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25691
February 2003

ESMAP

Urban Air Pollution

South Asia Urban Air Quality Management Briefing Note No. 1

Health Impacts of Outdoor Air Pollution

Every year an estimated 800,000 people die prematurely from illnesses caused by outdoor air pollution worldwide. Approximately 150,000 of these deaths are estimated to occur in South Asia alone. Air pollution has also been associated with a variety of illnesses. Calculating the health impacts of urban air pollution is an important step in urban air quality management, but is often made difficult by lack of data in developing country cities. This is the first in a series of three briefing notes that discuss options for quantification of health effects and their associated costs to the economy, and the science of how the pollutant of most concern in South Asia—fine particulate matter—affects human health.

The World Health Organization (WHO) estimates that every year 800,000 people die prematurely from lung cancer, cardiovascular and respiratory diseases caused by outdoor air pollution [1]. Other adverse health effects include increased incidence of chronic bronchitis and acute respiratory illness, exacerbation of asthma and coronary disease, and impairment of lung function. This note outlines how cities can estimate health gains to their residents as they take steps to reduce outdoor air pollution. It discusses the types of studies used to quantify the relationships between air pollution and human health, and the extent to which studies, mostly from North America and Europe, can be used to estimate the benefits of air pollution reductions in South Asia. These health gains provide the basis for cost-effectiveness or cost-benefit analysis of different air pollution reduction strategies.

Observed Health Effects

The most significant health effects of air pollution have been associated with particulate matter (PM) and, to a lesser extent, with ground-level ozone [1, 2, 3]. PM is a mixture of many subclasses of pollutants which vary in size and chemical composition. Most studies have examined the health effects based on particle size. Much less is known about the impact on health of varying PM chemical composition. The largest health impacts have been associated with particles small enough to penetrate deep into the respiratory tract: *fine* particles (**$PM_{2.5}$**, smaller than 2.5 microns or 2.5 x 10^{-6} meters in diameter) and **PM_{10}** (smaller than 10 microns). Combustion, metallurgical processes, automobile exhaust, and secondary sulfate and nitrate particles formed by the atmospheric transformation of sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) are the main sources of these smaller particles. Elevated levels of NO_x and SO_2 also result in higher hospital admissions and emergency room visits, but these effects are small compared to those of PM. Similarly the health effects of particles larger than 10 microns, arising primarily from resuspended dust and soil, are also small.

Since the health damage caused by elevated fine particulate concentrations in South Asia is much higher than that of all other pollutants combined, the remainder of this note focuses on studies on PM_{10} and $PM_{2.5}$.

How are Health Effects Estimated?

Estimating the health impacts of air pollution reductions entails three steps. First, the demographic groups susceptible to air pollution and associated health outcomes are identified based almost exclusively on epidemiological studies. These studies determine relationships—referred to as concentration-response (**CR**) functions—between air pollution and health effects in human populations. CR functions empirically explain variations in the number of cases of illness or death observed in a population based on changes in the ambient concentrations of the air pollutants and other known explanatory factors. These other factors, called **confounding factors** (those that also affect health outcomes, making it difficult to attribute cause), include demographics (such as age, gender, marital status, diet, body mass, smoking, health habits, occupational exposure, education, and income), other pollutants, and time-varying factors (temperature, seasonality, day of week). CR functions may apply to the whole population or to specific demographic groups only. Virtually all CR functions assume that each unit decrease in the ambient concentration of a pollutant results in a fixed percentage change in the cases of illness or deaths avoided, independent of the initial pollution level. This assumption may not be valid when ambient concentration levels are several-fold higher than in cities where studies have been conducted, as is the case when applying CR functions estimated in industrial countries for fine particles to cities in South Asia.

Ideally, cities considering significant policy changes would conduct an epidemiological study locally. In practice, the complexity and costs of undertaking these studies have limited the number of such studies. Instead, cities typically transfer information on health impacts of pollutants on the susceptible demographic groups from existing studies conducted elsewhere. Box 1 gives an example of a CR function transferred in a health impact estimation study of Mexico City [3]. Similar functions are available for other health impacts from PM_{10} as well as other pollutants such as ozone. The appropriateness of transferring these functions depends on whether the confounding factors for the city are similar to those for the cities included in the transferred epidemiological studies.

The second step in health impact estimation requires two pieces of information about the city: the baseline cases of illness or death and the change in the population exposure to the pollutant. Baseline cases are typically estimated from the total population and the case incidence rate. The change in the population exposure is the difference between the current exposure level and estimates of population exposure levels after air pollution reductions are achieved.

Pollutant exposure levels are difficult to estimate because of varying personal time-activity patterns. As a result, health impacts are generally based on the population-weighted average ambient concentration of the pollutant across the city's susceptible residents. These ambient levels are estimated from the concentrations of the pollutants measured at fixed monitoring sites located in different parts of the city. It is important to ensure that the included monitoring sites are representative of average exposure and are not unduly influenced by pollution hotspots such as inner city transport corridors or industrial zones.

The estimated burden of disease from air pollution cited above, 150,000 deaths annually in South Asia, provides a useful benchmark for comparing the relative magnitude of different health risk factors. However, they are not an appropriate basis for comparing different air pollution reduction strategies. Burden-of-disease estimates are based on reducing air pollution to the theoretically minimum levels (for example, PM_{10} concentration of 15 µg/m³ [1]). Pollution reductions to such low levels have not been achieved in many U.S. and European cities, and it would be unrealistic to assume that South Asian cities are in a position to reach these levels in the near future. Instead, health gain estimates should be determined for each pollution reduction strategy based on the expected population exposure reductions.

The estimated avoided cases of illness or disease are calculated in the third step using the information collected in the first two steps. Box 1 illustrates how the estimated avoided cases of hospital admissions for respiratory disease are calculated for Mexico City for a 20 percent reduction in population exposures to PM_{10} [3]. The avoided cases provide a concrete measure of health gains understandable to a wide range of policymakers.

Results from Existing Studies

Epidemiological studies can be grouped according to how exposure is measured (acute exposure studies and chronic exposure studies) and how health effects are measured (individual-based panel or cohort studies, and population-based or ecological studies). Most studies in the scientific literature have examined acute, not chronic, health consequences.

Box 1: Sample [illegible] impact of lowering PM_{10} [illegible] on avoided [illegible] admissions [illegible]

Step1: Epidemiological study (transferred)

- Demographic groups: all
- Concentration-response relationship: 0.139% change in hospital admissions for a change in the daily average PM_{10} concentration of 1 microgram per cubic meter (µg/m³)

Step 2: Data from Mexico City

- Population at risk: 18,787,934 persons
- Baseline rate of hospital admissions for respiratory problems: 411 admissions per 100,000 persons
- Baseline number of hospital admission: Population at risk x 0.00411 admissions/person = 77,218 admissions
- Current population-weighted annual average PM_{10} concentration: 64 µg/m³
- Population-weighted annual PM_{10} concentration after policy implementation: 51.2 µg/m³
- Change in PM_{10} concentration in response to policy implementation: 64 µg/m³ – 51.2 µg/m³ = 12.8 µg/m³

Step 3: Calculation of estimated avoided cases

Avoided hospital admissions: 77,218 admissions x 0.00139 change/µg/m³ x 12.8 µg/m³ = 1,376 admissions.

* Reduced hospital admissions are only one of the health benefits of reducing PM_{10} concentrations. Other impacts include premature death, and less serious illnesses not requiring hospitalization.

Human health impacts of acute exposure to particulate air pollution

Acute exposure studies examine the associations between short-term (daily or multi-day average) variations in PM concentrations and short-term counts of total deaths, cause-specific deaths, or incidence of specific illness in an area (typically a city). The popularity of these studies stem from their minimal data requirement compared to other study designs. Problems associated with confounding are reduced in these studies because population characteristics (such as smoking and occupational exposures) do not change much over the study period for the study population. In addition to air pollution, temporal and meteorological conditions and the age of the individual are the main factors that are included in these studies. While these studies provide health impact estimates for the city being studied, the CR functions obtained are not readily transferable to cities with different population characteristics.

However, the consistent findings across a wide array of cities, including those in developing countries, with diverse population and possibly PM characteristics strongly indicates that the health gains indeed result from PM pollution reductions. Meta-analysis—which pools results from several studies—of acute exposure studies provides health impact estimates that are more transferable than results from individual studies. These results indicate that every 10 $\mu g/m^3$ increase in the daily or multi-day average concentration of PM_{10} increases (1) non-trauma deaths by 0.8 percent; (2) hospital admissions for respiratory and cardiovascular diseases by 1.4 and 0.6 percent, respectively; (3) emergency room visits by 3.1 percent; (4) restricted activity days by 7.7 percent; and (5) cough in children with phlegm by 3.3 to 4.5 percent [1, 2, 3]. The studies also indicate higher risk for the elderly with chronic heart and lung disease and infants.

Human health impacts of chronic exposure to particulate air pollution

Chronic exposure studies examine the impact of long-term exposure to PM air pollution as well as the cumulative effects of short-term elevated PM levels. These studies compare differences in health outcomes across several locations at a selected period in time. Some portion of the long term impacts indicated by these studies corresponds to the impact of acute effects revealed in acute exposure studies. The remainder is due to latent or chronic effects of cumulative exposure.

Ecological studies, which use population-wide measures of health outcomes, have consistently found increased mortality rates in cities with higher PM levels. However, the inability to isolate the effects of PM from alternative explanatory factors (that is, confounding factors such as smoking, dietary habits, age, and income) which might vary among populations in different cities raises doubts about the reliability of these CR functions.

Cohort design studies overcome these questions by following a sample of individuals, thereby making it easier to isolate the effects of confounding factors. These studies provide the most compelling evidence about mortality effects from chronic exposure to PM. The largest study to date [4] indicates that a change in long-term exposure to $PM_{2.5}$ of 10 $\mu g/m^3$ leads to a 4, 6, and 8 percent increase in the risk of all-cause mortality, cardiopulmonary, and lung cancer mortality, respectively. The study did not find consistent relationships between long-term exposure to particles larger than 2.5 microns on one hand and premature death on the other.

Estimating Health Effects in South Asia

To date, studies based on measured ambient concentrations of PM_{10} or $PM_{2.5}$ have not been carried out in South Asia. One study [5] estimated the mortality (but not morbidity) impacts associated with increases in concentrations of total suspended particulates (TSP, which includes fine as well as larger particles). Acute and chronic exposure studies elsewhere as well as the above study [5] clearly suggest that reductions in fine particulate pollution would result in significant health gains to South Asian city residents. Quantitative estimates of health gains in the immediate future will have to rely on the transfer of CR functions. Uncertainties about these transfers due to confounding need to be addressed through scenario-based sensitivity analysis.

Because health risks from PM affect primarily the elderly with chronic heart and lung diseases and infants, transfer of cause- and age-specific CR functions is preferable [1]. Use of all-cause or all-age mortality is inappropriate when there are systematic differences in other health risks or the age distribution between the population in the city and those used in the epidemiological studies. For example, cardiovascular and respiratory diseases have been reported to account for a quarter of non-trauma deaths in Delhi, compared to half in the United States [5]. If the cardiopulmonary-specific CR function from a recent study [4] were transferred to Delhi, all-cause mortality would increase by 1.5 percent when $PM_{2.5}$ exposure is increased by 10 $\mu g/m^3$, compared to a 4 percent increase if the all-cause CR function from the same study were applied.

Three CR functions transferred to cities worldwide by WHO in one of its publications [1] can be a basis for CR function transfers to South Asian cities. They include two separate CR functions for cardiopulmonary and lung cancer mortality for adults over 30 years of age from chronic exposure [4] and a CR function for all-cause mortality in children from acute exposure. No morbidity CR functions were transferred because definitions of health outcomes differ across countries. The economic losses from the morbidity effects of PM pollution are significant so that excluding them would seriously under-estimate the cost of air pollution. CR functions for morbidity can be transferred provided that the differences in the confounding factors and definitions of health outcomes between the South Asian cities and those in the epidemiological studies are properly accounted for.

Uncertainty from three additional sources should be addressed through sensitivity analysis: lack of data on fine PM concentrations, lack of baseline health data and cases, and extrapolation of CR functions outside of the pollutant concentration ranges observed in the epidemiological studies. Some South Asian cities have historically monitored TSP. Recently, a few cities have begun to monitor PM_{10} regularly and in some cases $PM_{2.5}$. Because the size distribution of PM varies significantly depending on the sources of pollution and atmospheric conditions, estimating the concentration of fine particles in the absence of locally measured data is not straightforward. A World Bank study [6] found that after controlling for the fuel mix and local climatic factors, PM_{10} accounts for a smaller share of TSP as per capita income falls. Sensitivity of health outcomes to assumptions about PM size distribution where data is scarce can be found in two publications [1, 6].

Ambient PM concentrations are significantly higher in many South Asian cities than those found in epidemiological studies in North America and Europe, requiring extrapolation of CR functions above the maximum PM concentrations found in the original epidemiological studies. If CR functions were linearly extrapolated, then at high PM levels found in some South Asian cities a significant proportion of health outcomes would be estimated to be from exposure to PM rather than other competing factors such as smoking and high blood pressure. Since little collaborating evidence has been found to support such a conclusion, it would seem more reasonable to assume that, at these higher levels, the additional health impact per unit $\mu g/m^3$ increase in exposure would be smaller. Different assumptions about extrapolation can be used to estimate high, central and low estimates of health effects, as shown in a recent WHO publication [1].

Conclusions

- The health impacts of air pollution depend on the sensitivity and the exposure level of the susceptible population to the pollutant. The largest health impacts in South Asia result from exposure to fine particulate pollution. The elderly with cardiovascular and lung disease and infants are at greatest risks.
- In performing health impact analyses for South Asian cities, reliance has to be placed on CR transfer in the immediate future. For mortality, this should be limited to CR functions for cause- and age-specific mortality developed from PM_{10} and $PM_{2.5}$ measurements. CR functions for morbidity can be transferred provided that definitions of health outcomes are comparable and there are no large differences in confounding factors.
- Uncertainties in transferring CR functions should be fully addressed by examining the sensitivity of results to alternative assumptions. The most significant uncertainties are baseline health data, estimations of $PM_{2.5}$ and PM_{10} needed in the CR function if no local data exist, and extrapolation of CR function outside of the PM concentration range in the original studies.

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This briefing note was prepared in Febrary 2003 as part of the South Asia program on urban air quality management, funded in part by the joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP). The objective of the program is to support the region-wide process of developing and adopting cost-effective and viable policies and efficient enforcement mechanisms to reverse the deteriorating trend in urban air. A full set of briefs and other materials are available at <http://www.worldbank.org/sarurbanair>.

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