Application of DALYs in Measuring Health Effect of Ambient Air Pollution: A Case Study in Shanghai, China[1]

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Objective To investigate the effect of ambient air pollution on human health and the subsequent disability-adjusted life years (DALYs) lost in Shanghai. **Methods** We used epidemiology-based exposure-response functions to calculate the attributable number of cases due to air pollution in Shanghai in 2000, and then we estimated the corresponding DALYs lost in Shanghai based on unit DALYs values of the health consequences. **Results** Ambient air pollution caused 103 064 DALYs lost in Shanghai in 2000. Among all the health endpoints, premature deaths and chronic bronchitis predominated in the value of total DALYs lost. **Conclusion** The air pollution levels have an adverse effect on the general population health and strengthen the rationale for limiting the levels of air pollution in outdoor air in Shanghai.

Key words: Air pollution; Human health; DALYs

INTRODUCTION

Epidemiologic researches during the past 10-20 years confirmed that exposure to air pollution contributes to both mortality and morbidity in China or worldwide. The health consequences associated with air pollution include respiratory symptoms, reduced lung function, increased hospital admission, chronic bronchitis, and mortality, *etc*. Among the air pollutants, particulate matter measured as either total suspended particle (TSP), particulate matter less than 10 microns (PM_{10}), particulate matter less than 2.5 microns ($PM_{2.5}$), or black smoke appears to show the most consistent association with the outcomes.

As evidence of the adverse health effects of air pollution has accumulated, quantification of the impact of air pollution on public health and the subsequent cost-benefit analysis have become critical in policy decision-making. In fact, several studies have estimated the health damage due to air pollution both in physical and monetary terms[1-2], highlighting the impact of air pollution on public health.

Disability-adjusted life years (DALYs) are a standard measure of the health hazard. The concept combines life years lost due to premature death and fraction of years of healthy life lost as a result of illness or disability, thereby providing an aggregate measure to reduce all air pollution-related health effects to one denominator.

Urban air quality has become a serious public health concern. The global annual deaths due to air pollution are estimated to be more than 2.7 millions accounting for approximately 33% in cities[3]. In Shanghai more than 13-million residents are exposed to a particulate matter (PM) level greatly exceeding the normal population exposure level in the Western countries. As a case analysis, the present study was to express the health effect of ambient air pollution in DALYs.

METHODS

Air Pollutant Concentrations

MARKAL (market allocation) optimization

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model was used for estimation of pollutant emissions in Shanghai in 2000. MARKAL is a dynamic linear programming model that optimizes a technology-rich network representation of an energy system. A MARKAL model is a representation of (part of) the economy of a region. The economy is modeled as a system, represented by processes and physical and monetary flows between these processes. Details of the application of the MARKAL model on energy and environmental polices in Shanghai are discussed elsewhere[4].

Based on the principle of transfer matrix, an exposure level model was developed to link emission scenarios of MARKAL model and air pollutant concentrations.

The fundamental matrix was input by a long-range transport and deposition model (ATMOS model) for SO_2 and PM_{10}. The ATMOS model is a lagrangian parcel model with three vertical layers. For Shanghai project, the ATMOS model provides a 4 km by 4 km resolution of the concentration of SO_2 and PM_{10}. The total area of Greater Shanghai, 6341 km^2 was divided into 487 grids. Two transfer matrices for use in exposure level prediction were produced: a region-to-grid matrix for the area sources, and a large point source-to-grid matrix for the elevated point sources. Based on matrix output of the ATMOS model, the Shanghai exposure level model was developed in Excel to link the emission prediction of MARKAL, providing the exposure level for health impact analysis.

Human Exposure Level to Air Pollution

Ambient air pollution consists of a mix of various pollutants (e.g. ozone, SO_2, NO_2, particles, CO). However, these pollutants are correlated. Therefore, in most of the epidemiologic studies, it is impossible to attribute the health effects to one specific pollutant. A problem called “double counting effect” would arise when the health effects associated with several pollutants simultaneously are simply added up for assessment. In the present assessment, PM_{10} was selected as an indicator of air pollution to estimate the relevant health effects, since there is strongest epidemiologic evidence that all air pollutants support its association with adverse health effects. In this context, PM_{10} is a useful indicator of several sources of outdoor air pollution, such as fossil-fuel combustion. Our choice of indicator pollutant was also in line with other similar assessment[5].

All people living in the whole area of Greater Shanghai were considered as the exposed population in this analysis. An estimate of the number of Shanghai residents in each 4 km × 4 km grid cell was then made for the assessment based on the population data collected from Shanghai Bureau of Statistics. Of course, it was impossible to have accurate data on the population number in each 4 km × 4 km cell in Shanghai due to the fact that the borderline of communities is not in a 4 km × 4 km rectangular form. A modified approach based on pooling of population density in community within each grid cell adjusted to geographical size of the portion of communities in each grid cell was used. In addition, population growth in each grid cell was assumed to be at the same rate in the near future, and age distribution in each cell to be identical.

Combining the PM_{10} level and population number in each cell, we estimated the population exposure level to outdoor air pollution in 2000 in Shanghai.

Estimation of Health Effects

To develop estimates of public health impacts of air pollution, we relied on published studies on air pollution and health using concentration-response (C-R) coefficients derived from studies in China or worldwide.

Exposure-response functions of PM_{10} for each health endpoint derived from available epidemiologic studies were used to quantify the health effects of outdoor air pollution under various scenarios. Since most of the epidemiologic studies linking air pollution and health endpoints were based on a relative risk model in the form of Poisson regression, the cases at a given concentration C could be given by:

$$E = \exp(\beta\times(C-C_0))\times E_0 \qquad (1)$$

where C and C_0 are the PM_{10} concentration under one specific scenario and baseline scenario, respectively, E and E_0 are the corresponding health effect cases under the concentration of C and C_0, respectively. The health effect (benefit/damage) under the scenario with respect to baseline scenario is the difference between E and E_0. The value could be obtained if the following data components were available: exposure-response functions (β), population exposure levels (C and C_0), and baseline rate (E_0).

Exposure-response functions (β) link air quality changes and heath consequences. The preference for this analysis was decided to select C-R functions from Chinese studies whenever they were available. Only when the selected endpoints could not be found in Chinese literature the results of international peer-reviewed literature were used. If there were several studies describing the C-R function for the same health endpoint, we used the pooled estimate to get the mean and 95% confidence interval (CI) of the coefficient.

The baseline incidence data (E_0) for various health consequences were collected from actual data of Shanghai or proxy data from other regions of China or at the national level. These data were usually in the form of annual incidence rate.

Estimation of DALYs Lost Due to Ambient Air Pollution

In this study, we attempted to express the health impact of air pollution in DALYs. The adopted approach was recommended by the World Bank[6]. For mortality due to air pollution, the approach is straightforward: use of 10 DALYs lost per death. However, converting air pollution-induced morbidity to DALYs might be a tough challenge because of the lack of literature relating morbidity endpoint assessment to lost DALYs in air pollution dose-response studies.

RESULTS

Assessment of Exposure to PM_{10} of General Population in Shanghai

As mentioned above, we calculated the numbers of population exposed to a specific PM_{10} concentration and then pooled them in each 4 km × 4 km cell. Figure 1 describes the percent ages of population exposed to different levels of PM_{10} in 2000 in Shanghai.

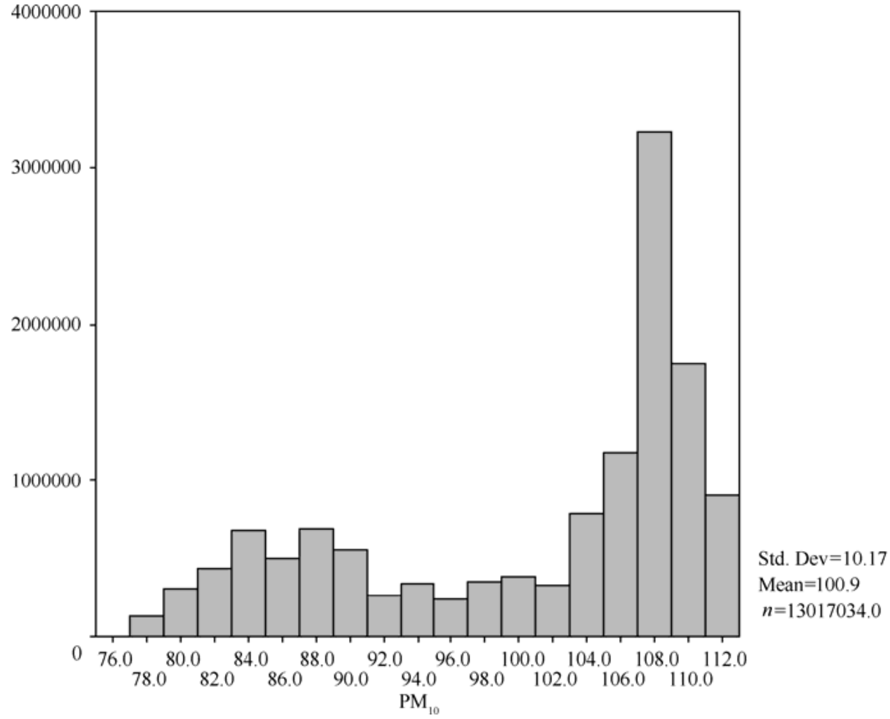

FIG. 1. Percent ages of Shanghai residents exposed to different levels of PM_{10} in 2000.

Estimation of Health Effects

The PM_{10} exposure-response coefficients (mean and 95%CI) and the incidence rates of selected health conquences in the analysis are summarized elsewhere.

Using the exposure-response functions, frequency of the outcome, exposure concentration and the threshold level, we calculated the attributable number of cases due to particulate air pollution of Shanghai residents (Table 1).

Particulate air pollution caused a total of 8220 attributable deaths in Shanghai in 2000 and resulted in 16 870 new cases of chronic bronchitis, 5240 respiratory hospital admissions, 2690 cardiovascular hospital admissions, 386 600 internal medicine visits, 40 040 pediatrics visits, 540 300 episodes of acute bronchitis, and 9990 asthma attacks.

DALYs Lost Due to Air Pollution

The health consequences due to air pollution were converted into DALYs (Table 2). Using the unit values and quantified health effects, we computed the corresponding DALYs lost (Table 3). The total DALYs lost due to air pollution in Shanghai in 2000 were about 103 064. Among all health consequences,

TABLE 1

Attributable Number of Cases Due to Particulate Air Pollution in Urban Area of Shanghai in 2000 (Mean and 95% CI)

Health Consequences	Mean	95%CI
Long-Term Mortality	8220	5570-10 870
Chronic Bronchitis	16870	7650-25 880
Respiratory Hospital Admission	5240	540-9920
Cardiovascular Hospital Admission	2690	1750-3610
Outpatient Visits-Internal Medicine	386600	226 300-547 000
Outpatient Visits-Pediatrics	40040	14 750-65 320
Acute Bronchitis	540300	0-1 080 500
Asthma Attack	9990	8290-11 680

TABLE 2

Valuesof DALYs per 10000 Cases of Health Endpoints Due to Air Pollution[6]

Health Endpoints	DALYs Lost per 10000 Cases
Premature Death	100 000
Chronic Bronchitis	12 037
Respiratory Hospital Admission	264
Cardiovascular Hospital Admission	264
Outpatient Visits-Internal Medicine	3
Outpatient Visits-Pediatrics	3
Acute Bronchitis	4
Asthma Attack	4

TABLE 3

DALYs Lost Due to Air Pollution in Shanghai in 2000

Health Endpoints	DALYs Lost (Mean and 95%CI)
Premature Death	82 200 (55 700-108 700)
Chronic Bronchitis	20 306 (9208-31 152)
Respiratory Hospital Admission	138 (14-262)
Cardiovascular Hospital Admission	71 (46-95)
Outpatient Visits (Internal Medicine)	116 (68-164)
Outpatient Visits (Pediatrics)	12 (4-20)
Acute Bronchitis	216 (0 –432)
Asthma Attack	4 (3-5)
Total	103 064 (65 044-14 0830)

premature deaths predominated in the value of the total DALYs lost, accounting for around 79.6% of the number. In addition, chronic bronchitis also had an important contribution to it.

DISCUSSION

Evaluation of health effects is critical in assessing the social costs of air pollution because it allows the performance of cost-benefit analysis of pollution control measures and provides a basis for setting priority of action. In our analysis, the impact of air pollution on public health was substantial in Shanghai.

To date, a widely used method to evaluate the health impact of air pollution is to use willingness-to-pay (WTP) and cost-of-illness (COI) techniques to conduct relevant economic assessment. For example, Kan and Chen[2] found the total economic cost of health impacts due to particulate air pollution in urban areas of Shanghai in 2001 was about 625.40-million US dollars, accounting for 1.03% of gross domestic product (GDP) of the city. However, the studies on the WTP for reducing the health risk of air pollution were mostly conducted in the developed countries, such USA and west Europe, but extremely sparse in China. Since there is no original valuation study on the health endpoints associated with air pollution in China, economic analysis has to estimate the values from previous studies. This procedure is often termed as benefit transfer or value transfer in economics. Characteristics of the concerned population, such as age distribution, income, health status, and culture, may have contextual effects on the valuation results. For example, different social and health insurance systems greatly influence the risk perception of local population, subsequently resulting in a different WTP to avoid the risk. Therefore, it is inappropriate to directly transfer the WTP values in the developed countries into the case studies in the developing countries.

To deal with such a problem, the present analysis tried to employ the concept of DALYs in measuring the health impact of air pollution. DALYs are capable of reducing all health effects, mortality and various morbidity endpoints to one denominator. It is similar to the economic valuation procedures, but is independent of income. Expression of the health impact of air pollution in DALYs has also the advantage of direct comparison with the overall impact of disease in various countries and cities, as well as with diseases from other major environmental problems (e.g. water-borne diseases). This is possible because of the significant amount of work by public health specialists in generating estimates of DALYs for various countries. For example, World Health Organization (WHO) and World Bank have taken DALYs as a standard measure of the burden of disease in the global burden of disease (GBD) study.

The limitations of our analysis should be noted. Our assessment only focused on the health impact of pollutants from outdoor air. However, indoor air pollution is also an important threat to people's health. In addition, outdoor air pollutants can be also an indoor problem when windows are left open. In the developing countries, a fairly large portion of the population depend on biomass for their energy requirements, which constitutes an important source of indoor air pollution. According to WHO, indoor air pollution accounts for 4% of the global burden of disease. However, in Shanghai, the research site of the current analysis, indoor air pollution from biomass combustion might not be a serious problem due to the wide use of natural gas and liquefied petroleum gas (LPG) as the cooking energy. We are to employ the indicator of DALYs to measure the health impact of indoor air pollution in Shanghai, and compare the disease burden of air pollution from different sources.

Recently, epidemiological studies in developed countries have shown that the health effects of outdoor air pollution are low. In the calculation of the impact of ambient air pollution on public health, it is crucial to decide what level of exposure may be considered as the threshold level or "reference exposure". Threshold concentration means that below such a concentration no adverse health effect occurs. There are many different recommendations as to where to impose a threshold in air pollution-related health impact assessment, including no threshold (or zero threshold), natural background level, the lowest level observed in epidemiological studies and established legal/policy standards. The possible existence of an effect threshold is a very import scientific issue for air pollution-related health impact assessment. However, there is no scientific basis for setting a particular threshold for the effects considered in this analysis.

In conclusion, air pollution-related health effect is a widespread cause of impaired health in Shanghai, and incurs a high social cost. Improvement in air quality can lead to great health benefits to society. The approaches recommended in this analysis could be further applied to other regions of China for local and nation-wide air pollution-related health risk assessment. Further health impact assessment method is needed, especially in the area with uncertainty, transference of exposure-response functions, and more common health indicators such as YOLL (years of life lost), *etc.*

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