

## **Estimating the Health Impact of Air Pollution: Methodology and an Application to Jakarta<sup>1</sup>**

This case study presents an illustration of the use of one increasingly accepted methodology - the damage function approach using dose-response relationships - to estimate the health impacts of air pollution reduction. Additional information can then be used to place monetary values on these health effects - by either using the cost-of-illness approach to estimate monetary values of reduced illness (morbidity) or, in the case of death, estimates usually based on willingness-to-pay to reduce premature mortality.

Dose-response relationships are functions mostly based on data from the US, Canada, and the United Kingdom that relate information on changes in ambient air quality for different pollutants to different health outcomes. The principle is that changes in ambient air pollution levels for certain pollutants can be statistically related to observed changes in morbidity (sickness) and mortality (death) in a population. Through regression analysis, coefficients are estimated that are then multiplied by changes in ambient pollution concentrations and the population exposed. Most of this work has previously been done in Europe and the US and this case study shows an application of the approach to Jakarta (Ostro, 1994).

The estimated health impact can be estimated by the following relationship:

$$dH_i = b_i * POP_i * dA$$

where:  $dH_i$  = change in population risk of health effect  $i$ ;  
 $b_i$  = slope from the dose-response curve for health impact  $i$ ;  
 $POP_i$  = population at risk of health effect  $i$ ;  
 $dA$  = change in ambient air pollutant under consideration.

### **An Application To Jakarta**

Jakarta, the capital of Indonesia, is located in the tropics just south of the equator. The population is between 8.2 to 9 million, and the city covers some 650 km<sup>2</sup>. Air and water pollution are both major environmental problems. The results presented here focus on air pollution, particularly suspended particulate matter, often referred to as TSP (total suspended particulates) and the finer, more damaging, portion called PM10, or particles smaller than 10 microns in size. Pollution exposure is measured in various ways, often in terms of micrograms of TSP or PM10 per m<sup>3</sup> of air. (One can convert directly from TSP to PM10: PM10 is about 55 percent of the total TSP; that is, a level of TSP of 100 micrograms/m<sup>3</sup> is equal to PM10 measurement of 55 micrograms/m<sup>3</sup>).

This study uses dose-response functions estimated in developed countries since none were available for local conditions in Jakarta. It is implicitly assumed, therefore, that the relationship between the levels of air pollution and subsequent health effects in the developed countries can be extrapolated to estimate the health impacts in Jakarta. It is recognized that there are significant differences between developed country and Indonesian populations in baseline health status, access to health care, demographics, and occupational exposures, among other factors. It is therefore likely that the model will under-estimate the health effects for Indonesia.

In the study, dose-response functions have been identified and adapted from the available literature (see Ostro, 1994, for details on the background studies). Since there are variations in the

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<sup>1</sup> This Annex is excerpted with permission from Dixon, *Economic analysis Environmental Impacts*, Second Edition Earthscan Publications Ltd, London 1994.

coefficients estimated by the various studies, three alternative assumptions about health effects are presented, with the central estimate being given the most weight. High (low) end estimates are calculated by increasing (decreasing) the coefficient by one estimated standard deviation.

Available epidemiological studies relate concentrations of ambient particulate matter and several adverse health outcomes including mortality, respiratory hospital admissions, emergency room visits, restricted activity days for adults, respiratory illness for children, asthma attacks and chronic disease. TSP is the measure particulates most commonly used in Indonesia. Therefore all dose response functions were adapted to be used with TSP concentrations.

Estimates were made of the benefits of reducing TSP levels from present levels in Jakarta (ranging from less than 100 to over 350mg/m<sup>3</sup> in certain parts of the city, to both the Indonesian standard (90mg/m<sup>3</sup>) and the midpoint of the WHO guidelines (75 mg/m<sup>3</sup>). In each case the estimates were based on information on population exposed to different levels of pollution. (This information is based on census data on population density and the results of citywide information on emissions and air quality monitoring and the use of a dispersion model.)

### **Mortality**

Premature mortality is a major problem associated with high levels of particulates. Based on a survey of the literature, a central estimate of the change in 'all-cause mortality' associated with a change in PM10 can be expressed as follows:

Central percentage change in mortality = 0.096 \* change in PM10 with upper and lower estimates having coefficients of 0.130 and 0.062, respectively. The central estimate of the number of cases of premature mortality can be expressed as:

$$\text{Change in mortality} = 0.096 * \text{change in PM10} * 1/100 * \text{crude mortality rate} * \text{population exposed.}$$

Assuming the crude mortality rate in Jakarta is 0.007, the range in changes in mortality (per person) is:

$$\text{Upper estimate of change in mortality} = 9.10 * 10^{-6} * \text{change in PM10}$$

$$\text{Central estimate of change in mortality} = 6.72 * 10^{-6} * \text{change in PM10}$$

$$\text{Lower estimate of change in mortality} = 4.47 * 10^{-6} * \text{change in PM10}$$

For example, if average PM10 levels decreased by 10 micrograms per m<sup>3</sup> for Jakarta, and if 5 million people were exposed to this reduction, the estimated health benefit would be 335 fewer cases of premature mortality per year:

$$6.72 * 10^{-6} \text{ (DRR coefficient)} * 10 \text{ (change in PM10)} * 5,000,000 \text{ (population)} = 335$$

### **Morbidity**

A similar approach was also used to estimate the effects of changes in air quality on air pollution-related illnesses. In each case a dose-response relationship was identified and was linked to a discrete health outcome:

*Respiratory Hospital Admissions (RHA).* Based on Canadian and US studies, there is a statistically significant relationship between the incidence of hospital admissions due to respiratory diseases (RHA) and ambient sulphate and TSP levels. The following functions are suggested per 100,000 population:

Upper change in RHA per 100,000 = 1.56 \* change in PM10

Central change in RHA per 100,000 = 1.20 \* change in PM10

Lower change in RHA per 100,000 = 0.657 \* change in PM10

*Emergency Room Visits (ERV).* The relationship between emergency room visits (ERV) and TSP exposure based on US studies was adjusted by plus or minus one standard deviation from the central coefficient to generate high and low estimates for Jakarta:

Upper change in ERV per 100,000 = 34.25 \* annual change in PM10

Central change in ERV per 100,000 = 23.54 \* annual change in PM10

Lower change in ERV per 100,000 = 12.83 \* annual change in PM10

*Restricted Activity Days (RAD).* Restricted activity days (RAD) include days spent in bed, days missed from work, and other days when normal activities are restricted due to illness, even if medical attention is not required. Studies from the US suggest a statistically significant relationship between particulates of various sizes and RAD. After standardizing on PM10 the relationship between RAD and PM10 is estimated as follows (these estimates are applied to all adults):

Upper change in RAD per person per year = 0.0903 \* change in PM10

Central change in RAD per person per year = 0.0575 \* change in PM10

Lower change in RAD per person per year = 0.0404 \* change in PM10

*Lower Respiratory Illness in Children (LRI).* US studies suggest the following relationship between the occurrence of chronic coughs, annual change in bronchitis and other respiratory diseases in children and PM10, adjusted for a number of variables including the incidence of bronchitis in children:

Upper change in annual bronchitis = 0.00238 \* change in PM10

Central change in annual bronchitis = 0.00169 \* change in PM10

Lower change in annual bronchitis = 0.0008 \* change in PM10

This relationship is applied to the 34.7 percent of the population below the age of 18 in Jakarta.

*Other estimates.* Estimates were also made for a number of other air pollution-related illnesses. These included asthma attacks, respiratory symptoms, and chronic bronchitis. Annex Table 1 summarizes the dose-response estimates of the morbidity outcomes of changes in PM10 levels for all of these possible health outcomes, and presents the central estimate and the high-side estimate. Note that some of the effects are estimated per 100,000 people in the general population, while others are person or group specific (e.g. RAD per person, or asthma attacks per asthmatic).

**Table 1 - Morbidity Effects of 10 microgram/m<sup>3</sup> Change in PM10**

Type of Morbidity	Central Estimate	High Estimate
RHA/100,000	12.0	15.6
ERV/100,000	235.4	342.5
RAD/person	0.575	0.903
LRI/child/per asthmatic	0.0169	0.0238
Asthma attacks/per asthmatic*	0.326	2.73
Respiratory symptoms/person	1.83	2.74
Chronic bronchitis/100,000	61.2	91.8

\* Applies to the 8.25% of the Indonesian population that is assumed asthmatic. High estimates are obtained by increasing the coefficient by one estimated standard deviation.

*An Application of the Approach to Jakarta.* When the coefficients listed in Annex Table 1 were applied to Jakarta, Ostro was able to estimate health impacts associated with decreasing particulate levels to both the Indonesian standards (90 micrograms/m<sup>3</sup>) and WHO standards (about 75 micrograms/m<sup>3</sup>). In 1989 many parts of the city had levels between 100 and 200, and 'hot spots' with readings of 300 or 350 were common. Annex Table 2 presents the health benefits of reducing particulate matter to the Indonesian standard (90 micrograms per m<sup>3</sup>). (Meeting the more stringent WHO standards would produce even larger benefits, of course, but would cost more to achieve).

The numbers of lives saved and illnesses avoided are impressive. Using the central or medium estimate of the dose-response relationships, Ostro estimated that each year in Jakarta the benefits from reducing particulates to Indonesian standards include 1,200 premature deaths avoided, 2,000 fewer hospital admissions, 40,600 saved emergency room visits, and over 6 million fewer restricted activity days, among other benefits for the population of 8.2 million.

Achieving Indonesian TSP standards will not be easy, however, and would involve major investments. To estimate which investments and control options should be undertaken, the policymaker would ideally like to compare the benefits to the costs. The benefits are largely due to health costs that are avoided, and a decrease in premature deaths. Placing monetary values on premature death or small changes in risks of mortality is very difficult, although estimating the cost of illness is easier (for a discussion of this, see the Box at the end of this case study). In this case monetary values were not placed on the health outcomes. Still, presenting the impacts of TSP pollution in physical terms, as is done in Annex Table 2, can still be a powerful message prompting government action. At a minimum, a cost-effective approach can be applied to identify those policy interventions that produce the largest health benefit per dollar invested.

**Table 2 - Health Benefits of Reducing Particulates in Jakarta to Indonesian Standards**

Health effect	Medium estimate
Premature mortality	1,200
Hospital admissions	2,000
Emergency room visits (ERV)	40,600
Restricted activity days (RAD)	6,330,000
Lower respiratory illness (LRI)	104,000
Asthma attacks	464,000
Respiratory symptoms	31,000,000
Chronic bronchitis	9,600

**Box**  
**Economic Valuation of Health Effects**

Ideally, valuation of health impacts should include both the out-of-pocket costs of illness such as medical costs, lost income and averting expenditures, and the less tangible effects of illness on well-being such as pain, discomfort and restriction in non-work activities. Health impacts valued by willingness-to-pay (WTP) incorporate all of these impacts, whereas a cost of illness (COI) approach only includes out-of-pocket expenses such as medical costs and lost income.

Ostro did not estimate the economic costs of mortality and morbidity in Jakarta, although estimates can be made fairly easily in the case of illness (morbidity). There is a sizeable literature on the cost of ill-health in the US.

WTP estimates to prevent or accept small changes in the risks of death are based on empirical evidence gathered in the US and Great Britain of people making actual tradeoffs between the risks of death and some benefit, such as income. In addition, some contingent valuation studies have been conducted in which respondents are asked directly what they would be willing to pay to reduce risks associated with, for example, work or traffic accidents. Considerable controversy exists over the 'value of life'. One commonly used value in the US is \$300 for a .0001 reduction in risk. Thus, for a large population, the reduction in risk translates to \$3 million per death avoided.

Economic costs for changes in morbidity are, of course, very country-specific. In the high cost, US medical care sector, some estimates of the costs of illness include the following (Ostro, 1992):

**Respiratory Hospital Admission, RHA:**

average stay - 10.13 days  
average cost of stay - \$26,898  
lost day wage rate - \$125  
So, each RHA is assumed to cost \$28,164

**Emergency Room Visit, ERV:**

average stay - 1 day  
average cost per stay \$133  
lost day wage rate - \$125  
So, each ERV is assumed to cost \$258

**Restricted Activity Day, RAD:**

20 percent of RAD result in lost work days, and the remaining 80 percent of RAD valued at one-third of the average wage rate.  
lost day wage rate - \$125  
So, each RAD is assumed to cost \$58

**Lower Respiratory Illness in children (LRI):**

2 weeks of illness per episode valued at \$15 per day  
two RAD per parent for care per episode  
So, total per episode of BC is assumed to cost \$326

These costs are for the US. To estimate the costs of ill-health in Jakarta, separate Indonesian-specific cost estimates are needed. These will be lower than US costs and may vary by type of illness, depending on relative differences between the US and Indonesia for labour and capital.

**Sources:**

Ostro, Bart. 1992 *Estimating the Health and Economic Effects of Particulate Matter in Jakarta: A Preliminary Assessment*, paper presented at the Fourth Annual Meeting of the International Society for Environmental Epidemiology, 26-29 August. Cuernavaca, Mexico.

Ostro, Bart. 1994 *Estimating Health Effects of Air Pollutants: A Methodology with an Application to Jakarta*. Policy Research Working Paper 1301. Washington, D.C. the World Bank.