Excess cancer risk and its damage cost due to indoor air pollution in Seoul

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ABSTRACT

We gathered exposure data on indoor air pollution and investigated the dose–response slope factor for indoor air pollutants, such as volatile organic compounds, aldehydes and radon. Population cancer risks (that is the theoretical cancer deaths) were estimated from exposure to the pollutants. In addition, the damage costs, due to their risks, were estimated using willingness to pay and value of a statistical life, which were investigated by a dichotomous contingent valuation method.

INDEX TERMS

Indoor air pollution; Excess cancer risk; Willingness to pay; Value of a statistical life; Damage costs

INTRODUCTION

As people are now spending over 90% of the day indoors, indoor air pollution has become an important problem. This is because indoor air cannot be purified as easily as outdoor air (MOE 2002). Moreover, it has been reported that indoor air in Seoul is significantly polluted, but there have been few health risk assessments associated with this problem, and therefore, no regulation for its management has been introduced. Moreover, there is little information with regard to cost–benefit analyses or policy priority setting for its risk management. Therefore, data were gathered by monitoring some indoor air pollutants that may be harmful to human health, their health risks and social damage costs estimated and finally preliminary information obtained for the management of indoor air quality in Seoul.

METHODS

We reviewed the Korean research results for the last seven years (IERY 1995–1998, 1998–2001) and then selected sufficient data on carcinogenic substances for the evaluation of quantitative risk assessments for these target chemicals. From the data collected, the indoor air pollutants were categorized into three groups: aldehydes, volatile organic compounds (VOCs) and radon. The aldehyde group included formaldehyde and acetaldehyde, and the VOCs included five chemicals: benzene, 1,2-dichloroethane, tri- and tetra-chloroethylene and carbon tetrachloride.

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The first indicator considered was theoretical cancer death, which was derived from dose–response assessment of the individual indoor air pollutants. Therefore, the annual population risk [= annual individual risk (= concentration × unit risk) × exposure population] was calculated as one of the final indicators. Although the sampling periods and numbers were different, the levels of indoor air pollution were assumed to be similar to those in Seoul at the present time. In addition, we estimated both the point estimate risks, using the mean concentration values only, and the risk ranges, using a probability distribution, in order to consider the uncertainties associated with the concentrations. Cancer slope factors were obtained from animal and epidemiological data (IERY 1998–2001; IRIS 2002). We tried to apply the values for the major exposure parameters to those of Koreans for the modified unit risks—body weight, 60kg; breathing rate, 20 m^3/day; life expectancy, 70 years—in order to reflect the inherent characteristics of Koreans (IERY 1998–2001). The concentrations and unit risks used to estimate the risks are presented in Table 1.

Table 1 Theoretical cancer deaths due to indoor air pollutants in Seoul

Sub-problems	Chemicals	Mean conc.	Unit risk[1]	Annual individual risk	Annual population risk	Population risk			RC[2] (%)
						Point	50 percen-tile	95 percen-tile	
Aldehydes[3,4] (μg/m^3)	Formaldehyde	81.75	1.52E–05	1.78E–05	135.8	148.4	125.6	406.7	15.7
	Acetaldehyde	44.76	2.57E–06	1.64E–06	12.6				
VOCs[2,3,4] (μg/m^3)	Benzene	4.05	9.57E–06	5.54E–07	4.24	5.4	4.4	17.1	0.6
	Carbon tetrachloride	0.13	4.33E–05	8.04E–08	0.62				
	Trichloroethylene	1.79	1.64E–06[5]	4.19E–08	0.32				
	Tetrachloroethylene	2.42	6.74E–07[6]	2.33E–08	0.18				
	1,2-Dichloroethane	0.02	3.03E–05	8.22E–09	0.06				
Indoor radon[4,7] (pCi/L)	Radon	1.22	5.92E–03[8]	1.03E–04	788.0	788.0	434.2	2,554.8	83.7
Total	—	—	—	—	941.8	941.8	616.3	2,726.7	100.0

[1]IRIS (2002).
[2]VOCs, volatile organic compounds; RC, relative contribution.
[3]IERY (2002).
[4]$p < 0.05$ (comparison among the theoretical cancer death estimates of agent classes), ANOVA.
[5]IERY (1995-1998).
[6]Calabrese and Kenyon (1991).
[7]MST (2002).
[8]NRC (1999).

We assumed the annual risk to be equal to the lifetime risk divided by the life expectancy (US EPA 1993). The population of exposed persons was 7,651,408 (NSO 2001), this being the number of adults over 20 years of age in Seoul. A cancer with chronic effects was selected as the target for its effects. The risks of sub-problems were assumed to be equal to the summation of the risks for the individual chemicals, as in Eqn (1) below (US EPA 1993).

$$\mathrm{TCD} = \sum[\mathrm{IR}_{ij} \times \mathrm{EP}_{ij}] \qquad (1)$$

TCD = theoretical cancer death
IR = individual risk
EP = exposed population
i = ith sub-problem
j = individual chemical

The willingness to pay (WTP) was surveyed for the reduction in risk (annually Δ5/10,000 risk reduction of cancer death) of indoor air pollution via individual interviews of 200 Seoul inhabitants. We developed an investigation tool and questionnaire to derive the WTP and estimated the WTP employing the developed model, using a contingent valuation method (CVM). With our model, initial bids of 10,000, 20,000, 40,000 and 60,000 won derived from pre-tests were used, in order to prevent a starting point bias that often exists in referendum models. A double-bounded dichotomous choice (DBDC) method and a contribution as payment vehicle were used. Three types of statistical model were used to obtain the mean WTPs, these being: the lower-bounded Turnbull, dichotomous Weibull and Spike models. The WTP for indoor air pollutant was assumed to be the same for each sub-problem. The value of a statistical life (VSL, $=\mathrm{WTP} \div \Delta\text{risk reduction}$) and damage costs (= theoretical cancer death × VSL) were then estimated, and the 50 and 95 percentiles of damage costs were predicted by an uncertainty analysis.

RESULTS

For the human health risk, the sub-problem priorities were ranked in the order radon, aldehydes and then VOCs. From multiple comparisons, the mean risk estimates between the sub-problems were found to be statistically significant. The annual individual risks of radon and formaldehyde exceeded 10^{-5}, and the annual population risks of these two were also much higher than the other chosen chemicals (Table 1).

We estimated the median WTP from the three models (Turnbull, Weibull and Spike) to derive the VSL. The WTPs of the three models were 16,900, 19,900 and 20,600 won, respectively, and the VSLs from these WTPs were 406, 477 and 495 million won, respectively. At this time, the Akaike information criterion (–2log likelihood) for the Weibull model gave the best estimation of the WTP of the three models, and so the estimated damage costs were calculated using the estimated WTP and VSL from this model. The 50 percentile health damage costs of the radon, aldehydes and VOCs were about 209, 60 and 2 billion won, respectively (Table 2).

Table 2 Health damage costs on indoor air pollution

Sub-problems	Health damage cost (billion ₩)[1]			Health damage cost (million $)			Health damage cost (million euros)		
	Mean	50 percentile	95 percentile	Mean	50 percentile	95 percentile	Mean	50 percentile	95 percentile
Aldehydes	85.2	59.9	238.5	68.1	47.9	190.8	65.5	46.1	183.5
VOCs	3.3	2.1	9.6	2.6	1.7	7.7	2.5	1.6	7.4
Radon	407.6	208.7	1,370.4	326.0	167.0	1,096.3	313.5	161.5	1,054.1

[1] 1$=1,250₩; 1euro = 1,300₩ (The Bank of Korea 2002).

DISCUSSION

Not all the problems of indoor air pollution were managed, and the results in this study are unlikely to be sufficient to evaluate the status for a specific community such as Seoul, but we tried to consider the important pollutants directly associated with human health. Hereafter, there will be the need to gather more current data, and further analysis of the important environmental pollutants, or sub-problems, in Seoul will be required.

When estimating the human health risk, the uncertainties were analyzed due to a problem in the representation of the measured concentration data. That is, theoretical cancer deaths were estimated using probability distributions and point estimates, and were likely to be lognormal according to the measured concentration distribution, as pollutants in the environment have been reported to usually be distributed as a lognormal type (US EPA 1996). We assumed that the distribution was lognormal (in this, mean and standard deviation were from measured data), and so analysed the uncertainties in the chemical concentrations using a Monte Carlo simulation.

In the risk characterization step, obtaining specific exposure information, such as exposure levels and exposure population for detailed areas, was very difficult, and so we assumed the exposure population to be the entire adult population of Seoul over 20 years of age.

Because we assumed the effects of the individual substances to have an additive interaction, the theoretical cancer deaths may have been overestimated. However, an assumption of an additive reaction is usually chosen in policy making as it is too difficult to account for all the chemical interactions and the synergy or antagonism of these interactions (US EPA 1993).

In the economic risk assessment, the WTP and VSL, derived from the Weibull model, as they were the best in this study, were compared with Krupnick's study (Krupnick *et al*. 2000) in relation to the mortality risk reductions from environmental pollution. The VSL in our study was 0.3–0.5 billion won compared with 0.9–1 billion won (the values were Canadian dollars converted to Korean won using the benefit transfer method)(Pearce and Howarth 2000) in Krupnick's, so our estimated VSLs were about two to three times lower. The differences between the two studies were the initial bid amounts, sample sizes and variables in the estimation model. There is a need to increase the sample size and reanalyse the new data for more reliable results.

In addition, compared with Choi's study (Choi 2000), the VSLs for car accidents and radiation exposure were different for employees in nuclear power plants and the general public. The VSLs for car accidents and radiation exposure for the employees in the nuclear industry were 2.4 and 3.9 billion won, respectively, compared with 5.4 and 4.2 billion won, respectively, for the general public. Choi's results were about 10 times higher than the VSL in this study, which was assumed mainly to be as a result of the differences in the target problems.

Uncertainties may occur whenever estimating theoretical cancer death and WTPs. Because it is impossible to account for all the uncertainties in every procedure, the uncertainties continuously need to be reduced after investigating and gathering reliable data. It is also better to use this type of result as an indicator for developing effective environmental policy and management than to emphasize quantitative results.

CONCLUSION AND IMPLICATIONS

As a priority for human health risks and damage costs, management strategies are required for both radon and formaldehyde as indoor air pollutants. When the numeric results of human risks and damage costs are applied for other purposes, some assumptions and uncertainties have to be considered to use the results as useful screening tools for the administration of practical risk-based priorities. In addition, we continuously need to reduce the uncertainties and validate the exposure and WTP data obtained from these processes to get more reliable results.

ACKNOWLEDGEMENTS

This study was funded by a grant from the Core Environmental Technology Development Project, the Ministry of Environment of Korea.

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