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# THE GLOBAL BURDEN OF DISEASE DUE TO OUTDOOR AIR POLLUTION

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*As part of the World Health Organization (WHO) Global Burden of Disease Comparative Risk Assessment, the burden of disease attributable to urban ambient air pollution was estimated in terms of deaths and disability-adjusted life years (DALYs). Air pollution is associated with a broad spectrum of acute and chronic health effects, the nature of which may vary with the pollutant constituents. Particulate air pollution is consistently and independently related to the most serious effects, including lung cancer and other cardiopulmonary mortality. The analyses on which this report is based estimate that ambient air pollution, in terms of fine particulate air pollution ($PM_{2.5}$), causes about 3% of mortality from cardiopulmonary disease, about 5% of mortality from cancer of the trachea, bronchus, and lung, and about 1% of mortality from acute respiratory infections in children under 5 yr, worldwide. This amounts to about 0.8 million (1.2%) premature deaths and 6.4 million (0.5%) years of life lost (YLL). This burden occurs predominantly in developing countries; 65% in Asia alone. These estimates consider only the impact of air pollution on mortality (i.e., years of life lost) and not morbidity (i.e., years lived with disability), due to limitations in the epidemiologic database. If air pollution multiplies both incidence and mortality to the same extent (i.e., the same relative risk), then the DALYs for cardiopulmonary disease increase by 20% worldwide.*

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The views expressed in this article are those of the authors and do not necessarily reflect the views of the Health Effects Institute (HEI) or its sponsors.

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In 2000 the World Health Organization (WHO) initiated a comparative risk assessment (CRA) as part of its ongoing Global Burden of Disease project. The burden of disease in terms of deaths and disability-adjusted life years (DALYs) was estimated for 26 major risk factors by age, sex, and disease, worldwide and for each of 14 world regions. The burden of disease attributable to urban outdoor air pollution was estimated, along with the burdens of other environmental factors such as indoor air pollution, water quality, lead, and climate change. The project involved more than 100 researchers from 30 different institutions, and some 200 peer reviewers. The groups charged with generating estimates for each risk factor agreed on minimal standards of quality and quantity of evidence, and agreed to use a common approach for estimating the attributable burden. As a result, the WHO CRA provides results that are coherent and reasonably comparable across factors. This comparability is further enhanced by use of the same international database of mortality and morbidity for the year 2000 (WHO, 2001a, 2001b) based on the Global Burden of Disease Database (Murray & Lopez, 1996). The summary results of the CRA were released in the World Health Report (WHO, 2002) and published in *The Lancet* (Ezzati et al., 2002); detailed descriptions of the methods and results how available (Ezzati et al., 2004), including a detailed description of the methods and results for Urban Outdoor Air Pollution (Cohen et al., 2004).

Current scientific evidence, derived largely from studies in North America and western Europe, indicates that air pollution from the combustion of fossil fuels causes a spectrum of health effects from eye irritation to death. Recent assessments suggest that the public health impacts may be considerable. This evidence has increasingly been used by national and international agencies to inform environmental policies, and quantification of the impact of air pollution on the public health has increasingly became a critical component in the policy discussion as governments weigh options for pollution control.

Quantifying the magnitude of those impacts in cities worldwide, however, presents considerable challenges due to limited information on both health effects and air pollution exposures in many parts of the world. Man-made outdoor air pollution in the world's cities, derived largely from combustion processes, is a complex mixture with many toxic components. We indexed this mixture in terms of particulate matter (PM), a component that has been consistently linked with serious health effects and, importantly, that can be estimated worldwide. Exposure to PM has been associated with a wide range of health effects, but its effects on mortality are arguably the most important, and are also most amenable to global assessment. Our estimates, therefore, consider only mortality. Currently, most epidemiological evidence and air quality data that could be used for such estimates come from the developed world. Therefore we have had, therefore, to make assumptions concerning factors such as the transferability of risk functions, exposure of the population, and its underlying vulnerability to air pollution, while trying to ensure that these assumptions are transparent and that the uncertainty associated with them is assessed through appropriate sensitivity analyses.

## METHODS

In order to provide comparable estimates of exposure to outdoor air pollution for all 14 WHO regions, models developed by the World Bank were used to estimate concentrations of inhalable particles ($PM_{10}$) (Pandey et al., 2004). Specifically, economic, meteorologic, and demographic data and available PM measurements in 304 cities were used to estimate $PM_{10}$ levels in all 3211 cities worldwide with populations greater than 100,000 and capital cities. The estimated distribution of the world's urban population and that of the urban population of each of the 14 regions are shown in Figure 1. To allow the most appropriate epidemiologic studies to be used for burden estimation, the $PM_{10}$ estimates were converted to estimates of fine particles ($PM_{2.5}$) using available information on geographic variation in the $PM_{2.5}$/$PM_{10}$ ratio. Population-weighted regional annual means for each $PM_{2.5}$ and $PM_{10}$ estimate were obtained using the city's population in the year 2000.

Burden estimates were based on the contributions of three health outcomes: mortality from cardiopulmonary causes in adults, mortality from lung cancer, and mortality from acute respiratory infections in children from 0 to 5 yr of age. Attributable numbers of deaths and years of life lost for adults and children (<5 yr) were estimated using risk coefficients from a large U.S. cohort study of adults (Pope et al., 2002) and a meta-analysis summary of five time-series studies of mortality in children, respectively. Base-case estimates

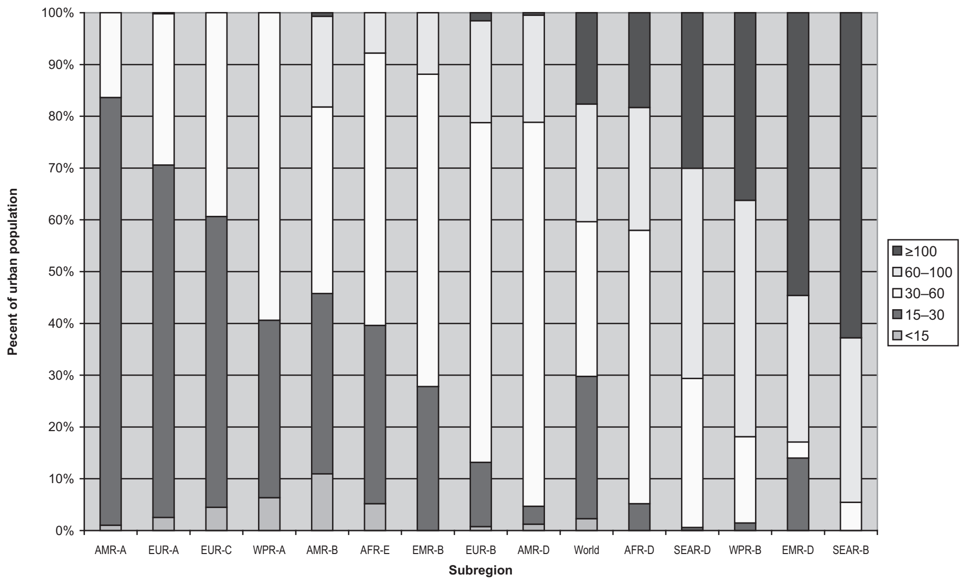


**FIGURE 1.** Distribution of the urban population according to estimated concentrations of $PM_{10}$ in cities with populations of >100,000 and in national capitals, by subregion. From Cohen et al. (2004).

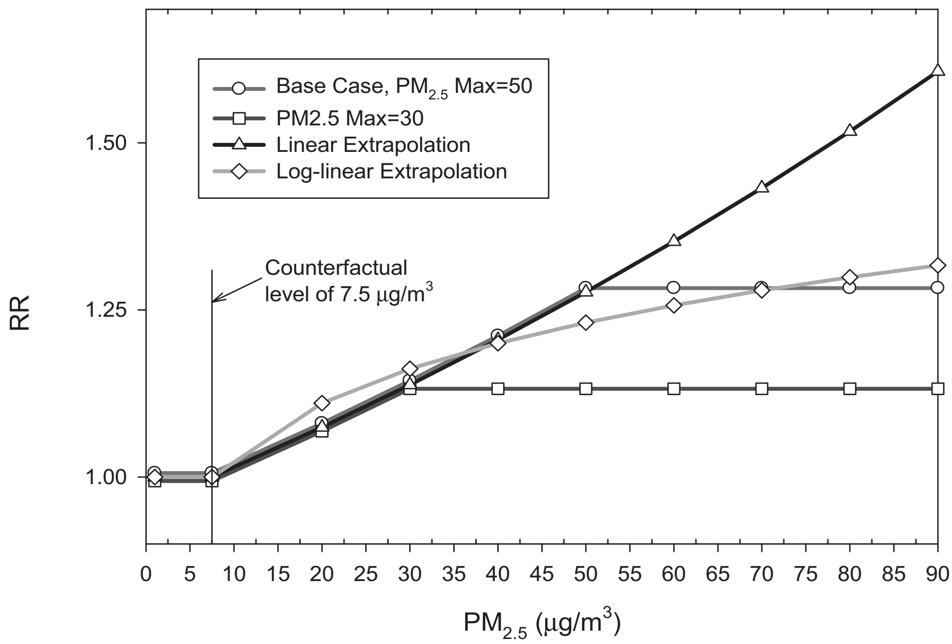


**FIGURE 2.** Alternative concentration-response curves for cardiopulmonary deaths. From Cohen et al. (2004).

were calculated with an assumption that the risk of death increases linearly over a range of annual mean concentrations of $PM_{2.5}$ between counterfactual value (or theoretical minimum) levels of 7.5 and 50 $\mu g/m^3$. The statistical uncertainty of the base-case estimates was quantified by estimating the joint uncertainty in the estimates of annual mean concentration and the estimates of the relative risks. The sensitivity of the base-case estimates to alternative choices of concentration-response function and counterfactual values was also assessed (Figure 2).

## RESULTS

Outdoor PM air pollution is estimated to be responsible for about 3% of adult cardiopulmonary disease mortality; about 5% of trachea, bronchus, and lung cancer mortality; and about 1% of mortality in children from acute respiratory infection in urban areas worldwide. This amounts to about 0.80 million (1.2%) premature deaths and 6.4 million (0.5%) lost life years (Table 1 and Figure 3). The worldwide estimates and most regional estimates varied by less than twofold (50% uncertainty interval). Model uncertainty due to assumptions about the shape of the concentration-response function, the choice of counterfactual level for PM, and other factors was assessed in sensitivity analyses. For the most part, the worldwide estimates in each sensitivity case are within the 50% uncertainty intervals for the base-case estimates. The sensitivity analyses

**TABLE 1.** Excess Deaths from Selected Environmental Factors

| Environmental risks | Global estimate | Asian estimate (S, SE Asia + W Pacific) | Asia as a percent of global |
|---|---|---|---|
| Unsafe water | 1,730,000 | 730,000 | 42% |
| Urban outdoor air | 799,000 | 487,000 | 65% |
| Indoor air | 1,619,000 | 1,025,000 | 63% |
| Lead | 234,000 | 88,000 | 37% |

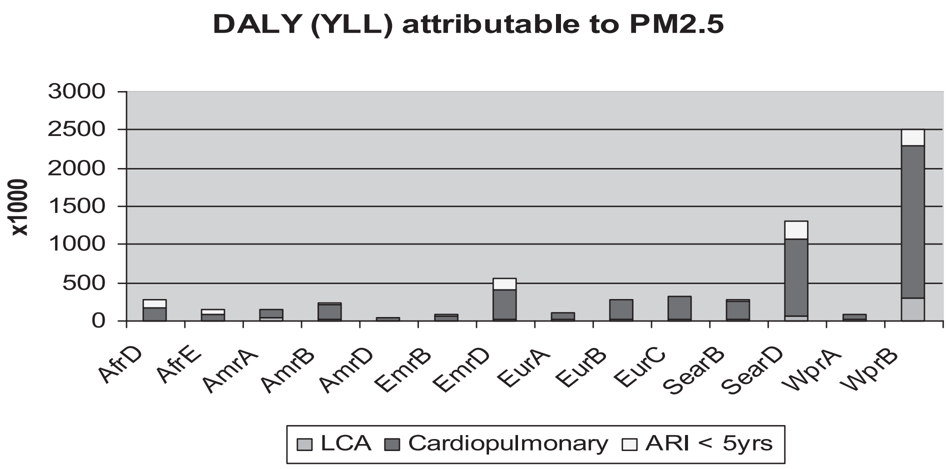


**FIGURE 3.** Years of life lost attributable to urban air pollution by region.

indicate that base-case estimates were most sensitive to the choice of concentration-response function and theoretical minimum level.

The burden of disease due to urban air pollution occurs predominantly in developing countries; developing Asia is estimated to contribute approximately two-thirds of the global burden (Table 1). Moreover, the burden of air pollution from all sources considered in the CRA (indoor, outdoor, occupational, and lead) accounts for about 1.9 million premature deaths annually, about 5.4% of the total disease burden in the 3 regions in terms of DALYs (Health Effects Institute [HEI], 2004). This burden is quite noteworthy: it is, for example, half again as much as that of tobacco and twice that of unsafe sex (due to acquired immunodeficiency syndrome and other risks) (WHO, 2002).

## DISCUSSION

The results indicate that the impact of outdoor air pollution on the burden of disease in the world's cities is large, but an assessment of sources of uncertainty, including the fact that only mortality impacts of exposure to PM were estimated, suggests that the impact is actually underestimated. Variation in the estimates is also considerable among the 14 WHO regions, with the greatest burden occurring (not surprisingly) in the more polluted and rapidly growing cities of the developing world.

As a consequence of the uncertainties in this global assessment, its quantitative results cannot be confidently extrapolated to smaller geographic areas, such as specific countries or cities. The methods for estimation of exposure and extrapolation of concentration-response functions were developed specifically for estimating burdens for large geographic regions, often in the absence of essential data on exposure and response. Where better data exist, as they currently do in some parts of the world, they should of course be used.

Future estimates of the global burden of disease due to outdoor air pollution would benefit from both additional research and methods development. There is a critical need for better information on the health effects of air pollution in developing counties. Exposure research should aim to provide better estimates not only of ambient concentrations but also the characteristics of outdoor air pollution, including the contribution of various sources and the size distribution of PM. Epidemiologic studies of mortality should be designed to provide age- and disease-specific estimates of air pollution effects. There is an obvious need for epidemiologic studies of the effect of air pollution on the incidence of chronic cardiovascular and respiratory disease. Estimates of uncertainty distributions should more fully incorporate model uncertainties, such as those related to the choice of concentration-response function (National Research Council, 2002).

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