

Health Effects of Air Pollution

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This brief paper provides background reading for the Population-Environment Research Network's online seminar on 'Air Pollution and Health Linkages,' scheduled for December 1-15, 2003. The purpose of this 'cyberseminar' is to foster a discussion that will lead to identification of key issues, knowledge gaps, and methodological shortcomings in understanding health impacts of air pollution, both indoor and outdoor.

The paper is not intended to be a comprehensive document covering all aspects of air pollution and health linkages, but instead it is to provide a starting point for the discussions in the cyberseminar. During the course of the seminar, additional discussion points will be posted by a panel of distinguished scientists working in this area of growing public health concern. It is expected that the cyberseminar participants will discuss the issues raised in this paper and those raised by the expert panel in greater detail and bring forth many new topics for discussion.

Background

That air pollution causes ill health and death is well recognized. Air pollution is caused by both natural and man-made sources. Major man-made sources of ambient air pollution include industries, automobiles, and power generation. In indoor environments, tobacco smoke and combustion of solid fuels for cooking and heating are the most significant sources. In addition, construction material, furniture, carpeting, air conditioning, and home cleaning agents and insecticides can also be significant sources of chemical and biological pollutants indoors. For the purposes of this seminar, I propose that we limit the discussion to man-made sources of air pollution. I also propose that we exclude health effects of tobacco smoke from this discussion, given a large body of well-researched literature on that subject. Of course, we should include both natural sources of air pollution and tobacco smoke in the discussion to the extent they confound or modify the health effects of man-made air pollution.

Fuel combustion is the primary source of a large number of health-damaging air pollutants, including fine and respirable particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds ($VOCs$), ozone (O_3), and atmospheric lead. Some of these pollutants are direct by-products of fuel combustion, but others (such as O_3) are formed in the air through chemical reactions with other agents in the atmosphere.

Air pollution has both acute and chronic effects on human health. Health effects range anywhere from minor irritation of eyes and the upper respiratory system to chronic respiratory disease,

heart disease, lung cancer, and death. Air pollution has been shown to cause acute respiratory infections in children and chronic bronchitis in adults. It has also been shown to worsen the condition of people with preexisting heart or lung disease. Among asthmatics, air pollution has been shown to aggravate the frequency and severity of attacks. Both short-term and long-term exposures have also been linked with premature mortality and reduced life expectancy.

Health impact of air pollution depends on the pollutant type, its concentration in the air, length of exposure, other pollutants in the air, and individual susceptibility. Different people are affected by air pollution in different ways. Poor people, undernourished people, very young and very old, and people with preexisting respiratory disease and other ill health, are more at risk. In cities, for instance, poor tend to live and work in most heavily polluted areas, and in rural areas poor are more likely to cook with dirtier fuels. In some countries, air quality standards tend to be more lax around industrial areas in cities, where many poor tend to live in squatter settlements. Poor also tend to be more malnourished, more likely to suffer from ill health and disease, and have less access to health care.

Air pollutants can also indirectly affect human health through acid rain, by polluting drinking water and entering the food chain, and through global warming and associated climate change and sea level rise.

As a result of several decades of tighter emission standards and closer monitoring, levels of certain types of air pollutants have declined in many developed countries. Although, even at much reduced levels, air pollution continues to threaten public health in these countries. On the other hand, the ambient air pollution levels are a growing problem in urban centers in many developing countries. Several factors contribute to the worsening air pollution levels in developing-country cities, including rapid growth in urban population, increasing industrialization, and rising demands for energy and motor vehicles. Other factors, such as poor environmental regulation, less efficient technology of production, congested roads, and age and poor maintenance of vehicles, also add to the problem.

In many rural areas of developing countries air pollution exposures tend to be highest indoors where majority of households use unprocessed solid fuels (biomass and coal) for cooking and space heating. These fuels are typically burned indoors in simple household cookstoves, such as a pit, three pieces of brick, or a U-shaped construction made from mud, which burn these fuels inefficiently and are often not vented with flues or hoods to take the pollutants to the outside. Under these conditions, high volumes of a number of health-damaging airborne pollutants are generated indoors, resulting in high exposures, especially among women who do the cooking and young children who stay indoors with mothers. The individual peak and mean exposures experienced in such settings are often much greater than the safe levels recommended by the World Health Organization.

Causal mechanism

Causal biological mechanisms about health effects of air pollution are only partly understood. Air pollution exposure has been associated with compromised pulmonary immune defense mechanisms in

both animals and humans. Tobacco smoking has also been shown to cause depressed immune system responses. Of the specific air pollutants, exposure to respirable particulate matter has been shown to induce a systemic inflammatory response involving stimulation of the bone marrow, which can contribute to cardiorespiratory morbidity. Other evidence indicates that exposure to polycyclic aromatic hydrocarbons—especially benzo[a]pyrene—can cause immune suppression and can increase the risk of infection and disease. Benzo[a]pyrene, a known carcinogen, also can increase the risk of lung and other types of cancers. Acute exposures to oxides of nitrogen and sulfur have been associated with increased bronchial reactivity and susceptibility to bacterial and viral infections. Carbon monoxide combines with hemoglobin to form carboxyhemoglobin, which reduces the oxygen-carrying capacity of the blood and can contribute to anemia and adverse pregnancy outcomes, including miscarriage, stillbirth, low birth weight, and early infant mortality. In cases where biological pathways of effect are not known, questions remain as to how to establish causality.

Approaches to measuring health impacts of air pollution

Prospective cohort studies. The best way to measure the health impacts of air pollution in a given area is to conduct prospective epidemiologic studies by following a large cross-section of people over a long period of time. These studies should measure air pollution concentrations, individual exposure levels, ill health and death, as well as other factors, such as nutritional status, smoking habits, and family history of disease. Due to high costs and time involved, very few such studies have been carried out so far, and all such studies have been carried out in the developed countries. Two most commonly cited studies, the Harvard Six Cities study and the American Cancer Society study, both in the United States, have measured the effects of exposure to particulate matter on the survival function. These studies allow estimation of effect of air pollution on number of life-years lost.

Time series studies. Time series studies correlate daily variations in air pollution levels with variations in daily incidence of ill health, hospital admissions, or deaths in a given area. Time series studies measure the effects of acute air pollution exposure on morbidity and mortality, primarily among people more susceptible to adverse effects due to their poor nutritional status or due to a preexisting condition. Time series studies have the advantage that they do not need to control for many confounding factors, such as smoking, age structure, nutritional status, and access to health care, because these factors do not change much during the course of the study. Although in many developing countries, information on disease incidence, hospital admissions, and deaths itself may be correlated with such factors. Time series studies also have the advantage of being much less expensive than prospective cohort studies, but they fail to capture the chronic health effects of long-term exposure to air pollution. Also, time series studies tend to overestimate the effects on premature deaths because many of these people would have had short life expectancies in any case. Another problem with such studies is that they typically combine community-level air pollution data with individual-level health data and assume same exposure levels for all individuals in the community.

Cross-sectional studies. Retrospective/cross-sectional studies are used to compare health effects of air pollution across several locations at a given point in time (or in a given time period). These studies tend to be much cheaper and require less time than prospective cohort studies, and have

the advantage over time series studies in that they capture both the acute and chronic effects of air pollution. A major constraint is that cross-sectional studies need to account for a large number of potentially confounding factors, such as differences in nutritional status, smoking rates, age distribution, and local industry.

Meta-analyses. In the absence of reliable epidemiologic studies of air pollution, meta-analyses of existing studies can be used to reduce uncertainty associated with individual studies and to obtain more reliable dose-response functions. Meta-analysis is a way to statistically pool results from several studies to obtain more reliable estimates of effects. For such pooling to be of good quality, studies need to be objectively selected to meet some basic standards of study design and data quality and to ensure that essential confounders have not been omitted. The recent comparative risk assessment effort of the World Health Organization used this approach to estimate and rank burden of disease estimates for selected major risks to health, including the estimates of disease burden due to indoor and outdoor air pollution discussed below.

Key issues

The quantity and quality of scientific literature on the health effects of air pollution vary considerably by pollutant type and by health outcome. Following is a list (in no particular order) of some of the issues in understanding health impacts of air pollution.

Uncertainty. According to the 2002 World Health Report, indoor air pollution from combustion of solid fuels for cooking and space heating is one of the eight most important risk factors in global burden of disease (measured as disability adjusted life years [DALY]). It accounts for an estimated 2.7% of the global disease burden and some 1.6 million premature deaths annually. In poor developing countries, indoor smoke from solid fuels ranks fourth, behind only under-nutrition, unsafe sex, and unsafe water/sanitation/hygiene, accounting for an estimated 3.7% of the disease burden. Urban air pollution additionally causes 1.4% of premature deaths and 0.8% of the global disease burden.

These estimates of disease burden are subject to considerable uncertainty, however. The estimates of disease burden due to urban air pollution are based only on the impact of air pollution on mortality. The impact of air pollution on morbidity could not be included in the calculations due to lack of reliable epidemiologic data. Similarly, disease burden estimates for indoor air pollution could not include several important health outcomes, such as tuberculosis, cataracts, asthma, and adverse pregnancy outcomes, that have been associated with indoor smoke but the evidence is not conclusive. These estimates also do not include health impacts of exposure to atmospheric lead and likely impacts of climate change.

Transfer of results from one setting to another. Most epidemiological studies of air pollution have been conducted in developed countries. Mainly due to the time and cost involved in establishing dose-response relationships from prospective epidemiologic studies, dose-response functions established in developed-country settings are often used in developing-country studies. How appropriate and applicable is this transfer of exposure-response functions? What are the options

for developing countries that do not have good local epidemiologic studies of air pollution? The level and composition of air pollutants vary considerably from one setting to the other, and overtime in the same setting. The relationships between ambient air pollution and health observed in developed countries at typically much lower levels of air pollution may not be applicable to developing-country situations with much higher air pollution levels. The disease composition in the underlying population may also differ between the settings. Moreover, the susceptibility of the populations to adverse health effects of air pollution may be quite different. Caution should be exercised when extrapolating the results from one study setting to another, keeping in mind the differences in pollutant mix, concentration levels, disease composition and prevalence levels, and susceptibility of underlying population.

A similar problem arises, when dose-response curves from ambient air pollution studies are applied to indoor air pollution studies in developing countries, where exposure levels tend to be many fold higher than from ambient sources. Also, the composition of air pollutants indoors may be very different from that outdoors. In some cases, exposure-response functions are derived from laboratory studies on animals, and questions remain about the uncertainty in applying these functions to humans.

Given that populations in developing countries are typically exposed to much higher air pollution levels and tend to have poorer nutritional status, higher prevalence of infectious diseases, and poorer access to health care, can we assume that the effects of air pollution are more severe for populations in developing countries? How do nutritional status and other factors modify the effects of air pollution on health?

Valuing the health impacts of air pollution. Another major issue relates to valuing the health impacts of air pollution. Policymakers often need to assess relative importance of air pollution in setting priorities for health programs. Estimating the costs of ill health, suffering, and premature death is a highly debated, controversial subject. The valuation of health impacts is usually done using 'willingness to pay' or 'cost of illness' approaches. Both these approaches need to make some heroic assumptions about value of lost life, or lost workdays, pain, and suffering. The task is made more difficult by non-availability of local epidemiologic studies, when additional assumptions about dose-response functions need to be made. Yet, policymakers cannot wait for more research, and decisions need to be made based on best available information, appropriately adapted to the local setting.

Pollutant mixtures. Given that air pollution is generated from many sources (including industry, motor vehicles, home cooking and heating, as well as from tobacco smoking and from numerous natural sources) and a variety of pollutants are present from each source, people are usually exposed to many air pollutants simultaneously. Air pollution contains complex mixtures of many pollutants, which vary overtime and from place to place depending on the sources of pollution and meteorological conditions. It is not clear if the effects of air pollution mixtures are additive or worse than the effects of individual pollutants. How do these effects differ in the short-term, and in the long term? How to disentangle the effects of various pollutants found together in the air? How to separate the short-term and long-term health effects of individual air pollutants and that of complex pollutant mixtures?

Much of the research on health impacts of air pollution has been conducted using single pollutants, and a majority of this research has focused on particulate matter. Is it appropriate to use one pollutant to represent a complex mixture of pollutants that people are exposed to? Does using several individual pollutants to estimate health effects in a study essentially leads to double counting and overestimation of effects?

Measurement of exposure and ill health. When estimating health risk from exposure to air pollution, it is critical to have good measures of exposure. In some studies, indirect surrogate measures of exposure are sometimes used. The examples include use of cooking fuel type as a measure of exposure to indoor smoke, traffic density for exposure to ambient air pollution, and chimney density as a proxy indicator for wood smoke pollution. How valid are these surrogate measures? Also, there are problems in assessing individual exposures from area samplers and community monitoring stations. Accuracy of exposure measurement equipment also raises questions about validity and reliability of results and their comparability across studies.

Measurement of health parameters also poses many challenges for the study of health impacts of air pollution. For example, in many developing countries, vital statistics and cause of death data are not routinely collected or are not reliable. Clinical data are also highly unreliable because there is often considerable selection due to differential access to health services and awareness of health problems. Multiple sources of health care, varying quality of services, poor diagnosis, and poor record keeping further complicate the study of health impacts.

Thresholds. Other questions relate to the shape of the dose-response curves. It is not entirely clear if the relationships between different air pollutants and health outcomes are linear? Are there thresholds below which no adverse health effects are expected to occur? For which pollutants and health outcomes?

Politics. Health effects of air pollution are studied more in developed countries, and more for more visible ambient air pollution. Health effects of indoor air pollution are also being investigated mostly for developed countries for indoor bio-allergens, such as dust mites and molds. However, the indoor air pollution problem is many orders of magnitude greater in poor, rural homes of developing countries, where half of the world population relies on unprocessed solid fuels for cooking and heating and is exposed to very high levels of many air pollutants on a daily basis. Because indoor air pollution from cooking and heating is often worst in poor, remote, rural areas, it tends to receive less attention than more visible ambient air pollution in cities and other proximate health problems that catch public attention. This raises questions about objectivity in the selection of topics to study health impacts of air pollution and availability of funding for such research.

Future directions

Needless to say that the science of air pollution and health linkages is less than conclusive. The biological mechanisms through which air pollutants affect health are not fully understood, and there is limited epidemiologic research on air pollution, limited mostly to the developed countries with very different pollution levels, exposure patterns, and underlying population characteristics than in developing countries. While there has been considerable research on health impacts of

tobacco smoking, and there is growing evidence on the effects of ambient air pollution, the research on health effects of indoor air pollution from household use of unprocessed solid fuels is particularly weak.

Clearly, there is need to strengthen both the quantity and quality of evidence linking air pollution and various health outcomes, especially for developing countries and for health conditions with weak or no evidence. This can be accomplished by measuring exposure levels more directly; by including clinical measures of disease outcomes; and by adequately accounting for social, behavioral, nutritional, and environmental confounding factors. In these efforts, there is need to use more powerful study designs, such as prospective cohort studies and randomized intervention trials, designed specifically for areas with weak data. A randomized intervention trial currently underway in upland Guatemala to study effects of improved stoves on acute respiratory infections in young children is a good example.

In addition to looking at health effects of individual pollutants, epidemiologic studies need to examine the effects of different pollutant mixtures and interactions between components of pollutant mixtures. It is also important to identify groups that are more susceptible to adverse health effects of air pollution, and to understand the interactions with poverty, nutritional status, and other factors.

In the meantime, policymakers in many developing countries need to design programs, set standards, and take action to mitigate adverse health effects of air pollution. These efforts need to carefully adapt available knowledge from other settings, keeping in mind the differences in pollutant mixtures, concentration levels, exposure patterns, and various underlying population characteristics.