users to examine the assumptions that others have made in their analyses.

Through the SAQMP, PM10 concentrations were estimated to be lowered by 15 $\mu g/m^3$ to 75 $\mu g/m^3$ depending on air quality modeling grid. Thanks to the lowered PM10, the reduced premature death was expected to be 5,569 (95% CI 3,264~7,809 deaths) comparing to those in 2001 base year. The economic value of the deaths avoided from implementing the SAQMP was estimated to $13.2 billion (95% CI from $890 million to $28.2 billion) using the unit value from benefit transfer studies. The estimated benefits from the SAQMP highlight the serious nature of air pollution. It also suggests the usefulness of providing easily accessible results to policy makers and stakeholders.

There are many sources of uncertainty that affect the final estimates during this study. These include the emission inventories, air quality models, estimates of the future emission, the deviation between the current and the future populations, estimates of health impact functions, and estimates of economic values per health effects. In addition, for some inputs, the necessary information is not available, particularly in Korea. Concentration-response function can be an example of lacking information in this study. Krewski *et al.*'s study result was adopted for this study based on the assumption that PM10-related mortality effects are the same among countries. Localization of concentration-response functions should be actively investigated in order to reduce the uncertainties.

The increasing need to understand the public health impacts of air pollution regulation requires the merging of data from many disciplines. With better characterization of uncertainties of the estimates and with developing better database and inputs, BenMAP could be a useful tool for developing effective air quality improvement policy, enabling the policy makers to anticipate the effects of regulatory changes on people's health and the economy.

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