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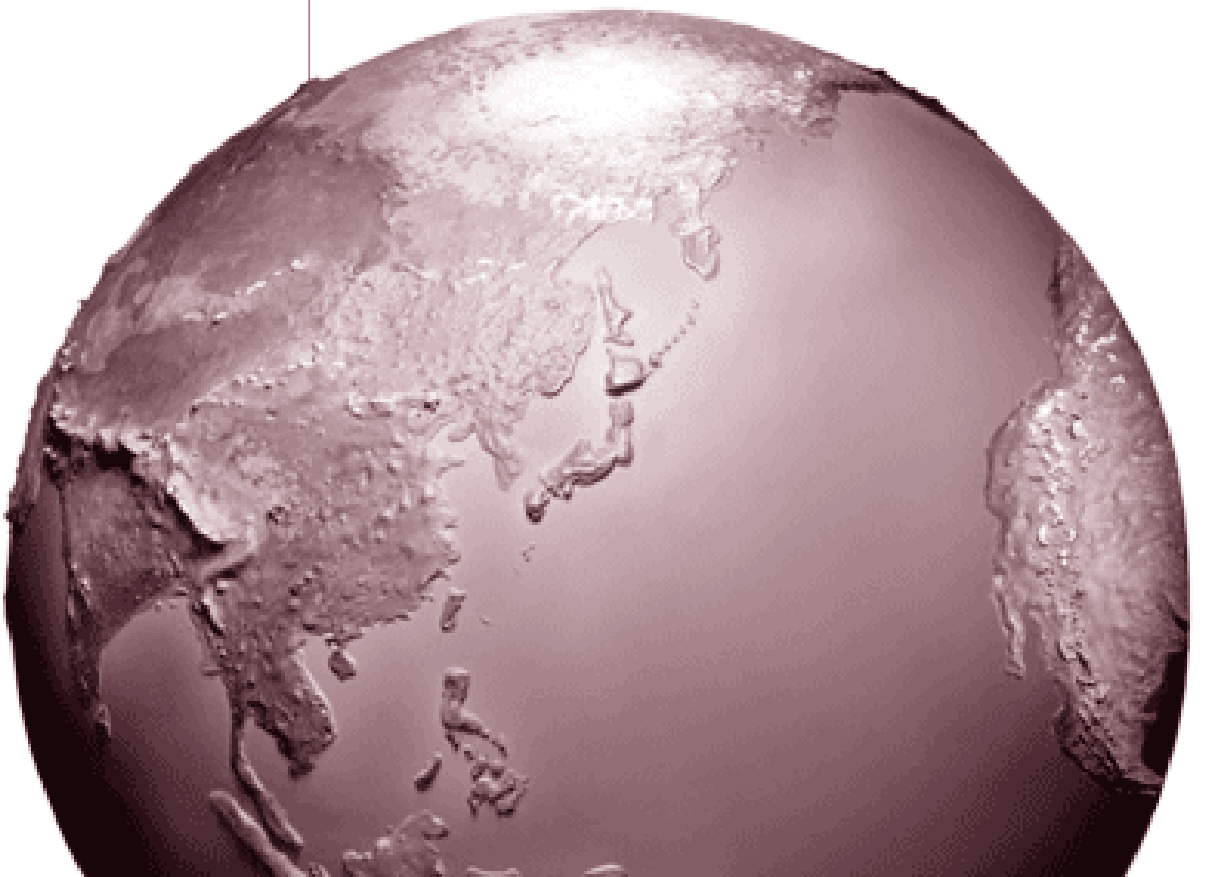
HEALTH EFFECTS INSTITUTE

April 2004

Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review

HEI International Scientific Oversight Committee
of HEI Public Health and Air Pollution in Asia Program
(a program of the Clean Air Initiative for Asian Cities)



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EXECUTIVE SUMMARY

The World Health Organization (WHO*) estimates that urban air pollution contributes each year to approximately 800,000 deaths and 4.6 million lost life-years worldwide (WHO 2002). This burden is not equally distributed: approximately two thirds of the deaths and lost life-years occur in the developing countries of Asia. Such estimates play an important role in decision making in a variety of policy contexts from setting of air quality guidelines to establishing public health priorities to international lending.

WHO's estimates suggest that the health impact of outdoor air pollution in Asian cities is substantial and warrants the attention of policy makers. The estimated impact is based largely on the results of research conducted in Europe and North America that have been extrapolated to other countries. While many similarities exist in the constituents of air pollution around the globe, Asia differs from Europe and North America in the nature of its air pollution, the conditions and magnitude of exposures to that pollution, and the health status, including the level of health care, of its populations. These differences create uncertainties when the results of studies from Western countries are used to estimate the health impact of air pollution in Asia. HEI initiated the Public Health and Air Pollution in Asia (PAPA) program to reduce these uncertainties by providing Asian decision makers with estimates of the health effects of air pollution in selected Asian cities over the next five years. The PAPA program's International Scientific Oversight Committee has prepared this current summary and critical review of the epidemiologic evidence on air pollution and health in Asia to guide the PAPA program's research.

The *Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review* has two objectives: (1) to identify and summarize the epidemiologic studies of outdoor air pollution that have been conducted in Asia; and (2) to examine in detail a subset of these studies—time-series studies that estimate the effect of short-term exposure to air pollution on daily mortality and on hospital admissions for cardiovascular and respiratory disease. In so doing, our goals are to provide a partial quantitative summary of what is known about the health effects of outdoor air pollution in Asia (focusing on estimates of the effects of short-term exposure to outdoor air pollution) and to identify gaps in knowledge that should be addressed in future research.

* A list of abbreviations and other terms appears at the end of the Executive Summary.

ASIAN LITERATURE IN CONTEXT

HEALTH EFFECTS OF AIR POLLUTION: KNOWLEDGE AND UNCERTAINTY

Interest in the health effects of outdoor air pollution in Asia is growing among policy makers, international lenders, nongovernmental organizations, industry, and others due to increasing knowledge about the health effects of air pollution and to the high levels of air pollution in Asia's burgeoning cities. Exposure to outdoor air pollution is now widely accepted as being associated with a broad range of acute and chronic health effects, ranging from minor physiologic disturbances to death from respiratory and cardiovascular disease (Bascom et al 1996a,b). This acceptance is based on observational epidemiologic studies of disease occurrence in human populations and the in vitro and in vivo studies of animals and humans (Health Effects Institute 2001, 2002). Epidemiologic research has provided estimates of the health effects from both short-term and long-term exposure to air pollutants (including particulate matter [PM], ozone, and other gaseous pollutants) in many parts of the world. Because these estimates apply to humans living in real-world conditions, they have been a key part of the scientific basis for increasingly stringent air quality regulations for some pollutants.

Despite this growth of knowledge, uncertainty remains about some critical questions of importance to public policy. How large is the effect of short-term exposure on daily mortality and morbidity? How does it vary across the globe? How

accurately can we measure the magnitude and variability of these effects with our current statistical tools? Which diseases, social conditions, or genetic factors place people at greatest risk when exposed to air pollution? To what extent does long-term exposure affect the development of chronic disease, and what shortening of life may result? Which constituents of the pollutant mixture are most toxic and which sources contribute to it? The answers to most of these questions might well be different in Asia than in the West. Beginning with this Special Report, the PAPA program provides an important opportunity to understand the similarities and differences in a manner that will enhance understanding in both the developing as well as the developed world.

DEVELOPMENT AND HEALTH

In many ways Asia is the most dynamic part of the world. Incomes are growing with concomitant increases in industrialization, urbanization, and motor vehicle use. Although hundreds of millions still live in poverty, continued slowing of population growth and steady growth of per capita income are real prospects. Population growth rates are falling dramatically. From 2000 to 2030, the population of China is expected to increase at only about 60% of the growth rate in the United States. India's growth rate is expected to fall by nearly a factor of two from its level in the late 20th century. Nevertheless, with such large populations to start with, the absolute increase in population will be substantial. In Asia as a whole, nearly a billion people will be added over the next three decades—the equivalent of another India in terms of population. Population growth itself does not necessarily mean much greater exposure to ambient air pollution. As more of the population moves to cities that contain many outdoor pollution sources, however, exposure increases substantially. Currently about two thirds of Asians still live in rural areas, but this is changing. More people already live in Chinese and Indian cities than inhabit all of Africa and twice as many as inhabit all of North America.

In this century, the pattern of morbidity and mortality in low-income Asian countries is in transition because of increasing life expectancy and greater prevalence of risk factors related to lifestyles, urbanization, and environmental degradation. Deaths and lost years of healthy life due to malnutrition, maternal causes, and communicable diseases continue to be great. But at the same time, the incidence and prevalence of chronic noncommunicable diseases (such as hypertension, diabetes, ischemic heart disease, and cancer) are also increasing (Murray and Lopez 1997). The growing burden of respiratory disease, circulatory disease, and cancer is due to multiple factors, but increased tobacco smoking is playing a major role (WHO 2002).

EXPOSURE TO AIR POLLUTION

In general, combustion is the chief process responsible for pollutant emissions. In poorer cities, burning refuse (garbage and biomass) still creates considerable air pollution. Although centralized refuse burning on a large scale contributes in some settings, the more diffuse, small-scale burning may have a greater impact in most Asian cities. It is expected, however, that the most egregious refuse combustion will probably be controlled within the next 30 years.

In most cities, the chief source of combustion is fuel use, which tends to increase along with population size and economic activity. Although emissions vary with combustion conditions and emission-control technology, fuel type is a useful indicator of potential emissions: coal and biomass are high-emitting solid fuels; gasoline, kerosene, and diesel are mid-emitting liquid fuels; and liquefied petroleum gas and natural gas are low-emitting gaseous fuels. Projections suggest that Asia, due to its expected economic growth, is likely to experience substantial increases in its use of both coal and motor-vehicle fuels.

Some of the highest levels of outdoor air pollution in the world are found in Asian cities. Figure 1 shows annual mean concentrations of total suspended particles (TSP), PM less than 10 μm in aerodynamic diameter (PM_{10}), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) in 2000 and 2001 in major Asian cities. Some cities in China and India have some of the world's highest recorded PM_{10} levels. Air pollution in Asian cities is closely tied to levels and trends in economic and social development. As well as rapidly increasing industrialization, urbanization, population growth, and demand for transportation, meteorologic conditions influence air pollution levels in most South and Southeast Asian cities. Although governments have

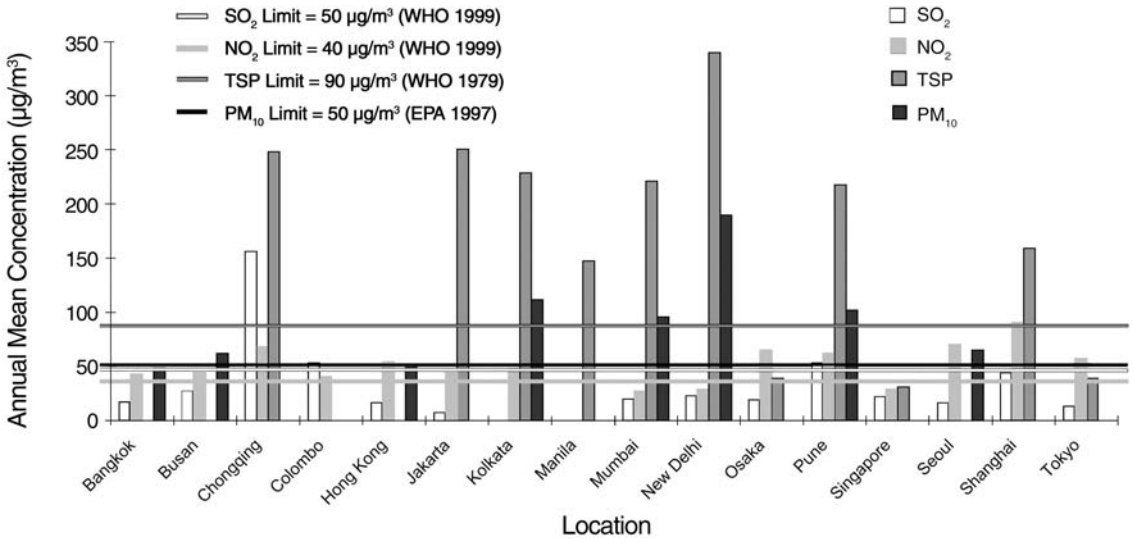

Figure 1. Annual mean concentrations of pollutants compared with their guidelines and standards in Asian cities, 2000 and 2001. Data from Air Pollution in Megacities of Asia 2004.

acted to reduce emissions and control pollution, continuing improvement in urban air quality will require sustained, long-term efforts to keep pace with rapid urban growth and development.

Indoor air pollution is also a serious concern in the developing countries of Asia, where 60% to 80% of households rely on solid biomass fuels for cooking and heat. These fuels are usually burned in low-efficiency, unvented traditional devices and result in high levels of indoor air pollution. Women and children incur the greatest exposures because they spend the most time indoors, working with or near combustion sources. As much as 30% to 60% of urban residents of low-income countries are thought to live in poor households and to be exposed to high indoor air pollution. Some households have recently shifted to cleaner gaseous fuels, but the shift has been slow and largely confined to high and middle income families. Epidemiologic studies show that smoke from indoor cooking fires affects a number of health outcomes, including acute lower respiratory infections in children under five years, chronic obstructive pulmonary disease (COPD), and lung cancer (the last from exposure to coal smoke only) (Smith et al 2004).

Epidemiologic studies of outdoor air pollution in Western countries have generally not considered indoor sources and total exposure. Although it is tempting to follow the same course in studies in developing countries of Asia, differences between indoor and outdoor sources, especially in poor neighborhoods, raise questions that should be addressed. For example, residents of slum households, who tend to have more health problems due to poverty, might also experience higher outdoor exposures because they live in slums. In such cases, the effect of poverty on health can be confused with (or confounded by) the effect of air pollution. Although this would not be expected to pose a threat to the validity of time-series studies of daily changes in air pollution and health (the effects of poverty do not change daily), studies of the effects of long-term exposure could be affected. Exposures to indoor air pollution or other factors associated with poverty may also increase the susceptibility of the poor to outdoor air pollution. Studies of short-term and long-term exposure should therefore consider the interaction of poverty-related factors and exposure to indoor and outdoor air pollution.

REGULATION OF AIR POLLUTION

Countries throughout Asia have taken action to address air pollution over the past decade. This action was prompted by the development of monitoring systems to document air pollution levels (although with widely varying comprehensiveness and sophistication) and growing public awareness

of the high levels of air pollution experienced in everyday life (especially in congested cities). Many Asian countries have now adopted national ambient air quality standards based on their local conditions and, at least in part, on WHO guidelines and standards adopted in Europe and the United States.

Some countries have also begun to reduce emissions from specific sources, most notably motor vehicles, industries, and electricity generating facilities. In recent years, these efforts have been augmented by the Clean Air Initiative for Asian Cities (CAI-Asia), which was organized (with assistance from the Asian Development Bank and the World Bank) to promote sharing of technical advice among regulatory agencies, industries, nongovernmental organizations, and other stakeholders in Asia.

These actions have resulted in measurable declines in the levels of some pollutants. For example, in countries that have removed lead from gasoline, exposures to lead and blood lead levels in children and others have declined markedly. Efforts to control sulfur levels in fuel and to reduce emissions from coal-burning industries and electricity generating facilities have resulted in even longer-term reductions in ambient SO_2 (Hedley et al 2002). In some locations (eg, Hong Kong and Bangkok), comprehensive programs targeting motor vehicles and other sources have substantially reduced the levels of several pollutants that historically were very high.

Despite this progress, considerable challenges to improving air quality in Asia remain. Although standards for new sources of air pollution (especially motor vehicles) have been tightened, a substantial number of older, high-emitting motor vehicles and factories are still operating. Further, rapid economic development and increased numbers of motor vehicles on the road could offset in whole or in part the reductions in emissions gained by recently adopted control measures. Addressing these existing sources will require extensive interventions. Asian cities also face an array of diffuse, difficult-to-control sources (eg, open burning, low-quality indoor fuels, and uncontrolled small businesses and industries).

The speed and strength of actions taken to improve air quality have been diminished by several factors: the need to focus on other challenges (including other environmental public health challenges such as waterborne diseases); the perceived conflict between objectives for economic growth and costs of environmental actions; and a reluctance to use results from studies conducted in Western countries to estimate health effects of air pollution in Asia.

Despite these challenges, several Asian cities have made substantial progress, especially when activities were informed by targeted efforts to document the local health consequences of air pollution and to estimate the economic impact. Improved local studies of the health effects of air pollution would be an important contribution to all future analyses of the health and economic consequences of actions to improve air quality.

REVIEW OF AIR POLLUTION EPIDEMIOLOGY STUDIES IN ASIA

The *Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review* identifies and describes original epidemiologic studies of the health effects of outdoor air pollution in Asia published in the peer-reviewed scientific literature from 1980 through 2003. Then the report presents a critical, quantitative review (or meta-analysis) of the time-series studies of daily mortality and hospital admissions. For the purposes of the overview and the subsequent meta-analysis, we define *Asia* to include all countries in East, South, and Southeast Asia. Relevant studies were identified by computer searches of the scientific literature by subject heading, region and country. These searches were augmented by review of leading preventive medicine and epidemiology journals in the Chinese-language literature and the bibliographic references to published papers.

OVERVIEW OF THE ASIAN LITERATURE

The Special Report identified 138 papers published in the peer-reviewed literature between 1980 and June 2003 that present original estimates of health effects of outdoor air pollution in Asia. Although the studies were conducted in 8 countries, most were conducted in East Asia (mainland China, Taipei,China, Hong Kong, South Korea, and

Japan). A few studies were conducted in South Asia (India) and Southeast Asia (Figure 2). Most of the studies were published in the past 10 years, a trend that is in keeping with the growth of the Western literature in this period (Figure 3).

Collectively, the studies examined the association of PM and gaseous pollutants with mortality, hospital admissions, respiratory symptoms, pulmonary function, and adverse reproductive outcomes (Table 1). The preponderant (70%) study designs were either cross-sectional prevalence studies of chronic respiratory symptoms or of pulmonary function or were time-series studies of the effects of short-term exposure on daily mortality or hospital admissions. Despite these many studies, the diverse effects of exposure to outdoor air pollution have not yet been comprehensively assessed in most Asian countries. One exception is China, where epidemiologic studies of both acute and chronic effects have been conducted over the past 25 years. These studies, often conducted on populations exposed to very high levels of PM and other pollutants, report adverse effects of short-term and long-term exposure on cardiovascular and respiratory health.

Most of the 138 studies identified by the Special Report describe increased risk or prevalence of a variety of adverse health outcomes in adults and children exposed to outdoor air pollution, often at levels considerably higher than those encountered in Western studies. Given the diversity of study designs and data sources, the Special Report does not attempt (with the exception of the daily time-series studies) to assess the quality of every individual study. The Special Report also does not assess the likelihood that only, or predominantly, positive studies were published (ie, publication bias).

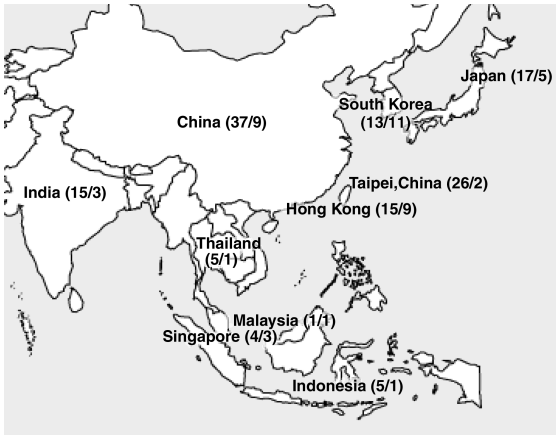

Figure 2. Epidemiologic studies of air pollution in Asia published from 1980 to June 2003. Numbers in parentheses are total studies/time-series studies conducted.

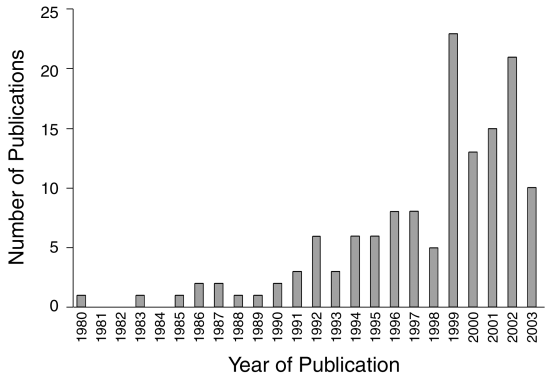

Figure 3. Number of publications of epidemiologic studies of air pollution in Asia by year. In 2003, published papers were collected only through June.

Table 1. Characteristics of 138 Epidemiologic Studies of Outdoor Air Pollution in Asia 1980–2003

	Number of Studies
Health Outcome	
Mortality	26
Hospital admissions, visits, discharges	17
Respiratory diseases, symptoms, function, asthma	57
Biomarker	9
Pregnancy or birth outcomes	9
Lung cancer	10
Other	10
Design	
Cross section	48
Time series[a] (total)	45
(Time series[a] used in meta-analysis, 28)	
Cohort	14
Case control	8
Panel	7
Ecologic	9
Case crossover	3
Impact assessment	4

[a] Includes episode studies.

Executive Summary

META-ANALYSIS OF DAILY TIME-SERIES STUDIES

Objectives of the meta-analysis were to summarize estimates from time-series studies of the effects of short-term exposure on daily mortality and morbidity in Asia and to compare these with estimates made in Europe and North America. To that end we conducted two analyses: (1) descriptive analyses of the full range of effect estimates; and (2) where there were sufficient studies, summary estimates of the effects of exposure to specific pollutants on specific outcomes.

Methods

The Special Report identified 28 time-series studies of daily mortality or hospital admissions that met prespecified criteria for inclusion in the meta-analysis. In order to be included, studies were required to be based on at least one year of data, to have controlled statistically for major time-varying, potentially confounding factors such as season and weather, and to have reported their results in terms of relative changes in daily mortality or morbidity (and estimates of their statistical variability) per unit of air pollution.

The 28 studies that met these criteria were conducted in eight locales. The largest number of studies was from South Korea (11), mainland China (6), and Hong Kong (6). Single studies were reported from Taipei,China, India, Singapore, Thailand, and Japan. Descriptive data were abstracted, including author names, journal citation, length of the study period, year of study, study location, average pollution levels during the study period, outcomes, and pollutants studied. The diverse effect estimators (reported using different statistical estimators) were converted to a standard estimator (percentage change in the mean number of daily events associated with a 10 $\mu g/m^3$ increase in the pollutant) in order to make the results from each study comparable. When more than one study had been reported from a given city, estimates from the most recent study were chosen. The impact of this decision on the results was evaluated in a sensitivity analysis.

When conducting a time-series study, investigators must deal with several sources of uncertainty. One source is the components of urban air pollution responsible for the health effects. Several important pollutants are emitted from the same sources and their ambient concentrations are often correlated over time. This makes it difficult to disentangle their effects on the statistical analysis. Investigators therefore frequently conduct analyses considering one pollutant at a time (single pollutant models) and may or may not conduct or report analyses that consider simultaneously more than one pollutant (multipollutant models). Our analyses focus on the results of single pollutant models only; at this stage, there are too few studies with results of comparable multipollutant models to allow meaningful analysis.

Another important source of uncertainty concerns the timing of exposure in relation to death or admission to a hospital. Some delay (lag) must be expected between exposure and the onset of death or hospital admission, but it is not clear what length of delay should be expected. Recent research suggests that the health effects of short-term exposure are due to air pollution over several days prior to the health event. However, most time-series studies to date, and all Asian time-series studies, estimate the effects of exposure on only one or perhaps a mean of 0 to 3 days prior to the event. Although some investigators reported that they had explored other lags, too few reported these results to allow meaningful analysis.

A third source of uncertainty is that the current literature does not geographically represent all of Asia and that South and Southeast Asia are substantially underrepresented. Although results might be similar in all of Asia, differences in the levels and composition of air pollution, source types, population health, and socioeconomic development might result in different health effects from short-term exposure to outdoor air pollution.

Characteristics of Time-Series Subset

Effect estimates were reported for seven pollutants (total suspended particles, PM_{10}, PM less than 2.5 μm in aerodynamic diameter [$PM_{2.5}$], SO_2, NO_2, carbon monoxide [CO], and ozone [O_3]) and a variety of specific outcomes, including all-cause[1] and cause-specific mortality, respiratory and cardiovascular hospital admissions, and community outcomes including emergency room visits, unscheduled primary care visits, and school

1. Throughout this Executive Summary, we define *all causes* as all natural causes (excluding accidents) unless otherwise noted.

absences. All-cause mortality was addressed in the largest number of studies (13 studies) and SO_2 was the most frequently studied pollutant (11 studies). Not all combinations of pollutants and outcomes were studied and many were addressed in only one study. For example, only one study estimated the effects of $PM_{2.5}$, and this only for all-cause mortality (Figure 4).

The statistical methods of the time-series studies were essentially the same as the contemporary methods used in the United States, Europe, and elsewhere. Indeed, several of the studies explicitly adopted the analytic approaches used in Western multicity time-series studies such as the Air Pollution and Health: A European Approach (APHEA) studies (Katsouyanni et al 1997, 2001). Questions and concerns regarding the statistical modeling used in these studies are, therefore, similar to those that have been posed about contemporary studies done in Western countries. Of the 28 ecologic time-series studies, most used Poisson regression analysis and approximately half of these used generalized additive models (GAMs) to estimate associations with air pollution while controlling for long-term time trends, seasonality, and weather. Under certain conditions, this modeling approach may understate the statistical uncertainty and provide inaccurate estimates of the pollution effects. Although use of GAMs may not have resulted in large inaccuracies, additional work on these studies—such as the revised analyses of US and European studies (Health Effects Institute 2003) using alternative modeling approaches—would be needed to fully address this issue.

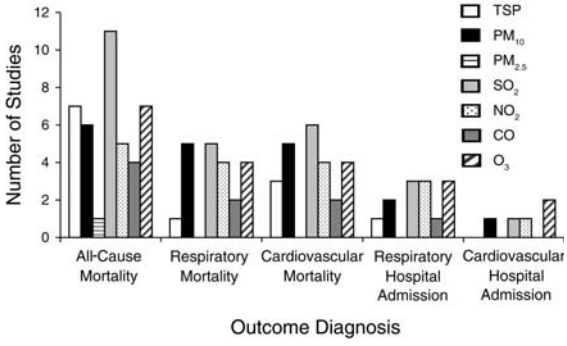

Figure 4. Outcome diagnosis by pollutant in the 28 Asian daily time-series studies.

Descriptive Results

Descriptive analyses of the range of pollutant–outcome pairs suggest that exposures to most particulate and gaseous pollutants are associated with increased rates of daily mortality and hospital admissions in Asian cities. The relatively small number of studies precludes detailed evaluation of how the magnitude of estimated effects may vary among the few cities that have been studied. However, the descriptive analyses suggest that the magnitude of increase in daily deaths may differ among cities for some pollutants (such as SO_2) but not others (such as PM_{10}) (Figure 5).

Summary Estimates

For pollutant–outcome pairs for which four or more estimates were available, we calculated a summary measure of the percent change in mean number of daily events associated with a 10 $\mu g/m^3$ increase in the pollutant. PM_{10}, total suspended particles, and the gaseous pollutants SO_2 and NO_2 were each associated with all-cause mortality. Although the current studies are not representative of the full range of Asian settings, the summary estimates for PM_{10} and SO_2 (an approximately 0.4%–0.5% increase in all-cause mortality for every 10 $\mu g/m^3$ of exposure) resemble those previously reported by the large US and European multicity studies that used comparable statistical methods (Table 2).

Statistical tests for publication bias suggested that this might be an issue for SO_2 and all-cause mortality. Correcting for this possible bias resulted in a small reduction in the magnitude of the estimated increase in daily mortality.

CONCLUSIONS AND RESEARCH NEEDS

The size of the Asian air pollution epidemiology literature exceeded our expectations. We identified 138 studies published in the peer-reviewed literature between 1980 and 2003, most published over the past decade. This number may well be an underestimate because we may have failed to identify some papers published only in local peer-reviewed literature. Asian investigators may also encounter difficulties in publishing their work in Western journals, so some research may simply go unreported. And although some countries are well

represented in the literature, others are not. The majority of studies have been conducted in the more-developed countries of East Asia with relatively few studies conducted in South and Southeast Asia, where rapid urban growth has been accompanied by extremely high levels of air pollution.

Although we did not conduct a critical, quantitative review, the Asian literature seems to be similar in many respects to the broader air pollution epidemiology literature: its recent growth, the health endpoints it addresses, and the relative frequency of certain study designs. Like in the broader literature, a number of time-series studies of short-term exposures and cross-sectional studies of respiratory health effects have been conducted. The latter studies report estimated effects of exposure to air pollution that are qualitatively similar to those in the broader literature (eg, Pope and Dockery 1999) although they may not accurately represent the health effects of exposure across the entire region. None of these studies of Asian populations estimate the effects of long-term exposure on mortality from nonmalignant cardiovascular and respiratory disease.

A sizeable body of good-quality time-series studies already exists in Asia, but the overwhelming majority published to date have been conducted in China (including Hong Kong and Taipei,China) and South Korea. In these studies,

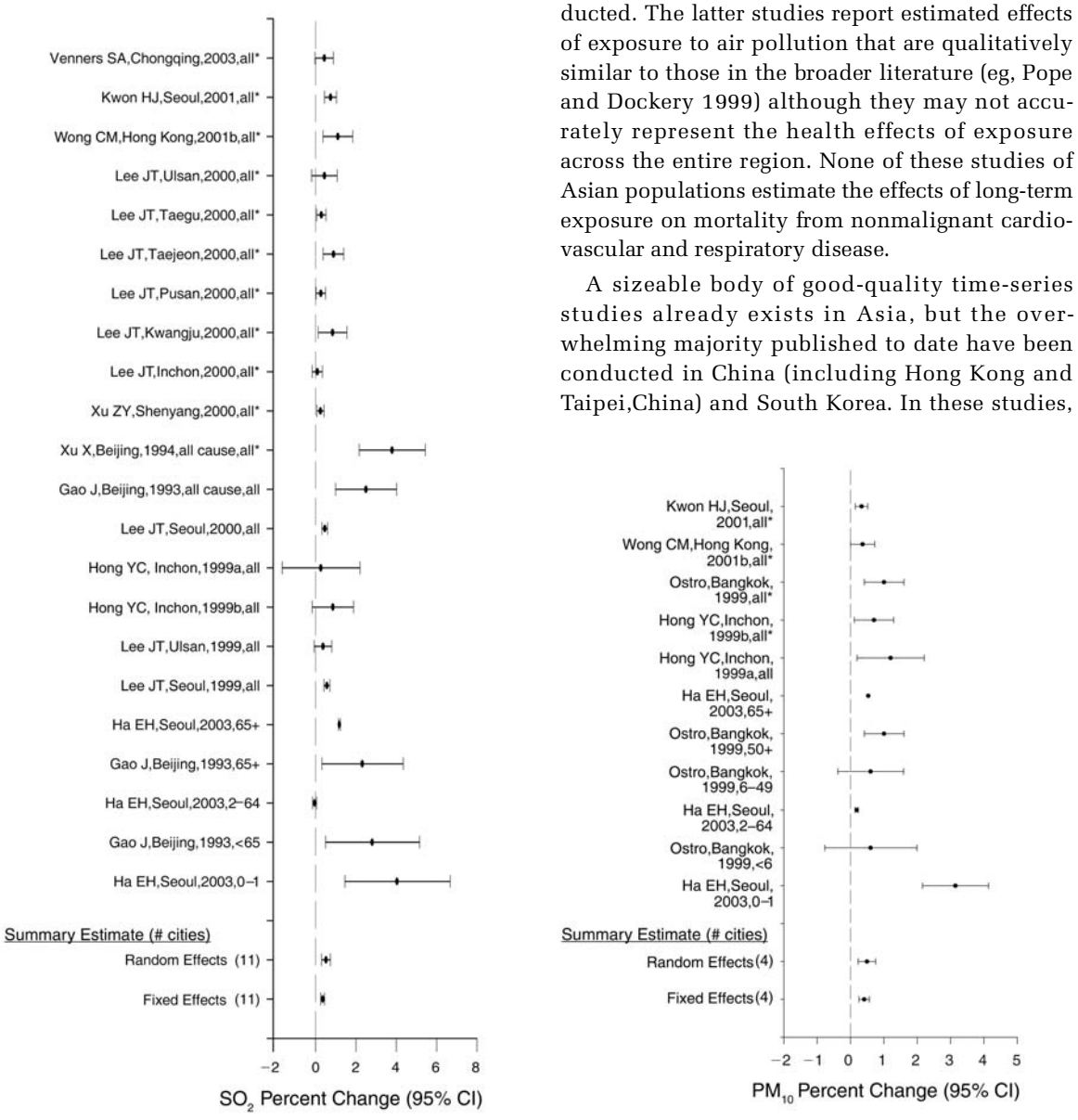

Figure 5. Percent change in mean number of daily deaths from all causes per 10 μg/m^3 increase in 24-hour mean level of SO_2 (left) and PM_{10} (right). Note the differences between x-axis scales. Y-axis labels give study information in the following sequence: first author name, study location, publication year, and age group (years). * Included in calculation of summary estimates.

increased daily morbidity and mortality are associated with PM and various gaseous pollutants although, in any quantitative review of published studies, difficulties necessarily occur because the studies vary considerably in presentation of their results and frequently comprise multiple studies of the same city. Although the existing studies do not yet represent the full range of Asian settings, when estimates from individual studies are combined into summary estimates, these resemble results from more extensive, coordinated multicity studies conducted recently in Europe and North America (at least for PM_{10} and SO_2).

These apparent similarities are noteworthy and in some ways surprising. On the one hand, we have found the not unexpected evidence of effects of short-term exposure to outdoor air pollution in Asian cities at high levels. The acute toxicity of short-term exposure to high air pollution concentrations has been appreciated since the mid 20th century, and recent multicity studies in Europe and North America have identified such effects at even lower concentrations. On the other hand, we also had good reason to expect that aspects of the relation between exposure to air pollution and health might differ, possibly with important implications for both scientific understanding and policy decisions. Differences in the age structures, health status, and lifestyle between Asian and Western populations might well be expected to alter susceptibility to air pollution. And the air pollution mixture itself, and its associated toxicity, might also be expected to be reflected in the results of the epidemiologic studies. The studies that have been reported to date do not show such differences, however. Future combined analyses of studies in a more fully representative range of Asian cities will help strengthen what conclusions can be drawn about the similarity of Asian results and those from the rest of the world.

Table 2. Summary of Estimates of Percent Change[a] in Health Outcomes[b]

Outcome	Pollutant	Number of Estimates	Heterogeneity[c]	Fixed-Effects Estimate (95% CI)	Random-Effects Estimate (95% CI)	Publication Bias Test[d]	Multicity Study Summary Estimates (95% CI)
All-Cause Mortality							
	PM_{10}	4	0.14	0.41 (0.25,0.56)	0.49 (0.23,0.76)		APHEA 2[e] 0.6 (0.4,0.8) NMMAPS[f] 0.41 (0.29,0.53)
	TSP	10	0.55	0.20 (0.14,0.26)	0.20 (0.14,0.26)	0.53	
	SO_2	11	< 0.001	0.35 (0.26,0.45)	0.52 (0.30,0.74)	0.03	APHEA 1[g] 0.40 (0.3,0.5)
Respiratory Admissions							
	NO_2	4	< 0.001	0.28 (0.09,0.47)	0.95 (−0.05,1.94)		
	SO_2	4	0.03	0.07 (−0.28,0.41)	0.16 (−0.46,0.77)		

[a] Per 10 $\mu g/m^3$ increase in ambient pollutant concentration.

[b] Calculated when four or more studies provided estimates for individual pollutant–outcome pairs.

[c] *P* value from χ^2 test. (*P* values < 0.05 were considered statistically significant.)

[d] *P* value from the Begg test. The test was not conducted for those pollutant–outcome pairs with too few estimates. (*P* values < 0.05 were considered statistically significant.)

[e] 29 European cities (Katsouyanni et al 2001).

[f] 90 US cities (Samet et al 2000b).

[g] 12 European cities (Katsouyanni et al 1997).

Executive Summary

GAPS IN CURRENT KNOWLEDGE

Gathering evidence from a wider range of Asian cities and using a more systematic approach to analyze and report results will help us learn more about the health effects of air pollution in Asia and how it compares to other regions of the world. The following gaps in current knowledge could be addressed in future research.

- *How are short-term exposures to outdoor air pollution related to daily morbidity and mortality across Asia?* Are effects of similar magnitude seen in India, Indonesia, Vietnam, Malaysia, and the Philippines and in China, Hong Kong, and South Korea? Differences in the relative prevalence of urban air pollution sources (such as open burning) and urban poverty may modify the effects of exposure. Studies of comparable design, analyzed consistently and conducted across the region, will provide more definitive answers.
- *Does the nature of the air pollution mixture affect the magnitude of observed health effects?* Air pollution sources in developing Asian cities differ from those in the West so the resulting urban air pollution mixture may differ as well. Detailed studies of the composition of air pollution and of the relative contribution of various sources have not yet been conducted extensively in Asia. Without such studies, epidemiologists have a difficult time assessing the relative effects of different pollution mixtures or specific pollution sources or even interpreting patterns of variation.
- *What is the shape of air pollution concentration–response function over the range of ambient air pollution observed across Asia?* The shape of the PM concentration–response function for daily mortality has been described in large multicity studies in the United States over a range of concentrations lower than that observed in many Asian cities. The shape of that function at higher concentrations has not been as extensively studied. A set of coordinated studies is needed to span the observed range of ambient concentrations in cities across Asia so that the results can be compared reliably.
- *Are the same subpopulations susceptible to effects of air pollution in Asia and the West?* Quantitatively similar estimates of relative increases in all-cause mortality may mask different patterns of susceptibility. Death at younger ages (due to acute respiratory infections, tuberculosis, or acute respiratory syndrome, for example) may play a larger role in Asia than in the West. Given the relatively larger proportion of younger age groups in Asian populations, the answer to this question has important implications for health-impact assessment of air pollution in Asia. In addition, although the prevalence of chronic cardiovascular and respiratory diseases is increasing in urban Asian populations, susceptibility to the effects of air pollution among those with chronic disease may be modified by diet or other factors, even among older people. As demographic and health patterns emerge, studies are needed that (at a minimum) estimate effects on morbidity and mortality by age and, preferably, by cause over time.
- *What role does indoor air pollution play in the health effects of outdoor air pollution?* The magnitude and prevalence of exposure to indoor air pollution is high in Asian cities, especially among the poor. We need to understand better how air pollution from indoor sources contributes to levels of outdoor air pollution and how indoor exposure to air pollution from indoor sources affects risk estimates for outdoor air pollution. Coordinated measurements of exposure and coordinated epidemiologic studies will be needed to address these questions.
- *What role does poverty play in the health effects of air pollution?* Limited evidence, largely from studies in Europe and North America, suggests that economic deprivation increases the risk of morbidity and mortality related to air pollution. One reason may be the higher air pollution exposures that people with lower socioeconomic status experience. But increased susceptibility can also be affected by factors related to socioeconomic status, such as health, nutritional status, and access to medical services. Studies of these issues have not yet been conducted in Asia,

where extreme poverty is more prevalent and results of the Western studies cannot be simply extrapolated. Studies in Asia that examine the effect of exposure on morbidity and mortality from diseases associated with poverty (such as acute respiratory infections in children and tuberculosis) and studies that estimate effects of exposure in different socioeconomic strata are needed.

- *What are the effects of long-term exposure to air pollution?* Health impact assessments of air pollution (such as the WHO Comparative Risk Assessment; WHO 2002) and cost–benefit analysis of air pollution control measures rely primarily on estimates of how exposure affects the incidence of and mortality from chronic cardiovascular and respiratory diseases. These estimates can only be provided by long-term observation of large study populations; time-series studies of daily effects will not suffice. To date, long-term studies have only been conducted in the United States and Europe. Extrapolation of their results raises some uncertainties. A detailed quantitative review of the larger Asian literature (including cross-sectional studies of chronic respiratory disease) may better inform extrapolations, but ultimately only long-term Asian studies will provide the most direct evidence.

Some of the research needs discussed here will be addressed by the PAPA program currently supported by HEI. In particular, a coordinated set of time-series studies is planned that will ultimately incorporate cities across Asia, including countries where few such studies have been performed to date. These studies will be designed with a common protocol that will allow common, up-to-date analysis and comparison of their estimates. Their shared design will yield more definitive pollutant-specific and age-specific results for common outcomes like all-cause mortality. The results may also address issues such as the shape of the air pollution concentration–response function and the relation between poverty and effects of exposure to air pollution. Studies of long-term exposure on infant and adult health are also under consideration by the PAPA program. Once completed, these studies will be included in a second, more comprehensive review of the Asian literature that will be prepared at the conclusion of the PAPA program.

SUMMARY

The current literature provides substantial information on the effects of outdoor air pollution on the health of Asia's people, information that can serve today as a resource for important Asian decisions. For the subset of cities that has been studied most closely, this Special Report indicates that short-term exposure to air pollution is associated with increases in daily mortality and morbidity. In the limited comparisons that can be made at this stage, these estimated effects are similar to those found in Western countries. Important gaps in the range of Asian settings studied and in the types of studies remain to be addressed in order to fully inform public policy decisions. Publication of this Special Report and subsequent funding of a targeted program of research in Asia aims to improve substantially our understanding of the problems posed by air pollution in Asia and to develop the capacity of Asian scientists to conduct additional scientific research toward their solution.

REFERENCES

Air Pollution in Megacities of Asia. 2004. Benchmarking Report on Urban Air Quality Management and Practice in Major and Mega Cities of Asia, Stage 2. Korea Environment Institute, Seoul, Korea. In press.

Bascom R, Bromberg PA, Costa DA, Devlin R, Dockery DW, Frampton MW, Lambert W, Samet JM, Speizer FE, Utell M (Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society). 1996a. Health effects of outdoor air pollution, Part 1. Am J Respir Crit Care Med 153:3–50.

Bascom R, Bromberg PA, Costa DL, Devlin R, Dockery DW, Frampton MW, Lambert W, Samet JM, Speizer FE, Utell M (Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society). 1996b. Health effects of outdoor air pollution, Part 2. Am J Respir Crit Care Med 153:477–498.

Gao J, Xu XP, Chen YD, Dockery DW, Long DH, Liu HX, Jiang JY. 1993. Relationship between air pollution and mortality in Dongcheng and

Xicheng Districts, Beijing [in Chinese]. Zhonghua Yu Fang Yi Xue Za Zhi 27:340–343.

Gibbs WW. 1995. Lost science in the Third World. Sci Am August:92–99.

Ha E-H, Lee J-T, Kim H, Hong Y-C, Lee B-E, Park H-S, Christiani DC. 2003. Infant susceptibility of mortality to air pollution in Seoul, South Korea. Pediatrics 111:284–290.

Health Effects Institute. 2001. Airborne Particles and Health: HEI Epidemiologic Evidence. HEI Perspectives. Health Effects Institute, Cambridge MA.

Health Effects Institute. 2002. Understanding the Health Effects of Components of the Particulate Matter Mix: Progress and Next Steps. HEI Perspectives. Health Effects Institute, Boston MA.

Health Effects Institute. 2003. Revised Analyses of Time-Series Studies of Air Pollution and Health. Special Report. Health Effects Institute, Boston MA.

Hedley AJ, Wong CM, Thach TQ, Ma S, Lam TH, Anderson HR. 2002. Cardiorespiratory and all-cause mortality after restrictions on sulphur content of fuel in Hong Kong: An intervention study. Lancet 360:1646–1652.

Hong YC, Leem JH, Ha EH. 1999a. Air pollution and daily mortality in Inchon, Korea. J Korean Med Sci 14:239–244.

Hong Y-C, Leem J-H, Ha E-H, Christiani DC. 1999b. PM_{10} exposure, gaseous pollutants, and daily mortality in Inchon, South Korea. Environ Health Perspect 107:873–878.

Katsouyanni K, Touloumi G, Samoli E, Gryparis A, Le Tertre A, Monopolis Y, Rossi G, Zmirou D, Ballester F, Boumghar A, Anderson HR, Wojtyniak B, Paldy A, Braunstein R, Pekkanen J, Schindler C, Schwartz J. 2001. Confounding and effect modification in the short-term effects of ambient particles on total mortality: Results from 29 European cities within the APHEA2 project. Epidemiology 12:521–531.

Katsouyanni K, Touloumi G, Spix C, Schwartz J, Balducci F, Medina S, Rossi G, Wojtyniak B, Sunyer J, Bacharova L, Schouten JP, Ponka A, Anderson HR. 1997. Short term effects of ambient sulphur dioxide and particulate matter on mortality in 12 European cities: Results from time series data from the APHEA project. BMJ 314:1658–1663.

Kwon H-J, Cho S-H, Nyberg F, Pershagen G. 2001. Effects of ambient air pollution on daily mortality in a cohort of patients with congestive heart failure. Epidemiology 12:413–419.

Lee J-T, Kim H, Hong Y-C, Kwon H-J, Schwartz J, Christiani DC. 2000. Air pollution and daily mortality in seven major cities of Korea, 1991–1997. Environ Res 84:247–254.

Lee J-T, Shin D, Chung Y. 1999. Air pollution and daily mortality in Seoul and Ulsan, Korea. Environ Health Perspect 107:149–154.

Murray CJL, Lopez AD. 1997. Global mortality, disability, and the contribution of risk factors: Global Burden of Disease Study. Lancet 349:1436–1442.

Ostro B, Chestnut L, Vichit-Vadakan N, Laixuthai A. 1999. The impact of particulate matter on daily mortality in Bangkok, Thailand. J Air Waste Manage Assoc 49:PM100–PM107.

Pope CA III, Dockery DW. 1999. Epidemiology of particle effects. In: Air Pollution and Health (Holgate ST, Samet JM, Koren HS, Maynard R, eds). Academic Press, London, England.

Samet JM, Zeger SL, Dominici F, Curriero F, Coursac I, Dockery DW, Schwartz J, Zanobetti A. 2000b. The National Morbidity, Mortality, and Air Pollution Study, Part II: Morbidity and Mortality from Air Pollution in the United States. Research Report 94. Health Effects Institute, Cambridge MA.

Smith KR, Mehta S, Feuz M. 2004. Indoor air pollution from solid fuel use. In: Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors (Ezzati M, Lopez AD, Rodgers A, Murray CJL, eds), vol 2. World Health Organization, Geneva, Switzerland. In press.

Venners SA, Wang B, Peng Z, Xu Y, Wang L, Xu X. 2003. Particulate matter, sulfur dioxide, and daily mortality in Chongqing, China. Environ Health Perspect 111:562–567.

Wong CM, Ma S, Hedley AJ, Lam T-H. 2001b. Effect of air pollution on daily mortality in Hong Kong. Environ Health Perspect 109:335–340.

World Health Organization. 2002. The World Health Report 2002: Reducing Risks, Promoting Healthy Life. WHO, Geneva, Switzerland.

Xu X, Gao J, Dockery DW, Chen Y. 1994. Air pollution and daily mortality in residential areas of Beijing, China. Arch Environ Health 49:216–222.

Xu Z, Yu D, Jing L, Xu X. 2000. Air pollution and daily mortality in Shenyang, China. Arch Environ Health 55:115–120.

ABBREVIATIONS AND OTHER TERMS

APHEA	Air Pollution and Health: A European Approach
CI	confidence interval
EPA	Environmental Protection Agency (US)
GAM	generalized additive model
NMMAPS	National Morbidity, Mortality, and Air Pollution Study
NO_2	nitrogen dioxide
PAPA	Public Health and Air Pollution in Asia
PM	particulate matter
PM_{10}	PM less than 10 μm in aerodynamic diameter
$PM_{2.5}$	PM less than 2.5 μm in aerodynamic diameter
SO_2	sulfur dioxide
TSP	total suspended particles
WHO	World Health Organization

HEALTH EFFECTS INSTITUTE

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Background

The World Health Organization (WHO*) estimates that each year approximately 800,000 deaths and 4.6 million lost life-years worldwide are attributable to urban air pollution (WHO 2002). This burden is not equally distributed, however: approximately two thirds of the deaths and lost life-years occur in the developing countries of Asia. Owing to limitations of the available epidemiologic studies in those countries, WHO's estimates are based largely on the results of research conducted in Europe and North America that have been extrapolated to developing countries.

Asia differs from Europe and North America in the nature of its air pollution, the conditions and magnitude of exposures to that pollution, and the health status of its populations. These differences create large uncertainties in estimating the burden of air pollution and any other effort to estimate health impact of air pollution in Asia (Cohen et al 2004). HEI initiated the Public Health and Air Pollution in Asia (PAPA) program to reduce these uncertainties by providing Asian decision makers with estimates of the magnitude of health effects related to air pollution in selected Asian cities over the next five years. The PAPA program is part of the Clean Air Initiative for Asian Cities—a partnership of lenders, governments, industry, environmentalists, and others to improve Asian air quality. The PAPA program International Scientific Oversight Committee (ISOC) has prepared this systematic review of the epidemiologic evidence on air pollution and health in the developing countries of Asia to help guide the development of the PAPA program's research program.

A major part of the PAPA program's research program is intended to provide epidemiologic evidence concerning health effects of air pollution in Asia that will aid development of public policy. New studies should therefore be designed to address clear objectives that fill important gaps in the current evidence. A systematic, quantitative review of the existing literature—a meta-analysis—can identify gaps, inform the design of future research, and provide a critical assessment of currently available evidence to inform present decisions.

The published literature currently contains more than 130 epidemiologic studies in nine Asian countries, which provide evidence about the effect of air pollution on a range of adverse health effects. In this Special Report, we first situate this literature in the current Asian context in terms of levels and trends in development, air quality, and human health. We then describe the published studies and conduct a meta-analysis of the subset of time-series studies—studies that estimate the effect of short-term exposure to air pollution on daily mortality and hospital admissions for cardiovascular and respiratory disease. Because they tend to be easier and less expensive to conduct, time-series studies are among the most frequently conducted studies of the health effects of air pollution in Asia and worldwide.

We focus on time-series studies for three reasons. (1) Time-series studies have been conducted in many regions of the world, including Europe and North America, where coordinated multicity studies have contributed to public-policy decisions. It is therefore possible to compare their results across regions. Such comparisons could inform the extrapolation to Asian populations of results from other types of epidemiologic studies of air pollution (such as studies of the effects of long-term exposure on mortality from chronic disease) that have only been conducted in developed Western countries. (2) Time-series studies that use routinely collected data are time-efficient, cost-efficient, and generally easy to implement compared with long-term follow-up studies of individuals (eg, cohort studies). Therefore, time-series studies might be easier to conduct in Asia over the short term. (3) We wished to assess the degree of need for additional time-series studies in Asia as part of the research program funded by the PAPA program. Once these studies are complete, we will undertake a second, more comprehensive review that integrates their results with the existing literature.

We begin by summarizing the health effects of air pollution and relevant current conditions in Asia with respect to air quality, patterns of disease and mortality, and economic development. We then briefly describe the current literature on the health effects of air pollution in Asia. Next we describe in some detail the findings of our meta-analysis of methods and results of the time-series studies, including quantitative numeric and graphic summaries by country,

* A list of abbreviations and other terms appears at the end of the report.

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health outcome, air pollutant, and other study features. We conclude with a discussion that places the Asian time-series studies in the context of the worldwide literature, identifies gaps in knowledge, and recommends approaches by which to address them.

EVIDENCE FOR HEALTH EFFECTS OF OUTDOOR AIR POLLUTION

The past 10 to 15 years have seen a remarkable increase in research on the health effects of air pollution. It is now widely accepted that exposure to outdoor air pollution is associated with a broad range of acute and chronic health effects, ranging from minor physiologic disturbances to death from respiratory and cardiovascular disease (Bascom et al 1996a,b; American Thoracic Society 2000). This knowledge is based on observational epidemiologic studies of disease occurrence in human populations and in-vitro and in-vivo experimental studies of animals and humans. Epidemiologic research on the health effects of air pollution provides estimates of the health effects of both short- and long-term exposure to a variety of air pollutants in human populations in many parts of the world. Because these estimates apply to humans living in real-world conditions, they have been the scientific basis for increasingly stringent air quality regulations for some pollutants.

The limitations of observational epidemiology are nonetheless well known: the difficulty of accounting for risk factors for death or disease other than exposure to air pollution (potential confounders) and the difficulty of estimating the relative toxicity of specific components of the complex urban air pollution mixture. Observational epidemiology is also not particularly well suited to studying the mechanisms by which exposure to air pollution produces disease. However, a limited but rapidly growing body of toxicologic evidence from in-vitro animal and human research has suggested mechanisms by which exposure to air pollution might produce the respiratory and cardiovascular outcomes observed in epidemiologic studies (Bascom et al 1996a,b; Kodavanti and Costa 1999; Godleski 2000; Health Effects Institute 2002).

Air pollution may elicit both acute and chronic biological responses. Acute responses to air pollution in otherwise healthy people may be confined to reversible physiologic adaptations resulting from natural defense mechanisms. They may also, however, increase the severity or duration of an already established respiratory infection or a disease (such as asthma or chronic obstructive pulmonary disease [COPD]) that has already made the individual vulnerable, thus increasing the risk of hospital admission or even death. There is also limited epidemiologic evidence to suggest that ambient air pollution contributes to development of chronic respiratory and cardiovascular disease.

The health effects of air pollution are associated with a number of the pollutants that make up the air pollution mixture in cities around the world, the ambient concentrations of which are monitored periodically. Disentangling the effects of one pollutant from the effects of others that follow similar spatial and atmospheric patterns is often difficult (Health Effects Institute 2001). At the same time, not all members of a population are equally sensitive to such effects. Some subgroups (eg, the elderly, asthmatics, children, and people with heart disease) may be more at risk from exposure to air pollution (Health Effects Institute 2002).

Despite some uncertainty, much is known about the effects of each of these pollutants. Several are discussed below (also see comprehensive reviews in Holgate et al 1999).

PARTICULATE MATTER

Particulate matter (PM), in the form of PM less than 10 µm and 2.5 µm in aerodynamic diameter (PM_{10} and $PM_{2.5}$), is inhalable material that is emitted directly from motor vehicles, power plants, and other sources or formed in the atmosphere through reactions with gaseous emissions (eg, nitrogen and sulfur oxides [NO_x and SO_x] react to form nitrates and sulfates, respectively). Although the health effects of PM have been of concern for many decades, short-term and long-term epidemiologic studies published in the United States and Europe in the 1990s found associations of PM with increased morbidity and mortality at ambient levels below the national air quality limit values at the time. These results have been the basis of action in both the European Union and the United States to establish more stringent standards for PM.

Recent epidemiologic studies have begun to strengthen the understanding of the relation between exposure to PM and morbidity and mortality (eg, Samet et al 2000a,b; Health Effects Institute 2001; Katsouyanni et al 2001). At the same time, although understanding of the biological mechanism that might be causing these effects at relatively low exposure has increased, no plausible biological mechanism has yet been agreed on, although several are currently being explored (Health Effects Institute 2002).

THE PM MIXTURE

Certain components and characteristics of the PM mixture have been suggested to be responsible for increased mortality and other health risks. Some have suggested that ultrafine particles (PM < 0.1 µm in aerodynamic diameter) (Oberdörster et al 2000), particles containing metals (eg, iron), and other types of particles may be the most toxic

components of the mixture (Ghio et al 2001), PM in diesel exhaust has been cited as a probable human carcinogen by several national and international agencies (including the International Agency for Research on Cancer [1989], California Environmental Protection Agency [1998], and the US Environmental Protection Agency [EPA] [2002]) because exposed workers were found to have lung cancer. Our ability to estimate a precise risk for such PM from diesel engines is limited, however (HEI Diesel Epide-miology Expert Panel 1999). To date these studies have not identified a component or characteristic that is significantly more toxic than others; different sets of characteristics may be important for different health effects (Health Effects Institute 2002).

CARBON MONOXIDE

Carbon monoxide (CO) is a gas emitted directly from motor vehicles and other combustion sources. When inhaled, it replaces oxygen in the bloodstream by binding with hemoglobin, thus interfering with normal transport of oxygen to the heart and brain. Exposure to high CO levels is lethal; low levels found in ambient settings are not likely to affect healthy individuals but can hasten the onset of angina (chest pain) in people with coronary artery disease and increase the incidence of cardiac effects. Some epidemiologic studies have found positive relations between CO level and morbidity, mortality, and adverse pregnancy outcomes (EPA 2000).

SULFUR DIOXIDE

Sulfur dioxide (SO_2) is a gaseous by-product of the combustion of fossil fuels that contain sulfur. These include solid fuels (such as certain coals), liquid fuels (such as gasoline, diesel, and fuel oil), and natural gas. Clinical studies have found that exposure to SO_2 at levels as low as 0.25 ppm elicits increased bronchoconstriction in people with asthma (Bascom et al 1996a). Reductions in lung function have been observed at higher concentrations. Exercise increases the likelihood of such responses, perhaps because at higher levels of pulmonary ventilation more SO_2 reaches the lower lung rather than being absorbed in the upper airways (Bascom et al 1996a). Acute declines in pulmonary function have also been observed in association with air pollution episodes during which levels of SO_2 and other pollutants were briefly but considerably elevated (Bascom et al 1996a).

SO_2 is also associated with increased daily mortality and hospital admissions from respiratory and cardiovascular disease, even at the low levels now observed in Europe and North America (Bascom et al 1996a). In a reanalysis of a large US cohort study (Krewski et al 2000), long-term exposure to SO_2 has been associated with reduced pulmonary function (Bascom et al 1996a) and mortality from cardiovascular and respiratory disease. Reductions in ambient SO_2 concentrations owing to regulatory action have recently been associated with decreased mortality and improved respiratory health in children in Hong Kong (sidebar 1).

NITROGEN DIOXIDE

Nitrogen dioxide (NO_2) is also a gaseous by-product of the combustion of fossil fuels in transportation and industrial applications such as waste incineration. In many contemporary urban locations mobile source emissions are the major source of outdoor NO_2. Unlike SO_2, NO_2 is relatively insoluble and is thus more likely to deposit in the lower airways. NO_2 is also an oxidant. In clinical experiments, it has elicited inflammatory responses at levels as low as 1 mg/m^3 and increased responsiveness to ozone (O_3, another oxidant gas) and certain allergens (Bascom et al 1996b; Ackermann-Liebrich and Rapp 1999). However, other clinical studies (Bascom et al 1996a) have reported considerably variable responsiveness to NO_2. In epidemiologic studies, NO_2 has been associated with increased respiratory morbidity (eg, asthma exacerbation and reduced lung function and rate of lung growth in children) (Bascom et al 1996b; Ackermann-Liebrich and Rapp 1999). Short-term exposure to NO_2, like SO_2, is associated with increased daily mortality and hospital admissions from respiratory and cardiovascular disease (Ackermann-Liebrich and Rapp 1999).

OZONE

O_3 is a gas formed in the atmosphere from the combination of NO_x and volatile organic compounds (both emitted from industrial facilities and motor vehicles) in certain meteorologic conditions, normally during summer. O_3 reduces lung function in some individuals. Epidemiologic studies have found evidence of increased asthma attacks and hospitalizations related to increased ambient O_3 levels (Bascom et al. 1996a). O_3 may also increase the lung's reaction to allergens and other pollutants. Although some recent studies (eg, Samet et al 2000b) have found associations of daily increases in O_3 with increased mortality, evidence that long-term exposure to O_3 causes chronic health effects is limited. Some evidence suggests that the lung may develop tolerance to O_3 after repeated short-term exposures (HEI Collaborative Ozone Project Group 1995; Expert Panel on Air Quality Standards 1997).

SIDEBAR 1. AIR POLLUTION IN HONG KONG

The Hong Kong Special Administrative Region (HKSAR) is now confronting problems that are or will soon be faced by other urban centers in Asia. Ambient air pollution levels have been monitored in Hong Kong for more than two decades, such that epidemiologists at several institutions have assessed trends in air quality and estimated health effects. A reduction in the sulfur content of fuel, imposed in 1990, provided a unique opportunity to assess the health impact of improvements in air quality (Hedley et al 2002).

Air Quality Levels and Standards

Air quality has changed in Hong Kong over the past 10 to 15 years, reflecting trends in the region's development. Annual mean ambient NO_2 concentrations have probably been increasing (Figure 1). Although most daily ambient NO_2 levels are below the current HKAQO of 80 μg/m^3, levels at the roadside monitoring stations are continuously above the HKAQO. The 2001 and 2002 mean ambient levels may represent a new downward trend, but they are still within the bounds of error for the fitted curve. Annual mean levels of ambient RSP in Hong Kong consistently exceeded the HKAQO of 55 μg/m^3 for several years but recently are on the decline (Figure 2). Annual mean ambient SO_2 and O_3 levels are well below their HKAQOs, but they are still associated with health risks.

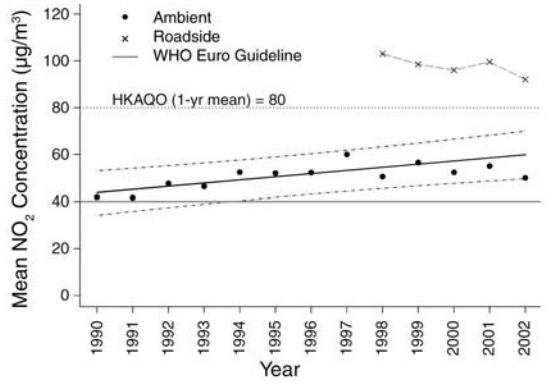


Figure 1. Mean ambient and roadside NO_2 concentrations in Hong Kong, 1990–2002. The paired dashed lines indicate the 95% confidence interval. Derived from air pollution monitoring data from the Hong Kong Environmental Protection Department.

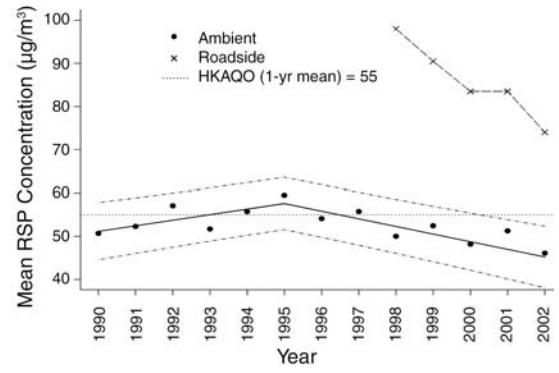


Figure 2. Mean ambient and roadside RSP concentrations in Hong Kong, 1990–2002. The paired dashed lines indicate the 95% confidence interval. Derived from air pollution monitoring data from the Hong Kong Environmental Protection Department.

The HKAQOs and National Ambient Air Quality Standards (NAAQS) for the Pearl River Region of the nearby Chinese southern mainland, called the Pearl River Delta Economic Zone (PRDEZ), are shown in the table. The region's mainland class 2 and class 3 standards for RSP are two to three times higher than those in Hong Kong. These higher standards attempt to reconcile the demand for better air quality with the need for industrial development. The mainland class 2 objective applies to commercial, industrial, and village areas; mainland class 3 to designated industrial zones. Transboundary air pollution from the class 3 areas affects Hong Kong's pollution levels. Annual pollutant levels for Hong Kong show a marked seasonal effect, with higher cool season levels for RSP, NO_2, and O_3. This effect is closely associated with the winter monsoon, when the wind comes from the north.

Like in most of the world, however, most harm to health (in terms of hospital admissions and deaths) occurs not during high-pollution episodes that exceed air quality standards, but rather when pollutants are at their lower mean daily concentrations. Mean levels of measured air pollutants in Hong Kong are well below both ambient and HKAQO levels in the Pearl River Delta. Readings from six Guangzhou air pollution monitoring stations show that most mean annual NO_x levels exceed the mainland class 2 NAAQS for NO_2 (see table).

Increasingly, in the dense populations in developing conurbations in Asia, about 50% of the population lives or works at the roadside. Air pollution data from Hong Kong demonstrate a marked gradient among local, regional, and roadside levels, a pattern that may be representative of other Asian cities. Roadside levels of RSP and NO_x and NO_2 are much higher than ambient levels in Hong Kong (Figures 1 and 2). In an RSP monitoring exercise from 1999 to 2000 in 11 south China urban centers, nine were at or above the annual HKAQO (55 μg/m^3) (Figure 3). Levels in Guangzhou were highest (annual mean, 267 μg/m^3; range, 96–608 μg/m^3).

Ambient Air Quality Standards in the Pearl River Delta Region[a]

		Pollutant Level (μg/m^3) by Averaging Time[b]		
Standard	Pollutant	1 Hour	24 Hour	1 Year
HKAQO				
	O_3	240[c]	—	—
	RSP	—	180[d]	55
	NO_2	300[c]	150[d]	80
Pearl River NAAQS (mainland class 2)				
	O_3	200	—	—
	RSP	—	150	100
	NO_2	240	120	80
Pearl River NAAQS (mainland class 3)				
	O_3	200	—	—
	RSP	—	250	150
	NO_2	240	120	80

[a] Adapted from Hong Kong Environmental Protection Department 2002.

[b] — = not applicable.

[c] 1-hour objective not to be exceeded more than three times per year.

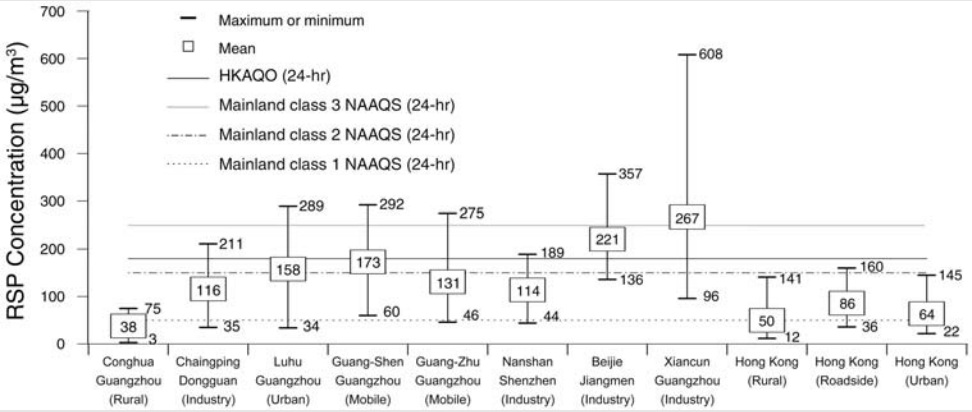


Figure 3. RSP levels monitored from December 1999 to May 2000 in south China urban centers. Sources of monitored levels indicated in parentheses on the x-axis. Adapted from Hong Kong Environmental Protection Department 2002.

Health Effects of Pollutants

Time-series analyses conducted in Hong Kong consistently observe increased risk of acute health effects with short-term exposure to air pollution at levels below the current HKAQOs.

Extensive studies (Peters et al 1996; Wong et al 1998; Hedley et al 2002) by investigators at the University of Hong Kong and the Chinese University of Hong Kong have reported that short-term exposures to NO_2 and SO_2, as well as PM_{10}, are associated with increases in daily rates of mortality from all causes and respiratory and cardiovascular causes. These exposures are also associated with hospital admissions for respiratory and cardiovascular disease and general practice consultations for respiratory illnesses (Wong et al 2002b).

These findings are supported by research from the University of Hong Kong on the health impact of a 1990 air-quality intervention. In July 1990, Hong Kong authorities regulated the sulfur content of fuel oil (used for power generation and road transport) to be 0.5% or less by weight. The change was implemented over a single weekend.

Ambient SO_2 was reduced for up to five years after the intervention by as much as 50%, with greater reductions in some areas (such as the highly polluted, poor Kwai Tsing area, where levels fell by 80%). Levels of sulfate in RSP initially fell but within two years rose again to preintervention or higher levels, reflecting the regional nature of the pollutant. During this period the levels of PM_{10}, NO_2, and O_3 were stable or increased (Figure 4) (Hedley et al 2002).

Differences in bronchitic symptoms in children 8 to 10 years of age between more-polluted and less-polluted districts were reduced or eliminated (Figure 5). The prevalence of bronchial hyperreactivity in nonasthmatic, nonwheezing children was also reduced and between-district differences eliminated two years after the intervention. These results suggest that the recovery process may continue for relatively long periods after the removal of pollutants (Wong et al 1998).

Analysis of both annual death counts and age-specific mortality rates for five years before and five years after the intervention shows that it increased life expectancy by reducing mortality from all causes and cardiovascular and respiratory disease (Figure 6) (Hedley et al 2002). Changes in mortality indicate that both short- and long-term gains in survival resulted from the intervention.

A cool-season peak in deaths six months after the intervention was reduced and then followed by an increase in cool-season deaths two and three years after. Thereafter the seasonal mortality pattern stabilized again. This evidence suggests reversed mortality displacement (or reversal of harvesting). Those who would have normally died in the first year after intervention instead died 12 to 24 months later (Hedley et al 2002).

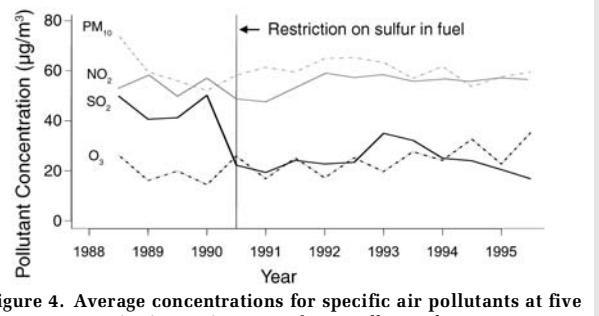


Figure 4. Average concentrations for specific air pollutants at five Hong Kong monitoring stations. Data from Hedley et al 2002.

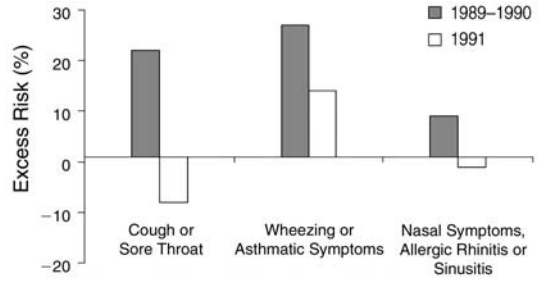


Figure 5. Excess risk for respiratory symptoms among primary school children in Hong Kong before and after intervention to reduce sulfur content of fuel oil. Excess risk percentage calculated by comparison of children in a more-polluted area with children in a less-polluted area. For all symptoms, excess risk dropped to nonsignificant levels in 1991, after intervention. Data from Peters et al 1996.

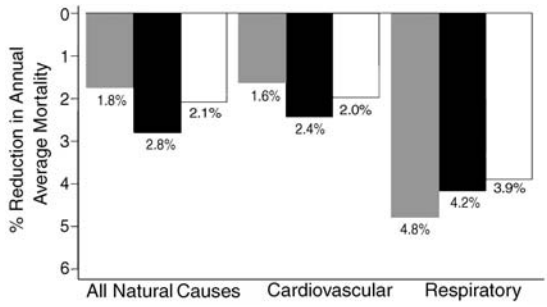


Figure 6. Percent reduction in annual average mortality due to all causes, cardiovascular disease, or respiratory disease after intervention to reduce sulfur content of fuel oil. Gray bars indicate people 15 to 64 years of age; black bars indicate people 65 years of more of age; white bars indicate people of all ages. Data from Hedley et al 2002.

AIR TOXICS

Air toxics have a variety of characteristics and effects. Many emitted from motor vehicles and other combustion sources are animal carcinogens. Benzene, for example, is a known human carcinogen. The toxic chemical 1,3-butadiene, for which motor vehicles are an important ambient source, was recently designated as a probable human carcinogen by the International Agency for Research on Cancer and a known human carcinogen by the US National Institutes of Health and the EPA. Several aldehydes (such as formaldehyde and acetaldehyde) have also been designated probable human carcinogens. In addition, several of the aldehydes have been shown to induce acute respiratory effects (Health Effects Institute 1993).

EPIDEMIOLOGIC EVIDENCE

The epidemiology of air pollution takes advantage of the fact that concentrations of outdoor air pollution, and thus human exposure, vary over both time and space. Epidemiologic research has focused on one or the other dimension but usually not both within the same population. Short-term temporal variation (over days and weeks) in air pollution concentrations has been used to estimate effects on daily morbidity and mortality. Spatial variation in long-term mean concentrations of air pollution has been the basis for cross-sectional and cohort studies of long-term exposure.

Studies of Short-Term Exposure

Episodes in which levels of air pollution increase rapidly and remain markedly elevated for days or weeks occurred in Europe and the United States in the mid 20th century. These episodes provided some of the earliest epidemiologic evidence of the health effects of short-term exposure to air pollution (Anderson 1999). Today, such episodes are much less frequent in developed Western countries (Wichmann et al 1989; Anderson et al 1995), but in Asia, very high levels of air pollution due to burning of biomass and very high daily concentrations during the winter in some cities still occur.

Since the early episodes, effects of short-term exposure to air pollution have been studied extensively. Time-series studies have been conducted to analyze daily rates of health events (eg, hospital admissions or deaths) in one or more locales in relation to contemporaneous daily concentrations of air pollutants and other risk factors (eg, weather) that vary over months or years. Regression techniques are used to estimate a coefficient that represents the relation between exposure to pollution and the health outcome. The usual regression method models the logarithm of the outcome to estimate the *relative risk*, or proportional change in the outcome per increment of ambient pollutant concentration.[1]

The number of time-series studies has increased rapidly as computing and statistical techniques have improved and data on outcomes and air pollution have become more extensive and easier to access from routine sources. A strength of time-series studies is that individual cofactors (such as smoking, nutrition, behavior, and genetic characteristics) are unlikely to be confounders because they are not generally associated day to day with daily concentrations of air pollution.

Time-series studies have found associations between concentrations of airborne PM and a large range of outcomes (which have been reviewed by Pope and Dockery [1999]), including daily mortality (from all causes[2], respiratory causes, or cardiovascular causes), hospital admissions for respiratory diseases (from all causes, COPD, asthma, or pneumonia), and hospital admissions for cardiovascular diseases (from acute myocardial infarction or congestive cardiac failure). However, recent work indicates that the magnitude of the relative risk estimates from time-series studies of daily mortality depends on the approach used to model both the temporal pattern of exposure (Braga et al 2001) and potential confounders that vary with time (such as season and weather) (Health Effects Institute 2003). As a result, further work is underway to refine time-series techniques for the future.

Although time-series studies of daily mortality (and, to a lesser extent, daily hospital admissions) have been conducted in cities worldwide, the majority have focused on North America and western Europe, where air pollution levels are low and still falling and populations are characterized by Western lifestyles and patterns of disease (Stieb et al 2002; Cohen et al 2004). The results of these studies indicate that, in virtually all these locales, daily mortality is positively associated with short-term exposure to approximately the same degree. Generally, the results showed that increased mortality occurred concurrently with, or within one to five days after, an increase in air pollution, although several more recent studies suggest even longer lags in effects related to air pollution[3] (Zeger et al 1999; Schwartz 2001; Zanobetti et al 2003).

1. The primary statistical approach in these studies has been formal time-series modeling of count data using a Poisson regression model. Counts of independent and random occurrences across time have typically been modeled as a Poisson process (DeGroot 1986), that is daily deaths are assumed to follow a Poisson distribution. If risk of death is influenced by seasonal changes, weather, air pollution, or other variables, then the Poisson process will be nonstationary—that is, the underlying expected mean death count will change over time depending on these variables. Poisson regression modeling provides a formal way to evaluate possible associations between daily mortality counts and daily concentrations of air pollution while controlling for other variables (such as seasonality and weather). For more details see Pope and Schwartz (1996) and McCullagh and Nelder (1983).

2. Throughout this Executive Summary, we define *all causes* as all natural causes (excluding accidents) unless otherwise noted.

Many daily time-series mortality studies also provide a breakdown of mortality by broad cause-of-death categories. In terms of cause-specific relative risks of mortality associated with increases in exposure to pollution, particulate pollution affects mortality from respiratory disease more than mortality from cardiovascular disease. Because cardiovascular deaths are much more common than respiratory deaths, however, cardiovascular deaths account for a much larger percentage of the excess deaths attributable to pollution.

In the last decade, large studies have been conducted using uniform methods for assembling and analyzing data from multiple cities. Examples are Air Pollution and Health: A European Approach (APHEA) 2 (Katsouyanni et al 1997, 2001) and the US National Morbidity and Mortality Air Pollution Study (NMMAPS) (Samet et al 2000a,b). These multicity studies have confirmed the findings of earlier studies in single cities: daily mortality and daily hospital admissions rates are positively associated with concentrations of PM and other pollutants, such as O_3. Multicity studies have also attempted to explain the differences (heterogeneity) among cities in relative risks associated with exposure to air pollution. For example, the APHEA 2 investigators found that the mortality relative risk of PM was greater in cities with higher annual mean concentrations of NO_2 (Katsouyanni et al 2001). In the NMMAPS study, the same pattern was observed for cities with greater annual mean concentrations of PM_{10}. Levy and colleagues (2000) reported that the effects of PM_{10} were greater in cities in which $PM_{2.5}$ comprised a higher proportion of PM_{10}. Large multicity studies also have the statistical power to explore more definitively the shape of the air pollution concentration–response function (Daniels et al 2000; Schwartz and Zanobetti 2000), the timing of effects related to air pollution, and the extent of life shortening (also known as *harvesting*) due to air pollution (Zeger et al 1999; Zanobetti et al 2000; Schwartz 2001).

Approaches other than time series have also been used to study acute health effects of short-term exposure to air pollution. In panel studies, small groups (or panels) of individuals are followed over short time intervals, during which health outcomes, exposure to air pollution, and potential confounders are ascertained for each subject on one or more occasions. Panel studies have generally reported that exposure to outdoor air pollution is associated with increased upper and lower respiratory symptoms and increased rates of asthma attacks and asthma medication use. Associations of outdoor air pollution exposures with short-term reduction in lung function and the prevalence of cough symptoms have been reported in studies in the United States (Pope and Dockery 1999), but these results are not consistently supported by studies in Europe (Roemer et al 1999).

In the case-crossover study design (Maclure 1991) exposures of each case of death or disease in the study population are compared for period near the time of death (*case period*) and one or more periods during which the death did not occur (*control periods*). The relative risk is then estimated using methods for matched case-control studies, a common epidemiologic design. Ideally, control periods are chosen so that there is no need to statistically adjust for factors such as seasonality, and long-term time trends in mortality. Data on each individual (such as aspects of their medical histories) can be considered as well, if available. Although case-crossover studies of air pollution are few, the design is increasing in use. It appears to provide results comparable to those of standard time-series analysis (Neas et al 1999).

Cohort Studies of Long-Term Exposure

Cohort studies take advantage of spatial variation in air pollution concentrations to compare incidence of disease and death in populations exposed over the long term to differing levels of air pollution. By following large populations for many years, cohort studies estimate both numbers of deaths and, more importantly, mean reductions in life span attributable to air pollution.

Evidence from cohort studies of populations in Europe and the United States indicates that long-term exposure to outdoor air pollution is associated with an increase in total mortality and cardiopulmonary mortality in adults (Dockery et al 1993; McDonnell et al 2000; Hoek et al 2002; Pope et al 2002; Lipfert et al 2003). Each of these studies used regression analyses that adjusted for the effects of potential confounders (such as cigarette smoking, occupation, and prior medical history). Most studies found the strongest and most consistent associations between mortality and exposure to PM. $PM_{2.5}$ appears to be more closely associated with mortality than PM_{10} or total suspended particles (TSP, sometimes referred to as *suspended particulate matter* [SPM]) (Dockery et al 1993; Pope et al 2002). The recently published results of a study conducted in the Netherlands confirm the effects of long-term exposure to air pollution (in particular, air pollution related to road traffic) on mortality (Hoek et al 2002).

3. Effects of air pollution on mortality occur after some delay. That delay may be brief (eg, within 24 hours) or prolonged (ie, lagged). Successful modeling of the effects of pollution requires a model that allows estimation of a lag structure (Pope and Schwartz 1996). Until recently, most time-series studies have evaluated lag structure between exposure and time of event by only including pollution concentrations for the same day as the exposure or the previous 1 to 5 days in the regression models. However, for studies in a single city and for studies in which pollution levels on a given day are correlated with those on subsequent days (as they nearly always are), then the lagged pollution variables will be highly correlated with each other and estimation of the lag structure will be inefficient and unstable. Therefore, effective estimation of lag structures requires a multicity approach.

Unfortunately, the current cohort studies provide little information about when exposure to air pollution increases the risk of mortality (ie, the induction time for long-term exposure to air pollution). For example, does exposure in early life confer an increased risk for mortality in adulthood by affecting development of lung function? Does air pollution act in conjunction with cigarette smoking or diet in later life to increase the risk of mortality from cardiovascular or respiratory disease?

Another limitation of cohort studies is that they have not yet been conducted in developing countries. One opportunity to directly measure the impact of reducing air pollution on long-term mean mortality, however, was the restriction of sulfur in fuel used for power generation and transportation in Hong Kong that was instituted over one weekend in 1990 (Hedley et al 2002). Hedley and colleagues documented changes in ambient air quality after the restriction as well as associated declines in annual mean rates of mortality from cardiovascular and respiratory diseases. Comparing changes in mortality in more and less polluted areas of Hong Kong accounted (to some degree) for secular changes in other risk factors for mortality that could have produced the observed decrease in mortality.

A similar study was published by Clancy and colleagues (2002), who quantified decreases in annual mean mortality in Dublin after the sale of bituminous coal was banned.

Air Pollution and Reproductive and Child Health

Infant and child mortality from respiratory disease and other adverse pregnancy outcomes (such as low birth weight and malformations) in a small but growing number of studies have also been associated with exposure to air pollution (Woodruff et al 1997; Bobak and Leon 1999; Wilhelm and Ritz 2003). Time-series studies of daily mortality in developing countries (Mexico, Thailand, and Brazil) have documented associations between short-term exposure to particulate pollution and daily mortality from all causes or acute respiratory infections in children less than five years of age (Romieu et al 2002; Cohen et al 2004).

Gaps and Limitations in Current Knowledge

We have learned much about the adverse health effects of outdoor air pollution in the past 20 years, with epidemiologic research playing a critical role in the growth of this knowledge. Nonetheless, important gaps remain, especially the following questions that are critical to public policy. How large is the effect of short-term exposure on daily morbidity and mortality, and how accurately can we measure the magnitude and variability of these effects with our current statistical tools? Which constituents of the pollutant mix, and which sources that contribute to it, are the most toxic? Which diseases, social conditions, or genetic factors place people at greatest risk when exposed to air pollution? To what extent does long-term exposure affect the development of chronic, life-threatening disease? The answers to these questions might well be different in Asia than in the developed West, where to date the vast majority of studies have been conducted.

DEVELOPMENT AND POPULATION HEALTH IN ASIA

Developing Asia is in many ways the most dynamic part of the world. Incomes are growing with concomitant increases in industrialization, urbanization, and vehicularization. Although hundreds of millions still live in poverty, continued slowing of population growth and steady growth of per capita income are real prospects. Table 1

Table 1. Major Indicators of Economic Growth and Population Size in Asia[a]

	Total Population in 2000 (millions)	Projected Total Population in 2030 (millions)	Projected Population Growth Rate 2000–2030	Population Growth Rate 1971–2000	GDP[b] Per Capita	PPP[c] Per Capita	Projected Annual Growth of PPP[c] Per Capita 2000–2030	Projected Annual Total Economic Growth (GDP[b])
China	1275	1480	0.5%	1.4%	860	3980	0.9%	4.8%
India	1009	1400	1.1%	2.1%	450	2360	1.0%	4.6%
Indonesia	212	285	1.0%	1.9%	570	3040	0.9%	3.9%
United States	283	360	0.8%	1.0%	34,000	34,000	0.2%	2.0%
World	6057	8160	1.0%	1.7%	5245	7450	0.7%	3.0%

[a] Sources: East-West Center 2002 and United Nations Development Programme 2002.

[b] Gross domestic product in US dollars at prevailing exchange rates.

[c] Purchasing power parity = gross domestic product adjusted by local prices and normalized to US conditions.

shows projections of economic growth and population size in three of the most populous Asian countries as compared with the United States and the world. Although Asian regions and nations differ, the economic future looks relatively bright in Asia compared with developing countries in Africa and the Near East. In the next decades, if current trends continue, developing Asia may well be nearing the per capita income of middle-income Latin America (United Nations Department of Economic and Social Affairs 2004).

In this section, we discuss two major factors in Asia that most influence the health effects of exposure to urban air pollution over the next 20 to 30 years: (1) population trends (degree of urbanization, urban population growth, and city size); and (2) health trends (age structure and background disease rates). Emission trends (eg, energy, fuel, and vehicle use) are a third important factor; they are dealt with in a separate section on exposure to air pollution in Asia. Other important factors (such as broad changes in regulatory approaches, improvements in control technology, and shifts in climate that affect sunlight and wind patterns) are beyond the scope of this Special Report.

Wherever possible, we differentiate among the three major Asian regions: South Asia; Southeast Asia; and East Asia. In particular, we focus on the most populated country in each region: India, Indonesia, and China, respectively. About half the world lives in these regions, and 80% of that half lives in those three countries.

URBANIZATION

Population growth rates are falling dramatically in Asia (Table 1). From 2000 to 2030, the population of China is expected to increase at only about 60% of the growth rate in the United States. Even India's growth rate is expected to fall by nearly a factor of two from its level in the late 20th century. Nevertheless, with such large populations to start with, the absolute increase in population will be substantial. In Asia as a whole, nearly a billion people will be added over the next three decades—the equivalent of another India in terms of population.

So many more people do not necessarily mean much greater exposure to ambient air pollution except in cities, which contain many outdoor sources. Currently about two thirds of Asians still live in rural areas (Figure 1). But more people already live in Chinese cities than in all of Latin America. More people inhabit Chinese and Indian cities than inhabit all of Africa, twice as many as inhabit all of North America.

And by 2030, more Asians will inhabit cities than villages. Thus, urban populations will grow much faster than the nation as a whole. Annually, the overall urban population will grow at about 2.6% and the proportion of the population living in cities will increase about 1.5%. In contrast, the absolute increase in rural populations over the first part of this century will be essentially zero (Figure 2).

Over the next few decades, considerable urban construction will be needed to provide housing and other infrastructure for these billion new city-dwellers in Asia. The PM and other pollution from this urban construction alone will likely be substantial.

Discussions about urbanization and its prospects and problems tend to focus on megacities, cities with populations exceeding 10 million people. Developing Asia contains many of the world's megacities and will contain even more over time (Table 2). Even though megacities are large, however, they do not now and will not soon contain a large fraction of the urban population. For example, the proportion of urban population in megacities will only rise to 14% by 2015 (Figure 3). Even by then, most Asian city dwellers (52%) will actually inhabit cities of less than half a million people.

Growth rate has been highest, however, in megacities as a class compared with the class of smaller cities (Figure 3). But this fact is due to a great extent to smaller cities achieving

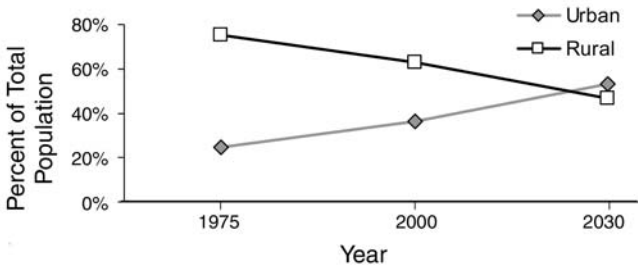


Figure 1. Past and predicted percentages of the total Asian population living in urban or rural areas. Data from United Nations 1995, 2001, 2002 and United Nations Centre for Human Settlements (Habitat) 1996.

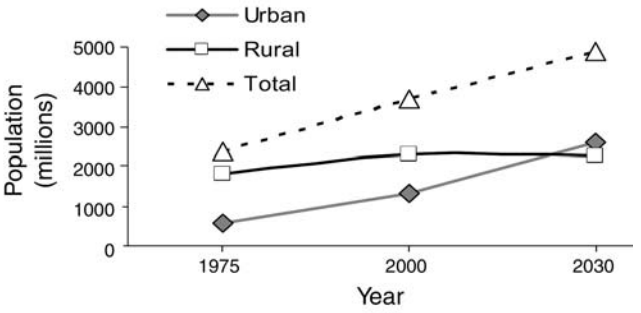


Figure 2. Past and predicted population size in Asia. Data from United Nations 1995, 2001, 2002 and United Nations Centre for Human Settlements (Habitat) 1996.

Table 2. Past and Predicted Populations of All World Megacities[a,b]

1950		2000		2015	
Megacity[c]	Population (millions)	Megacity[c]	Population (millions)	Megacity[c]	Population (millions)
Tokyo	19.8	Tokyo	26.4	Tokyo	26.4
New York	15.9	Mexico City	18.1	**Mumbai**	**26.1**
Shanghai	**15.9**	**Mumbai**	**18.1**	Lagos	23.2
Mexico City	11.2	Sao Paulo	17.8	**Dhaka**	**21.1**
Sao Paulo	10.0	**Shanghai**	**17.0**	Sao Paulo	20.4
		New York	16.6	**Karachi**	**19.2**
		Lagos	13.4	Mexico City	19.2
		Los Angeles	13.1	New York	17.4
		Kolkata	**12.9**	**Jakarta**	**17.3**
		Buenos Aires	12.6	**Kolkata**	**17.3**
		Dhaka	**12.3**	**Delhi**	**16.8**
		Karachi	**11.8**	**Manila**	**14.8**
		Delhi	**11.7**	**Shanghai**	**14.6**
		Jakarta	**11.0**	Buenos Aires	14.1
		Osaka	11.0	Los Angeles	14.1
		Manila	**10.9**	Cairo	13.8
		Beijing	**10.8**	Istanbul	12.5
		Cairo	10.6	**Beijing**	**12.3**
		Rio de Janeiro	10.6	Rio de Janeiro	11.9
				Osaka	11.0
				Tianjin	**10.7**
				Hyderabad	**10.5**
				Bangkok	**10.1**
Total	72.8		266.7		374.8

[a] More than 10 million residents.

[b] Source: United Nations 1995, 2001, 2002.

[c] Cities in developing Asia are shown in bold type.

megacity size. The growth rates of most individual megacities are lower than the urban average. In general, smaller cities have higher growth rates. In 2015, nearly half of the yearly increase in urban populations in all developing countries worldwide will occur in cities of less than a million people, nearly three quarters in cities of less than 5 million.

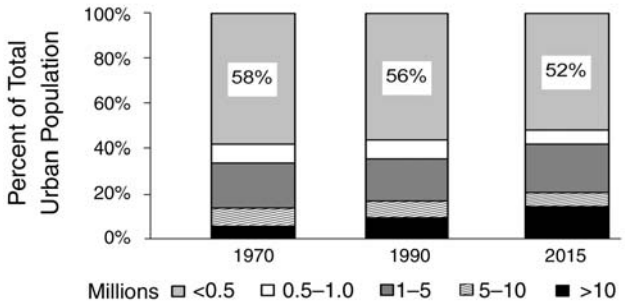


Figure 3. Past and predicted percentages of the total Asian urban population living in cities of different sizes (defined by millions of residents). Data from United Nations 1995, 2001, 2002 and United Nations Centre for Human Settlements (Habitat) 1996.

POPULATION HEALTH

Burden of Disease

In the new millennium, the pattern of morbidity and mortality in low-income Asian countries is in transition because of increasing life expectancy and greater prevalence of risk factors related to lifestyles, urbanization, and modern environmental degradation.

The burden of disease from malnutrition, maternal conditions, and communicable diseases in terms of numbers of deaths and lost years of healthy life, continues to be great. But at the same time the incidence and prevalence of chronic noncommunicable diseases (such as hypertension, diabetes, and ischemic heart disease [IHD], and cancer) is

Table 3. Cause-Specific Mortality in Asia[a]

	Child and Adult Mortality Stratum		
	Southeast Asia	South Asia	East Asia
Population[b]	297,525	1,262,285	1,546,770
All deaths[b]	2194	12,273	10,475
Cause[c]			
Communicable diseases, maternal and perinatalconditions,nutritionaldeficiencies	644 (29.4%)	5171 (42.1%)	1572 (15.0%)
Noncommunicable diseases	1275 (58.1%)	5913 (48.2%)	7805 (74.5%)
Malignant neoplasm	231 (10.5%)	882 (7.2%)	1859 (17.7%)
Diabetes mellitus	62 (2.8%)	176 (1.4%)	162 (1.5%)
Cardiovascular diseases	571 (26.0%)	3226 (26.3%)	3350 (32.0%)
COPD and asthma	87 (4.0%)	614 (5.0%)	1357 (13.0%)
Cirrhosis of liver	42 (1.9%)	172 (1.4%)	168 (1.6%)
Injuries	275 (12.5%)	1188 (9.7%)	1098 (10.5%)

[a] Source: WHO 2002 Annex Table 2.

[b] Data are in thousands.

[c] Cause data are thousands with percentages of all deaths in parentheses.

also increasing the contribution of these diseases to the regional burden (Murray and Lopez 1997b). The growing fraction of the burden of disease from COPD, IHD, and cancer is due to multiple factors, but increasing tobacco smoking is playing a major role (WHO 2002). Indoor air pollution resulting from domestic use of solid and fossil fuels is widespread, particularly in rural areas, where it accounts for a large fraction of cases of several diseases (including respiratory infections and COPD), especially among young children and women. High levels of outdoor air pollution from stationary and mobile sources also contribute considerably to the burden of disease from disorders of the cardiovascular and respiratory systems (WHO 2002).

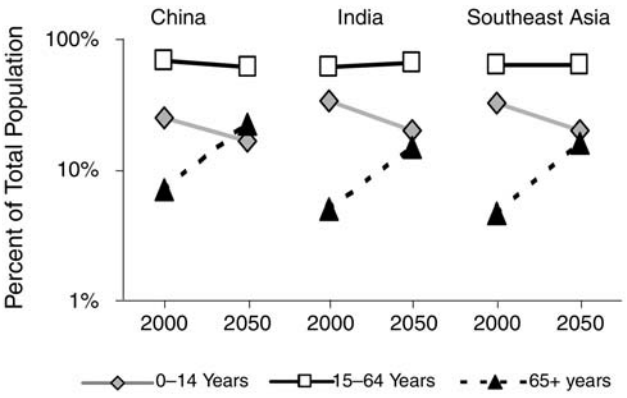


Figure 4. Projected shifts in Asian age distributions. Data from East-West Center 2002 and United Nations Development Programme 2002.

Age-Specific and Cause-Specific Mortality

Economic and social development varies widely across the different regions and countries of Asia. This variation is reflected by health indicators. Whereas most of East Asia has low mortality, the reverse is true in most South and Southeast Asian countries (with some notable exceptions) (Table 3).

The fraction of people over 65 years is expected to at least triple over the first half of the century throughout Asia (Figure 4). By 2050, China will experience a major demographic milestone: people 65 years and older will outnumber those under 15 years. This shift in age distribution means that the diseases of late adulthood will become relatively more important because relatively more people will be affected by them (Table 4).

To varying degrees, Asia is also rapidly moving through the epidemiologic transition: the shift from mortality due mainly to infectious disease, malnutrition, and maternal conditions (Type I) to mortality due to heart disease, cancer, and other more chronic conditions (Type II) (Figure 5). Infectious diseases including acute respiratory infection in children (Romieu et al 2002), malaria, and tuberculosis remain an important causes of morbidity and mortality in developing Asian countries, however (WHO 2002). (The percentage of Type III deaths, due to accidents, violence, and similar actions, is not expected change appreciably.) In fact, China completed this transition well before 1990; Southeast Asia, closer to 1990. India, the most populous

Table 4. Health Indicators for Some Asian Countries in 2001[a]

Country	Total Population (thousands)	% Population > 60 Years	Male & Female Life Expectancy at Birth (years)	# Deaths in Males < 5 Years/1000
Bangladesh	140,386	5.0	61.8	82
China	1,292,378	10.0	71.2	34
India	1,025,095	7.7	60.8	89
Indonesia	214,839	7.8	65.9	50
Japan	127,339	23.8	81.4	5
Malaysia	22,632	6.7	71.7	13
Mynamar	48,363	6.8	57.2	121
Nepal	23,592	5.9	58.3	100
Pakistan	144,971	5.8	61.3	105
Phillipines	77,130	5.6	67.7	46
Singapore	4107	10.8	78.8	4
Sri Lanka	19,103	9.5	69.9	22
Thailand	63,583	8.3	68.9	38

[a] Source: WHO 2002 Annex Table 1.

South Asian country, on the other hand, completed the transition around 2000. Sidebar 2 discusses the trends in cardiovascular and respiratory diseases in greater detail.

As everyone must die of something and different types of disease tend to affect different age groups, the epidemiologic transition viewed in terms of lost healthy life-years gives another picture. Figure 6 shows projected changes in mortality using one such measure: the disability-adjusted life year (DALY). The transition in India occurred a bit later than in China or Southeast Asia (Murray and Lopez 1996; WHO 2002). All three locales have a larger fraction of Type I disease at the end of the period than indicated just by deaths. All three regions will, however, experience a second transition point at which Type I disease has less of an effect on DALYs than Type III does. Type III mainly affects people of middle years (15–65).

Environmental Risk Transition

Overall, environmental health risks generally seem to decline with economic development, both in absolute and relative terms. In other words, poor populations have a larger environmental burden of disease as well as a larger portion of their entire disease burden due to environmental risk factors than do populations living in more-developed regions (Smith et al 1999). Within this trend lies an environmental risk transition framework, in which different types of environmental health risks dominate at different stages of development (Figure 7) (Smith 1997). In

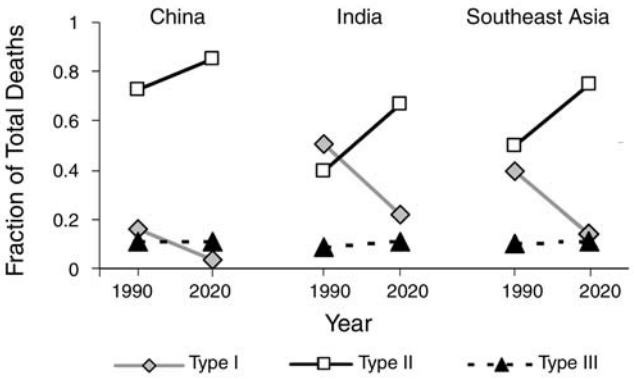


Figure 5. Fraction of total deaths due to Type I, II, or III causes. Type I = infectious disease, malnutrition, and maternal effects. Type II = heart disease, cancer, and other chronic conditions. Type III = accidents, violence, and similar causes. Data from WHO 2002 and Murray and Lopez 1996.

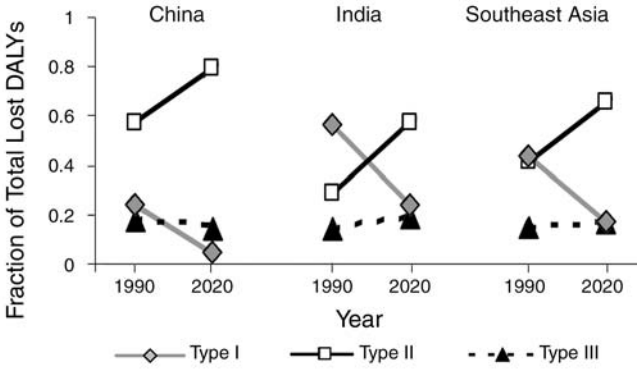


Figure 6. Fraction of total lost DALYs due to Type I, II, or III causes. See Figure 5 for category descriptions. Data from WHO 2002 and Murray and Lopez 1996.

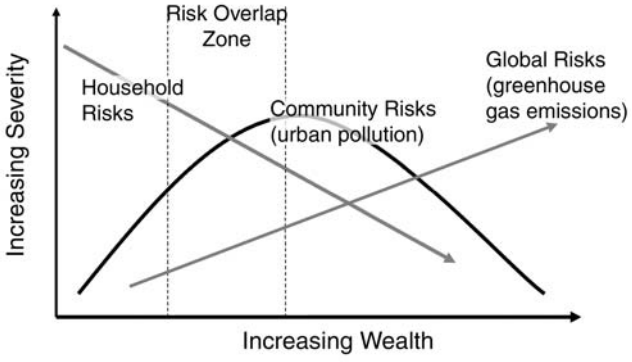


Figure 7. The environmental risk transition. Source: Smith 1997.

particular, *household risks* (such as poor fuel and water quality and poor ventilation and sanitation) dominate the environmental burden in the poorest populations, mostly rural residents in poor developing countries.

As part of development, however, a set of processes are often set into place—including urbanization, industrialization, agricultural modernization, and vehicularization. These tend to produce *community risks*, or environmental risks from urban activities: (outdoor air pollution, solid and hazardous waste, lead exposure, pesticide use, and others).[4] As countries modernize further and environmental controls are tightened, these community-level risks tend to decline. This decline leads to the third stage, in which the richest countries contribute most to *global risks* that are due to greenhouse gas emissions and other causes of global change. As with other conceptual transition frameworks (eg, demographic, epidemiologic), however, there can be significant local departures from this overall trend. Such frameworks should be used to aid understanding and management, not as a forecast of inevitable processes.

The recent global Comparative Risk Assessment organized by WHO (2002) makes it possible for the first time to systematically compare some important environmental risks within the risk transition framework. Figure 8 shows the results of using one metric, disease burden per capita. Household and community risks do seem to generally follow the risk transition framework: household risks start high and decline with increasing development; community risks rise at first and then decline (note the y-axis log scale).

Global risks (due to climate change) might seem to be an exception, as they decline rather than rise with development (Figure 8). But if it indicated causes of the risk (greenhouse gas emissions in wealthier countries) rather than how the risk was manifested (health damage in poor countries), the trend would be reversed, thus agreeing with the risk transition framework.[5]

The position of the three major Asian developing regions are also shown in Figure 8. As a region, South Asia lies primarily within the first stage of environmental risk, the stage dominated by household risks. East Asia and Southeast Asia, however, have moved near the second stage, with community risks nearly equaling

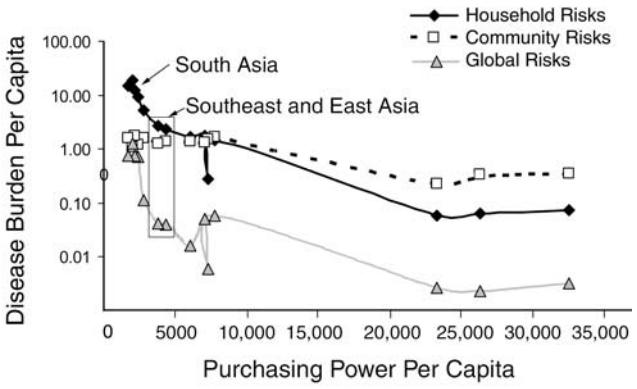


Figure 8. Case study of the environmental risk transition. Disease burden per capita = (DALYs × 365)/population size. The positions of three major developing Asian regions are shown; the box delineates data for Southeast and East Asia. Data from WHO 2002 and United Nations Development Programme 2002. Y-axis uses a log scale.

household risks. Of course, this example is an overview; within every region some groups are at each level. In addition, the urban poor are particularly numerous. They lie in the *risk overlap zone* (see Figure 7), experiencing considerable risk from both community and household sources (Smith 1990). Some of these groups also seem to be among the most vulnerable to global change as well.

All the projections in this section are based on the assumption that primary determinants of public health (economic growth, spread of public health infrastructure, funding for assistance to the poor, improvements in housing and nutrition, education of women, and others) continue to develop similarly in the future compared with recent years. They also assume that the acquired immunodeficiency syndrome (AIDS) epidemic becomes controlled, that tobacco smoking increases slowly, and that war, economic collapse, civil disruption, terrorism, and climate change do not interrupt life in unforeseen ways.

AIR POLLUTION IN ASIAN CITIES

EMISSIONS

In general, combustion is the chief process responsible for the emissions of most PM and gaseous pollutants. In poorer cities of developing Asia (as in North American and European cities in the past), burning refuse (garbage and biomass) still creates noticeable and perhaps considerable air pollution, although detailed source apportionment studies do not appear to have been conducted. The disposal practices of Manila are an example of relatively centralized

4. Occupational risks seem to rise as a part of these processes as well, although the occupational hazards of farming in traditional poor populations in rural areas are not well documented. Occupational risks of the informal sector in cities are not well known either, although they are probably considerable.

5. One metric to use for this purpose is natural debt, the cumulative depleted greenhouse gas emissions per capita, which is a direct measure of impact on global warming (Smith 1997).

SIDEBAR 2. CARDIOVASCULAR AND RESPIRATORY DISEASE IN ASIA

Short-term exposure to outdoor air pollution is consistently associated with mortality and morbidity among people with preexisting cardiovascular and respiratory disease. More limited evidence suggests that long-term exposure may increase the risk of developing disease. It is therefore critical to understand the current levels and likely trends in cardiovascular and respiratory disease and their major causes, such as tobacco smoking and diet, in the developing countries of Asia.

Cardiovascular Disease

Cardiovascular diseases pose a serious health burden in developing countries (Yusuf et al 2001a,b). More than half of the 16.7 million deaths worldwide from cardiovascular disease occurred in developing countries in 2000. The burden of disease is particularly heavy in Southeast Asian countries (including India, Pakistan, Bangladesh, Nepal, and Sri Lanka), which represent a quarter of the developing world's population. Cardiovascular disease is likely to pose a major and growing problem in these countries for several reasons. The most important of these are the lack of an effective programs to combat tobacco use and otherwise promote a healthy lifestyle, limited availability of advanced medical care for disease management, and genetic susceptibility for gene–environment interactions with changing diet and other factors. For example, the increased occurrence of the metabolic syndrome among Southeast Asians may interact with an increasingly Westernized diet to increase the risk of cardiovascular disease (Nishtar 2002; Ramachandran et al 2003). Of the 1.3 billion people living below the poverty line worldwide, almost 40% reside in Southeast Asia. Given the high cost of curative services for disease, well-designed preventative strategies will be critical to curb mortality from cardiovascular disease in this region.

Regional Variation in Cardiovascular Disease

Population-based morbidity and mortality data from Southeast Asia are sparse because national reporting systems are not sufficiently developed. Nonetheless, WHO and the World Bank estimate that mortality from cardiovascular disease has increased in proportion to population growth (Murray and Lopez 1996). Southeast Asian immigrants in the United Kingdom, South Africa, Singapore, and North America have 1.5 to 4.0 times higher mortality compared with indigenous populations (Enas et al 1992).

The prevalence of IHD and its risk factors is probably increasing at a faster rate in urban than in rural areas of India (Gupta and Gupta 1996), although the data (from health facilities) may be unreliable. Unhealthy lifestyles and environmental pollution in urban India may be partially responsible for this trend. Dyslipidemia and glucose intolerance are more prevalent in urban than in rural India, although the opposite is true of tobacco smoking.

Mortality in China from IHD is low but mortality from stroke is high compared with the United States. Like in India and other Southeast Asian countries, death rates from cardiovascular disease, particularly IHD, have been increasing in China in recent decades (Woo and Donnan 1989). Hypertension continues to be poorly detected and treated in most of Southeast Asia. Thus, hemorrhagic stroke remains an important cause of cardiovascular disease (Thorvaldsen et al 1995). Only 6% to 12% of strokes in Europeans are hemorrhagic compared with 25% to 30% in Chinese.

Japan has the highest life expectancy in the world. In tandem with remarkable achievements on the economic front, mortality from cardiovascular disease has declined rapidly. Current rates are among the lowest worldwide, despite high prevalence of smoking in recent years (Yusuf et al 2001b). Like other Asian regions such as China, however, more Japanese die from cerebrovascular disease than from IHD (WHO 2000b).

Cardiovascular Risk Factors

Risk factors for IHD are widely prevalent in Southeast, and especially South Asia. Although obesity is much less common there than in North America, Southeast Asians have higher body fat percentages and waist/hip ratios for the same body mass index (Deurenberg-Yap et al 2002), apparently owing to less physical activity and lower muscle mass. The percentage of men aged 15 to 30 years with hypertension is alarmingly high: 36.4% in India, 17% in Pakistan and Sri Lanka, and 9.8% in Bangladesh (Nishtar 2002). The case is similar for women and also holds in both rural and urban areas.

Frequency of tobacco smoking continues to rise in several Southeast Asian countries. In Nepal, almost 74% of men smoke, as do almost half of men in Bangladesh and Sri Lanka. In India and Pakistan, nearly one third of the male population is tobacco smoker. Almost 60% of men smoke tobacco in China. And no decline in smoking prevalence is in sight (Yang et al 1999b).

These countries are also experiencing a rapid increase in prevalence of diabetes mellitus and metabolic syndrome, probably related to fetal malnutrition and low birth weight. Reports of childhood obesity and type II diabetes mellitus are on the rise. Hypercholesterolemia and dyslipidemia are particularly prevalent in Indian adults; 37.4% of men aged 15 to 30 years are afflicted (Nishtar 2002).

The role that genetic factors may well play in the high prevalence of cardiovascular disease in Southeast Asians is suggested by studies of migrant populations. Numerous studies report high incidence of coronary artery disease (not explained by conventional risk factors) among Indian immigrants in Canada, United Kingdom, United States, and the Caribbean (Anand et al 2000). Genetic predisposition to cardiovascular disease is particularly apparent when these populations migrate to the West and adopt its high-fat and high-cholesterol diet and physical inactivity. Blood levels of lipoprotein(a) are highly influenced by genetic factors and seem to be related to occurrence of coronary artery disease (Geethanjali et al 2003).

Indian life expectancy is currently 62 years and is expected to increase to 72 years by 2030. The infant mortality rate is expected to halve during this period. These projections suggest considerable changes in age structure and increase in burden from cardiovascular disease over the next three decades. Declining rates of cardiovascular disease in immigrant Indian populations in the United Kingdom and Canada (Sheth et al 1999) emphasize the potential for reducing mortality rates by timely intervention.

refuse burning on a large scale, but more diffuse, small-scale burning may have a greater impact in many settings (United Nations Environment Programme 1996). Given current trends, we expect that the most egregious refuse combustion will probably be controlled within the next 30 years.

In most of the world's cities, the chief source of combustion is fuel use, which tends to increase along with population size and economic activity. Although emissions also depend on combustion conditions and emission-control technology, fuel type is a useful indicator of potential emissions: coal and biomass are high-emitting solid fuels; gasoline, kerosene, and diesel are mid-emitting liquid

Chronic Respiratory Disease

Prevalence of chronic respiratory diseases (including COPD and tuberculosis) in most Asian countries is quite high. COPD is predicted to become a leading cause of death in the next two decades because of increasing smoking rates (Murray and Lopez 1997a), despite national efforts to mitigate them.

COPD affects 3% of Chinese; this percentage is expected to increase substantially to reflect a tenfold increase in smoking prevalence between 1950 and 1990 (Zhang and Cai 2003). COPD is estimated to affect 6.7% of the population over 30 years of age in 12 Asia-Pacific countries (Regional COPD Working Group 2003). In India, 11 population-based studies suggest that COPD affects 5.6% of males and 2% of females over 30 years of age (Jindal et al 2001).

Tuberculosis continues to be a major health problem in Asia despite implementation of directly observed therapy (in which a health care worker meets with the patient to help him or her remember to take the prescribed medicine) in most regions (Khatri and Frieden 2002; Gajalakshmi et al 2003). Tobacco smoking is a risk factor for the acquisition of tuberculosis in these populations.

Acute Lower Respiratory Infections in Children

Acute lower respiratory infection (ALRI) is the chief cause of death among children in the world, killing an estimated 2.1 million per year in 2000 (WHO 2001a). Although the disease affects both young and old, pneumonia kills so many children younger than two years that these deaths account for a large number of lost life-years. Indeed, with 6.3% of the global burden of disease in 2000 (as measured in DALYs), ALRI is the most important single disease category in the world (WHO 2001b).

All young children in the world apparently suffer from similar rates of acute respiratory infection of the upper respiratory tract (Rudan et al 2004). In developed countries, these infections are usually viral, mild, and self-limiting. In contrast, most serious ALRI in developing-country children is thought to be bacterial and consequently treatable by antibiotics. Unfortunately, the infection can establish in the deep lung in as little as 36 hours, such that even prompt seeking of health care and rapid and appropriate responses of health-care facilities are insufficient to achieve complete control over mortality. A large fraction of cases progress to serious and sometimes fatal ALRI, consisting of bronchiolitis and pneumonia. Vaccines show promise to deal with perhaps 20% to 40% of serious cases. Prevention through better nutrition and cleaner environments will therefore be essential to substantially reduce ALRI incidence and mortality (Kirkwood et al 1995).

The three developing Asian regions bear a significant fraction of the ALRI burden (see table). Indeed, 1.5% of the entire burden of disease from all diseases, regions, and age groups is due to one disease in one age group in one region: ALRI in children younger than five years in South Asia. Considering that India makes up about 80% of this region, the bulk of this burden in fact falls on just one country.

There are several known risk factors for ALRI, the most important of which is malnutrition. The WHO comparative risk assessment (CRA) exercise (WHO 2002; sidebar 3 in this Special Report) estimated that some 40% of ALRI cases are directly attributable to protein malnutrition in the world, 16% to zinc deficiency (Black et al 2003).† Other risk factors include those that affect diarrhea, malaria, and measles, because children with those diseases are more likely to contract severe ALRI. Crowding and chilling have also been associated with ALRI, but with less consistency. Nearly one-third of global ALRI in children is attributed to indoor air pollution in developing countries (Smith et al 2000); about 1% is attributed to urban air pollution (WHO 2002; sidebar 3 in this Special Report).

Although ALRI (pneumonia) was the chief cause of death at the turn of the 19th century in much of the currently developed world, including the United States, mortality rates in children from severe ALRI are now low (eg, 3/100,000 in US children today compared with 900/100,000 in South Asia). For this reason, few epidemiologic studies of outdoor air pollution have included ALRI as an endpoint, because it is a minor concern in society and because the sample sizes of even large studies would be too small to statistically discern an effect (Romieu et al 2002).

In developing countries, however, ALRI should be included as an endpoint in air pollution epidemiology studies, in addition to those endpoints that are also of interest in developed countries. ALRI rates are generally highest in rural areas, which are usually more affected by indoor than outdoor air pollution, but urban slums tend to have both types of pollution and high childhood ALRI rates as well. Studies, therefore, should probably focus on the urban poor.

† Interventions to reduce protein malnutrition and zinc deficiency together would reduce ALRI by less than the sum, however; attributable burdens cannot be added directly without subtracting the degree of double counting, which is sometimes difficult to quantify.

Burden of Disease Due to ALRI in 2000[a]

Region	Deaths Due to ALRI (thousands)	Deaths in Children < 5 Years (thousands)	Percent of Regional Burden Due to ALRI	Percent of Regional Burden Due to ALRI in Children < 5 Years
South Asia	1200	611	8.3%	81%
Southeast Asia	141	76	3.8%	69%
East Asia	439	320	4.6%	76%
World	3870	2130	6.3%	79%

[a] Data from WHO 2002.

fuels; and liquefied petroleum gas (LPG) and natural gas are low-emitting gaseous fuels.

In general, emissions per unit fuel are also inversely proportional to scale of combustion (EPA 1995). Small-scale residential and commercial emitters produce relatively more outdoor pollution than large-scale central sources of emissions. The intake fraction for primary pollutants from small sources also tends to be greater than from large ones; in other words, the population exposure per ton of emissions from small sources is higher because they release pollutants at ground levels near people.

Overall, then, small sources burning solid fuels may produce greater exposures per unit fuel (and possibly larger health effects) than do nearly any other outdoor

source of emissions. Shifting fuel use in households and commercial enterprises to gaseous fuels or electricity can substantially reduce such exposures. Liquid-fueled motor vehicles also have relatively high intake fractions because of their proximity to the population, although they are not as polluting as devices that combust solid fuels. Uncontrolled motor vehicles, particularly those with diesel and two-stroke engines are therefore important potential sources of urban pollution.

Without delving into the many factors that could affect emissions at the local level, the extent to which coal and transport fuels are used is a useful indicator of the potential for outdoor emissions that could affect health.[6] Table 5 shows the dramatic projected increase in coal use in Asia over the next quarter century; it is greater than in any other part of the world (International Energy Agency 2002). Indeed, half the increase in the entire world's coal use during that time will occur in China alone (International Energy Agency 2002). India's rate of increase is expected to be even greater. And Indonesia, although starting from a much lower level of use, will increase coal use twice as much as the bigger countries of China and India.

The growth in fuel use for transportation over the next 30 years is expected to be dramatic within Asia, twice the global average and substantially faster than any other region (International Energy Agency 2002) (Table 6). Although some suggest an income threshold for car ownership, Figure 9 shows a remarkably constant relation between car ownership and every income level. This relation suggests that some people can afford cars at even low national average incomes. As incomes increase, India, China, and Indonesia are expected to mimic South Korea's car ownership trend, perhaps eventually reaching levels of ownership of the United States and Germany. Developing Asian countries are less likely to mimic Japan's plateau in ownership that occurred because of land (parking) scarcity. The private auto fleet is therefore likely to double in size in Asia by 2020.

OUTDOOR AIR POLLUTION

Some of the highest levels of outdoor air pollution in the world are found in Asian cities. Figure 10 shows the annual mean concentrations of suspended PM (TSP), PM_{10}, SO_2, and NO_2 in 2000 and 2001 in major Asian cities (Air Pollution in Megacities of Asia 2004). Some cities in China and India have some of the world's highest recorded outdoor PM_{10} levels (Figures 10 and 12).

6. For poor cities with large slums, however, household use of biomass and coal will continue to be important sources of local ambient pollution and exposures. As much as one third of the population in poor Asian cities is classified in this way today (International Energy Agency 2002).

Table 5. Past and Projected Coal Consumption[a,b]

	Year				
Country	2000	2010	2020	2030	2000–2030 Mean Annual Rate
China	989	1281	1589	1917	2.2%
Share[c]	69%	66%	62%	60%	−0.5%
India	248	303	390	512	2.4%
Share[c]	55%	49%	46%	45%	−0.7%
Indonesia	21	36	60	95	5.2%
Share[c]	14%	16%	19%	23%	1.7%
Total	1257	1620	2039	2523	2.3%

[a] In million tonnes coal equivalent.

[b] Source: International Energy Agency 2002.

[c] Share of total national energy use.

Table 6. Past and Projected Transport Oil Consumption[a,b]

					2000–2030 Mean Annual
Country	2000	2010	2020	2030	Rate
China	77	130	200	279	4.3%
India	44	68	107	158	4.3%
Indonesia	21	32	45	59	3.4%
Total	142	230	352	496	4.2%

[a] In million tonnes oil equivalent.

[b] Sources: International Energy Agency 2002 and personal communication with M Walsh, 10/01.

The most commonly reported indicator of particulate pollution is the concentration of TSP. Annual mean TSP concentrations exceeded the TSP guideline of 90 μg/m^3 (WHO 1979) in most cities; moreover, several cities in China, India and Southeast Asia had TSP concentrations that exceeded 150 μg/m^3 (Figure 10). In most cities where levels have been continuously monitored, declines in mean annual TSP concentrations were observed during the 1990s (Air Pollution in Megacities of Asia 2002). However, particulate removal techniques used since then in Asian cities are more effective at removing the largest, rather than smaller, inhalable particles that comprise PM_{10}.

The mass concentration of PM_{10} is measured in a limited number of cities in the region. PM_{10} concentrations have increased since the 1990s, even as the reductions in TSP were reported (Air Pollution in Megacities of Asia 2002). Annual mean PM_{10} levels tend to be higher in middle-income East Asian (mainly Chinese) cities and in lower-income South Asian (mainly Indian) cities compared with

middle-income or high-income Asian cities (ie, Bangkok, Busan, Hong Kong, and Seoul). PM_{10} levels in the cleanest locales (eg, Singapore) are about the same as those in relatively polluted cities in developed regions (Air Pollution in Megacities of Asia 2002).

SO_2 is mainly emitted during combustion of fuel containing sulfur and during metal smelting and other industrial processes. SO_2 is also a major precursor of fine particles ($PM_{2.5}$) formed in the atmosphere. Annual mean concentrations of SO_2 do not generally exceed the SO_2 guideline of 50 µg/m^3 (WHO 1999), except in some Chinese cities (ie, Chongqing) (Figure 10). In many Chinese cities, coal burning is the major power source for domestic heating and industrial processes. It contributes considerably to urban air pollution, resulting in much higher SO_2 levels in China than in other Asian countries. However, in recent years, conversion from coal to natural gas and increasing use of low-sulfur coal has resulted in decreasing SO_2 levels. Mean SO_2 levels in 47 major Chinese cities have declined 5% to 10% annually between 1998 and 2002, dropping to 47 µg/m^3 by 2002 (China State Environmental Protection Administration 2002).

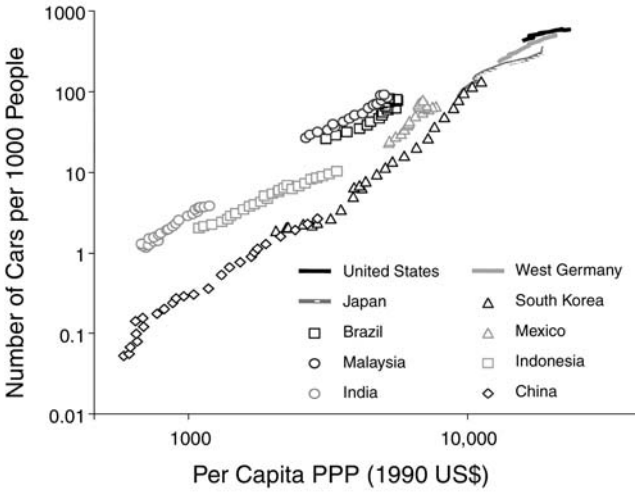


Figure 9. Car ownership by per capita PPP. PPP = purchasing power parity = GDP adjusted by local prices and normalized to US conditions. Data from Schipper et al 2000. Both axes use log scales.

Major sources of NO_2 are high-temperature combustion processes (such as those occurring in automobiles and power plants). In Asia, however, vehicular traffic is the main source of urban ambient NO_2 (Air Pollution in Megacities of Asia 2002). Annual mean concentrations of NO_2 exceed the WHO guideline of 40 µg/m^3 (WHO 1999) in a number of Asian cities (Figure 10). Some cities in which vehicular traffic has been increasing over the past decade (eg, Shanghai, Seoul) are experiencing especially elevated and increasing levels of NO_2; maintaining NO_2 concentrations even at current levels will be difficult in the face of rapid increases in total energy consumption, vehicle numbers, and vehicle-miles traveled. Increasing NO_2 concentrations combined with high levels of ultraviolet radiation are also expected to contribute to increasing ambient levels of photochemical air pollutants such as O_3.

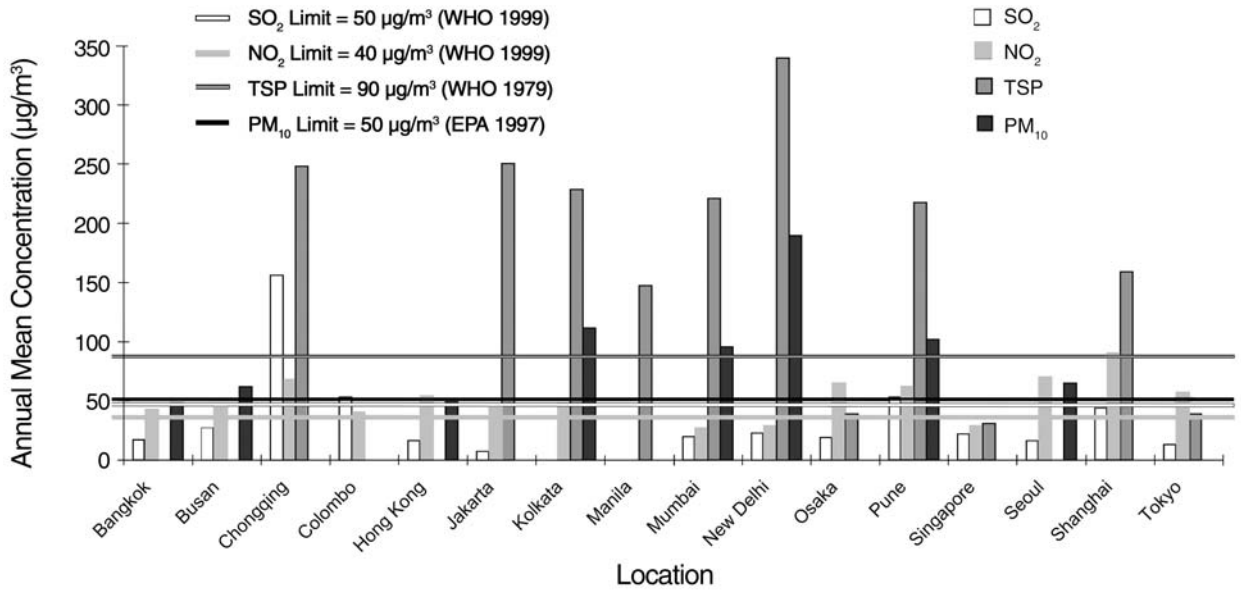


Figure 10. Annual mean concentrations of pollutants compared with their guidelines and standards in Asian cities, 2000 and 2001. Data from Air Pollution in Megacities of Asia 2004.

Outdoor ambient air pollution levels vary widely across Asia, largely as a function of development. The specific cases of Delhi, Beijing, and Hong Kong illustrate this variation.

Delhi

Delhi is one of the most populated and polluted cities in world. Levels of TSP and RSP (respirable suspended particulates, equivalent to PM_{10}) exceed Indian standards at most monitoring sites in Delhi (Central Pollution Control Board 2003, 2004). Particulate emissions mostly come from combustion in a variety of human activities: emissions from motor vehicles, small-scale industry, coal combustion, refuse burning, and domestic sources. Annual mean levels of TSP remained relatively stable between 1991 and 2001: about 360 µg/m^3 in residential areas (Figure 11). The annual mean level of RSP reached 170 µg/m^3 in 2003 (Central Pollution Control Board 2003). In 2001, however, SO_2 and NO_2 levels were generally found to be within WHO 1999 guidelines (Figure 11). Various actions have recently been taken to address air pollution problems in Delhi, including tightening limits on vehicular emissions, switching to cleaner fuels, phasing out old motor vehicles and maintaining those in use, and closing or relocating industries that pollute or that operate in nonconforming areas. As a result, SO_2 and lead levels in outdoor air have been decreasing, although the particulate levels remain high.

Beijing

As of 2002 in Beijing, the main air pollutants were TSP, PM_{10}, SO_2, and NO_x. Levels of TSP and PM_{10} are very high, primarily as a result of increased construction activity and meteorologic events, such as sandstorms (Beijing Environmental Protection Bureau 2004). Annual mean levels of TSP and PM_{10} were relatively stable between 1999 and 2002: 370 µg/m^3 and 160 µg/m^3, respectively (Figure 12). SO_2 concentrations in Beijing rapidly increased in the early 1990s mainly because of industrialization, urbanization, and increased domestic coal consumption. Annual mean SO_2 levels decreased 44% from 120 µg/m^3 in 1998 to 67 µg/m^3 in 2002, however, as a result of switching to cleaner fuel and implementing control measures to reduce industrial emissions. Increasing numbers of motor vehicles and relatively slow increases in transportation infrastructure have resulted in annual mean levels of NO_2 that remained fixed at a relatively high level: about 75 µg/m^3 between 1999 and 2002. Recent actions that restrict vehicle emissions and phase out older vehicles are expected to further reduce NO_2 emissions from individual vehicles, even as the number of vehicles continues to grow rapidly.

Hong Kong

Hong Kong is one of the largest commercial centers and one of the largest developed cities in Asia. Major air pollution from mobile emissions, particularly diesel emissions, has resulted in relatively high levels of PM_{10} and NO_2 in Hong Kong compared with other developed Asian cities (Hong Kong Environmental Protection Department 2004; sidebar 1). Annual mean RSP levels for Hong Kong as a whole have remained below the Hong Kong Air Quality Objective (HKAQO) of 55 µg/m^3 for RSP since 1996, although the HKAQOs are exceeded in some districts. Ambient NO_2 levels have also remained consistently between 40 and 60 µg/m^3 in the last decade, but levels along busy roads often exceed the HKAQO of 80 µg/m^3 for NO_2. Annual mean SO_2 levels have been greatly reduced since high sulfur fuels were banned in Hong Kong in the early 1990s; they are now well below the HKAQO. Whereas other pollutants remain controlled in Hong Kong, annual mean O_3 levels increased more than 80% over the past decade and reached 35 µg/m^3 in 2002. O_3 levels are higher in Hong Kong and other subtropical and tropical areas in the cool season when cloud cover is less than in the warm

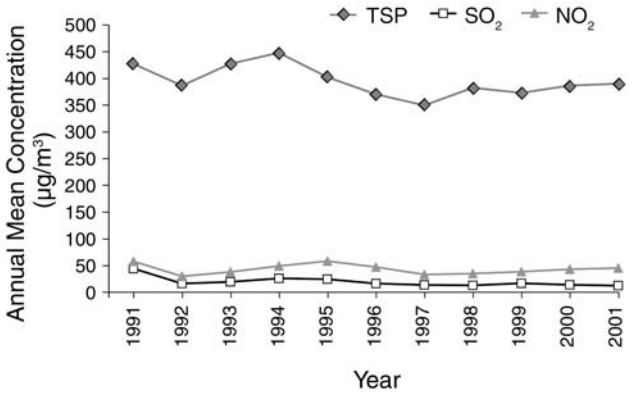


Figure 11. Annual mean concentrations of pollutants in residential areas of Delhi. Data from Central Pollution Control Board 2004.

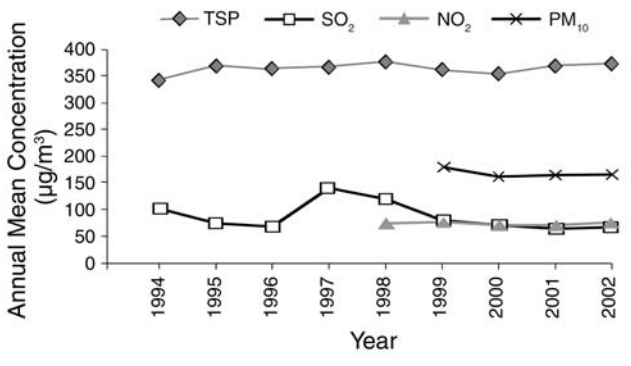


Figure 12. Annual mean concentration of pollutants in Beijing. Data from Beijing Environmental Protection Bureau 2004.

(monsoon) season. The converse tends to be true in temperate climates like that in London, which was the subject of a comparative health effects study with Hong Kong (Wong et al 2002a). Transboundary pollution from mainland China (including sulfate fine particles from SO_2 emitted when coal is burned) also adversely influences local air quality during the winter months when north winds prevail.

Air pollution in Asian cities is closely tied to levels and trends in economic and social development. In addition to rapidly increasing industrialization, urbanization, population growth, and demand for transportation in most Asian cities, meteorologic conditions also contribute to high levels of air pollution in most South and Southeast Asian cities. Although governments have acted through legislative measures and other policies and programs to reduce emissions and control pollution, continuing improvement in urban air quality will require sustained, long-term efforts to keep pace with the rapid urban growth and development.

INDOOR AIR POLLUTION

Indoor air pollution is a serious concern in the developing countries of Asia, where 60% to 80% of households rely on solid biomass fuels for cooking and other needs (WHO 2002). These fuels are usually burned in low-efficiency, unvented traditional devices, resulting in high levels of indoor air pollution. Women and children incur the greatest exposures because they spend the most time indoors working with or near combustion sources. Although some households have recently shifted to cleaner gaseous fuels, the shift has been slow and largely confined to high- and middle-income families.

Most studies of indoor air pollution levels have been carried out in rural households. The results available for urban households are nevertheless striking (Table 7). Even fewer studies have estimated daily exposure to indoor air pollution in developing cities in Asia; results for two such cities are presented in Table 8.

The complexity of indoor air pollution sources is evident in Table 9, which summarizes the major pollutant and source categories identified in previous research. Combustion of household fuels for heating and cooking is responsible for many of the pollutants emitted indoors. Because of its high emission per unit fuel, household fuel combustion causes most indoor air pollution in poor areas. This situation is true in both rural developing areas, where solid fuels (such as biomass [wood, crop residues, and dung] and coal) are commonly used, and in the poorest parts of Asian cities, the slums. Because some three quarters of households use solid fuels in Asia, this source is probably the major contributor to total exposure to combustion-related pollutants.[7]

7. Databases of all published household indoor air pollution studies are available at *http://ehs.sph.berkeley.edu/krsmith/*.

The other forms of indoor air pollution listed in Table 9 are also undoubtedly important in many Asian households, but no systematic exposure estimates for them are currently available. With development, however, more and more indoor air pollution is caused by environmental tobacco smoke, volatile organic compounds, and other more modern pollutant sources (although household fuel combustion remains an issue with more modern fuels, such as kerosene and natural gas). As in the West, studies in Asian cities such as Hong Kong report acute effects of exposure to

Table 7. Indoor Particulate Concentrations from Burning of Solid Fuel in Urban Areas

Location	Fuel	Particulate Type, Concentration ($\mu g/m^3$)[a]
China[b]		
Shanghai	Coal	RSP, 500–1000
Beijing	Coal	RSP, 17–1100
Shenyang	Coal	RSP, 125–270
Taiyuan	Coal	RSP, 300–1000
Harbin	Coal	RSP, 390–610
Guangzhou	Coal	RSP, 460
Chengde	Coal	RSP, 270–700
India		
Urban slums[c]	Biomass	RSP, 400–520
Urban[c]	Biomass	RSP, 2860
Delhi[d]	Wood	RSP, 1370
Pune[e]	Wood	RSP, 1100
Ahmedabad[f]	Cattle dung	TSP, 3470
	Wood	TSP, 2630
	Coal	TSP, 1190
	Kerosene	TSP, 520
	Gas	TSP, 500
Philippines[g]		
Manila	Biomass	RSP, 70–800
Bangladesh[h]		
Urban slums, Dhaka	Biomass	TSP, 4445–9455

[a] Average concentration over cooking period (typically 2–4 hours).

[b] Source: WHO 1997.

[c] Source: Smith 1996.

[d] Source: Saksena et al 2003.

[e] Source: Smith et al 1994.

[f] Source: Raiyani et al 1993.

[g] Source: Guha-Sapir 1996.

[h] Source: Dana 2002.

environmental tobacco smoke (Lam et al 2000; McGhee et al 2002). Because household conditions (including ventilation) vary dramatically by income, culture, and climate, however, generalizing about emissions trends in the absence of field surveys is difficult. Few data are available for indoor air pollution conditions in schools, occupational settings (especially the so-called informal sector that is so important in poor countries), public buildings, motor vehicles used for transport, and other nonhousehold indoor locations where people spend much time.

Table 8. Estimated Daily[a] Exposures to PM_{10} (mg/m^3) from Burning of Cooking Fuels[b]

Fuel	Pune, India	Beijing, China
Biomass	0.71–1.08	
Coal[c]		0.10–0.15
Kerosene	0.1–0.15	
LPG	0.02	0.06
National ambient standard (for residential areas)	0.10	0.15

[a] 24 hour.

[b] Source: Smith et al 1994.

[c] Burned in vented stove.

Epidemiologic studies show that smoke from indoor cooking fires affects a number of health outcomes (Table 10). The three with the largest and most consistent bodies of evidence are acute lower respiratory infections in children under five years and COPD and lung cancer in adults over 15 years (the latter from exposure to coal smoke only) (Smith et al 2004).

EXPOSURE

Several aspects of exposure to outdoor air pollution in Asian cities may be particularly relevant to the design, conduct, and interpretation of epidemiologic studies.

High levels of emissions from solid fuels in simple stoves creates not only high indoor pollution levels but, in dense communities with many stoves in use, also considerable local, or neighborhood, outdoor air pollution levels. Urban ambient pollution monitors do not usually fully capture these neighborhood hotspots. Thus, when they are common, the monitors may substantially underestimate true exposure to ambient air pollution.

Figure 13 shows the large neighborhood effect of solid fuel use in an Indian city. Note in addition the high exposures from solid-fuel (biomass) use compared with LPG or kerosene use. Because of differences in usage

Table 9. Major Indoor Sources of Health-Damaging Air Pollutants[a]

Pollutant	Major Indoor Sources
Fine particles[b]	Fuel or tobacco combustion, cleaning, cooking
CO	Fuel or tobacco combustion
PAHs	Fuel or tobacco combustion, cooking
NO_x	Fuel combustion
SO_x	Coal combustion
As & Fl	Coal combustion
Volatile & semivolatile organic compounds	Fuel or tobacco combustion, consumer products, furnishings, construction materials, cooking
Aldehydes	Fuel or tobacco combustion, furnishings, construction materials, cooking
Pesticides	Consumer products, dust from outside
Asbestos	Remodeling or demolition of construction materials
Pb[c]	Remodeling or demolition of painted surfaces
Biological pollutants	Moist areas, ventilation systems, furnishings
Radon	Soil under building, construction materials
Free radicals, other short-lived, highly reactive compounds	Indoor chemistry (interaction of pollutants from indoor and outdoor sources)

[a] Source: Zhang and Smith 2003.

[b] Incense sticks and mosquito coils are important sources in some areas as well.

[c] Lead-containing dust from deteriorating paint is an important indoor pollutant for occupants in many households, but the most critical exposure pathways for lead are not usually via air.

Table 10. Health Risks of Household Exposure to Solid-Fuel Smoke

Health Outcome	Population Affected	Relative Risk[a] (95% CI)	Evidence
COPD[b]	Females ≥ 30 years	3.2 (2.3,4.8)[c]	Strong
	Males ≥ 30 years	1.8 (1.0,3.2)[c]	Strong
Acute lower respiratory infections[b]	Children < 5 years	2.3 (1.9,2.7)[c]	Strong
Lung cancer[b,d]	Females ≥ 30 years	1.9 (1.1,3.5)[c]	Strong
	Males ≥ 30 years	1.5 (1.0,2.5)[c]	Strong
Blindness (cataracts)[e]	Females ≥ 15 years	1.3–1.6[f]	Intermediate
Tuberculosis[e]	Females > 15 years	1.5–3.0[f]	Intermediate
Asthma[e]	Females > 15 years	1.4–2.5[f]	Intermediate

[a] Relative risk based on binary classifications for exposure to indoor air pollution from cooking with solid fuels.

[b] Data from meta-analyses from WHO Comparative Risk Assessment (Smith et al 2004).

[c] Point and interval estimates for summary relative risks. See source for details.

[d] From exposure to coal smoke only.

[e] Data from Smith 2000.

[f] Range of reported relative risk estimates. See source for details.

patterns and dependence on weather, neighborhood pollution may vary differently over time than the citywide pollution measured by the urban monitoring network does.

The marked gradient of local, regional, and roadside levels of air pollution also should be considered in risk assessments in Asian cities. More and more, dense populations in developing conurbations live or work at the roadside. Simultaneously, roadside air pollution levels appear to be increasing. In Hong Kong, for example, roadside levels of RSP, NO_x, and NO_2 are very high relative to ambient levels (see sidebar 1).

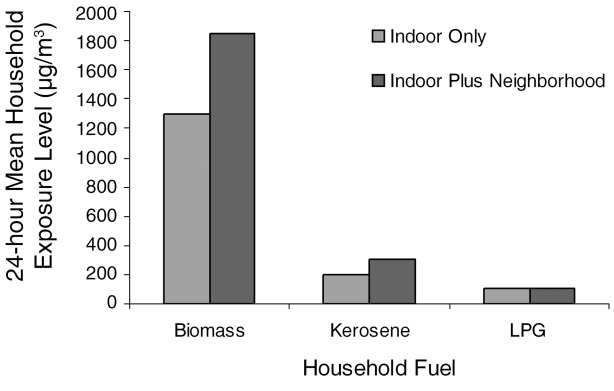


Figure 13. Exposures to indoor and neighborhood pollution from burning of household fuel in three communities of Pune, India. The three were in the same part of the city (and would have been accorded the same ambient pollution level by the nearest monitor). Data from Smith et al 1994.

The possible effects of such gradients on epidemiologic risk estimates have been recently observed in a European cohort study. Hoek and colleagues (2002) found that mortality from cardiopulmonary diseases was affected more by air pollution in proximity to major roads than by urban and regional air pollution. Recent health impact assessments have used risk estimates based on measurements from central monitors only; these assessments may therefore underestimate the burden of disease due to air pollution (Cohen et al 2004).

The relation between what ambient monitors measure and what people actually breathe may therefore be quite different in cities with such pollutant gradients than in developed cities, which tend to have smaller neighborhood effects. The difference depends on the pollutant, of course; it is less of an issue with secondary pollutants such as O_3 or sulfate particles.

Some 25% to 50% of people in developing Asian cities are estimated to live in slums, defined as poor urban communities that lack complete access to city services like piped water and sanitation. Many slum households rely on solid fuels for cooking, which may expose residents to high levels of indoor pollution. In many cities, even nonslum households rely to some extent on solid fuels, although most use LPG, kerosene, or (increasingly in China) natural gas.

In India, for example, the recent national census indicated that about 31% of all urban households rely on solid fuels whereas 91% of all rural households do (Registrar General and Census Commissioner 2001). Asia-wide estimates of

solid-fuel use in urban areas in combination with the conservative assumption that all rural households use solid fuels suggest that about one third of Asian households use solid fuels (with considerable variation by region).

Although to our knowledge no large-scale systematic surveys have been conducted, anecdotal accounts suggest that slum communities tend to be located in areas with the most ambient pollution (eg, near industries or heavily trafficked roads). This suggestion has implications for epidemiologic studies, such as the possibility that the effects of poverty will be confused (confounded) with the effects of air pollution. High household use of solid fuels in these slum communities is a further complication. (Occupational exposures, particularly in the informal sector [which tends to be concentrated in poor areas], may also complicate interpretation of outdoor epidemiologic data.)

EXPOSURE–RESPONSE RELATIONS

The issues discussed above may have implications for estimation of the exposure–response relation between outdoor air pollution and health and should be considered when interpreting epidemiologic studies.

In most cities worldwide, even those with high levels of outdoor air pollution, total exposures to air pollution are influenced strongly by indoor pollution sources. Indoor sources such as the combustion of fuels for cooking and heating, tobacco smoking, and cleaning products probably account for the majority of total exposures to some important pollutants. Although changes in outdoor air pollution levels often correlate well with changes in total exposure, absolute exposures (which also depend on indoor and other nearby sources) are not necessarily well predicted by outdoor levels. To the extent that one is interested in estimating the effect of exposure to air pollution from *outdoor* sources this may not pose a problem, as we discuss below. If, however, one is interested in estimating the effects of *total* exposure to a pollutant such as PM, which has both outdoor and indoor sources, some measure of total exposure is needed along with source apportionment information to effectively target future interventions.

The temporal pattern of exposure to pollutants such as PM from indoor sources, however, appears to be quite different than that of outdoor sources. Specifically, short-term temporal variation in exposure to air pollution from outdoor sources on the order of hours and days (ie, the temporal frequency that is of interest in daily times-series studies) is not well correlated with exposure to air pollution from indoor sources, at least in developed countries (eg, Janssen et al 1999). This may be true as well in the developing cities of Asia. Tsai and colleagues (2000) observed that total particle exposures inside some Bangkok homes were less than those outdoors because penetration rates were less than 1.0 and indoor sources were few. In other homes, however, total exposures were much greater than those nearby outdoors. Except as noted above, these results imply that exposure to indoor air pollution need not be taken explicitly into account when estimating the effects of short-term exposure to air pollution from outdoor sources in daily time-series studies in Asian cities, although more study is needed. The same conclusion does not necessarily apply to studies of the chronic effects of long-term exposure to outdoor air pollution, in which long-term mean exposure to indoor and outdoor air pollution may be well correlated.

Epidemiologic studies of outdoor air pollution in developed countries have generally not considered indoor sources and total exposures. Although it is tempting to follow the same course in studies in the developing countries of Asia, differences in relations between indoor and outdoor sources and even larger differences between poor neighborhoods in developing and developed cities raise questions that should be addressed. For example, residents of slum households, who tend to have more health problems due to poverty, might also experience higher outdoor exposures because they live in slums. In such cases, the effect of poverty on health could be confused with (confounded by) the effect of air pollution. Exposures to indoor air pollution or other factors associated with poverty may increase the risk of adverse effects of exposure to outdoor air pollution by increasing the susceptibility of the poor. Studies of both short-term and long-term exposure should therefore consider the interaction of poverty-related factors and exposure to outdoor air pollution.

Movement up the exposure–response curve to a nonlinear region could affect interpretation because of a high exposure background due to indoor or neighborhood effects. Variation in exposure to city-wide pollution may occur exclusively within higher ranges of the exposure–response curve where, some believe, different mathematical models fit better than at the low end.

AIR QUALITY POLICY

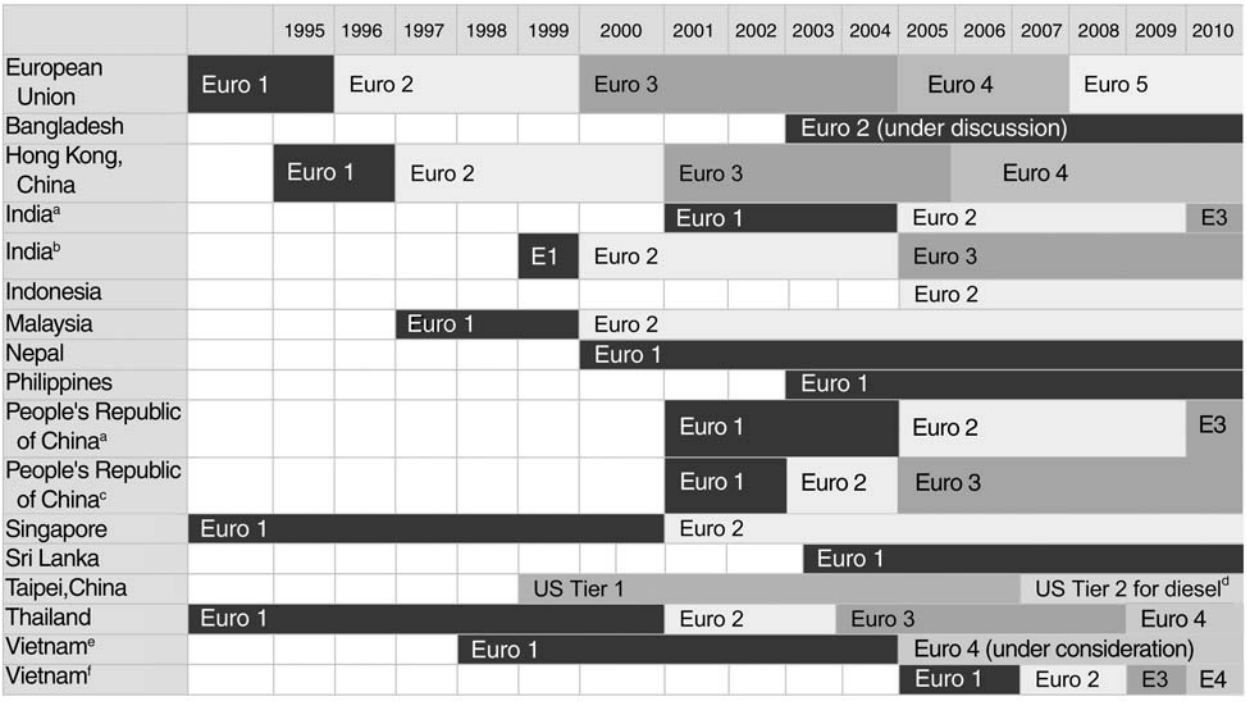
AWARENESS AND PROGRESS

Countries throughout Asia have taken action to address air pollution over the past decade. This action was prompted by the development of monitoring systems that document air pollution levels (although with widely varying comprehensiveness and sophistication) and growing public awareness of the high levels of air pollution

experienced in everyday life, especially in congested cities. Many Asian countries have now adopted National Ambient Air Quality Standards, usually based on WHO guidelines or standards adopted in Europe or the United States.

Some countries have also begun to reduce emissions from specific sources, most notably motor vehicles, industries, and electricity-generating facilities (see *www.cleanairnet.org/caiasia/1412/channel.html*). For example, many Asian countries now require that new automobiles sold in their countries meet minimum standards equivalent to Euro 1 standards; several countries also require or are planning to require compliance with more advanced European standards (Figure 14). In recent years, these efforts have been augmented by the formation of the Clean Air Initiative for Asian Cities (CAI-Asia), which was organized (with assistance from the Asian Development Bank and the World Bank) to promote sharing of technical advice among regulatory agencies, industries, nongovernmental organizations, and other key stakeholders in Asia.

These actions have resulted in measurable declines in the levels of some pollutants. In countries that have removed lead from gasoline, exposures to lead and blood lead levels in children and other exposed groups have declined markedly (eg, Vichit-Vadakan 2003). In many areas, efforts to control sulfur levels in fuel and to reduce emissions from coal-burning industries and electricity-generating facilities have resulted in even longer-term reductions in ambient SO_2 levels (Hedley et al 2002). And in some locations (eg, Hong Kong and Bangkok), comprehensive programs targeting motor vehicles and other sources have resulted in substantial reductions in levels of several pollutants that were historically very high.



[a] Entire country.
[b] Delhi and other cities. Euro 2 introduced in Mumbai, Kolkata, and Chennai in 2001 and in Bangalore, Hyderabad, Khampur, Pune, and Ahmedabad in 2003. Euro 3 to be introduced in Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, and Ahmedabad in 2005.
[c] Beijing and Shanghai.
[d] Gasoline vehicles under consideration.
[e] Gasoline vehicles.
[f] Diesel vehicles.

Figure 14. Timetable for automobile emissions standards in Asia. European Union (top row) provided for comparison. Asian countries have largely adopted versions of European standards for automobile emissions, which include Euro 1 (the first requirements for catalytic converters in the late 1980s) through Euro 4 (more sophisticated controls required for all new vehicles sold in 2005 and beyond). Source: M Walsh, personal communication, 11/03.

CONTINUING CHALLENGES

Despite this progress, however, significant challenges to improving air quality in Asia remain.

Although standards for new sources of air pollution (especially motor vehicles) have been tightened, a substantial number of older, high-emitting motor vehicles and factories are still operating in most of Asia. Addressing these existing sources will require extensive interventions: maintenance and inspection programs, enhanced fuels to reduce emissions, retrofitting of control technology, and use of alternative fuels and technology (eg, clean natural gas).

In addition to more common mobile and stationary sources, Asian cities face a wide array of diffuse, difficult-to-control sources (eg, open burning, ambient emissions from low-quality indoor fuels, and large numbers of uncontrolled small business and industries).

Rapid economic development and increased numbers of motor vehicles on the road could offset in whole or in part the reductions in air pollution emissions gained by recently adopted control measures.

FUTURE DIRECTIONS

To date, the decision to take action to improve air quality in Asia have been driven by a number of factors: (1) growing public awareness of (and negative reaction to) very high, visible levels of pollution; (2) understanding of the health effects of air pollution derived from European and North American studies (most notably the WHO's Air Quality Guidelines [WHO 2000a] based on that literature); and (3) a small but growing number of local health studies conducted in Asian cities that have documented health effects of air pollution. In a few instances, action has also been spurred by concern over air pollution's effect on historical monuments (eg, the Taj Mahal in Agra, India) and visibility.

Actions have for the most part been taken by legislatures and regulatory agencies in Asia on the basis of reviews of existing information and technologies. The most notable progress in this regard has been (in some countries) the removal of lead from gasoline and the adoption of increasingly stringent emissions standards for new automobiles.

The speed and strength of such actions has, however, been lessened by several factors: the need of Asian governments to focus on a wide variety of other challenges (including other environmental public health challenges such as waterborne diseases); the perceived conflict between objectives for economic growth and potential costs of environmental actions; and a reluctance to extrapolate from studies conducted in Western countries probable health effects of air pollution in Asia. In some cases (especially recently in India), frustration with this slow pace has led to intervention by the courts, which have given direct orders to take action (eg, to ban the driving of older motor vehicles and to require conversions to cleaner, alternative fuels).

Despite these challenges, several Asian cities have made substantial progress in implementing new measures, most often when those activities were informed by targeted efforts to document the local health consequences of air pollution and to estimate the economic impact. For example, air quality agencies in both Thailand and Hong Kong have sponsored health studies and economic analyses by local scientists; these studies have provided some rationale for substantial interventions to improve industrial fuel quality, vehicle emission standards, and other actions. As a result, both Bangkok and Hong Kong have been among the leaders in Asia in implementing comprehensive air quality management programs.

Over the past several years, other efforts have been undertaken to better quantify the impact of air pollution on health and the economy both in Asia and around the world. As part of its Integrated Environmental Strategies program, the EPA has worked with investigators in Shanghai, China; Hyderabad, India; Manila, Philippines, and others to conduct systematic analyses of the health and economic consequences of alternative energy and air pollution control policies (*www.nrel.gov/environment/environmental_strategies.html*).

These EPA analyses have attempted to use local health studies (eg, the meta-analysis of Chinese studies cited in sidebar 5) to estimate the health impact of air pollution. In many cases, however, the absence of local data has necessitated the extrapolation to Asian populations of effect estimates from North American and European studies. In 2002, the WHO also published the results of its Global Burden of Disease project (WHO 2002). WHO estimates that in 2000 Asian urban air pollution was responsible for approximately 520,000 premature deaths (sidebar 3). Although the analysis was conducted carefully, it also relied on US data and modeled rather than measured air pollution levels in order to achieve a consistent set of analyses across all countries.

Substantial improvement of local studies of the health effects of air pollution will be an important contribution to all future analyses of the health and economic consequences of actions to improve air quality.

SIDEBAR 3. COMPARATIVE RISK ASSESSMENT USING THE WHO GLOBAL BURDEN OF DISEASE DATABASE

In 2000 the WHO initiated as part of its ongoing Global Burden of Disease project the largest CRA exercise ever attempted. The burden of disease in terms of deaths and DALYs was estimated for 26 major risk factors by age, sex, disease, and 14 world regions. The burden of disease attributable to urban outdoor air pollution and indoor air pollution was estimated along with the burden of other environmental factors such as water quality and climate change. More than 100 researchers from 30 different institutions were involved, along with some 200 peer reviewers. Under the principle of consensual discipline, the groups charged with generating estimates for each risk factor agreed on minimal standards of quality and quantity of evidence. The final estimates reflect this self-imposed discipline and the rigor imposed by extensive blind peer review and strong editorial management.

Unlike previous single-factor risk assessments, which have normally been conducted in isolation, the WHO CRA is the first assessment with 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 (*www3.who.int/whosis/menu.cfm?path=whosis,burden,burden_estimates&language=english*) based on the Global Burden of Disease Database (Murray and 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 are in press (Ezzati et al 2004).

Urban Outdoor Air Pollution

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}). 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. 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. The estimated mean $PM_{2.5}$ levels in three regions of developing Asia are shown in the table.

Continued

Estimated Burdens of Disease Due to Air Pollution in Developing Asia[a]

	East Asia	Southeast Asia	South Asia	Asian Total
Population (millions)	1533	294	1242	3069
Percent living in rural areas	65%	64%	72%	68%
Percent of households using solid fuels	78%	66%	83%	79%
Estimated urban mean $PM_{2.5}$ concentration ($\mu g/m^3$)	42	47	38	41
Household air pollution				
Deaths (thousands)	503	37	522	1082
% Total DALYs	2.5%	1.6%	4.0%	3.2%
Workplace air pollution				
Deaths (thousands)	176	13	47	236
% Total DALYs	0.90%	0.30%	0.20%	0.47%
Airborne lead air pollution				
Deaths (thousands)	31	9	57	97
% Total DALYs	1.1%	1.2%	0.75%	0.9%
Urban outdoor air pollution				
Deaths (thousands)	355	32	132	519
% Total DALYs	1.4%	0.55%	0.42%	0.8%
Total deaths (thousands)[b]	1065	91	758	1934
% Total DALYs[b]	5.9%	3.7%	5.4%	5.4%

[a] East Asia (called Western Pacific B by WHO) includes China, Vietnam, South Korea, Mongolia, Cambodia, Malaysia, Laos, and the Pacific Island states. Southeast Asia (called Southeast Asia B by WHO) includes Indonesia, Thailand, and Sri Lanka. South Asia (called Southeast Asia D by WHO) includes India, Bangladesh, Myanmar, Nepal, Maldives, Bhutan, and North Korea. The first country listed in each region is the most influential with regard to regional burden estimates. China, Indonesia, and India make up 83% of the population in these regions and about 42% of the global population. The second countries listed, which have some economic and cultural similarities to the first, bring the total percentages to 92% and 47%, respectively.

[b] Double counting is possible when adding impacts from CRA categories calculated separately. Here, however, the degree of potential overlap seems minimal.

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 years of age. Attributable numbers of deaths and years of life lost for adults and children (< 5 years) were estimated using risk coefficients from a large US 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 were calculated with an assumption that the risk of death increases linearly over a range of annual mean concentrations of $PM_{2.5}$ between a counterfactual value (or theoretical minimum) level of 7.5 and 50 $\mu g/m^3$.

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 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. 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. This burden occurs predominantly in developing countries; developing Asia is estimated to contribute approximately two thirds of the global burden.

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 worldwide 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 indicate that base-case estimates were most sensitive to the choice of concentration–response function and theoretical minimum level (Cohen et al 2004).

Indoor Air Pollution

Much human exposure to most types of outdoor pollution probably occurs indoors, where people (particularly city dwellers) spend the most time. Thus, indoor air pollution is even more complex than outdoor because it reflects penetration indoors of pollutants from outdoor sources as well as considerable concentrations of pollutants from indoor sources. Because indoor exposure to outdoor pollution sources has been addressed in the urban outdoor air pollution CRA (Cohen et al 2004), the indoor air pollution CRA reflects the health impact of exposures from indoor sources, *not* the total impact of indoor exposures.

The WHO CRA required that considerable information be available in the peer-reviewed literature about exposures across the world as well as health risks (exposure–response estimates from epidemiologic studies). At the time, this information was fully available for only one category of indoor air pollution: pollutants from combustion of household fuels for heating and cooking.† In general, because of the large emission factors per unit fuel, indoor air pollution is dominated by household fuel combustion in poor areas (including most of rural developing Asia), where solid fuels (such as biomass [wood, crop residues, and dung] and coal) dominate household fuel use. Such fuels are also still important in the poorest parts of Asian cities (the slums). Because some three-quarters of households use such fuels in Asia, this source probably dominates total exposure of combustion-related pollutants from all sources.

One important nonresidential indoor setting was characterized in the WHO CRA, however: industrial workplaces. These included organized workplaces only, however; not the so-called informal sector so important in poor countries. The calculated burden included occupational disease from exposure to airborne particulates and carcinogens (WHO 2002).

Although some epidemiologic studies show an effect of indoor cookfire smoke on a number of health endpoints (including adverse pregnancy outcomes, asthma, and tuberculosis) (Smith et al 2004), the burden estimates considered the contribution from only the three with the largest and most consistent databases: acute lower respiratory infections in children less than five years of age, COPD, and lung cancer (from coal use only) (Smith et al 2004). The simple binary exposure measure used in the majority of the epidemiologic studies was use of solid or nonsolid fuels for cooking or space heating. Thus, a model was developed to estimate this parameter globally for all countries on the basis of existing survey data for about 50 countries. Some two dozen demographic, economic, and energy variables were used at first, but the final model was sufficiently good with just four: gross national product per capita, percent of the population living in rural areas, petroleum consumption per capita, and eastern Mediterranean location. The table shows the results for the three regions of developing Asia.

The results of the CRAs for indoor, outdoor, and workplace air pollution for the three regions of developing Asia are shown in the table.‡ Also included are the effects of lead pollution, assuming it is all airborne. Shown first are the exposure levels considered for indoor and outdoor air pollution: the fraction of households using solid fuels and the estimated mean annual $PM_{2.5}$ level in cities. The burden of disease is shown in terms of premature deaths as well as the percent of each region's total burden of disease as measured in DALYs. The sum comes to about 1.9 million premature deaths annually, about 5.4% of the total disease burden in the three regions in terms of DALYs. 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).

† Lead exposures, which are caused by both indoor and outdoor sources, were the subject of a separate CRA (Fewtrell et al 2004). A number of exposure–response studies have been published related to environmental tobacco smoke and radon in a limited number of predominantly Western countries, but although exposures to these pollutants are also known for other locales, it is not possible to estimate global CRA values. These two additional sources would likely add 5%–15% to the totals for household indoor air pollution globally.

‡ WHO also estimated the risks from other workplace exposures (noise, ergonomics, and injuries) but these are not included here.

Literature Review

LITERATURE SEARCH AND DESCRIPTION

The objective of this section is to describe epidemiologic studies of the health effects of air pollution in Asia. For the purposes of this Special Report, we chose three regions of Asia: *East Asia*, including China (mainland China, Hong Kong, and Taipei,China), Japan, and South Korea; *South Asia*, including India; and *Southeast Asia*, including Indonesia and Thailand.

SEARCH METHODS

The first step in this literature review was to identify all studies of populations in the Asian region. To this end, HEI assembled a database comprising studies on the health effects of outdoor air pollution in Asia published in the peer-reviewed literature from 1980 through early 2003. The databases of time-series studies (studies of the short-term changes in population-based health indicators over time) at St Georges Hospital Medical School were also searched for relevant studies. From these two sources, a common list of studies was compiled.

At HEI, results of past searches of the published literature, in-house research files, and reference sections of published papers were used as a starting point for the search for epidemiologic time-series studies. In June 2003 and December 2003, we performed structured literature searches in PubMed (*www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=PubMed*), US National Library of Medicine Gateway (*http://gateway.nlm.nih.gov/gw/Cmd*), and Medline (*http://medlineplus.gov/*) for all available years.

The PubMed search used as keywords "(country/region), health, air pollution," or "(country/region), morbidity, air pollution," or "(country/region), mortality, air pollution." "(Country/region)" was substituted with each of the following terms: Asia, China, Hong Kong, India, Indonesia, Japan, South Korea, Malaysia, Philippines, Singapore, Thailand, Taiwan, and Vietnam. The Gateway search used medical subject headings (MeSH) terms and this search string: "Asia[mh], air pollution[mh], adverse effects[sh], epidemiology[sh]". The Medline search was performed using the search string "*air pollutants, environmental/ae[adverse effects]."

We also conducted limited searches of leading preventive medicine and epidemiology journals in the Chinese-language literature. These searches yielded more than 60 articles from mainland China and six from Taipei,China. A similar search of the South Korean–language literature yielded six papers.

We also searched the St Georges Hospital Air Pollution Epidemiology Database (APED)[1], which contains details of ecologic and panel time-series studies identified using systematic search methods of three on-line databases: Medline (*http://medlineplus.gov/*), Embase (*www.embase.com/*), and Web of Science (*www.isinet.com/products/citation/wos/*). We searched APED using the search string "[(air pollution or pollution or smog or particle* or particulate* or ozone or black smoke or sulphate* or sulphur dioxide* or nitric oxide* or nitrogen dioxide* or carbon monoxide*) and (timeseries or time-series or time series or daily) and (mortality or death* or dying or hospital admission* or admission* or emergency room or visit* or attendance* or A and E or accident and emergency or general pract* or physician* or consultation* or emergency department*)]". The string was refined during routine database searches. Published and nonpublished reports not in the peer-reviewed literature covered by the bibliographic databases mentioned above were not searched.

Finally, we reviewed the results of these searches to remove duplicates and articles not pertinent to the literature review. We removed articles published before 1980, those concerning studies outside the target region (eg, northern and west-central Asia), and those that did not report original estimates of the health effects of outdoor air pollution (eg, reviews, editorials, exposure measurement studies, papers reporting only the effects of occupational or indoor air pollution).

The results of the searches at each institution were combined. A full reference and abstract for each article were downloaded from the source bibliographic databases into Reference Manager (Professional Edition, version 10; ISI ResearchSoft, Carlsbad CA).

SEARCH RESULTS

Our searches identified a total of 138 papers published in the peer-reviewed literature published between 1980 and June 2003 that report original estimates of health

1. The database and its methodology are described in greater detail in Annex 2 of WHO 2003.

effects of outdoor air pollution in Asia (see Appendices A through H for a complete list with study details). The studies cover 8 countries, mainly China (mainland China, Hong Kong, and Taipei,China), with India, South Korea, and Japan each contributing about 10% of the total (Figure 15). Most of the studies have been published in the past 10 years, a trend that is in keeping with the growth of the Western literature over this period (Figure 16).

Most studies (118) estimated the health effects of exposure to both PM and gaseous pollutants, whereas the remainder estimated the effects of exposure to PM only (9) or gaseous pollutants only (9). Most studies (115) also estimated the effects of exposure to air pollution without differentiation by source. The remainder estimated the effects of exposure from stationary sources on the basis of residential proximity to petrochemical or other industrial facilities (13), mobile sources, for example on exposure to motor vehicle emissions among people employed on or near busy roads (4), and regional pollution from forest fires (6) (sidebar 4).

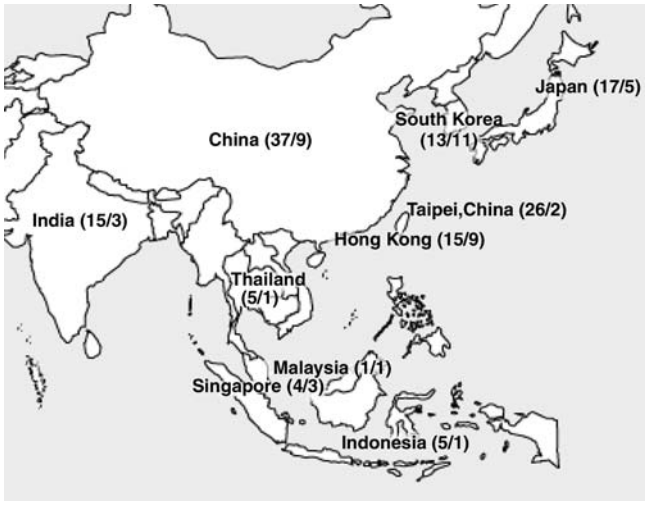


Figure 15. Epidemiologic studies of air pollution in Asia published from 1980 to June 2003. Numbers in parentheses are total studies/time-series studies conducted.

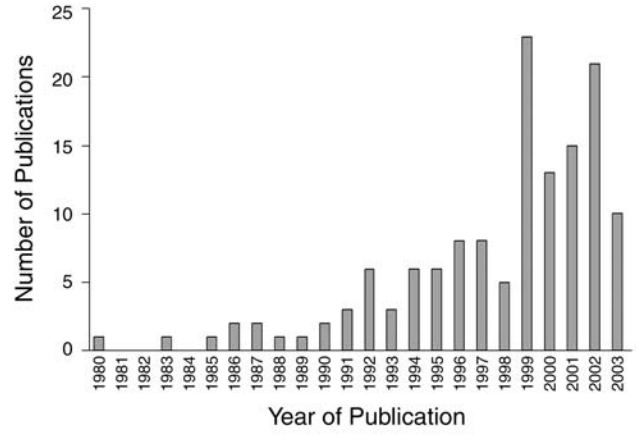


Figure 16. Number of publications of epidemiologic studies of air pollution in Asia by year. In 2003, published papers were collected only through June.

Collectively, the studies examined health outcomes that span the range of health effects recently identified as *adverse* by the American Thoracic Society (2000) (including mortality, respiratory symptoms, pulmonary function, and adverse reproductive outcomes) (Table 11). Several also examined biomarkers of exposure and intermediate effects, including admission to the hospital. The studies used a variety of designs (Table 12). Cross-sectional studies (chiefly of respiratory symptoms and pulmonary function) and time-series studies (including episode studies) comprised nearly 70% of the total.

We conducted a critical quantitative review of the time-series studies of daily morbidity and mortality only, not of

Table 11. Health Outcomes in Epidemiologic Studies of Outdoor Air Pollution in Asia 1980–2003

Health Outcome	Number of Studies
Mortality	26
Hospital admissions, visits, discharges	17
Respiratory diseases, symptoms, function, asthma	57
Biomarker	9
Pregnancy or birth outcomes	9
Lung cancer	10
Other	10
Total	138

Table 12. Designs Used in Epidemiologic Studies of Health Effects of Outdoor Air Pollution in Asia 1980–2003

Study Design	Number of Studies
Cross section	48
Time series[a]	45
Cohort	14
Case control	8
Panel	7
Ecologic	9
Case crossover	3
Impact assessment	4
Total	138

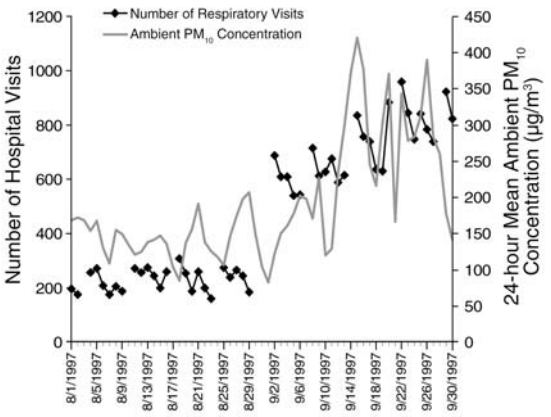
[a] Includes episode studies.

SIDEBAR 4. EFFECTS OF AIR POLLUTION FROM BIOMASS BURNING

The intentional burning of selected forest areas in Indonesia caused massive forest fires that resulted in extremely high levels of particulate air pollution throughout Southeast Asia from roughly July to December 1997 (Brauer and Hisham-Hashim 1998; Sastry 2002). Although similar events had occurred in the region before (as well as in Latin America), the so-called Southeast Asian Haze was largely unprecedented in terms of the size and duration of the fires and their effects on air quality. As much as 2% to 3% of Indonesia's land area may have been burned (Levine 1999); total particulate levels as high as 930 μg/m^3 were observed in neighboring Malaysia (Brauer and Hisham-Hashim 1998). Only the advent of the monsoon season finally quenched the fires.

Studies of the health effects of this major air pollution episode were conducted in several countries in the region, although reliable estimates of preepisode rates of disease were lacking in some. Increased hospital visits for respiratory disease were reported in Malaysia (see figure) (WHO 1998; Brauer and Hisham-Hashim 1998), Singapore (Emmanuel 2000), and Indonesia (Aditama 2000). Kunii and colleagues (2002) reported adverse effects on respiratory function and self-reported respiratory symptoms.

Perhaps the most detailed and sophisticated analysis was reported by Sastry (2002), who evaluated the effects of the episode on mortality in Kuala Lumpur, Malaysia. He reported that mortality from all nontraumatic causes increased by approximately 19% for the entire population after a high air pollution day (defined as a day where 24-hour mean PM_{10} exceeded 210 μg/m^3) after having controlled for temperature, humidity, and long-term trends in population size and mortality. Larger effects were estimated for older adults: 70% increase in risk for adults 65 to 74 years. The increased mortality associated with a high air pollution day persisted for days to weeks.



Numbers of hospital visits for all respiratory conditions and ambient concentrations of PM_{10} in Kuala Lumpur, Malaysia, August–September 1997. Visit data were not available for some days during each week. Data from Brauer 1997.

all 138 studies. On the basis of their reported results alone (Appendices A–H), however, we found that most studies conducted in Asia report estimates of increased risk or prevalence associated with air pollution for a wide variety of adverse health outcomes in adults and children (American Thoracic Society 2000). Given the wide diversity of study designs and data sources, we did not attempt (with the exception of the daily time-series studies) to assess the quality of each of the individual studies in this Special Report. In this initial review it was also not possible to assess the likelihood that only, or predominantly, positive studies had been published (ie, publication bias).

Effects of short-term and long-term exposure to outdoor air pollution have been comprehensively assessed in few Asian countries. The exception is China, where epidemiologic studies of both acute and chronic effects have been conducted over the past 25 years. These studies, frequently of populations exposed to very high levels of PM and other pollutants, often estimate increased risk of cardiovascular and respiratory disease associated with short-term and long-term exposure (sidebar 5).

Time-series studies of the effects of short-term exposure to air pollution, including studies of daily and monthly morbidity and mortality and regional pollution episodes (see time-series and episode studies in Appendices A–H), comprised about one third (45/138) of all identified studies. They have been conducted in 10 countries; most in China (mainland China, Hong Kong, and Taipei,China) and South Korea.

QUANTITATIVE ASSESSMENT OF DAILY TIME-SERIES STUDIES

Time-series studies have been conducted in a wide range of cities and countries around the world using broadly comparable methods of analysis and reporting of results. The evidence they provide contributes to public-policy decisions at national and international levels. The contribution of the Asian literature to this international body of evidence has not yet been critically evaluated. Such an evaluation could enhance scientific understanding of the effects of short-term exposure and support the development of sound public policy.

This section presents results of the quantitative analysis of the time-series studies of daily mortality and hospital admissions. For this analysis we focus on a subset of the 45 Asian time-series and episode studies. First we review their methodologic characteristics and quantitative results. Then

SIDEBAR 5. AIR POLLUTION AND HEALTH EFFECTS IN MAINLAND CHINA

Historically, coal combustion has been a predominant source of air pollution in large cities, but as the number of motor vehicles has increased, motor-vehicle emissions contribute increasingly to urban air pollution in many cities (Chen and Kan 2003). Although economic development in China during the past decade has been remarkable, emissions of SO_2 and suspended particulate have remained relatively stable, even decreased during the past several years (China State Environmental Protection Administration 1990–1998).

Ambient air pollution in China was severe in the 1980s. Annual mean ambient levels of SO_2 in Beijing were approximately 100 to 130 μg/m^3 and TSP levels approximately 250 to 450 μg/m^3 (WHO United Nations Environment Programme 1992). In the late 1990s, annual mean levels of TSP and SO_2 were declining slowly in spite of rapid economic growth (China State Environmental Protection Administration 1990–1998). For example, from 1990 to 2000, annual gross domestic product in Shanghai increased from 75,600 million to 455,100 million Chinese yuan, whereas TSP levels decreased from 360 to 156 μg/m^3 (a 67% reduction) and SO_2 levels decreased from 95 to 45 μg/m^3 (a 53% reduction) (Shanghai Municipal Statistics Bureau 1991–1999). However, NO_x levels in ambient air increased from 65 to 90 μg/m^3 due to fivefold increase of total number of vehicles in Shanghai.

In areas where gas or hydroelectric power is not available, particularly in small cities and the countryside, many people still use coal for cooking and heating. Coal is generally burned in simple stoves that often lack chimneys, resulting in TSP and SO_2 concentrations indoors that far exceed outdoor levels (as discussed elsewhere in this Special Report).

Overview of Existing Studies

This Special Report has identified more than 30 studies of the health effects of exposure to outdoor air pollution in mainland China published between 1980 and 2003. These comprise chiefly time-series studies of daily mortality and hospital admissions and cross-sectional or follow-up studies of respiratory symptoms and pulmonary function. We provide a brief and selective discussion of this literature, highlighting in particular some research that has been published only in the Chinese-language literature. Our goal is to indicate the breadth of the current literature.

Chinese scientists began studying problems related to air pollution in the early 1950s. Studies conducted in Shenyang were primarily field studies of severe air pollution due to industry emissions; TSP levels sometimes reached nearly 1000 μg/m^3. Later studies addressed the distribution of pollutants over time and space, although the technical know-how and monitoring equipment were limited. Since China joined the United Nations Environment Programme Global Environment Monitoring System in the late 1980s, monitoring air pollutants has become routine and reliable. Automatic, continuous air quality monitoring is now available in many large cities.

Today, studies of health endpoint and air pollution in China address changes in morbidity and mortality from all causes and respiratory, cardiovascular, and cerebrovascular disease, as well as the number of outpatient and emergency room visits. Increase in respiratory and other clinical symptoms and decrease in lung and immune functions are also studied. Compared with air monitoring data, however, data on human health effects are quite scarce. Scarcity of PM_{10} and $PM_{2.5}$ data in most cities further limits the interpretation of published studies.

Lead levels in ambient air have been declining since leaded gasoline was banned in 1997 in large Chinese cities. Unleaded gasoline became available nationwide in 2000. Just one year later, average blood lead levels in Shanghai children gradually decreased from 83 μg/dL to 80 μg/dL, and after two years, to 76 μg/dL (Yan et al 2002).

Recently, interest has grown in the impact of air pollution on human health and sustainable development, leading to quantitative assessments and estimates of the economic impact of health effects. A recent Shanghai study estimated a 1.6% loss in GDP due to health effects of air pollution in 2000 (Kan and Chen 2002a,b).

Epidemiologic Studies: Effect of Air Pollution on Mortality

Acute Effects The relation between air pollution and daily mortality was examined in two Beijing residential areas (population 1,419,123) in 1989 (Gao et al 1993; Xu et al 1994) and again in 1991 (Dong et al 1995). In Beijing coal stoves were the major source of air pollution, used for heating and cooking in 90% and 50% of households, respectively. The effect of air pollution on total and cause-specific mortality in Shenyang, the center of heavy industry in northeast China, was studied in 1992 using time-series analysis (Xu et al 2000). These studies, which describe increases in daily mortality associated with exposure to various air pollutants, are reviewed and included in the meta-analysis of time-series studies in this Special Report.

Acute health effects of short-term exposure to air pollution have also been studied in Shanghai, which has grown tremendously in recent years. These studies are mostly unpublished in the peer-reviewed literature. They are summarized below.

The relation between outdoor air pollution and daily mortality from June 2000 to December 2001 was assessed using semiparametric generalized additive models (HD Kan and BH Chen, unpublished data). In single-pollutant models, an increase of 10 μg/m^3 of PM_{10}, SO_2, and NO_2 corresponded to relative risk estimates of 1.003 (95% CI 1.001,1.005), 1.014 (1.008,1.020), and 1.015 (1.008,1.022) for total (nonaccidental) mortality. Cardiovascular and COPD mortality risk estimates were associated more strongly than total mortality with every pollutant. In multipollutant models, the association between SO_2 and daily mortality was not affected by inclusion of other pollutants, but such inclusion may have lessened PM_{10} and NO_2 effects on mortality.

Case-crossover analysis of the same data estimated relative risks of total mortality as 1.003 (95% CI 1.001,1.005), 1.016 (1.011,1.021), and 1.020 (1.012,1.027) for each 10 μg/m^3 (48-hour moving average) of PM_{10}, SO_2, and NO_2. The association between air pollution and mortality for COPD and cardiovascular diseases was stronger than that for all causes of death combined (Kan and Chen 2003).

A time-series study of acute effects of air pollution on diabetes and stroke mortality was conducted in an urban district of Shanghai (population 700,000) from January 1 to December 31, 2001 (HD Kan, unpublished data). Each 10 μg/m^3 increase of PM_{10}, SO_2, and NO_2 corresponded to 1.017 (95% CI 1.000,1.033), 1.029 (0.990,1.068), and 1.059 (1.000,1.118) relative risk estimates of mortality from diabetes. Pollutant effects on mortality were greater for diabetics than nondiabetics. Each 10 μg/m^3 increase of PM_{10}, SO_2, and NO_2 corresponded to 1.008 (95% CI 1.000,1.016), 1.017 (0.998,1.036), and 1.029 (1.001,1.057) relative risk estimates of mortality from stroke.

The association between daily mortality and ambient $PM_{2.5}$ levels in two Shanghai districts in fall and winter 2000 and 2001 was studied using time-series analysis. Relative risks associated with each 10 μg/m^3 increase of $PM_{2.5}$ for total mortality, cardiovascular mortality, and respiratory mortality were 1.028 (95% CI 1.008,1.048), 1.02 (1.006,1.046), and 1.035 (1.009,1.081) (HX Dai and WM Song, unpublished data).

Meta-analysis of data pooled from various Chinese cities indicates a 0.38% increase in mortality with each 10-μg/m^3 PM_{10} increase (Kan and Chen 2002a,b). This result is comparable to those from studies in Europe and North America (which report a 0.4–1.0% increase in mortality [Samet et al 2000b; Katsouyanni et al 2001; Stieb et al 2002). After a recent revision, however, European and North American estimates, while still indicating an increased risk, have now been reduced (Health Effects Institute 2003). These relations might not persist if the Chinese estimates were similarly revised.

Chronic Effects Several recent cross-sectional studies in large Chinese cities have reported increased prevalence of respiratory symptoms in adults associated with outdoor air pollution. Notably, the large four-city study conducted by the EPA and the China State Environmental Protection Administration in the 1990s estimated the effects of outdoor air pollution on respiratory health in adults (Zhang et al 1999) and elementary school children (Qian et al 2000; Zhang et al 2002). They found associations with reduced lung function and increased respiratory symptoms in both adults and children (see Appendix A).

Two studies were reported only in the Chinese-language literature. A Shanghai study indicated that a 100 μg/m^3 increase in TSP level was associated with odds ratios for incidence of respiratory symptoms and diseases from 1.13% to 1.59% (Ma and Hong 1992). A Chongqing study reported an attributable risk of 20% for upper respiratory symptoms from exposure to air pollution (Zhou et al 1996). The results of all of these cross-sectional studies may in part represent chronic disease caused by long-term exposure, but longitudinal studies are necessary to definitively address this issue.

Several studies have used aggregate-level or ecologic analysis to estimate the effects of long-term exposure (Appendix A). Two were reported only in the Chinese language literature. The chronic effects of air pollution on mortality were examined in Shenyang (Xu et al 1996b). Annual daily TSP means in a high-pollution area, medium-pollution area, and relatively low-pollution area (populations 151,300; 130,800; and 156,500) were 518, 477, and 361 μg/m^3; the means for SO_2 were 235, 128, and 64 μg/m^3. The areas differed significantly in rates of mortality from all causes, COPD, cerebrovascular disease, cardiovascular disease, cancer of all sites, and tuberculosis.

Jin and colleagues (1999) studied mortality in three districts of Benxi (total population of 667,553) with different air pollution levels in 1993 and 1994. A major base of iron and steel industry in China surrounded by mountains, Benxi was once one of the most polluted cities in China. Annual daily mean TSP and SO_2 concentrations varied from 290 to 620 μg/m^3 and 160 to 240 μg/m^3, respectively. With each 100 μg/m^3 increase in TSP, mortality from all causes, COPD, cardiovascular disease, and cerebrovascular disease were estimated to increase by 8% (95% CI of odds ratio = 1.02,1.14), 24% (1.04,1.44), 24% (1.08,1.41), and 8% (1.00,1.15).

Lung Cancer

Lung cancer is a serious public health problem in China, due largely to cigarette smoking among males and indoor air pollution exposure among rural women from coal burning. But how it is affected by outdoor air pollution has not been studied extensively. Mortality from lung cancer has increased significantly in cities and rural areas during the last three decades. In the early 1970s, lung cancer mortality in urban areas was 12.61 per 100,000 people (16.48 for males, 8.46 for females). It increased to 27.50 per 100,000 people (38.08 for males, 16.16 for females) in the early 1990s (Li et al 1997).

A distinctive geographic gradient of lung cancer mortality has been noted particularly among women residents: the higher the latitude of the city of residence, the higher the lung cancer mortality (r = 0.69, P < 0.01) (Xu et al 1986). An earlier national survey of 500,000 Chinese showed that only 7% of women smoked tobacco, however, in contrast to an alarming 61% of men older than 15 years. Unfortunately, Chinese women appear to be smoking with increasing frequency, especially in urban areas.

The highest rates of female lung cancer have historically been found in Xuanwei County, Yunnan Province, southwestern China. The ratio of male to female lung cancer mortality in China is approximately 2:1. Lung cancer mortality in Xuanwei County is eight times the national average for women (25.3/100,000) and four times the national average for men (27.7/100,000). Mumford and colleagues (1987) inferred that domestic coal (called smoky coal) was probably a major determinant of the geographic distribution of lung cancer in Xuanwei (a finding corroborated by experiments in animals [Mumford et al 1990]). Lan and colleagues (2002) recently confirmed the importance of smoky coal as an etiologic factor for lung cancer. They demonstrated that risk of lung cancer decreased markedly after installation of chimneys and attendant reduction of indoor air pollution levels in Xuanwei homes.

Case-control studies conducted elsewhere in mainland China (Xu et al 1989; Wu-Williams et al 1990) and Taipei,China (Ger et al 1993) further implicate coal use as a risk factor for lung cancer. Another case-control study in Shanghai, where most homes are unheated, reported no association between coal use and lung cancer risk (Gao et al 1987). Exposure to coal burning in preadult years spent in China was associated with lung cancer risk in a case-control study of women who had emigrated to Los Angeles County (Wu et al 1985).

Multidisciplinary studies of risk factors for lung cancer reached three major conclusions: (1) smoky coal use is the most important risk factor for lung cancer mortality among rural Chinese women (He et al 1991; Lan et al 1993). (2) Smoky coal emissions contain high concentrations of polycyclic aromatic hydrocarbons (PAHs). (3) Frequent combustion of smoky coal indoors is associated with increased lung cancer risk, as is the null genotype of glutathione *S*-transferase (*GSTM1*-null), which does not allow the GSTM1 enzyme (involved in detoxification of carcinogens) to be produced (Lan et al 2000).

A Shenyang case-control study evaluated the role of outdoor air pollution, chiefly from coal combustion, on lung cancer mortality (Xu et al 1989). Newly diagnosed cases of primary lung cancer (1249) among residents aged 30 to 69 years were compiled from 1985 to 1987. Although tobacco smoking was the dominant cause of lung cancer among men, lung cancer risk and indoor air pollution were also associated with increased risk. Lung cancer risk was 50% to 70% higher among those who spent most of their time in houses heated by coal and used coal for cooking. A twofold increase in lung cancer risk was observed among residents in the most smoky areas of the city and a 50% increase among those in somewhat or slightly smoky areas relative to residents of cleaner areas.

we consider studies of selected combinations of pollutants and health outcomes, assess variation (heterogeneity) in the direction and size of the estimated effects, and (where sufficient estimates are available) calculate summary estimates for comparison with other regions of the world. We also evaluate the possibility that publication bias (eg, selective publication by journals of positive results) may have influenced the results of the meta-analysis.

DATA ABSTRACTION

Study Selection

The first step in the quantitative analysis of the time-series studies was to identify which of the 45 daily time-series studies were appropriate for inclusion in the analysis. We used the following criteria for selection:

1. The study was based on at least one year of daily data.
2. The analysis included some attempt to control for important confounding factors (such as season and long-term trends).
3. The study reported sufficient information for the calculation of a standard effect estimate for comparison in the quantitative analysis. For this to be true, regression coefficients must have been reported. (A study that reported only correlation coefficients would not meet this criterion.)

The 28 time-series studies that we selected for analysis are described in Table 13 (and are shown in bold type in Appendices A–H). The 16 remaining time-series and episode studies were not selected for a variety of reasons (Table 14). For example, studies that did not use the day as the unit of analysis (Tseng et al 1992) or that only presented seasonal analyses were excluded (Piver et al 1999).

Case-crossover studies (Lee and Schwartz 1999; Kan and Chen 2003) and other studies that did not use time-series or episode study designs were also excluded. They are nonetheless important and are discussed below.

Data Entry

For each selected study, we recorded data on a coding sheet and entered them into Microsoft Access (version 2002; Microsoft Corp, Redmond WA) in a two-level database. The first level contained data related to the study as whole: title, authors, journal name, volume, and page number; length of the study period; year of study; continent and Asian subregion in which study occurred; mean or median pollution levels during the study period; and outcomes and pollutants studied. The second level was specific to each regression coefficient that quantified the change in a given health outcome per unit change in a given pollutant. This level was used to calculate effect estimates and their 95% confidence intervals (CI) for the meta-analysis.

The studies reported relative risks, regression coefficients, or percent changes in the mean number of events per day as measures of the association between pollutant levels and health outcomes. In order to make results comparable across the studies, we used Microsoft Access queries to convert estimates into a standard form: the percent change in the mean number of daily events associated with a 10 $\mu g/m^3$ increase in pollutant level (or a 1 mg/m^3 increase for CO), which we refer to as simply *estimates*. When the logarithm of pollutant level was used to specify exposure in the model, the estimates were calculated for a 10 $\mu g/m^3$ increase about the mean/median pollutant level.

Lag Selection

The short-term relations between air pollution and health effects are complex and are not wholly captured by regression techniques that are generally employed. The number of hospital admissions or deaths on any one day is likely to have been affected by exposure to air pollution on the same day and a number of previous days. Also, air pollution on a particular day is likely to affect health on a number of subsequent days. In time-series analyses, the cumulative effects of several days of prior exposure are sometimes investigated by averaging exposure over two or more previous days. More recently, distributed-lag models have been used to estimate the independent contribution to health outcomes on a given day of exposure of each of several previous days. Both analytic approaches tend to estimate larger effects than analyses based on single-day lags (Samet et al 2000b; Zanobetti et al 2002), although single-day lags are used far more commonly.

Investigators vary in which lag (single, cumulative or distributed) they choose to analyze and present in publications. They may systematically choose results that indicate larger or smaller effects. Particularly in studies with low statistical power, the play of chance (random error) will lead to a wider scatter of estimates from which to choose. This fact has led some analysts to test or report a relatively restricted range of lagged estimates. Many studies report one or more single-day models, but these are not generally chosen or presented in a consistent way. For this reason, we could not select a particular lag a priori (eg, one day prior to the health event) without having to remove studies from the analysis. We therefore adopted the following approach for selecting a lag for analysis.

First, we focused our selection on single-pollutant rather than multipollutant models. Single-pollutant analyses are reported in virtually all studies. The pollutants

Table 13. Description of the 28 Asian Daily Time-Series Studies Selected for the Meta-Analysis

Study Citation, Location	Outcome	Diagnosis	ICD Code[a]	Age (years)	Pollutants[b]
China					
Gao et al 1993 Beijing	Mortality	COPD, cardiovascular, all cause, all respiratory, pulmonary, bronchitis, cancers	—	All, < 65, 65+	TSP, SO_2
Hwang and Chan 2002 Taipei,China 50 townships	General practitioner consultation	Lower respiratory	466, 480–486	0–14, 15–64, 65+, all	PM_{10}[e], NO_2, O_3 (1 hr), SO_2, CO
Venners et al 2003 Chongqing	Mortality	All cause, all respiratory, cardiovascular, cancers	< 800, 490–493, 390–414	All	$PM_{2.5}$[c], SO_2
Wong et al 1999b Hong Kong	Hospital admission	All respiratory, cardiovascular, asthma, COPD, pneumonia, cerebrovascular, IHD, heart failure	460–466, 471–478, 480–487, 490–496, 410–417, 420–438, 440–444, 493, 430–438, 410–414, 428	All, 0–4, 5–64, 65+	PM_{10}[d], NO_2, O_3 (8 hr), SO_2
Wong et al 1999c Hong Kong	Hospital admission	Cardiovascular, IHD, dysrhythmias, heart failure, cerebrovascular	390–459, 410–414, 427, 428, 430–438	65+	O_3 (24 hr)
Wong et al 2001a Hong Kong	Hospital admission	Asthma	493	0–14	PM_{10}[d], NO_2, SO_2
Wong et al 2001b Hong Kong	Mortality	All cause, cardiovascular, all respiratory	< 800, 390–459, 460–519	All	PM_{10}[d], NO_2, O_3 (8 hr), SO_2
Wong et al 2002a Hong Kong, London	Hospital admission	Asthma, all respiratory, cardiac, IHD	493, 460–519, 390–429, 410–414	All, 15–64, 65+	PM_{10}[d], NO_2, O_3 (8 hr), SO_2
Wong et al 2002b Hong Kong	Mortality	All respiratory, COPD, pneumonia & influenza, cardiovascular, IHD, cerebrovascular, all respiratory	461–519, 490–496, 480–487, 390–459, 410–414, 430–438	All	PM_{10}[d], NO_2, O_3 (8 hr), SO_2

Table continues next page

[a] ICD = *International Classification of Diseases* (World Health Organization). – = ICD codes not provided.

[b] Hours given in parentheses after O_3 listings are averaging times.

[c] Measured by gravimetric method.

[d] Measured by TEOM method.

[e] Measurement method not described.

[f] Measured by β-ray absorption.

Table 13. (*continued*) Description of 28 Asian Daily Time-Series Studies

Study Citation, Location	Outcome	Diagnosis	ICD Code[a]	Age (years)	Pollutants[b]
China (*continued*)					
Xu et al 1994 Beijing	Mortality	All cause	< 800	All	TSP, SO_2
Xu et al 1995b Beijing	Primary care	Surgery, nonsurgery, pediatrics, internal medicine, other	—	All, children	TSP, SO_2
Xu et al 1995c Beijing	Primary care	All	All	All	TSP, SO_2
Xu et al 2000 Shenyang	Mortality	All cause, COPD, cardiac, cancers	< 800, 490–493, 390–414, 417–448, 140–208	All	TSP, SO_2
India					
Cropper et al 1997 Delhi	Mortality	All cause, cardiovascular, all respiratory	—	All, 0–4, 5–14, 15–44, 45–64, 65+	TSP
Japan					
Ye et al 2001 Tokyo	Emergency transport	Hypertension, angina pectoris, acute MI, heart failure, asthma, bronchitis, chronic bronchitis, pneumonia	401–405, 413, 410, 428, 493, 466, 491, 486	65+	PM_{10}[e], NO_2, O_3 (24 hr), SO_2, CO
Singapore					
Chew et al 1999b Singapore	Emergency room visit	Asthma	493	3–12	TSP, O_3 (1 hr), SO_2
South Korea					
Cho et al 2000 Daejeon, Suwon, Ulsan	Hospital admission	All respiratory	—	All	TSP, NO_2, O_3 (24 hr), SO_2, CO

Table continues next page

[a] ICD = *International Classification of Diseases* (World Health Organization). – = ICD codes not provided.

[b] Hours given in parentheses after O_3 listings are averaging times.

[c] Measured by gravimetric method.

[d] Measured by TEOM method.

[e] Measurement method not described.

[f] Measured by β-ray absorption.

Table 13. (*continued*) Description of 28 Asian Daily Time-Series Studies

Authors, Year	Outcome	Diagnosis	ICD Code[a]	Age (years)	Pollutants[b]
South Korea (*continued*)					
Ha et al 2003 Seoul	Mortality	All cause, all respiratory	—	0–1, 2–64, 65+	PM_{10}[f], NO_2, O_3 (8 hr), SO_2, CO
Hong et al 1999a Inchon	Mortality	All cause, cardiovascular	—	All	PM_{10}[e], TSP, NO_2, O_3 (24 hr), SO_2, CO
Hong et al 1999b Inchon	Mortality	All cause, cardiovascular, all respiratory	< 800	All	PM_{10}[e], NO_2, O_3 (8 hr), SO_2, CO
Hong et al 2002a Seoul	Mortality	Cerebrovascular	160–169	All	PM_{10}[f], NO_2, O_3 (8 hr), SO_2, CO
Hong et al 2002b Seoul	Mortality	Ischemic stroke	431	All	TSP, NO_2, O_3 (8 hr), SO_2, CO
Kwon et al 2001 Seoul	Mortality	All cause	< 800	All	PM_{10}[f], NO_2, O_3 (1 hr), SO_2, CO
Lee et al 1999 Seoul, Ulsan	Mortality	All cause	< 800	All	TSP, O_3 (1 hr), SO_2
Lee et al 2000 Inchon, Kwangju, Pusan, Seoul, Taejeon, Taegu, Ulsan	Mortality	All cause	< 800	All	TSP, O_3 (1 hr), SO_2
Lee et al 2002 Seoul	Hospital admission	Asthma	J45–J46	0–14	PM_{10}[e], NO_2, O_3 (1 hr), SO_2, CO
Park et al 2002 Seoul	School absence	Illness-related school absence	—	Children	PM_{10}[f], NO_2, O_3 (8 hr), SO_2, CO
Thailand					
Ostro et al 1999 Bangkok	Mortality	All cause, cardiovascular, all respiratory	< 800, 390–459, 460–519	All, < 6, 6–49, 50+	PM_{10}[f]

[a] ICD = *International Classification of Diseases* (World Health Organization). – = ICD codes not provided.

[b] Hours given in parentheses after O_3 listings are averaging times.

[c] Measured by gravimetric method.

[d] Measured by TEOM method.

[e] Measurement method not described.

[f] Measured by β-ray absorption.

Table 14. Epidemiologic Time-Series Studies Excluded from the Meta-Analysis

Excluded Study	Location	Reason for Exclusion
Aditama 2000	Indonesia	Episode study[a]
Bladen 1983	Bombay, India	Only correlation coefficient estimates presented
Chang et al 2003a	Beijing, China	Study came to our attention too late to be included
Chang et al 2003b	Beijing, China	Study came to our attention too late to be included
Dong et al 1996	Beijing, China	Data for < 1 year
Emmanuel 2000	Singapore	Episode study[a]
Hedley et al 2002	Hong Kong, China	Monthly, not daily, mortality rate
Knöbel et al 1995	Taipei,China	Insufficient information for calculating regression estimates of percent change in daily rates
Pande et al 2002	Delhi, India	Insufficient information for calculating regression estimates of percent change in daily rates
Piver et al 1999	Japan	Summer season (July–August) only
Sastry 2002	Multiple cities, Malaysia	Episode study[a]
Sawaguchi et al 1997	47 prefectures, Japan	Insufficient information for calculating regression estimates of percent change in daily rates
Shimizu et al 2001	Yokohama, Japan	Insufficient information for calculating regression estimates of percent change in daily rates
Tan et al 2000	Singapore	Episode study[a]
Tanaka et al 1998	Japan	Insufficient information for calculating regression estimates of percent change in daily rates
Tseng and Li 1990	Hong Kong, China	Seasonal, not daily, asthma rates
Tseng et al 1992	Hong Kong, China	Quarterly, not daily, asthma rates

[a] Episode studies were excluded because they focus on air pollution episodes, not daily exposure to air pollution.

included in multipollutant models frequently differ among studies; therefore their results are more difficult to compare. However, when only results from multipollutant models were given, the results from the model with the most pollutants were selected and recorded. This act simplified the abstraction of data from papers in which many combinations of pollutants were examined.

Using this approach, we identified selected lags from the results presented in the papers. If only one lagged estimate was presented (either because only one was analyzed or only one was reported in the paper), this estimate was recorded in the Access database for the outcome–pollutant pair. If more than one lag measure was presented, we selected one for meta-analysis according to the following algorithm:

1. The lag that the author focused on or stated a priori,
2. The lag that was the most statistically significant (positive or negative), or
3. The lag with the largest effect estimate (positive or negative).

Results for lag 0 and lag 1 were also recorded (if different than results for the selected lag). When available, results for a cumulative lag (mean of pollution measures over two or more days) chosen by the same selection criteria were also recorded.

In order to assess the sensitivity of the findings to our selection approaches, we examined in more detail those papers that provided estimates for the effects of TSP, SO_2, and PM_{10} on all-cause mortality. These studies were selected because they provided the greatest number of estimates. We recorded the lag selected for meta-analysis, whether it was selected by authors or by us, the range of lags studied, and the range of lags reported in the papers. We anticipated conducting an alternative meta-analysis using an a priori lag selection (lag 0 or lag 1) to compare results with those obtained using the selected lag.

For TSP, four studies provided data (Table 15); all results were author selected. Although other lags were analyzed by the investigators, no other results were quoted. For SO_2, 10 studies provided estimates. Five of the

Table 15. Details of Models Fit for TSP in the 28 Time-Series Studies: Lagged and Multipollutant Models[a]

Study Citation, Location	Selected Lag	Selected By	Other Lags Analyzed by Authors	Other Lags Reported by Authors	Comments	Multipollutant Models
Xu et al 1994[b] Beijing	Unreported	Authors	Unreported	NA[c]	No indication that other lags were considered	See Table 16
Xu et al 2000 Shenyang	Mean of 0,1,2,3	Authors	Yes but not specified	None	0–3 selected by authors on basis of "biological plausibility and significance of effect"	See Table 16
Cropper et al 1997 Delhi	2	Authors	0,1,2,3	None	Other lags may also have been analyzed (not clear from text)	TSP and SO_2 analyzed jointly. Only results for TSP given from these models. No quantitative results for SO_2 reported as negative associations for most mortality endpoints
Lee et al 2000 7 Korean Cities	Mean of 0,1	Authors	0,1,2,3,4 plus various unspecified combinations (means)	None	Mean of 0,1 selected by authors on basis of "preliminary explorations"	See Table 16

[a] Meta-analysis includes only single-pollutant models.

[b] Authors analyzed ln(TSP).

[c] Not applicable.

ten did not report other results, although four of these five analyzed other lags (Table 16). Three studies analyzed and presented results for more than one lag. In two of the three studies, we chose the selected lag. For PM_{10} and all-cause mortality all selected results were author selected and in two of the five studies providing data results from other lags were presented (Table 17).

We concluded from our review of these studies that the data in the published papers were insufficient for conducting extensive sensitivity analyses of our approach to lag selection. We considered the procedure that we adopted to select lags for the quantitative meta-analysis the best available, considering both the need to obtain an estimate from each study and to use estimates that are likely to fit the model best.

Tables 15 through 17 also summarize the multipollutant models reported in these papers. Some studies did not analyze multipollutant models; others conducted series of two-pollutant models, often with the purpose of assessing the robustness of the pollutant of interest to the inclusion of other pollutants into the models. In most cases, reporting of results from multipollutant models was limited. This limitation precluded undertaking a detailed meta-analytic assessment of the results of single-pollutant versus multipollutant models.

Multicity Studies

Several studies presented meta-analyses of results from multiple locations together with summary estimates. If such studies used previously published data, we recorded only the summary estimates. If previously unpublished city-specific results were presented, we recorded those as well as summary estimates.

META-ANALYSIS METHODS

Multiple Studies of a Single City

A number of studies were conducted in the same city, with varying degrees of overlap in the years studied. Some studies were by the same investigators; others were not.

Table 16. Details of Models Fit for SO_2 in the 28 Time-Series Studies: Lagged and Multipollutant Models[a]

Study Citation, Location	Selected Lag	Selected By	Other Lags Analyzed by Authors	Other Lags Reported by Authors	Comments	Multipollutant Models
Lee et al 2000 7 Korean cities	Mean of 0,1	Authors	0,1,2,3,4 plus various unspecified combinations (means)	None	Mean of 0,1 selected by authors on basis of "preliminary explorations"	Model with SO_2, TSP, & O_3 fitted. Results for all three presented
Wong et al 2001b Hong Kong	1	Authors	0,1,2,3	None	Authors selected lag on basis of modified version of AIC. Some comment on pattern of results across lags	Pairs of pollutants analyzed (NO_2, SO_2, PM_{10} & O_3). Estimates for each pollutant given after "adjustment for copollutant giving the least significant effect"
Kwon et al 2001 Seoul	Unreported	Authors	Unreported	NA[b]		Series of two-pollutant models analyzed (PM_{10}, CO, NO_2, SO_2, & O_3). Full set of results from these models given
Venners et al 2003 Chongqing	2	Reviewers	0,1,2,3,4,5	0,1,3,4,5	Authors highlighted lags 2 & 3 in text and in separate table. We selected lag 2 on basis of magnitude of *t* statistic	SO_2 and $PM_{2.5}$ models analyzed. Results for SO_2 from two-pollutant models given for respiratory and cardiovascular mortality
Hong et al 1999a Inchon	0–4	Authors	0,1,2,3,4,5,6 + multiple-day means	None		Series of two-pollutant models for PM_{10} and one of NO_2, SO_2, O_3, and CO. Results described as significant or not but no estimates given
Xu et al 2000 Shenyang	Mean of 0,1,2,3	Authors	Yes but not specified	None	0–3 selected by authors on basis of "biological plausibility and significance of effect"	TSP and SO_2 analyzed. Estimated effects for both pollutants presented
Hong et al 1999b Inchon	1	Reviewers	0,1,2,3,4,5,6 + multiple-day averages	0–4	Lag 1 chosen because single-day lags are preferred in protocol (to averages)	PM_{10} and one of NO_2, SO_2, O_3, and CO and a single model with all pollutants. Results quoted for model with all pollutants
Lee et al 1999 Seoul, Ulsan	0–2	Authors	0,1,2,3 + 3-day multiple means	0–2	3-day mean "resulted in highest relationship with mortality"	TSP, SO_2, & O_3 modeled as multipollutant model. TSP was not significant; it was then excluded from the multipollutant model and a two-pollutant model of SO_2 and O_3 fitted. Results for both pollutants are given
Xu et al 1994 Beijing	Unreported	Authors	Unreported	NA[b]	No indication that other lags were considered	TSP and SO_2 analyzed jointly using quintiles of the pollutant distributions. Results presented in a figure
Gao et al 1993 Beijing	0	Authors	None	None		Only single-pollutant model results reported

[a] Meta-analysis includes only single-pollutant models.

[b] Not applicable.

[c] Authors analyzed $\ln(SO_2)$.

Table 17. Details of Models Fit for PM_{10} in the 28 Time-Series Studies: Lagged and Multipollutant Models[a]

Study Citation. Location	Selected Lag	Selected By	Other Lags Analyzed by Authors	Other Lags Reported by Authors	Comments	Multipollutant Models
Wong et al 2001b Hong Kong	1	Authors	0,1,2,3	None	Authors selected lag on basis of modified version of AIC. Some comment on pattern of results across lags	See Table 16
Ostro et al 1999 Bangkok	3	Authors	0,1,2,3, 3-day & 5-day moving mean	0,1,2, 3-day & 5-day mean	Lag 3 and 5-day average referred to; single day preferred to cumulative	None reported
Kwon et al 2001 Seoul	Unreported	Authors	Unreported	NA[b]		See Table 16
Hong et al 1999b Inchon	1	Reviewers	0,1,2,3,4, 5, 6 + multiple-day means	0–4	Authors quote 0–4 results in text and refer to significant lag 1 result. We chose lag 1 because single-day lags are preferred in protocol (to averages)	See Table 16
Hong et al 1999a Inchon	0–4	Authors	0,1,2,3,4, 5,6 + multiple-day means	None		Series of two-pollutant models for PM_{10} and 1 of NO_2, SO_2, O_3, and CO analyzed. Significance of results described but no estimates given

[a] Meta-analysis includes only single-pollutant models.

[b] Not applicable.

We recorded all results from all studies. However, when calculating summary estimates across cities, we used the most recent estimate for each city on the basis that it would be the most likely to reflect current analytic techniques and recent pollution levels. By not including several estimates from one city in the meta-analysis, we avoided weighting that city disproportionately at the cost of losing informative estimates. Because this approach is debatable, we compared the summary estimate it obtained for TSP and all-cause mortality with the summary estimate obtained by using all available results for the various cities.

Computation of Summary Estimates

For pollutant–outcome pairs for which there were four or more estimates, we computed summary estimates of the percent change and their 95% CIs using a fixed-effects model (with inverse variance weighting) and a random-effects model (using the method of DerSimonian and Laird [1986]). Both summary estimates are presented in forest plots. We tested the study-specific estimates for evidence of differences in result size or direction (heterogeneity) using the χ^2 test for heterogeneity. Because of the relatively low power of this test to detect such differences, we chose a P value of 0.2 to indicate evidence of heterogeneity.

Investigation of Publication Bias

The meta-analysis used results published in peer-reviewed journals. These may not represent all available evidence because some relevant reports may be published in other formats or not published at all. The lack of representation of

these reports could affect our findings: *publication bias* refers to the tendency for findings that support a particular hypothesis (in this case, that air pollution has an adverse effect) to be published preferentially in peer-reviewed journals (Sterling 1959; Mahoney 1977; Simes 1986; Begg and Berlin 1989; Dickersin 1997). Publication bias can have two consequences. First, it could lead to a false conclusion regarding the degree of support in the literature for an association between air pollution and a health outcome. Second, the size of a true association could be estimated inaccurately.

Time-series studies of routine health data might be subject to publication bias for particular reasons. One is that the data are relatively cheap to obtain and analyze, so that authors (having invested relatively little effort to conduct the analysis) may be less inclined to publish findings thought to be uninteresting or to contradict the prevailing scientific consensus. Another reason is that the analytic techniques used in time-series studies affect the results to some extent; analysts may choose the techniques that give the results that they think are most plausible. Finally, as discussed above, time-series studies have the potential to generate a large number of results for various outcomes, pollutants, and lags; the author's prior beliefs may affect the choice of which results to present.

Until recently, little attention has been paid to this possible source of bias in the air pollution literature (Anderson et al 2004; Peacock et al 2004). Publication bias is mitigated in planned multicity studies (such as APHEA and NMMAPS) that commit to publishing results from all locations and that may adopt an a priori lag specification.

Methods of detecting publication bias exist, but they are not without problems. One method is the funnel plot, in which estimates are plotted against their standard error. If the data lack publication bias, the resulting scatter should be symmetric like a funnel (Light and Pillemer 1984). Apparent asymmetry in the funnel plot can be verified by regressing the estimates on the inverse of the standard error (Egger et al 1997).

We investigated the estimates for TSP and SO_2 and all-cause mortality for evidence of publication bias because these pollutants had sufficient estimates for a meaningful analysis (10 and 11 respectively). Tests for asymmetry (the Begg and Egger tests) were supplemented by funnel plots. Finally, a procedure known as *trim and fill* was applied to further assess asymmetry (Duval and Tweedie 2000). The trim-and-fill technique also adjusts for asymmetry and provides a revised meta-analysis estimate.

STATISTICAL METHODS OF ASIAN TIME-SERIES STUDIES

The statistical methods used in the 28 Asian daily time-series studies are essentially the same as the contemporary methods for regression analysis of longitudinal data used in the United States, Europe, and elsewhere. Many analyses in the selected studies were conducted in collaboration with researchers from (or with research experience in) the United States or Europe. Many other analyses were based on protocols developed outside of Asia (eg, methods used in APHEA or APHEA 2).

Detailed review of the 28 studies indicates that all but a few used Poisson regression analysis. Approximately half of those utilized generalized additive models (GAMs) to estimate associations of health effects with air pollution (while controlling for long-term time trends, seasonality, and weather variables using flexible nonparametric smoothing). Under certain conditions, this modeling approach may understate statistical uncertainty and provide possibly biased estimates of pollution effects (Health Effects Institute 2003).

Several factors suggest that estimation bias from the use of GAMs in these studies is small, however. First, the problem of estimation bias is greater for models with large numbers of smooth functions that are highly flexible (having many degrees of freedom). The 28 studies generally included only a few smooth functions with fewer degrees of freedom. Second, results from the studies that used GAMs were similar to those reported in the studies that used alternative fully parametric Poisson regression models. Third, one study (Kwon et al 2001) employed a case-crossover analysis in addition to the GAM Poisson regression approach; both analyses yielded similar estimates of pollution effects. For these Asian studies as well as for recent studies in the United States and western Europe (Health Effects Institute 2003), however, additional analysis using alternative modeling approaches is needed to fully address the extent of estimation bias.

Regarding other modeling choices, the 28 studies were not unique. Those using GAMs typically used nonparametric smoothing of time, temperature, and humidity to control for long-term time trends, seasonality, and weather. Other studies controlled for seasonality and weather through various alternative parametric approaches (trigonometric functions of time, temperature, and humidity; seasonal dummy variables and quintile dummies for temperature and humidity; or simple linear functions of temperature and humidity and stratification by season).

Nearly all 28 studies evaluated lag structure by simply including concurrent-day pollution, various single-day lags, or lagged moving averages and by selecting lags on

the basis of statistical significance. Similarly, multiple pollutants were nearly always evaluated by comparing effect estimates across various single-pollutant models or by adding pollutants into the models.

The 28 Asian time-series studies have two main methodologic limitations, however. First, in most of them, only very limited sensitivity analysis was conducted (or reported). Second, as with most studies worldwide, the time-series studies from Asia mostly used data from a single city or a few neighboring cities. A well-designed multicity study of representative Asian cities is lacking. This lack limits opportunities to more rigorously explore effect modification of copollutants, the shape of exposure–response functions, and longer lag structures and the extent of harvesting.

RESULTS

Study Characteristics

Geographic Distribution Most of the selected daily time-series studies were conducted in South Korea (11), followed by mainland China (6) and Hong Kong (6). India, Japan, Singapore, Taipei,China, and Thailand each contributed one study. All 28 studies are summarized in Table 13 (and Appendices A–H, where they are listed in bold type).

Health Outcomes A range of health outcomes were studied. We grouped them into three broad categories: mortality, hospital admissions, and community care (Table 18). Among studies of mortality, the most common outcome (13 studies) was mortality from all causes (excluding accidents), followed by mortality from all respiratory disease (7) and cardiovascular disease (8). A smaller group of mortality studies examined more specific causes of cardiovascular and respiratory mortality, such as stroke and COPD.

Studies of hospital admissions (including emergency room admissions but not visits) covered a range of respiratory and cardiovascular diagnoses, the most common single diagnosis being asthma (4 studies) and IHD (3).

Studies of community care were fewer; outcomes in those studies included emergency transport (1 study), emergency room visit (1), primary care consultation (2) and school absence (1).

The various age groups studied are listed in Table 19. Mortality studies tended to include either people of all ages (21 studies) or people 65 years and older (8), the group in which most deaths occur. However, in some Asian countries and cities infant mortality is substantial. In some of these locations, researchers have been able to study the association between air pollution and mortality in infants and children. Hospital admissions tend to be subdivided by age to reflect the relative importance of admissions in younger age groups and the fact that some conditions (such as asthma) differ clinically between young and older patients.

Pollutants Most pollutants studied in North America and Europe were represented in the 28 selected studies, with the exception of black smoke (which is measured using reflectance and is measured almost exclusively in Europe). For the other pollutants, the number of studies reporting data was: SO_2 (24), O_3 (19), NO_2 (16), PM_{10} (15), TSP (11), and CO (11) (Table 13). Only one study reported $PM_{2.5}$ data (measured gravimetrically). Some studies reporting PM_{10} data did not give the method of measurement, but those that did cited β-ray absorption or tapered element oscillating microbalance (TEOM) methods, not gravimetric methods. Averaging times for O_3 varied: 24-hour and maximum 8-hour and 1-hour running means were used.

Figure 17 presents long-term average levels of daily mean PM and gaseous pollutant concentrations reported in the 28 time-series studies. Most studies used data from the late 1980s through the mid 1990s and reported annual average levels. Two studies reported seasonal average concentrations as well (Wong et al 2001a,b). Some studies (conducted in multiple cities) reported the long-term average levels averaged across cities (Lee et al 1999; Cho et al 2000). For PM_{10} and NO_2, the reported levels exceeded current guidelines (EPA 1997; WHO 1999). For other pollutants, notably SO_2, they did not (WHO 1999). Most of the Chinese studies were conducted in the early 1990s when SO_2 and TSP levels (due largely to coal combustion) were high. These levels have declined since 1998 (China State Environmental Protection Administration 2002). O_3 was only studied in the relatively more developed cities (ie, Hong Kong, South Korean cities, and Taipei,China).

Effect Estimates

Effect estimates for the main pollutant–outcome pairs from the 28 time-series studies are summarized in forest plots (Figures 18–45). The estimates are presented as the percent change in the mean number of daily deaths or hospital admissions per 10 $\mu g/m^3$ increase in mean pollutant level (or 1 mg/m^3 for CO) and the associated 95% CI, which indicates the precision of the estimate.

For each pollutant, estimates are plotted separately for daily all-cause mortality, daily respiratory mortality, daily cardiovascular mortality, daily respiratory hospital admissions, and (if available) daily cardiovascular hospital admissions. Within these broad groups, all diagnoses for

Table 18. Outcome and Diagnosis by Pollutant in 28 Asian Daily Time-Series Studies

Outcome/Diagnosis	Total Number of Studies	Number of Studies by Pollutant						
		TSP	PM_{10}	$PM_{2.5}$	SO_2	NO_2	CO	O_3
Mortality								
All cause	13	7	6	1	11	5	4	7
All respiratory	7	1	5		5	4	2	4
Bronchitis	1	1			1			
Cancers	3	2			3			
Cardiac	1	1			1			
Cardiovascular	8	3	5		6	4	2	4
Cerebrovascular	2		2		2	2	1	2
COPD	3	2	1		3	1		1
IHD	1		1		1	1		1
Pneumonia and influenza	1		1		1	1		1
Pulmonary	1	1			1			
Ischemic stroke	1	1			1	1	1	1
Hospital Admissions								
All respiratory	3	1	2		3	3	1	3
Asthma	4		4		4	2	1	3
Cardiac	1		1		1	1		1
Cardiovascular	2		1		1	1		2
Cerebrovascular	2		1		1	1		2
COPD	1		1		1	1		1
Dysrhythmias	1							1
Heart failure	2		1		1	1		2
IHD	3		2		2	2		3
Pneumonia	1		1		1	1		1
Community Care								
Emergency transport								
Acute MI	1		1		1	1	1	1
Angina pectoris	1		1		1	1	1	1
Asthma	1		1		1	1	1	1
Bronchitis	1		1		1	1	1	1
Chronic bronchitis	1		1		1	1	1	1
Heart failure	1		1		1	1	1	1
Hypertension	1		1		1	1	1	1
Pneumonia	1		1		1	1	1	1
Emergency room visit								
Asthma	1	1			1			1
Consultation with general practitioner								
Lower respiratory	1		1		1	1	1	1
Primary care								
All	1	1			1			
Internal medicine	1	1			1			
Nonsurgery	1	1			1			
Other	1	1			1			
Pediatrics	1	1			1			
Surgery	1	1			1			
School-related absences	1		1		1	1	1	1

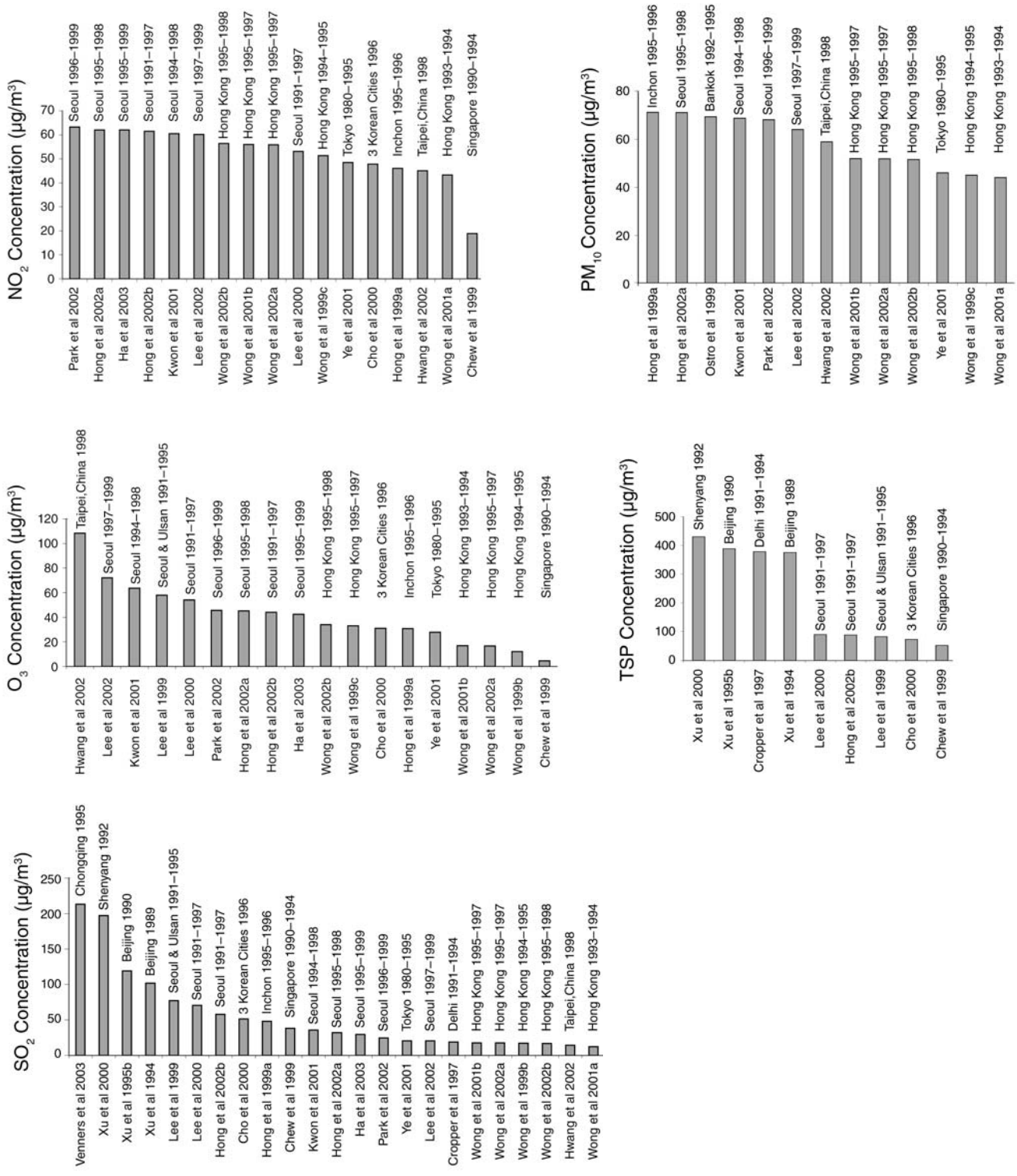


Figure 17. Reported annual average concentrations of ambient pollutants in Asian cities. Study citations are given on the x-axis; study locations and years during which data were collected are given above each bar.

Table 19. Age Classification in the 28 Asian Daily Time-Series Studies

Age Group (years)	Number of Studies
All Ages	
0+	21
Children	
Age not specified	2
0–1	1
0–4	2
0–5	1
0–14	3
3–12	1
5–14	1
Children Plus Adults	
2–64	1
5–64	1
6–49	1
0–64	1
15–44	1
15–64	2
45–64	1
Older Adults	
50+	1
65+	8

which estimates were available are plotted. Each estimate is labeled by first author name, study location, publication year, specific cause of death or admissions, age group (in years), and averaging time (for O_3).

Summary estimates are shown at the bottom of some of these figures. These estimates were calculated by random-effects and fixed-effects models when four or more studies provided estimates for individual pollutant–outcome pairs. They are discussed in the next section.

PM_{10} The method by which PM_{10} was measured is given in Table 13. The β-ray absorption method was used in Bangkok and most Seoul studies, the TEOM method in Hong Kong, the gravimetric method in Chongqing. Measurement methods were not reported in one Seoul study and the studies in Inchon, Taipei,China, and Tokyo.

Eleven estimates for PM_{10} and daily mortality were reported from four cities: Bangkok, Seoul, Inchon, and Hong Kong (Figure 18). All estimates indicated increased risk for mortality at all ages. Similar findings were observed for analyses restricted to age groups of 50+ and 65+ years. Two estimates were for children alone; both estimated increased risk, but the Bangkok estimate was lower and less precise. Two studies included both children and adults (Bangkok 6–49 years; Seoul, 2–64 years).

The ranking of estimates by age was inconsistent. In Bangkok, estimates for the three age groups analyzed (0–6, 6–49, 50+ years) did not differ greatly. In Seoul (Ha et al 2003), however, the highest estimate was for the 0–1 age group, followed by those for the 65+ and 2–64 age groups, which were similar.

Nine reports of daily respiratory deaths were available from the same four cities (Figure 19). All estimates indicated an increased risk. Two estimates for mortality from specific diagnoses (pneumonia and influenza, COPD) from Hong Kong were positive and also similar in size to estimates for mortality from all respiratory causes. One study (in Seoul) compared different age groups; estimates were much higher in the 0–1 year age group than the other groups.

The same four cities were the source of estimates of PM_{10} and daily cardiovascular deaths (Figure 20). Risk for all cardiovascular deaths from three cities was elevated; the estimates varied in size and precision. The two estimates from Hong Kong from different investigators were very similar, as were the two estimates for cerebrovascular deaths (Hong Kong and Seoul). Risk of mortality from IHD in Hong Kong was also elevated (1.3%; 95% CI 0.10,2.51).

Estimates for PM_{10} and respiratory hospital admissions were calculated for only two cities (Figure 21). Three separate studies in Hong Kong investigated the association between PM_{10} and respiratory hospital admissions for all respiratory diseases combined and for cause-specific admissions (asthma, COPD, and pneumonia). The only other city with a result for respiratory admissions was Seoul (asthma admissions). Each of the Hong Kong studies reported roughly the same increase in risk of hospital admissions for all respiratory causes.

Only two studies, both from Hong Kong, reported positive estimates in all cardiovascular hospital admissions per unit increase in PM_{10} (Figure 22).

$PM_{2.5}$ Only one small study (Venners et al 2003) reported estimates for $PM_{2.5}$ and daily mortality. The study included data for only a single year. It was conducted in Chongqing, China, where the mean ambient concentration of $PM_{2.5}$ during the study period was 147 μg/m^3 (measured gravimetrically). Results were reported for both $PM_{2.5}$ and SO_2, measured for 213 and 365 days, respectively. The authors observed no association of $PM_{2.5}$ levels at any lag (0–5 days) with all-cause mortality (relative risk for lag 1 = 0.98 per 100 μg/m^3 [95% CI 0.91,1.04]). SO_2 was, however, associated with an increased risk of all-cause mortality relative risk for lag 1 = 1.03 per 100 μg/m^3 [95% CI 0.0.98,1.08]).

Figure 18. PM_{10} and All-Cause Mortality

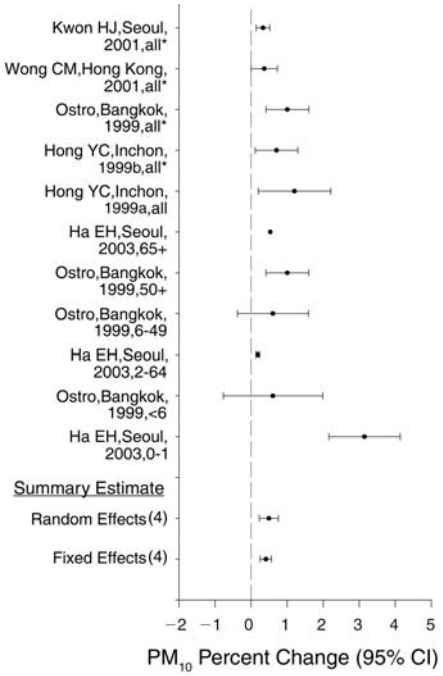


Figure 19. PM_{10} and Respiratory Mortality

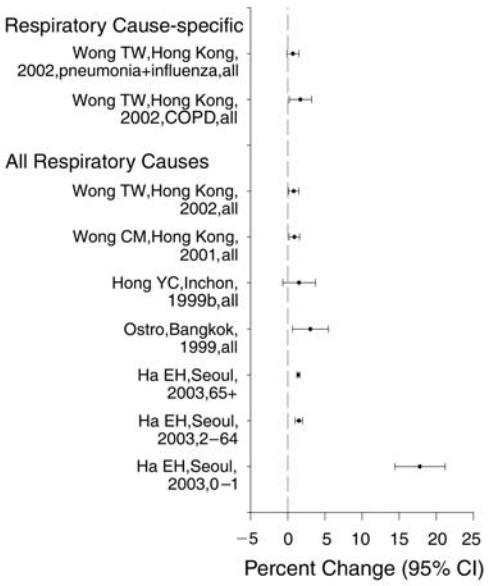


Figure 20. PM_{10} and Cardiovascular Mortality

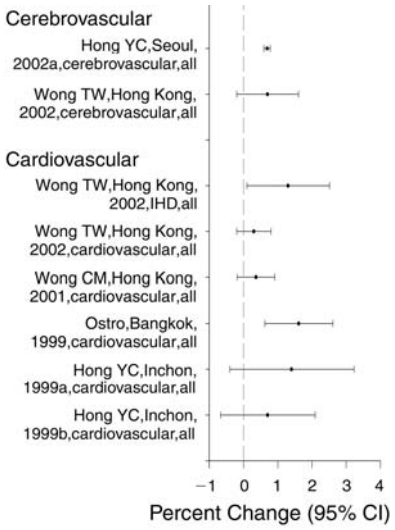


Figure 21. PM_{10} and Respiratory Hospital Admissions

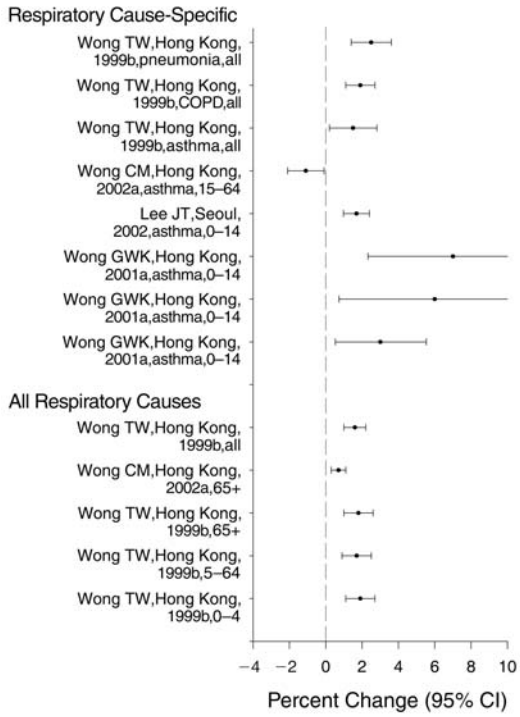
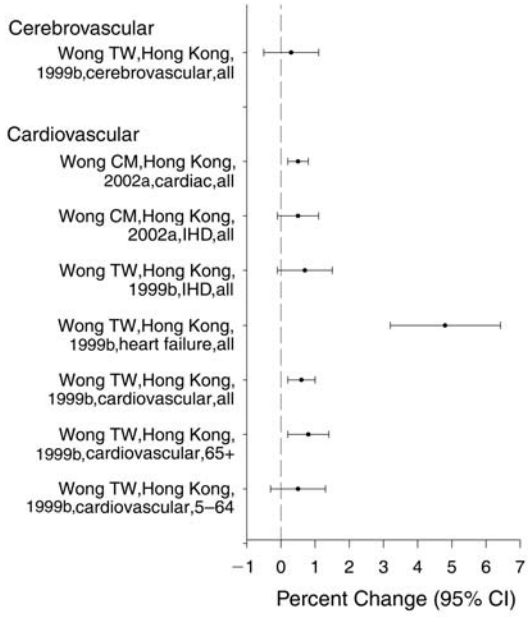


Figure 22. PM_{10} and Cardiovascular Hospital Admissions



Figures 18–22. Percent change in mean number of daily deaths or hospital admissions per 10 µg/m³ increase in 24-hour mean PM_{10} level. Note differences among x-axis scales. Y-axis labels give study information in the following sequence (as needed): first author name, study location, publication year, specific cause of death or admission, and age group (years). * Included in calculation of summary estimates.

TSP We identified 21 estimates for TSP and all-cause mortality from 10 cities (Figure 23). Most were positive but measured with poor precision. For Delhi and one Beijing study (Gao et al 1993), the data were divided by age group. The age-specific relative risks in Delhi appeared to be increased to the approximately the same degree, although the effects in the 5–65 age group were not estimated as precisely as in the youngest (0–4) and oldest (65+) age groups. The increase in mortality for the youngest (0–4) age group was slightly higher than that in the oldest (65+) age group. (A similar pattern was observed for PM_{10} and all-cause mortality in Seoul.) In the Beijing study, risk of mortality was increased only for people 65 years or older. The estimate for people younger than 65 years was negative but was estimated imprecisely.

Five estimates for a range of respiratory mortality subgroups were reported from three cities (Figure 24). All estimates were positive (approximately 0.5% to 2%). The studies are too few to infer differences among diagnoses.

Most reported estimates for cardiovascular mortality were similarly positive (Figure 25). The estimates range from about 0.3% to 2% with varying degrees of precision. The study in Beijing estimated no change in risk.

Three studies provided estimates of increased risk of hospital admissions for respiratory causes, all approximately 0.3% (Figure 26). No results were reported for TSP and cardiovascular hospital admissions.

Figure 23. TSP and All-Cause Mortality

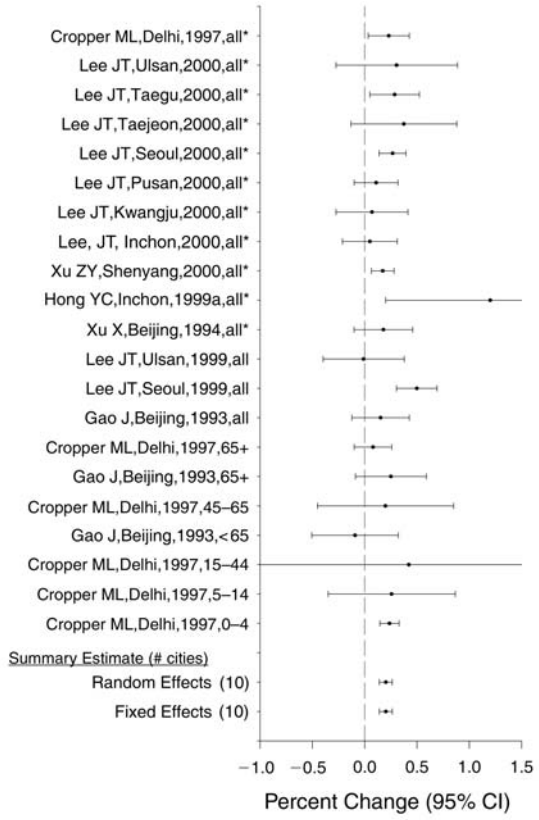


Figure 24. TSP and Respiratory Mortality

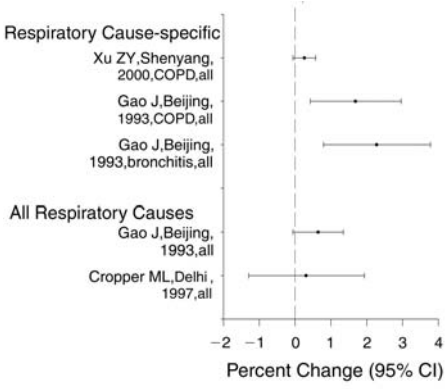


Figure 25. TSP and Cardiovascular Mortality

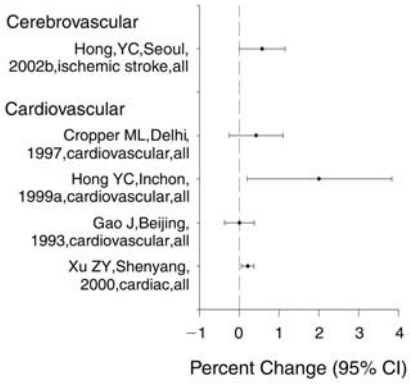
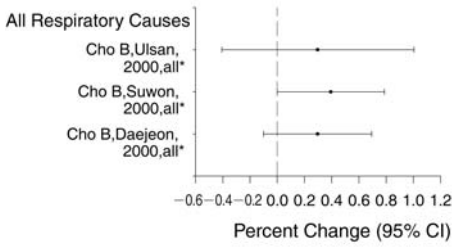


Figure 26. TSP and Respiratory Hospital Admissions



Figures 23–26. Percent change in mean number of daily deaths or hospital admissions per 10 µg/m³ increase in 24-hour mean TSP level. Note differences among x-axis scales. Y-axis labels give study information in the following sequence (as needed): first author name, study location, publication year, specific cause of death or admission, and age group (years). * Included in calculation of summary estimates.

NO_2 All studies of NO_2 used a 24-hour averaging time. Seven estimates were reported for NO_2 and mortality from three cities: all were positive with varying degrees of precision (Figure 27). The studies of mortality at all ages estimate 1% to 2% increases in daily mortality, with the Hong Kong and Seoul studies providing lower but more precise estimates than those for Inchon. One study from Seoul (Ha et al 2003) reported age-specific relative risks: the highest risk was in the 65+ age group followed by the 2–64 age group. The 0–1 age group showed little evidence of increased mortality, although the estimate was imprecise.

Eight estimates for NO_2 and respiratory mortality were reported from three cities (Figure 28). All estimates were positive except an extremely imprecise estimate for the 0–1 age group from Seoul. In Hong Kong, estimates for all-ages respiratory mortality were similar in studies by two different sets of investigators. In addition, the relative risks for some diagnostic subgroups (pneumonia and influenza, COPD) were similar to the estimates for all respiratory causes.

The same three cities yielded a total of seven estimates for cardiovascular mortality or subgroups thereof (Figure 29). For all cardiovascular causes the risks were elevated in both Hong Kong and Inchon to roughly the same extent, but the Inchon estimates were quite imprecise. The results for cerebrovascular mortality differed: risk was increased in Seoul but not in Hong Kong.

Figure 27. NO_2 and All-Cause Mortality

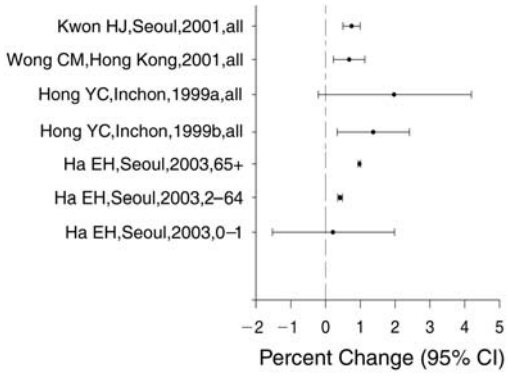


Figure 28. NO_2 and Respiratory Mortality

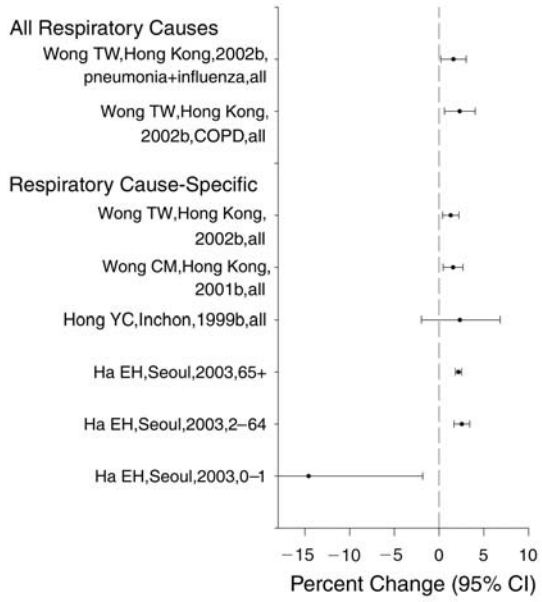
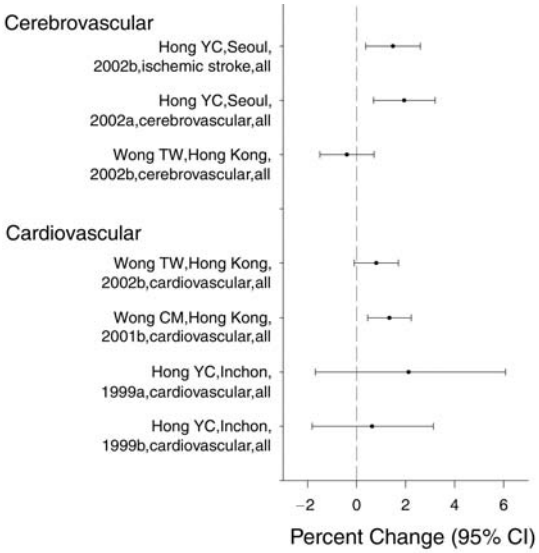


Figure 29. NO_2 and Cardiovascular Mortality



Figures 27–31. Percent change in mean number of daily deaths or hospital admissions per 10 µg/m^3 increase in 24-hour mean NO_2 level. Note differences among x-axis scales. Y-axis labels give study information in the following sequence (as needed): first author name, study location, publication year, specific cause of death or admission, and age group (years). (*Continued*)

Figure 30. NO_2 and Respiratory Hospital Admissions

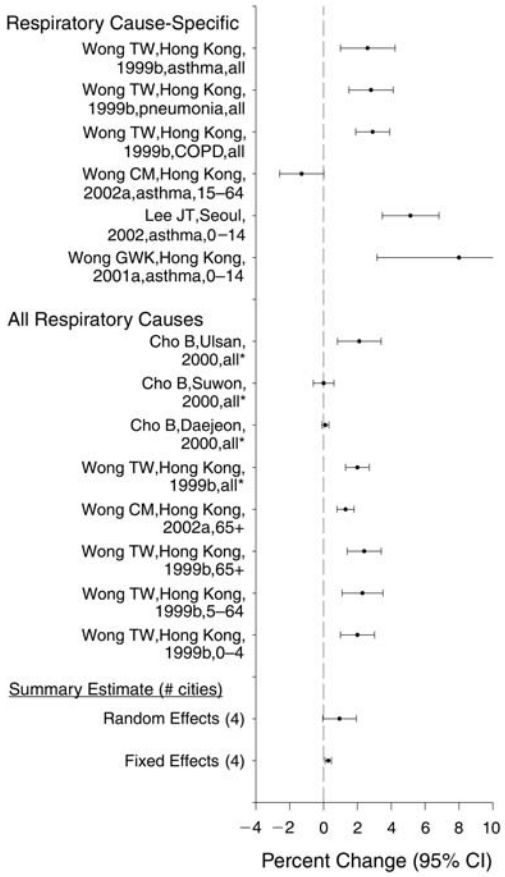
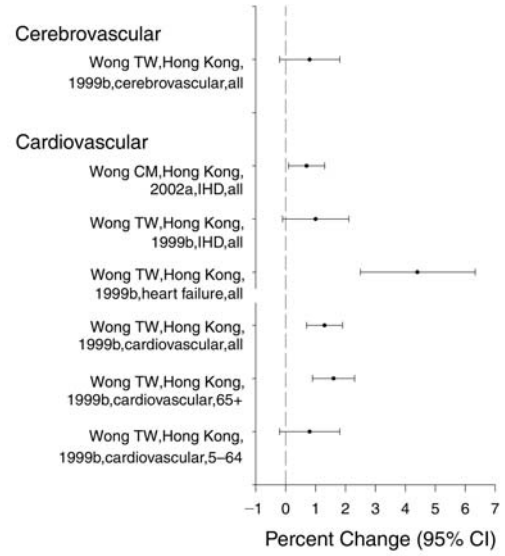


Figure 31. NO_2 and Cardiovascular Hospital Admissions



Figures 27–31 (*continued*). Percent change in mean number of daily deaths or hospital admissions per 10 µg/m³ increase in 24-hour mean NO_2 level. Note differences among x-axis scales. Y-axis labels give study information in the following sequence (as needed): first author name, study location, publication year, specific cause of death or admission, and age group (years).

Fourteen estimates were available for NO_2 and respiratory admissions, but all were from multiple studies of a variety of diagnosis and age subgroups in Hong Kong and four cities in South Korea (Figure 30). Of the four estimates for all respiratory diagnoses for all ages, estimates for Hong Kong and Ulsan were positive whereas those for Suwon and Daejeon were not. In Hong Kong, all age-specific estimates (0–4, 5–64, 65+ years) for all respiratory causes were positive and of similar size, as were the all-ages estimates for various subdiagnoses (asthma, pneumonia, COPD). The Hong Kong study estimated increased risk of asthma admissions in people of 0–14 years but not 15–64 years.

Seven estimates for NO_2 and cardiovascular admissions were available, all from Hong Kong (Figure 31). All were positive. The results for IHD from two different studies were similar. For one study (Wong et al 1999b), diagnostic subgroups could be compared: estimates for cerebrovascular and IHD were similar, but the estimate for heart failure was much higher.

O_3 A total of 19 studies reported results for year-round O_3 but variation in the averaging times used complicated our meta-analysis. Six studies used 1 hour, nine studies used 8 hours, three studies used 24 hours, and one did not specify averaging time (Table 13). Concentrations for 1-hour, 8-hour, and 24-hour averaging times are usually closely correlated, which means that any of the three could be used when investigating an association with adverse health effects. But simply combining studies that differed in their averaging time would not be appropriate for a quantitative meta-analysis. We were not sufficiently confident of the consistency of the relation among averaging times across cities to adjust for comparability.

Results for all-cause mortality were available for Hong Kong and a number of South Korean cities (Figure 32) on the basis of three different averaging times. The seven results for mortality at all ages differed, but the most precise South Korean studies and the Hong Kong study indicated little or no elevation in risk. One estimate from a meta-analysis of seven South Korean cities estimated no increased risk for year-round daily exposure (Lee et al 2000). In one study, estimates for three age groups were presented (Ha et al 2003); adults older than 65 years were at increased risk, although people aged 2–64 years were not.

Eight results for respiratory mortality and O_3 were available for Hong Kong, Inchon, and Seoul (Figure 33). Most estimates for all respiratory causes were 1% to 3%. For cardiovascular mortality, eight results were available from the same cities (Figure 34). Two studies from Hong Kong (Wong et al 2002b; Wong et al 2001b) found no increased risk for all cardiovascular causes, but one (Wong et al 2002b) found

increased risk of IHD mortality. No association with cerebrovascular mortality was reported for Hong Kong, but an increased risk was observed in Seoul.

Studies from Hong Kong and various South Korean cities provided 13 estimates for respiratory hospital admissions in various age groups (Figure 35). All estimates were positive, although the Hong Kong estimates (based on 8-hour averages) were almost twofold higher than most estimates from individual South Korean cities (calculated using 24-hour averages).

The only estimates for cardiovascular admissions were from two different investigations in Hong Kong using similar time series of hospital admissions data (Figure 36). Most results for cardiovascular causes, variously defined, indicated increased risk of hospital admissions. The two studies examined various subcategories of cardiovascular admissions; their estimates agreed reasonably well. Both found somewhat larger elevations in admission risk for heart failure than other subcategories. Neither found evidence of increased risk of admission for cerebrovascular disease.

Figure 32. O_3 and All-Cause Mortality

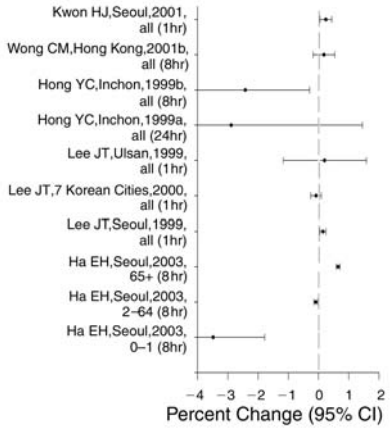


Figure 33. O_3 and Respiratory Mortality

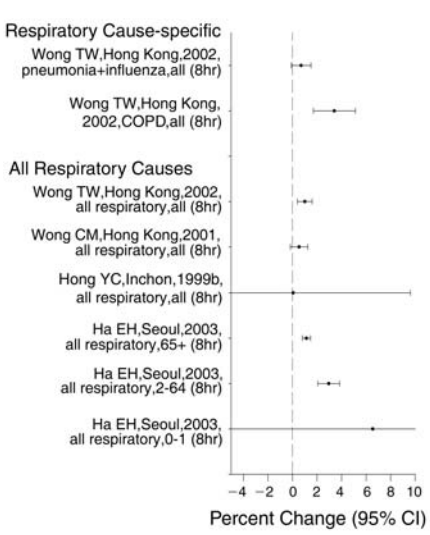


Figure 34. O_3 and Cardiovascular Mortality

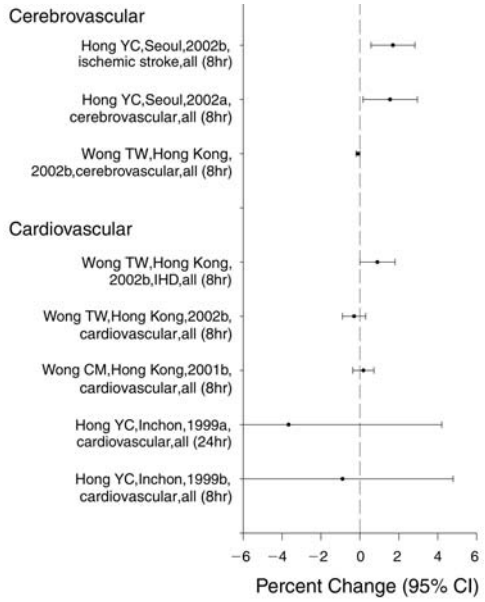


Figure 35. O_3 and Respiratory Hospital Admissions

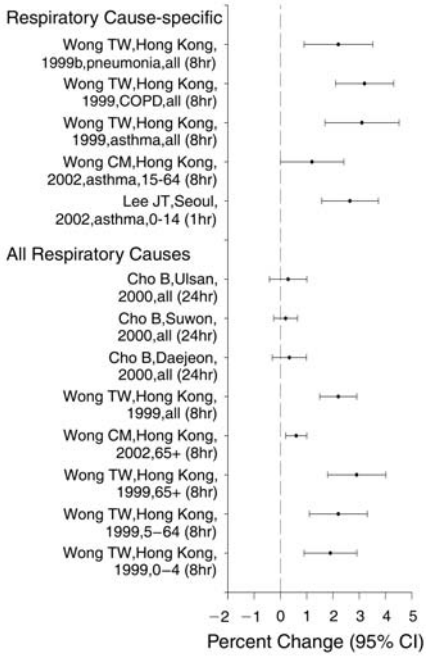
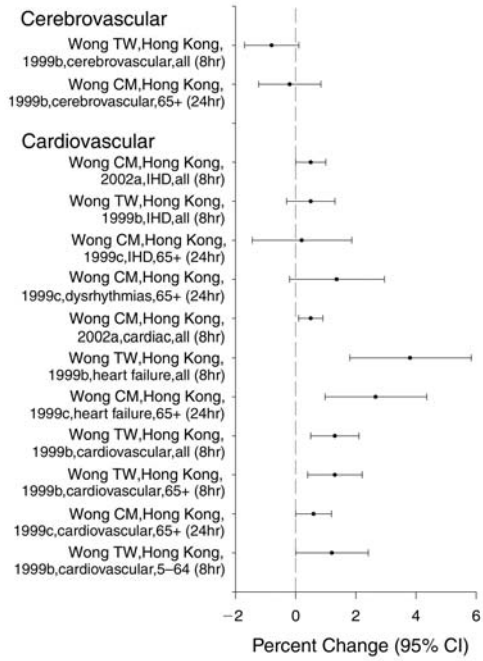


Figure 36. O_3 and Cardiovascular Hospital Admissions



Figures 32–36. Percent change in mean number of daily deaths or hospital admissions per 10 μg/m³ increase in 24-hour mean O_3 level. Note differences among x-axis scales. Y-axis labels give study information in the following sequence (as needed): first author name, study location, publication year, specific cause of death or admission, age group (years), and averaging time.

SO_2 We obtained 22 estimates of the effect of SO_2 on daily all-cause mortality from 12 cities (Figure 37). All but three were for people of all ages or 65 years or older. All but one indicated an increased risk with varying degrees of precision. The most precise estimates from mainland China, Hong Kong, and South Korea estimated increases of 1% or less. One study from Seoul reported relative risks by age (Ha et al 2003). The largest estimate was for the 0–1 age group; even the low end of its 95% CI (1.46) was high compared with other estimates.

A total of 13 estimates for respiratory mortality (including various subcategories like COPD and bronchitis) were available from six cities (Figure 38). Most were positive. Estimates for all respiratory causes were similar for mainland China, Hong Kong, and Seoul.

Figure 37. SO_2 and All-Cause Mortality

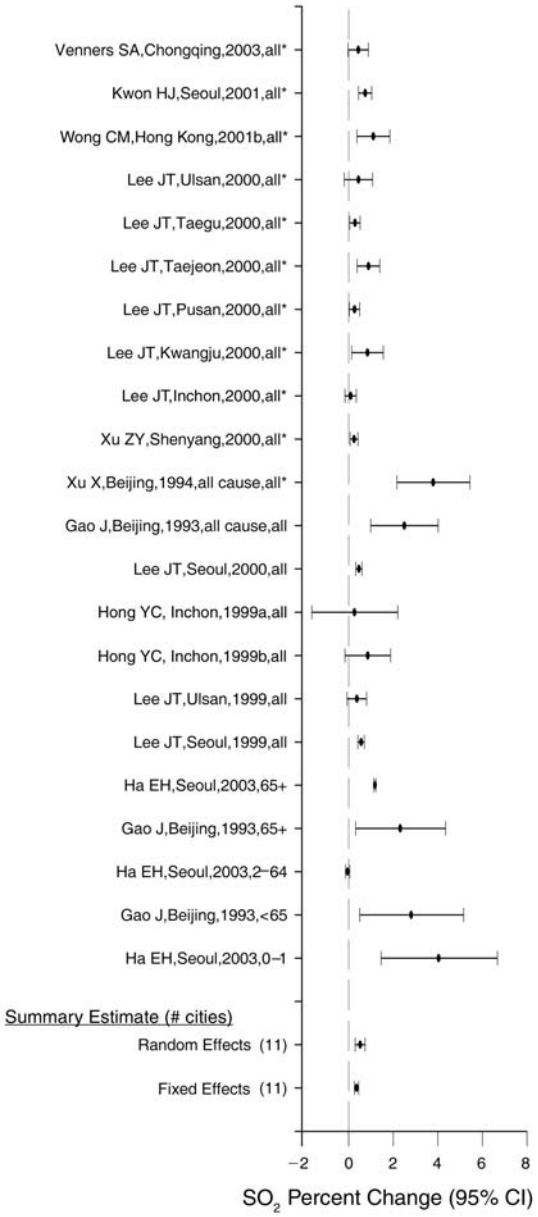
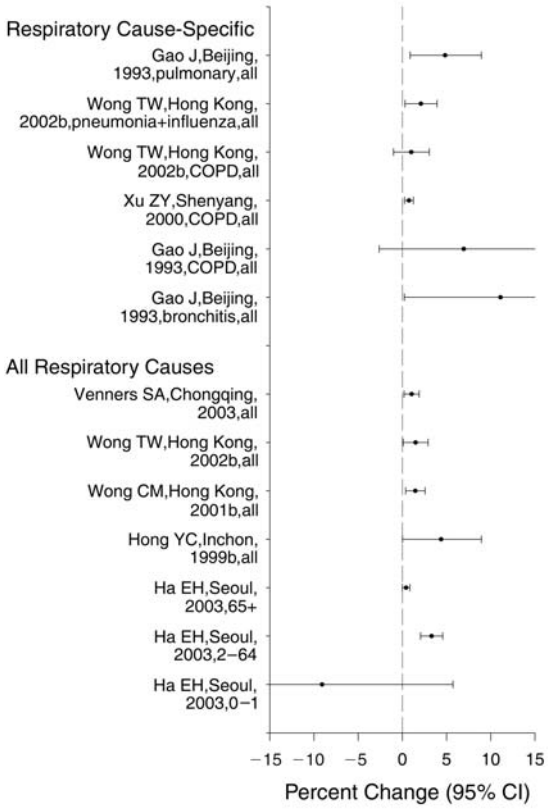


Figure 38. SO_2 and Respiratory Mortality



Figures 37–41. Percent change in mean number of daily deaths or hospital admissions per 10 µg/m³ increase in 24-hour mean SO_2 level. Note differences among x-axis scales. Y-axis labels give study information in the following sequence (as needed): first author name, study location, publication year, specific cause of death or admission, and age group (years). * Included in calculation of summary estimates.

Studies from six cities provided 11 estimates for cardiovascular mortality or various subdiagnoses (Figure 39). All estimates for all cardiovascular causes and IHD were positive; the most precise were approximately 2% (in both Hong Kong and Chongqing). As with NO_2, estimates for cerebrovascular deaths were positive in the two South Korean studies but not in Hong Kong (Wong et al 2002b).

There were 14 estimates for respiratory admissions from Hong Kong and four South Korean cities (Figure 40), 10 of which showed an increase in respiratory admissions associated with SO_2. Risk of admissions for all respiratory causes was elevated in Hong Kong but not in three South Korean cities, although asthma admissions in children 0–14 years were elevated in both Seoul and Hong Kong. Fewer estimates were available for cardiovascular admissions; all were from two Hong Kong studies (Figure 41). The studies estimated an approximate 2% increase in cardiovascular (Wong et al 1999b) and cardiac (Wong et al 2002a) admissions at all ages. Risk of cerebrovascular admissions were reduced.

Figure 39. SO_2 and Cardiovascular Mortality

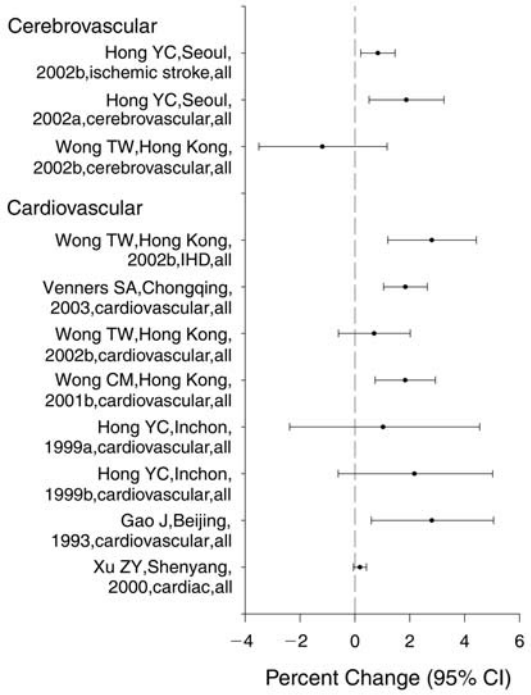


Figure 40. SO_2 and Respiratory Hospital Admissions

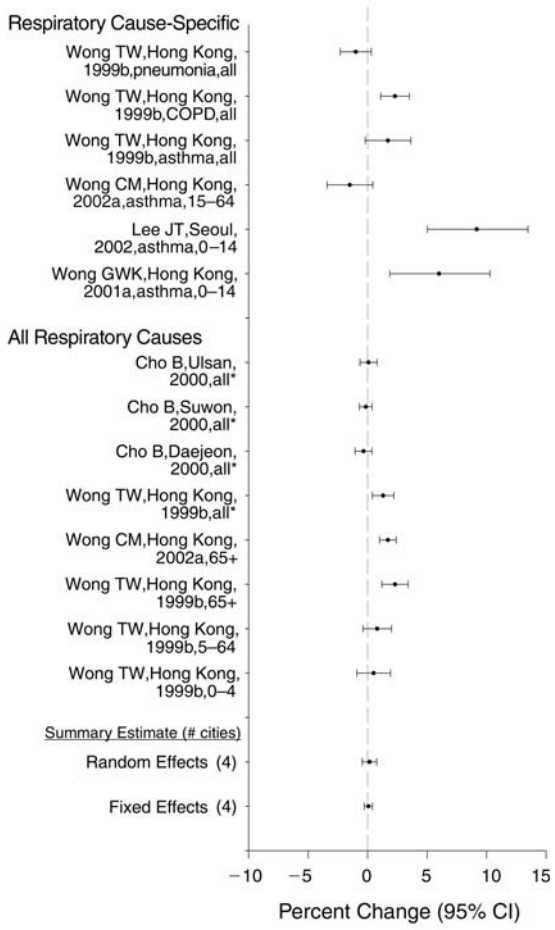


Figure 41. SO_2 and Cardiovascular Hospital Admissions

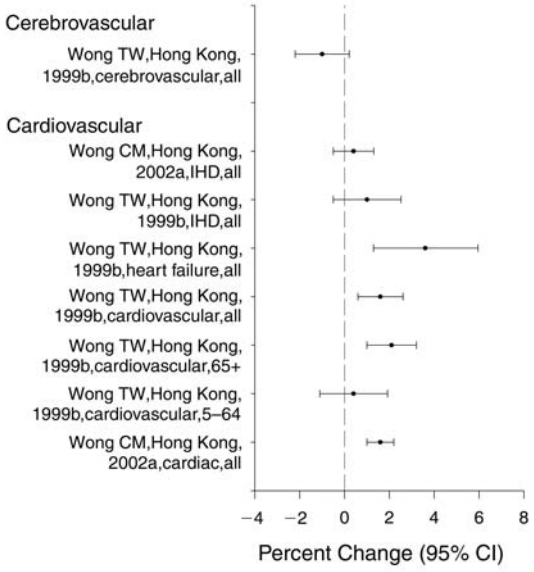


Figure 42. CO and All-Cause Mortality

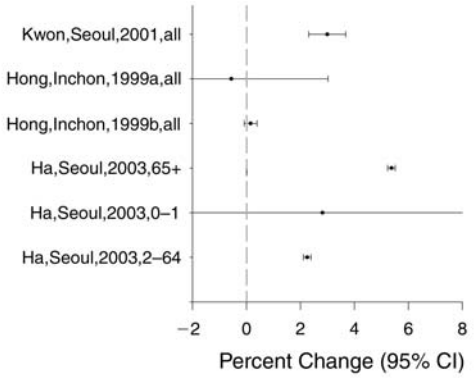


Figure 43. CO and Respiratory Mortality

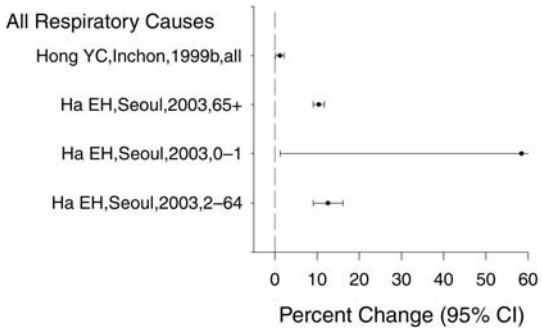


Figure 44. CO and Cardiovascular Mortality

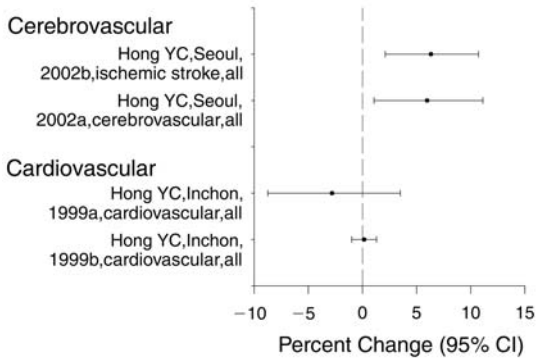
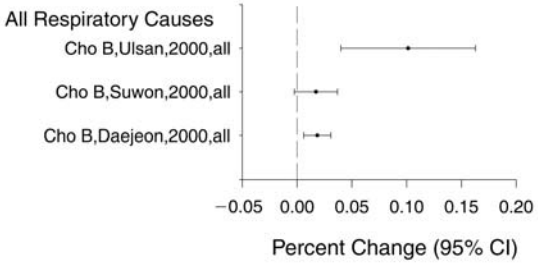


Figure 45. CO and Respiratory Hospital Admissions



Figures 42–45. Percent change in mean number of daily deaths or hospital admissions per 1 mg/m^3 increase in 24-hour mean CO level. Note differences among x-axis scales. Y-axis labels give study information in the following sequence (as needed): first author name, study location, publication year, specific cause of death or admission, and age group (years).

CO Only two cities in South Korea reported estimates for all-age, all-cause mortality (Figure 42). Increased risk of mortality was observed in both Seoul and in the largest study in Inchon, although the estimate for Seoul was much higher. In Seoul, the estimates were presented for three age groups. The largest increase was observed in the 65+ age group, but comparison with other age groups is limited because the individual estimates were imprecise. Even fewer estimates were available for respiratory and cardiovascular mortality. These were positive for all respiratory but not for all cardiovascular causes (Figures 43–44).

Studies in three South Korean cities provided varying estimates of increased risk of respiratory hospital admissions (Figure 45). No estimates were available for cardiovascular admissions and CO.

Summary Estimates

Summary estimates were calculated when four or more studies provided estimates for individual pollutant–outcome pairs. They are given in Table 20.

Mortality Only four estimates were available for the effect of exposure to PM_{10} on daily all-cause, all-age mortality in different cities. The fixed-effects and random-effects estimates (and 95% CIs) were 0.41% (0.25,0.56) and 0.49% (0.23,0.76) increase in risk of mortality for each 10 µg/m^3 of PM_{10}. Estimates for cause-specific mortality were too few to permit calculation of summary estimates.

In total, 14 results for TSP and all-cause mortality were available from 11 separate cities. Ten studies estimated the effect of exposure to TSP on daily all-cause, all-age mortality. The estimates show little evidence of heterogeneity when inspected visually (Figure 23) or tested statistically (χ^2 test; $P = 0.55$). The fixed-effects and random-effects summary estimates (per 10 µg/m^3) are equal: 0.20% (95% CI 0.14,0.26). The relatively symmetric distribution of study results and results of their analysis using the Begg test ($P = 0.53$) provide no evidence of publication bias. Estimates for cause-specific mortality were too few to permit calculation of summary estimates.

The 0.20% summary estimates were calculated from 10 individual estimates, one per city. One city, however, provided four estimates from which one (the most recent) was

Table 20. Summary of Estimates of Percent Change[a] in Health Outcomes[b]

Outcome	Pollutant	Number of Estimates	Heterogeneity[c]	Fixed-Effects Estimate (95% CI)	Random-Effects Estimate (95% CI)	Publication Bias Test[d]	Multicity Study Summary Estimates (95% CI)
All-Cause Mortality							
	PM_{10}	4	0.14	0.41 (0.25,0.56)	0.49 (0.23,0.76)		APHEA 2[e] 0.6 (0.4,0.8) NMMAPS[f] 0.41 (0.29,0.53)
	TSP	10	0.55	0.20 (0.14,0.26)	0.20 (0.14,0.26)	0.53	
	SO_2	11	< 0.001	0.35 (0.26,0.45)	0.52 (0.30,0.74)	0.03	APHEA 1[g] 0.40 (0.3,0.5)
Respiratory Admissions							
	NO_2	4	< 0.001	0.28 (0.09,0.47)	0.95 (−0.05,1.94)		
	SO_2	4	0.03	0.07 (−0.28,0.41)	0.16 (−0.46,0.77)		

[a] Per 10 μg/m^3 increase in ambient pollutant concentration.

[b] Calculated when four or more studies provided estimates for individual pollutant–outcome pairs.

[c] P value from χ^2 test. (P values < 0.05 were considered statistically significant.)

[d] P value from the Begg test. The test was not conducted for those pollutant–outcome pairs with too few estimates. (P values < 0.05 were considered statistically significant.)

[e] 29 European cities (Katsouyanni et al 2001).

[f] 90 US cities (Samet et al 2000b).

[g] 12 European cities (Katsouyanni et al 1997).

chosen. To test the sensitivity of the summary estimate to this approach, we compared it with a summary estimate calculated using all four individual estimates from that city. The latter calculation gave a random-effects summary estimate of 0.22% (95% CI 0.14,0.30) for a 10 μg/m^3 increase in TSP. The compared summary estimates are very similar. We thus concluded that using one estimate per city was sufficiently unbiased and that, furthermore, little precision is gained by using all estimates available per city.

Eleven studies estimated the effect of exposure to SO_2 on daily all-cause, all-age mortality (Figure 37). The estimates appear somewhat more heterogeneous than those for TSP; when tested statistically (χ^2 test; $P < 0.001$), they show evidence of heterogeneity. The random-effects summary estimate (per 10 μg/m^3) is 0.52% (95% CI 0.30,0.74). The asymmetric distribution of study results (Figure 46) and results of their analysis using the Begg test ($P = 0.06$) suggest that some degree of publication bias is present for studies of SO_2 and daily mortality. A similar analysis found no evidence of publication bias for the studies of TSP and daily mortality (Figure 47).

Hospital Admissions Four estimates of the effect of pollutants on respiratory admissions were available for SO_2 and NO_2. The NO_2 estimates were highly heterogeneous

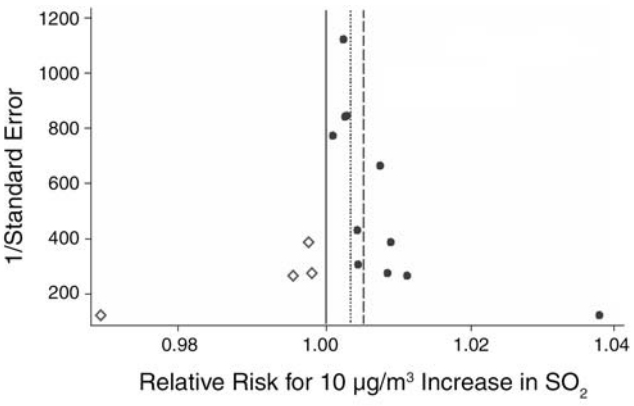


Figure 46. Analysis of publication bias in summary estimates of SO_2 and all-cause mortality. Circles are actual estimate data; diamonds are hypothetical results required to achieve symmetry. Solid line, at relative risk = 1.00, indicates no association. Long-dashed line shows the unadjusted summary estimate; short-dashed line shows the adjusted summary estimate.

(χ^2 test; $P < 0.001$), but the random-effects estimate of 0.95% (95% CI −0.05,1.94) was high but imprecise. The estimates for SO_2 were heterogeneous (χ^2 test; $P = 0.03$) and the random-effects estimate was 0.16% (95% CI −0.46,0.77).

Analysis of Publication Bias

No evidence of asymmetry was found for TSP. This result leads to the conclusion that the summary estimate for TSP is unlikely to be subject to publication bias. Evidence for asymmetry was found for SO_2, however. Both the parametric Egger test and the nonparametric, less powerful Begg test indicated asymmetry, as did the funnel plot (Figure 46). The trim-and-fill technique indicated that four more studies were required to make the funnel plot symmetric. The adjusted summary estimate (based on 15 studies) was 1.003 (95% CI 1.001,1.006), compared with the unadjusted summary estimate of 1.005 (95% CI 1.003,1.007).

This finding suggests the impact that publication bias can have on summary estimates, given the assumptions of the trim-and-fill analysis. The summary estimates may change, but the overall suggestion of a positive association between pollutant and health outcome will not. This conclusion is to some degree expected, given earlier discussions of this issue (Greenland 1998).

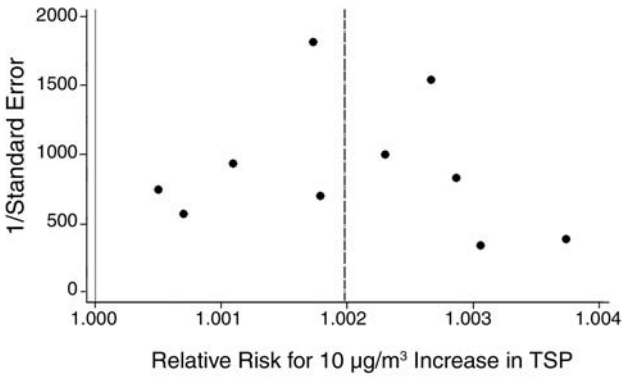


Figure 47. Analysis of publication bias in summary estimates of TSP and all-cause mortality. Circles are actual estimate data. Solid line, shown at relative risk = 1.000, indicates no association. Dashed line shows the unadjusted summary estimate.

SIZE OF ESTIMATES IN ASIAN STUDIES

In addition to summary estimates calculated as part of the meta-analysis, Table 20 reports some summary estimates from multicity studies carried out in Europe and the United States. Recent discoveries about statistical modeling have led to some revision of these estimates (Health Effects Institute 2003), but because the analysis methods used in the Asian studies are more similar to those used in the original multicity analyses, only the original multicity estimates are given.

For PM_{10} and daily all-cause mortality, the Asian random-effects estimate of 0.49% based on four cities is close to that of 0.6% found in the European study of 29 cities (Katsouyanni et al 2001) and that of 0.41% reported in the US study of the 90 largest cities (part of NMMAPS; Samet et al 2000b).

The estimate of 0.51% for SO_2 and daily all-cause mortality in 11 Asian cities is similar to the 0.40% reported in the APHEA study from 12 European cities (Katsouyanni et al 1997).

Studies that compare estimates from single-city studies are generally less persuasive than those that compare summary estimates, but one such study should be mentioned: a study of air pollution and daily hospital admissions in Hong Kong and London, in which investigators in each city collaborated to ensure an identical statistical approach (the APHEA 2 protocol) (Wong et al 2002a).

Wong and colleagues found similar annual mean levels of NO_2, O_3, and SO_2 in the two cities. In contrast, PM_{10} levels were almost twice as high in Hong Kong (52 µg/m^3) than in London (29 µg/m^3). O_3 levels were higher in the winter in Hong Kong and in the summer in London. This result might be explained the lower humidity in the cool season in Hong Kong and in the warm season in London.

Respiratory admissions among people 65 years and older were increased in both cities in association with daily levels of PM_{10}, NO_2, SO_2, and O_3. However, the single-day lag pattern (0–3 days) differed: associations tended to be present at earlier lags in Hong Kong and at later lags in London (Figure 48). These results illustrate that although associations were found in both cities, their comparison was sensitive to the choice of lag. The very different primary-care systems in Hong Kong and London might explain this sensitivity.

Positive associations were observed for cardiac admissions (of people of all ages) and mean levels of PM_{10}, NO_2, and SO_2. In contrast to the associations with respiratory admissions, however, the lag-specific patterns tended to be similar in both cities (Figure 49).

In Hong Kong, associations between respiratory admissions and each of the four pollutants studied tended to be robust to the inclusion of a second pollutant. Notable exceptions were the reduction in PM_{10} and SO_2 estimates when NO_2 was included in the analysis. This finding was not repeated in the London data. For cardiac admissions in Hong Kong, the addition of NO_2 and SO_2 to the models reduced the associations with PM_{10}, NO_2, and SO_2. O_3 was not associated with cardiac admissions. These results were largely replicated in the London analysis.

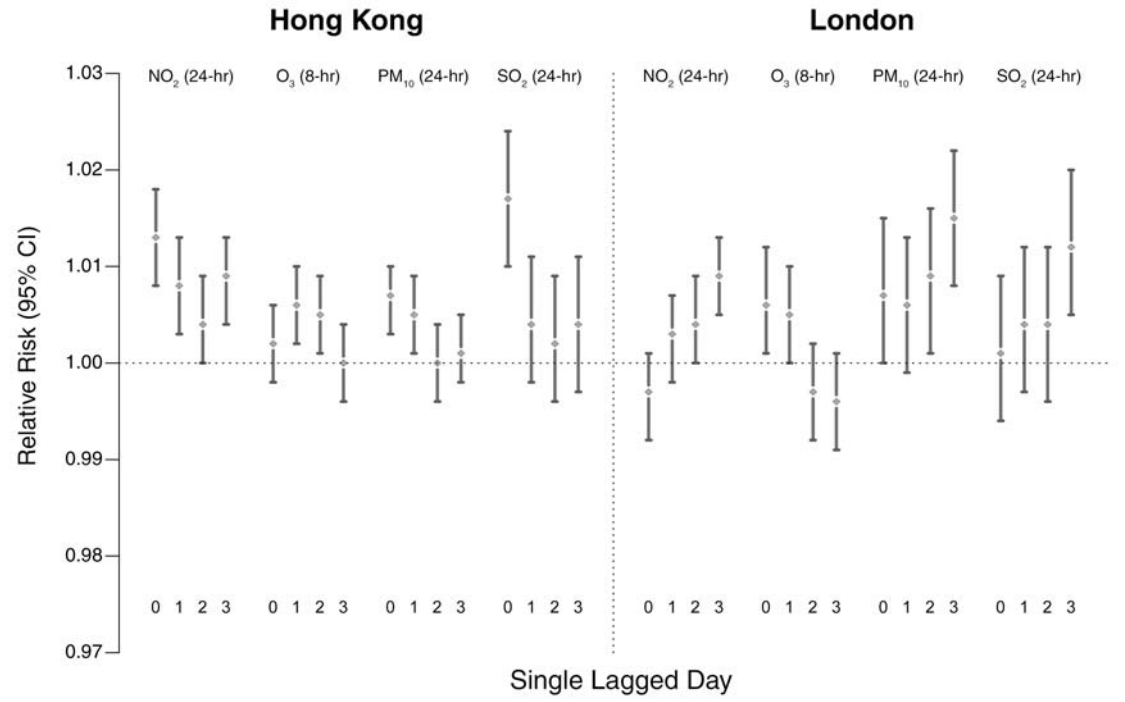


Figure 48. Relative risks for 10 μg/m³ increase in pollutant level for respiratory admissions (65+ years) in single lagged days. Pollutant averaging times are given in parentheses. Data from Wong et al 2002a.

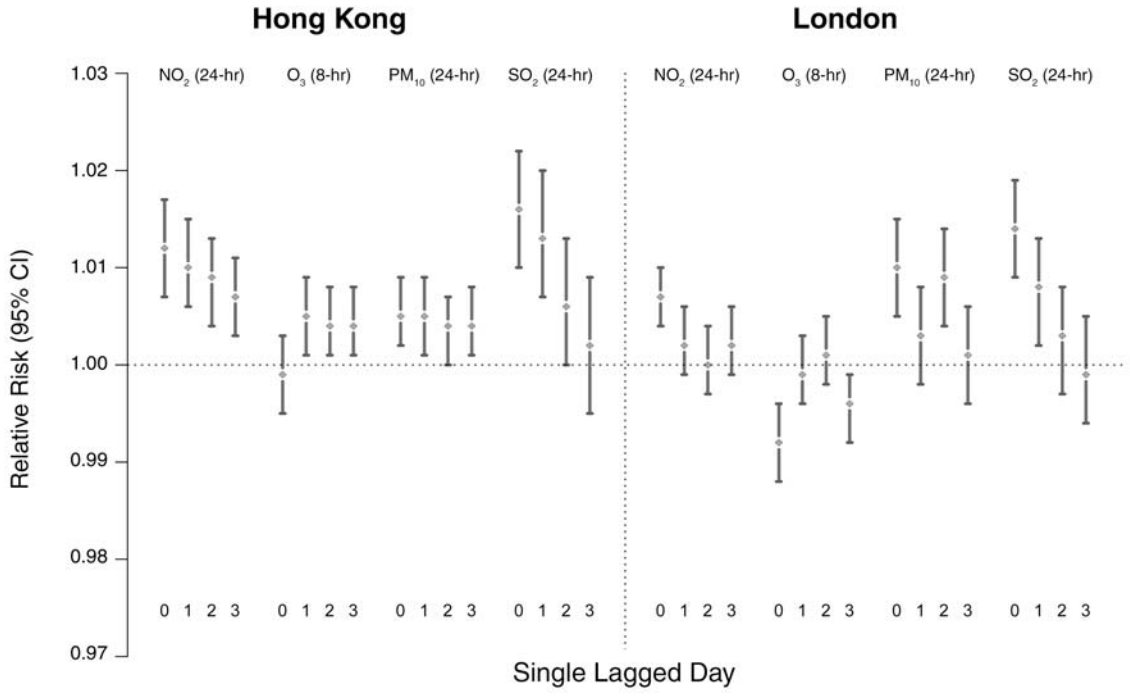


Figure 49. Relative risks for 10 μg/m³ increase in pollutant level for cardiac admissions (all ages) in single lagged days. Pollutant averaging times are given in parentheses. Data from Wong et al 2002a.

Associations between short-term pollutant exposures and health in Hong Kong and London were quite similar. Because the two cities differ widely in climate, seasonality, population health status and health care, and lifestyle, these results strengthen the argument that the associations are causal rather than due to unknown or uncontrolled confounding factors.

The results also provide some support for extrapolating epidemiologic findings from studies in the West to those in Asia. Such extrapolation must be done carefully, however. Current knowledge about factors that may modify the effects of short-term exposure to air pollution is limited (Samet et al 2000b; Katsouyanni et al 2001), and choosing statistical models is uncertain (Health Effects Institute 2003). It is worth noting that the largest increases in hospital admissions were observed in the cool season in Hong Kong and in the warm season in London, highlighting the possible differences in epidemiology of the health effects of air pollution between Asia and the West.

DISCUSSION OF META-ANALYSIS

Some limitations can be expected to affect our findings. The two independent searches of the published literature may have failed to find some publications in the local Asian literature. Two Chinese papers that were recently brought to our attention by colleagues (Chang et al 2003a,b) were not identified in searches of the major computerized databases. To avoid this problem in the future, additional methods of identifying papers should be used, including targeted searches of the local peer-reviewed literature.

Relevant results may never have been published or published only partially. This is especially likely to be true for results of time-series studies. Our analyses revealed some evidence of publication bias for SO_2 and all-cause mortality but not for TSP and all-cause mortality. We were only able to test selected results because, in most cases, studies were too few for informative analysis.

The cities of South and Southeast Asia were for the most part unrepresented in this literature. Although results in these regions might be similar to those in East Asia, the levels and composition of air pollution, source types, and factors related to population health and socioeconomic development might result in differences in the health effects of short-term exposure to outdoor air pollution.

The meta-analysis results suggest that the various measures of particles (TSP, PM_{10}, $PM_{2.5}$) are generally positively associated with mortality and hospital admissions. Quantifying these associations was difficult, however, because different measures of particles were used among studies. In addition, studies that measured PM_{10} used different techniques (eg, TEOM, β gauge). TSP was the most frequently reported metric of particles, but many countries now instead report PM_{10}, a more accurate measure of respirable particles. In Europe, the relation between TSP and PM_{10} has been estimated to be PM_{10} = TSP × 0.55 (Katsouyanni et al 1997). Using this scaling factor, the summary random-effects estimate for TSP (0.22%) is equivalent to a PM_{10} effect of 0.4%. This estimate is very close to the summary estimate for PM_{10} (0.49%).

Fine particles ($PM_{2.5}$) are a better measure than TSP or PM_{10} of particles that result from combustion, but only one study reported results for this metric. The summary estimate for PM_{10} and daily mortality (0.49%), although based on only four cities, was similar to that obtained in the much larger APHEA and NMMAPS multicity studies (0.6% and 0.51%, respectively). The summary estimates for SO_2 were also similar to those reported by APHEA.

Most estimates for NO_2 were from Hong Kong and Seoul, two cities in which motor-vehicle traffic is a major source of pollution. Because NO_2 tends to correlate well with other vehicle emissions (such as particles), multipollutant models might provide additional insight. For instance, hospital admissions in Hong Kong were strongly associated with NO_2 in two-pollutant models including PM_{10}.

Estimation of the effects of short-term O_3 exposure was limited by variation in averaging times, and the evidence for an association between O_3 and daily mortality was not consistent. Another limitation was that all studies reported estimates for the entire year. Western studies that include season-specific analyses of O_3 report the strongest effects in the warmest seasons (eg, Samet et al 2000b).

The largest number of estimates were available for SO_2. This pollutant was consistently, positively associated with mortality (both respiratory and cardiovascular) in the Asian studies as well as in European studies. This association was not as apparent for respiratory and cardiovascular admissions, however.

Many pollutant–outcome relations showed considerable heterogeneity. Heterogeneity can result from noncomparability in the quality of data or the methods of analysis. For example, errors in measurement of exposure among cities can produce the appearance of differences in effects where none truly exist (Samet et al 2000a). Heterogeneity can also reflect real differences in the magnitude of the effect estimate (called *effect modification*).

Effect modification can be related to factors such as differences in underlying population vulnerability to air pollution or differences in toxicity of the air pollution mixture in different cities. The small number of studies and lack of data on possible effect-modifying factors precluded a detailed evaluation of effect modification in the Asian literature, but the

results of large multicity US and European studies (Samet et al 2000b, Katsouyanni, et al 2001) and recent meta-analyses of the broader literature (Levy et al 2000) suggest that such factors exist.

O'Neill and colleagues (2003) recently reviewed the evidence for effect modification related to economic deprivation. They noted that several time-series studies in the United States, Europe, and Latin America have frequently reported larger relative effects in the poorest subpopulations. This finding may be of particular relevance in Asia, where extreme poverty is prevalent in major cities.

We found two studies of short-term associations between air pollution and health that use the case-crossover design. Lee and Schwartz (1999) reported evidence from Seoul of adverse associations between daily mortality and SO_2. Reported associations with O_3 and TSP were less convincing, however. Effect estimates were also sensitive to the control strategy that was employed. Kan and Chen (2003) used a bidirectional control strategy and reported associations of daily mortality and PM_{10}, SO_2, and NO_2 in Shanghai. Both studies therefore reinforce the conclusions from time-series studies of daily data in the same cities: adverse pollutant–outcome associations are present.

In the non-Asian literature, studies of outcomes besides mortality and hospital or emergency room admissions are uncommon (except in studies based on short-term observation of panels). In contrast, the Asian literature contains few panel studies but relatively numerous studies of outcomes in the primary-care setting. Such studies are important in that they contribute to a more comprehensive body of evidence for assessing causality and provide a basis for health-impact assessments that are more comprehensive than those based on mortality and hospitalizations alone. Outcomes in the Asian studies included emergency visits (Pande et al 2002) and emergency transports (Ye et al 2001) to the hospital, primary-care visits to a community hospital (Xu et al 1995; Hwang and Chan 2002), consultation with a general practitioner (Hwang and Chan 2002), and school absence (Park et al 2002).

Summary and Conclusions

Recent estimates of the impact of outdoor air pollution, based largely on results of epidemiologic studies conducted in the United States and extrapolated to Asia, suggest that outdoor air pollution in Asian cities is having significant negative impact on public health (Cohen et al 2004). Whatever conclusions may be drawn from such estimates with regard to public policy, few would disagree that future health-impact assessments for the region would benefit if based on results of studies in Asian cities. This basis is important in part because current environmental and social conditions in Asia differ demonstrably from those in the developed West and are changing dramatically.

In this Special Report, we have described and summarized the current epidemiologic evidence from studies of outdoor air pollution conducted in Asia in the context of levels and trends in development, air quality, and health. We have then examined in detail a subset of these studies: time-series studies that estimate the effect of short-term exposure to air pollution on daily mortality and hospital admissions for cardiovascular and respiratory disease. Finally, we have identified gaps in current knowledge that could be addressed with additional research.

HEALTH EFFECTS OF SHORT-TERM EXPOSURE IN ASIAN CITIES

The Asian air pollution epidemiology literature is larger than we had expected. We identified more than 130 studies published in the peer-reviewed literature between 1980 and 2003, most published over the past decade. This number may well be an underestimate, because we may have failed to identify some papers published only in local peer-reviewed literature. Asian investigators may also encounter difficulties in publishing their work in Western journals, so some research may simply go unreported (Gibbs 1995). And although some countries are well-represented in the literature, others are not. The majority of studies have been conducted in the more-developed countries of East Asia with relatively few studies conducted in South, Southeast, and Western Asia, where rapid urban growth is accompanied by extremely high levels of air pollution.

Although we did not conduct a critical, quantitative review of the entire Asian literature, it seems to be similar in many respects to the broader air pollution epidemiology literature: its recent growth, the health endpoints it addresses, and the relative frequency of certain study designs. Like in the broader literature, a number of time-series studies of acute effects of short-term exposures and cross-sectional studies of respiratory health effects have been conducted. The latter studies report estimated effects of exposure to PM that are qualitatively similar to those in the broader literature (eg, Pope and Dockery 1999), although they need to be reviewed in more detail and may not accurately represent the health effects of exposure across the entire region. Even more than in the broader literature, a paucity of longitudinal studies of chronic effects of long-term exposure exists in Asia. Indeed, no studies of Asian populations describe the effects of long-term exposure on mortality from nonmalignant cardiovascular and respiratory disease.

We reviewed the time-series studies of acute effects of short-term exposure in some detail. A sizeable body of good-quality time-series studies already exists in Asia, although the overwhelming majority published to date have been conducted in China (including Hong Kong and Taipei,China) and South Korea. In these studies, increased daily morbidity and mortality are associated with PM and various gaseous pollutants. The existing studies do not yet represent the full range of Asian settings, but when estimates from individual studies are combined into summary estimates they resemble results from more extensive, coordinated multicity studies conducted recently in Europe and North America (at least for PM_{10} and SO_2). Any quantitative review of the published studies is necessarily limited, however, because they vary considerably in presentation of their results. They also frequently include multiple studies of the same city.

The Asian literature contains a number of important studies of community-level health outcomes that were too few for combined analysis but nonetheless may be important for understanding causal relations and conducting health-impact assessments. The literature also contained analyses of mortality in infancy and childhood; further work in this area is needed to examine the effects of air pollution on vulnerable subpopulations.

The apparent similarities between Asian and Western results are noteworthy and in some ways surprising. On the one hand, we have found the not unexpected evidence of effects of short-term exposure to outdoor air pollution in

Asian cities at high levels. The acute toxicity of short-term exposure to high air pollution concentrations has been appreciated since the mid 20th century, and recent multicity studies in Europe and North America have identified such effects at even lower concentrations. On the other hand, we also had good reason to expect that aspects of the relation between exposure to air pollution and health might differ, possibly with important implications for both scientific understanding and policy decisions. Differences in the age structures, health status, and lifestyle between Asian and Western populations might well be expected to alter susceptibility to air pollution. And the air pollution mixture itself, and its associated toxicity, might also be expected to be reflected in the results of the epidemiologic studies. The studies that have been reported to date do not show such differences, however. Future combined analyses of studies in a more fully representative range of Asian cities will help strengthen what conclusions can be drawn about the similarity of Asian results and those from the rest of the world.

GAPS IN CURRENT KNOWLEDGE

Gathering evidence from a wider range of Asian cities and using a more systematic approach to analyze and report results will help us learn more about the health effects of air pollution in Asia and how it compares to other regions of the world. The following gaps in current knowledge could be addressed in future research.

- *How are short-term exposures to outdoor air pollution related to daily morbidity and mortality across Asia?* Are effects of similar magnitude seen in India, Indonesia, Vietnam, Malaysia, and the Philippines and in China, Hong Kong, and South Korea? Differences in the relative prevalence of urban air pollution sources (such as open burning) and urban poverty may modify the effects of exposure. Studies of comparable design, analyzed consistently and conducted across the region, will provide more definitive answers.
- *Does the nature of the air pollution mixture affect the magnitude of observed health effects?* Air pollution sources in developing Asian cities differ from those in the West, so the resulting urban air pollution mixture may differ as well. Detailed studies of the composition of air pollution and of the relative contribution of various sources have not yet been conducted extensively in Asia. Without such studies, epidemiologists have a difficult time assessing the relative effects of different pollution mixtures or specific pollution sources or even interpreting patterns of variation.
- *What is the shape of air pollution concentration–response function over the range of ambient air pollution observed across Asia?* The shape of the PM concentration–response function for daily mortality has been described in large multicity studies in the United States over a range of concentrations lower than that observed in many Asian cities. The shape of that function at higher concentrations has not been as extensively studied. A set of coordinated studies is needed to span the observed range of ambient concentrations in cities across Asia so that the results can be compared reliably.
- *Are the same subpopulations susceptible to effects of air pollution in Asia and the West?* Quantitatively similar estimates of relative increases in all-cause mortality may mask different patterns of susceptibility. Death at younger ages (due to acute respiratory infections, tuberculosis, or acute respiratory syndrome, for example) may play a larger role in Asia than in the West. Given the relatively larger proportion of younger age groups in Asian populations, the answer to this question has important implications for health-impact assessment of air pollution in Asia. In addition, although the prevalence of chronic cardiovascular and respiratory diseases is increasing in urban Asian populations, susceptibility to the effects of air pollution among those with chronic disease may be modified by diet or other factors, even among older people. As demographic and health patterns emerge, studies are needed that (at a minimum) estimate effects on morbidity and mortality by age and, preferably, by cause over time.
- *What role does indoor air pollution play in the health effects of outdoor air pollution?* The magnitude and prevalence of exposure to indoor air pollution is high in Asian cities, especially among the poor. We need to understand better how air pollution from indoor sources contributes to levels of outdoor air pollution and how indoor exposure to air pollution from indoor sources affects risk estimates for outdoor air pollution. Coordinated measurements of exposure and coordinated epidemiologic studies will be needed to address these questions.
- *What role does poverty play in the health effects of air pollution?* Limited evidence, largely from studies in Europe and North America, suggests that economic deprivation increases the risk of morbidity and mortality related to air pollution. One reason may be the higher air pollution exposures that people with lower socioeconomic status experience. But increased susceptibility can also be affected by factors related to socioeconomic status, such as health, nutritional status,

and access to medical services. Studies of these issues have not yet been conducted in Asia, where extreme poverty is more prevalent and results of the Western studies cannot be simply extrapolated. Studies in Asia that examine the effect of exposure on morbidity and mortality from diseases associated with poverty (such as acute respiratory infections in children and tuberculosis) and studies that estimate effects of exposure in different socioeconomic strata are needed.

- *What are the effects of long-term exposure to air pollution?* Health impact assessments of air pollution (such as the WHO Comparative Risk Assessment; WHO 2002) and cost–benefit analysis of air pollution control measures rely primarily on estimates of how exposure affects the incidence of and mortality from chronic cardiovascular and respiratory diseases. These estimates can only be provided by long-term observation of large study populations; time-series studies of daily effects will not suffice. To date, long-term studies have only been conducted in the United States and Europe. Extrapolation of their results raises some uncertainties. A detailed quantitative review of the larger Asian literature (including cross-sectional studies of chronic respiratory disease) may better inform extrapolations, but ultimately only long-term Asian studies will provide the most direct evidence.

SUMMARY

The current literature provides substantial information on the effects of outdoor air pollution on the health of Asia's people, information that can serve today as a resource for important Asian decisions. For the subset of cities that has been studied most closely, this Special Report indicates that short-term exposure to air pollution is associated with increases in daily mortality and morbidity. In the limited comparisons that can be made at this stage, these estimated effects are similar to those found in Western countries. Important gaps in the range of Asian settings studied and in the types of studies remain to be addressed in order to fully inform public policy decisions. Publication of this Special Report and subsequent funding of a targeted program of research in Asia aims to improve substantially our understanding of the problems posed by air pollution in Asia and to develop the capacity of Asian scientists to conduct additional scientific research toward their solution.

References

Ackermann-Liebrich U, Rapp R. 1999. Epidemiological effects of oxides of nitrogen, especially NO_2. In: Air Pollution and Health (Holgate ST, Samet JM, Koren HS, Maynard R, eds). Academic Press, London, England.

Aditama TY. 2000. Impact of haze from forest fire to respiratory health: Indonesian experience. Respirology 5:169–174.

Agarwal KS, Mughal MZ, Upadhyay P, Berry JL, Mawer EB, Puliyel JM. 2002. The impact of atmospheric pollution on vitamin D status of infants and toddlers in Delhi, India. Arch Dis Child 87:111–113.

Air Pollution in Megacities of Asia. 2002. Benchmarking Urban Air Quality Management and Practice in Major and Mega Cities of Asia, Stage 1. Korea Environment Institute, Seoul, Korea. Available at *www.cleanairnet.org/asia/1412/article-47960.html.*

Air Pollution in Megacities of Asia. 2004. Benchmarking Report on Urban Air Quality Management and Practice in Major and Mega Cities of Asia, Stage 2. Korea Environment Institute, Seoul, Korea. In press.

American Thoracic Society. 2000. What constitutes an adverse health effect of air pollution? Am J Respir Crit Care Med 161:665–673.

Anand SS, Yusuf S, Vuksan V, Devanesen S, Teo KK, Montague PA, Kelemen L, Yi C, Lonn E, Gerstein H, Hegele RA, McQueen M, for the SHARE Investigators. 2000. Differences in risk factors, atherosclerosis, and cardiovascular disease between ethnic groups in Canada: The Study of Health Assessment and Risk in Ethnic groups (SHARE). Lancet 356:279–284.

Anderson HR. 1999. Health effects of air pollution episodes. In: Air Pollution and Health (Holgate ST, Samet JM, Koren HS, Maynard R, eds). Academic Press, London, England.

Anderson HR, Atkinson RW, Peacock JL, Sweeting M. 2004. Publication bias in studies of ambient particulate pollution and daily mortality. Epidemiology. In press.

Anderson HR, Limb ES, Bland JM, Ponce de Leon A, Strachan DP, Bower JS. 1995. Health effects of an air pollution episode in London, December 1991. Thorax 50:1188–1193.

Awasthi S, Glick HA, Fletcher RH, Ahmed N. 1996. Ambient air pollution & respiratory symptoms complex in preschool children. Indian J Med Res 104:257–262.

Bascom R, Bromberg PA, Costa DA, Devlin R, Dockery DW, Frampton MW, Lambert W, Samet JM, Speizer FE, Utell M (Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society). 1996a. Health effects of outdoor air pollution, Part 1. Am J Respir Crit Care Med 153:3–50.

Bascom R, Bromberg PA, Costa DL, Devlin R, Dockery DW, Frampton MW, Lambert W, Samet JM, Speizer FE, Utell M (Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society). 1996b. Health effects of outdoor air pollution, Part 2. Am J Respir Crit Care Med 153:477–498.

Begg CB, Berlin JA. 1989. Publication bias and dissemination of clinical research. JNCI 81:107–115.

Beijing Environmental Protection Bureau. 2004. Environmental Annual Reports, 1994–2002 [in Chinese]. www.bjepb.gov.cn/newhb/file/filelist3.asp?path=html/hjgb/hjzkgb&title=环境状况公报&image=images/title/hjgb.jpg. Accessed 2/04. Some data available in English at *www.bjepb.gov.cn/English_homepage/environmental_bulletin/en_bulletin.htm*.

Black RE, Morris SS, Bryce J. 2003. Where and why are 10 million children dying every year? Lancet 361:2226–2234.

Bladen WA. 1983. Relationship between acute respiratory illness and air pollution in an Indian industrial city. J Air Pollut Control Assoc 33:226–227.

Bobak M, Leon DA. 1999. The effect of air pollution on infant mortality appears specific for respiratory causes in the postneonatal period. Epidemiology 10:666–670.

Braga AL, Zanobetti A, Schwartz J. 2001. The lag structure between particulate air pollution and respiratory and cardiovascular deaths in 10 US cities. J Occup Environ Med 43:927–933.

Brauer M. 1997. Assessment of health implications of haze in Malaysia. Mission report to the Government of Malaysia. RS/97/0441. WHO Regional Office for the Western Pacific, Manila, Philippines.

Brauer M, Hisham-Hashim J. 1998. Fires in Indonesia: Crisis and reaction. Environ Sci Technol 32:404A–407A.

Browne DR, Husni A, Risk MJ. 1999. Airborne lead and particulate levels in Semarang, Indonesia and potential health impacts. Sci Total Environ 227:145–154.

California Environmental Protection Agency. 1998. Part B: Health Risk Assessment for Diesel Exhaust. Office of Environmental Health Hazard Assessment, Sacramento CA. Available at *www.arb.ca.gov/regact/diesltac/diesltac.htm,* Public Hearing Notice and Related Materials, Appendix III, Part B.

Central Pollution Control Board. 2003. Air Quality of Delhi. *www.cpcb.delhi.nic.in/bulletin/bul.htm*. Accessed 10/03.

Central Pollution Control Board. 2004. National Air Quality Monitoring Programme Ambient Air Quality Trends, Delhi, 1991–2001. *www.cpcb.delhi.nic.in/cpcb/advance_ser/a.php*. Accessed 2/04.

Chang G-Q, Pan X-C, Xie X-Q, Gao YL. 2003a. Time-series analysis on the relationship between air pollution and daily mortality in Beijing [in Chinese]. J Hyg Res 32:565–567.

Chang G-Q, Wang L-G, Pan X-C. 2003b. Study on the associations between ambient air pollutant and hospital outpatient visitor emergency room visit in Beijing [in Chinese]. Chin J School Doctor 17:295–297.

Chen Z, Chen C, Dong S, Chen WQ, Hua ZM. 1995. Epidemiological studies on risk for adverse pregnancy outcomes in women neighboring a petrochemical works [in Chinese]. Zhonghua Yu Fang Yi Xue Za Zhi 29:209–212.

Chen BH, Kan HD. 2003. Air pollution and health impacts: Experience and challenge in China. Environ Health Perspect (Chinese language edition) 111(1C):3.

Chen P-C, Lai Y-M, Chan C-C, Hwang J-S, Yang C-Y, Wang J-D. 1999. Short-term effect of ozone on the pulmonary function of children in primary school. Environ Health Perspect 107:921–925.

Chen P-C, Lai Y-M, Wang J-D, Yang C-Y, Hwang J-S, Kuo H-W, Huang S-L, Chan C-C. 1998. Adverse effect of air pollution on respiratory health of primary school children in Taiwan. Environ Health Perspect 106:331–335.

Chew FT, Goh DY, Lee BW. 1999a. Geographical comparison of the prevalence of childhood asthma and allergies in Singapore. Ann Trop Paediatr 19:383–390.

Chew FT, Goh DYT, Ooi BC, Saharom R, Hui JKS, Lee BW. 1999b. Association of ambient air-pollution levels with acute asthma exacerbation among children in Singapore. Allergy 54:320–329.

Chhabra SK, Chhabra P, Rajpal S, Gupta RK. 2001. Ambient air pollution and chronic respiratory morbidity in Delhi. Arch Environ Health 56:58–64.

Chhabra SK, Gupta CK, Chhabra P, Rajpal S. 1999. Risk factors for development of bronchial asthma in children in Delhi. Ann Allergy Asthma Immunol 83:385–390.

China State Environmental Protection Administration. 1990–1998. China Environment Report (1990–1998) [in Chinese]. *www.zhb.gov.cn/64936826882962272/index.shtml*. Accessed 2/04.

China State Environmental Protection Administration. 2002. China Air Quality Report 2002 [in Chinese]. *www.zhb.gov.cn/64936829889439344/20030606/1038755.shtml*. Accessed 2/04.

Cho B, Choi J, Yum Y-T. 2000. Air pollution and hospital admissions for respiratory disease in certain areas of Korea. J Occup Health 42:185–191.

Choi K-S, Inoue S, Shinozaki R. 1997. Air pollution, temperature, and regional differences in lung cancer mortality in Japan. Arch Environ Health 52:160–168.

Clancy L, Goodman P, Sinclair H, Dockery DW. 2002. Effect of air-pollution control on death rates in Dublin, Ireland: An intervention study. Lancet 360:1210–1214.

Cohen AJ, Anderson HR, Ostro B, Pandey KD, Krzyzanowski M, Kuenzli N, Gutschmidt K, Pope CA, Romieu I, Samet JM, Smith KR. 2004. Mortality impacts of urban air pollution. In: Comparative Quantification of Health Risks: Global and Regional Burden of Disease Due to Selected Major Risk Factors (Ezzati M, Lopez AD, Rodgers A, Murray CJL, eds), vol 2. World Health Organization, Geneva, Switzerland. In press.

Cropper ML, Simon NB, Alberini A, Sharma PK. 1997. The health effects of air pollution in Delhi, India. PRD Working Paper 1860 (unpublished). New Ideas in Pollution Regulation, World Bank, Washington DC. Available from *www.worldbank.org/nipr/work_paper/1860/index.htm*.

Dana T. 2002. Study on indoor air pollution. Presented at the Regional Workshop on Household Energy, Indoor Air Pollution and Health, New Delhi, May 9–10, 2002. The World Bank and the Tata Energy Research Institute, New Delhi, India.

Daniels MJ, Dominici F, Samet JM, Zeger SL. 2000. Estimating particulate matter-mortality dose-response curves

and threshold levels: An analysis of daily time-series for the 20 largest US cities. Am J Epidemiol 152:397–406.

Deb SK. 1998. Acute respiratory disease survey in Tripura in case of children below five years of age. J Indian Med Assoc 96:111–116.

DeGroot MH. 1986. Probability and Statistics, 2nd ed. Addison-Wesley, Reading MA.

DerSimonian R, Laird N. 1986. Meta-analysis in clinical trials. Control Clin Trials 7:177–188.

Deurenberg-Yap M, Chew SK, Deurenberg P. 2002. Elevated body fat percentage and cardiovascular risks at low body mass index levels among Singaporean Chinese, Malays and Indians. Obes Rev 3:209–215.

Dickersin K. 1997. How important is publication bias? A synthesis of available data. AIDS Educ Prev 9(Suppl 1):15–21.

Dockery DW, Pope CA III, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG Jr, Speizer FE. 1993. An association between air pollution and mortality in six US cities. N Engl J Med 329:1753–1759.

Dong JW et al. 1995. Relationship between air pollution and daily mortality in urban districts of Beijing [in Chinese]. J Hyg Res 24:212–214.

Dong J-W, Xu X-P, Dockery DW, Chen YD. 1996. Association of air pollution with unscheduled outpatient visits in Beijing Longfu Hospital, 1991 [in Chinese]. Zhonghua Liu Xing Bing Xue Za Zhi 17:13–16.

Duval S, Tweedie R. 2000. Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. Biometrics 56:455–463.

East-West Center. 2002. The Future of Population in Asia. East-West Center, Honolulu HI.

Egger M, Smith GG, Schneider M, Minder C. 1997. Bias in meta-analysis detected by a simple, graphical test. BMJ 315:629–634.

Emmanuel SC. 2000. Impact to lung health of haze from forest fires: The Singapore experience. Respirology 5:175–182.

Enas EA, Yusuf S, Mehta JL. 1992. Prevalence of coronary artery disease in Asian Indians. Am J Cardiol 70:945–949.

Environmental Protection Agency (US). 1995. Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources. Office of Air Quality Planning and Standards, Research Triangle Park NC. Available at *www.epa.gov/ttn/chief/ap42/*.

Environmental Protection Agency (US). 1997. National Ambient Air Standards for PM_{10}. Office of Air and Radiation, Washington DC. Available at *www.epa.gov/air/criteria.html*.

Environmental Protection Agency (US). 2000. Air Quality Criteria for Carbon Monoxide. Office of Research and Development, Washington DC.

Environmental Protection Agency (US). 2002. Health Assessment Document for Diesel Engine Exhaust. EPA/600/8-90/057F. National Center for Environmental Assessment, Office of Research and Development, Washington DC.

Expert Panel on Air Quality Standards. 1997. Ozone. Her Majesty's Stationery Office Publications Centre, London, England.

Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S, Murray CJ, Comparative Risk Assessment Collaborating Group. 2002. Selected major risk factors and global and regional burden of disease. Lancet 360:1347–1360.

Ezzati M, Rodgers AD, Lopez AD, Murray CJL, eds. 2004. Comparative Quantification of Health Risks: Global and Regional Burden of Disease Due to Selected Major Risk Factors. World Health Organization, Geneva, Switzerland. 3 vols. In press.

Fewtrell LJ, Prüss-Üstün A, Landrigan P, Ayuso-Mateos JL. 2004. Estimating the global burden of disease of mild mental retardation and cardiovascular diseases from environmental lead exposure. Environ Res 94:120–133.

Gajalakshmi V, Peto R, Kanaka TS, Jha P. 2003. Smoking and mortality from tuberculosis and other diseases in India: Retrospective study of 43 000 adult male deaths and 35 000 controls. Lancet 362:507–515.

Gao J, Xu XP, Chen YD, Dockery DW, Long DH, Liu HX, Jiang JY. 1993. Relationship between air pollution and mortality in Dongcheng and Xicheng Districts, Beijing [in Chinese]. Zhonghua Yu Fang Yi Xue Za Zhi 27:340–343.

Gao YT, Blot WJ, Zheng W, Ershow AG, Hsu CW, Levin LI, Zhang R, Fraumeni JF Jr. 1987. Lung cancer among Chinese women. Intl J Cancer 40:604–609.

Geethanjali FS, Luthra K, Lingenhel A, Kanagasaba-Pathy AS, Jacob J, Srivastava LM, Vasisht S, Kraft HG, Utermann G. 2003. Analysis of the apo(a) size polymorphism in Asian Indian populations: Association with Lp(a) concentration and coronary heart disease. Atherosclerosis 169:121–130.

Ger L-P, Hsu W-L, Chen K-T, Chen C-J. 1993. Risk factors of lung cancer by histological category in Taiwan. Anticancer Res 13:1491–1500.

Ghio AJ, Devlin RB. 2001. Inflammatory lung injury after bronchial instillation of air pollution particles. Am J Respir Crit Care Med 164:704–708.

Gibbs WW. 1995. Lost science in the Third World. Sci Am August:92–99.

Godleski JJ. 2000. Cardiovascular responses to inhaled particles. In: Relationships Between Acute and Chronic Effects of Air Pollution (Heinrich U, Mohr U, eds), pp 141–155. ILSI Press, Washington DC.

Greenland S. 1998. Meta-analysis. In: Modern Epidemiology, 2nd edition (Rothman KJ, Greenland S, eds). Lippincott-Raven Publishers, Philadelphia PA.

Guha-Sapir D. 1996. Environment of Urban Poor Communities in Asia: Study on Effects of Indoor Air Pollution Among Infants in Delhi and Manila. Catholic University of Louvain Department of Public Health, Brussels, Belgium.

Guo YL, Lin Y-C, Sung F-C, Huang S-L, Ko Y-C, Lai J-S, Su H-J, Shaw C-K, Lin R-S, Dockery DW. 1999. Climate, traffic-related air pollutants, and asthma prevalence in middle-school children in Taiwan. Environ Health Perspect 107:1001–1006.

Gupta D, Boffetta P, Gaborieau V, Jindal SK. 2001. Risk factors of lung cancer in Chandigarh, India. Indian J Med Res 113:142–150.

Gupta R, Gupta VP. 1996. Meta-analysis of coronary heart disease prevalence in India. Indian Heart J 48:241–245.

Ha E-H, Hong Y-C, Lee B-E, Woo B-H, Schwartz J, Christiani DC. 2001. Is air pollution a risk factor for low birth weight in Seoul? Epidemiology 12:643–648.

Ha E-H, Lee J-T, Kim H, Hong Y-C, Lee B-E, Park H-S, Christiani DC. 2003. Infant susceptibility of mortality to air pollution in Seoul, South Korea. Pediatrics 111:284–290.

Han C-Z, Guo Y, Jing J-X, Zhao XW, Li C, Miao L, Ma XL, Zhou J. 1995. A study on the relationship between malignant tumour mortality and environmental pollution in Beicun countryside of Datong City [in Chinese]. Zhonghua Liu Xing Bing Xue Za Zhi 16:101–104.

Han C-Z, Jing J-X, Sun G-X, Miao L, Guo Y, Zhao XW, Li C, Guo JG. 1997. Study of environmental pollution and damage of cytogenetic materials in urban residents [in Chinese]. Zhonghua Liu Xing Bing Xue Za Zhi 18:83–85.

He X, Chen W, Liu Z, Chapman RS. 1991. An epidemiological study of lung cancer in Xuan Wei County, China: Current progress. Case-control study on lung cancer and cooking fuel. Environ Health Perspect 94:9–13.

Health Effects Institute. 1993. Research Priorities for Mobile Air Toxics. HEI Communication 2. HEI, Cambridge MA.

Health Effects Institute. 2001. Airborne Particles and Health: HEI Epidemiologic Evidence. HEI Perspectives. Health Effects Institute, Cambridge MA.

Health Effects Institute. 2002. Understanding the Health Effects of Components of the Particulate Matter Mix: Progress and Next Steps. HEI Perspectives. Health Effects Institute, Boston MA.

Health Effects Institute. 2003. Revised Analyses of Time-Series Studies of Air Pollution and Health. Special Report. Health Effects Institute, Boston MA.

Hedley AJ, Wong CM, Thach TQ, Ma S, Lam TH, Anderson HR. 2002. Cardiorespiratory and all-cause mortality after restrictions on sulphur content of fuel in Hong Kong: An intervention study. Lancet 360:1646–1652.

HEI Collaborative Ozone Project Group. 1995. Part XI: Integrative summary. In: Consequences of Prolonged Inhalation of Ozone on F344/N Rats: Collaborative Studies. Research Report 65. Health Effects Institute, Cambridge MA.

HEI Diesel Epidemiology Expert Panel. 1999. Diesel Emissions and Lung Cancer: Epidemiology and Quantitative Risk Assessment. Special Report. Health Effects Institute, Cambridge MA.

Hoek G, Brunekreef B, Goldbohm S, Fischer P, van den Brandt PA. 2002. Association between mortality and indicators of traffic-related air pollution in the Netherlands: A cohort study. Lancet 360:1203–1209.

Holgate ST, Samet JM, Koren HS, Maynard R, eds. 1999. Air Pollution and Health. Academic Press, London, England.

Hong Kong Environmental Protection Department. 2002. Study of Air Quality in the Pearl River Delta Region. Prepared under agreement CE 106/98. Government of Hong Kong Special Administrative Region, Hong Kong, China. Available at *www.epd.gov.hk/epd/english/environmentinhk/air/studyrpts/study_pearl.html*.

Hong Kong Environmental Protection Department. 2004. Hong Kong Environmental Annual Reports (last updated

7/25/03). *www.epd.gov.hk/epd/english/environmentinhk/air/air_quality/aq_annualrpt.html*. Accessed 2/04.

Hong Y-C, Lee J-T, Kim H, Ha E-H, Schwartz J, Christiani DC. 2002a. Effects of air pollutants on acute stroke mortality. Environ Health Perspect 110:187–191.

Hong Y-C, Lee J-T, Kim H, Kwon H-J. 2002b. Air pollution: A new risk factor in ischemic stroke mortality. Stroke 33:2165–2169.

Hong YC, Leem JH, Ha EH. 1999a. Air pollution and daily mortality in Inchon, Korea. J Korean Med Sci 14:239–244.

Hong Y-C, Leem J-H, Ha E-H, Christiani DC. 1999b. PM_{10} exposure, gaseous pollutants, and daily mortality in Inchon, South Korea. Environ Health Perspect 107:873–878.

Huang J-L, Wang S-Y, Hsieh K-H. 1991. Effect of short-term exposure to low levels of SO_2 and NO_x on pulmonary function and methacholine and allergen bronchial sensitivities in asthmatic children. Arch Environ Health 46:296–299.

Hwang J-S, Chan C-C. 2002. Effects of air pollution on daily clinic visits for lower respiratory tract illness. Am J Epidemiol 155:1–10.

Hwang J-S, Chen Y-J, Wang J-D, Lai Y-M, Yang C-Y, Chan C-C. 2000. Subject-domain approach to the study of air pollution effects on schoolchildren's illness absence. Am J Epidemiol 152:67–74.

International Energy Agency. 2002. World Energy Outlook, 2002. International Energy Agency, Paris, France.

International Agency for Research on Cancer. 1989. Diesel and Gasoline Engine Exhausts and Some Nitroarenes. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 46. WHO, IARC, Lyon, France.

Janssen NAH, Hoek G, Harssema H, Brunekreef B. 1999. Personal exposure to fine particles in children correlates closely with ambient fine particles. Arch Environ Health 54:95–101.

Jin LB, Qin Y, Xu Z, Chen B. 1999. Association between air pollution and mortality in Benxi [in Chinese]. Chin J Public Health 15:211–212.

Jindal SK, Aggarwal AN, Gupta D. 2001. A review of population studies from India to estimate national burden of chronic obstructive pulmonary disease and its association with smoking. Indian J Chest Dis Allied Sci 43:139–147.

Joseph AE, Sawant AD, Srivastava A. 2003. PM_{10} and its impacts on health: A case study in Mumbai. Int J Environ Health Res 13:207–214.

Kagamimori S, Katoh T, Naruse Y, Watanabe M, Kasuya M, Shinkai J, Kawano S. 1986. The changing prevalence of respiratory symptoms in atopic children in response to air pollution. Clin Allergy 16:299–308.

Kamat SR, Doshi VB. 1987. Sequential health effect study in relation to air pollution in Bombay, India. Eur J Epidemiol 3:265–277.

Kamat SR, Godkhindi KD, Shah BW, Mehta AK, Varsha N, Gregrat J, Papewar VN, Tyagi NK, Rashid SSA, Bhiwankar NT, Natu RB. 1980. Correlation of health morbidity to air pollutant levels in Bombay City: Results of prospective 3 year survey at one year. J Postgrad Med 26:45–62.

Kamat SR, Patil JD, Gregart J, Dalal N, Deshpande JM, Hardikar P. 1992. Air pollution related respiratory morbidity in central and north-eastern Bombay. J Assoc Physicians India 40:588–593.

Kan H, Chen B. 2003. A case-crossover analysis of air pollution and daily mortality in Shanghai. J Occup Health 45:119–124.

Kan HD, Chen BH. 2002a. Meta analysis of exposure-response functions of air particulate matter and adverse health outcomes in China [in Chinese]. J Environ Health 19:422–424.

Kan HD, Chen BH. 2002b. Assessment on the health impact of residents in Shanghai due to improvement in energy efficiency and structure [in Chinese]. Shanghai Environ Sci 21:520–524.

Karita K, Yano E, Jinsart W, Boudoung D, Tamura K. 2001. Respiratory symptoms and pulmonary function among traffic police in Bangkok, Thailand. Arch Environ Health 56:467–470.

Katsouyanni K, Touloumi G, Samoli E, Gryparis A, Le Tertre A, Monopolis Y, Rossi G, Zmirou D, Ballester F, Boumghar A, Anderson HR, Wojtyniak B, Paldy A, Braunstein R, Pekkanen J, Schindler C, Schwartz J. 2001. Confounding and effect modification in the short-term effects of ambient particles on total mortality: Results from 29 European cities within the APHEA2 project. Epidemiology 12:521–531.

Katsouyanni K, Touloumi G, Spix C, Schwartz J, Balducci F, Medina S, Rossi G, Wojtyniak B, Sunyer J, Bacharova L, Schouten JP, Ponka A, Anderson HR. 1997. Short term effects of ambient sulphur dioxide and particulate matter

on mortality in 12 European cities: Results from time series data from the APHEA project. BMJ 314:1658–1663.

Khatri GR, Frieden TR. 2002. Controlling tuberculosis in India. N Engl J Med 347:1420–1425.

Kirkwood BR, Gove S, Rogers S, Lob-Levyt J, Arthur P, Campbell H. 1995. Potential interventions for the prevention of childhood pneumonia in developing countries: A systematic review. Bull World Health Organ 73:793–798.

Knöbel HH, Chen C-J, Liang K-Y. 1995. Sudden infant death syndrome in relation to weather and optimetrically measured air pollution in Taiwan. Pediatrics 96:1106–1110.

Ko Y-C, Lee C-H, Chen M-J, Huang C-C, Chang W-Y, Lin H-J, Wang H-Z, Chang P-Y. 1997. Risk factors for primary lung cancer among non-smoking women in Taiwan. Int J Epidemiol 26:24–31.

Kodavanti UP, Costa DL. 1999. Animal models to study for pollutant effects. In: Air Pollution and Health (Holgate ST, Samet JM, Koren HS, Maynard R, eds). Academic Press, London, England.

Krewski D, Burnett RT, Goldberg MS, Hoover K, Siemiatycki J, Jerrett M, Abrahamowicz M, White WH. 2000. Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality. A Special Report of the Institute's Particle Epidemiology Reanalysis Project. Health Effects Institute, Cambridge MA.

Kumar KS, Prasad CE, Balakrishna N, Rao KV, Reddy PUM. 2000. Respiratory symptoms and spirometric observations in relation to atmospheric pollutants in a sample of urban population. Asia Pac J Public Health 12:58–64.

Kunii O, Kanagawa S, Yajima I, Hisamatsu Y, Yamamura S, Amagai T, Ismail ITS. 2002. The 1997 haze disaster in Indonesia: Its air quality and health effects. Arch Environ Health 57:16–22.

Kuo HW, Lai JS, Lee MC, Tai RC, Lee MC. 2002. Respiratory effects of air pollutants among asthmatics in central Taiwan. Arch Environ Health 57:194–200.

Kwon H-J, Cho S-H, Nyberg F, Pershagen G. 2001. Effects of ambient air pollution on daily mortality in a cohort of patients with congestive heart failure. Epidemiology 12:413–419.

Lam TH, Ho LM, Hedley AJ, Adab P, Fielding R, McGhee SM, Aharonson-Daniel L. 2000. Environmental tobacco smoke exposure among police officers in Hong Kong. JAMA 284:756–763.

Lan Q, Chen W, Chen H, He XZ. 1993. Risk factors for lung cancer in non-smokers in Xuanwei County of China. Biomed Environ Sci 6:112–118.

Lan Q, He X, Costa DJ, Tian L, Rothman N, Hu G, Mumford JL. 2000. Indoor coal combustion emissions, *GSTM1* and *GSTT1* genotypes, and lung cancer risk: A case-control study in Xuan Wei, China. Cancer Epidemiol Biomarkers Prev 9:605–608.

Lan Q, Chapman RS, Schreinemachers DM, Tian L, He X. 2002 Household stove improvement and risk of lung cancer in Xuanwei, China. J Natl Cancer Inst 94:826–835.

Lee J-T, Kim H, Hong Y-C, Kwon H-J, Schwartz J, Christiani DC. 2000. Air pollution and daily mortality in seven major cities of Korea, 1991–1997. Environ Res 84:247–254.

Lee J-T, Kim H, Song H, Hong Y-C, Cho Y-S, Shin S-Y, Hyun Y-J, Kim Y-S. 2002. Air pollution and asthma among children in Seoul, Korea. Epidemiology 13:481–484.

Lee J-T, Schwartz J. 1999. Reanalysis of the effects of air pollution on daily mortality in Seoul, Korea: A case-crossover design. Environ Health Perspect 107:633–636.

Lee J-T, Shin D, Chung Y. 1999. Air pollution and daily mortality in Seoul and Ulsan, Korea. Environ Health Perspect 107:149–154.

Lee Y-L, Shaw C-K, Su H-J, Lai J-S, Ko Y-C, Huang S-L, Sung F-C, Guo YL. 2003. Climate, traffic-related air pollutants and allergic rhinitis prevalence in middle-school children in Taiwan. Eur Respir J 21:964–970.

Levine JS. 1999. The 1997 Fires in Kalimantan and Sumatra, Indonesia: Gaseous and particulate emissions. Geophys Res Lett 26:815–818.

Levy JI, Hammitt JK, Spengler JD. 2000. Estimating the mortality impacts of particulate matter: What can be learned from between-study variability? Environ Health Perspect 108:109–117.

Li H, Jin S, Shi S. 1994. The trend of mortality of lung cancer and its association with air pollution [in Chinese]. Zhonghua Liu Xing Bing Xue Za Zhi 15:38–41.

Li LD, Lu F, Zhang S, Mu R, Sun X. 1997. Analysis on the trend on mortality of malignant tumors in recent 20 years in China and the estimation for the near future [in Chinese]. Chin J Oncol 19:3–9.

Liao D, Creason J, Shy C, Williams R, Watts R, Zweidinger R. 1999. Daily variation of particulate air pollution and poor cardiac autonomic control in the elderly. Environ Health Perspect 107:521–525.

Light RJ, Pillemer DB. 1984. Summing Up: The Science of Reviewing Research. Harvard University Press, Cambridge MA.

Lin M-C, Chiu H-F, Yu H-S, Tsai S-S, Cheng B-H, Wu T-N, Sung F-C, Yang C-Y. 2001a. Increased risk of preterm delivery in areas with air pollution from a petroleum refinery plant in Taiwan. J Toxicol Environ Health A 64:637–644.

Lin M-C, Yu H-S, Tsai S-S, Cheng B-H, Hsu T-Y, Wu T-N, Yang C-Y. 2001b. Adverse pregnancy outcome in a petrochemical polluted area in Taiwan. J Toxicol Environ Health A 63:565–574.

Lin RS, Sung FC, Huang SL, Gou YL, Ko YC, Gou HW, Shaw CK. 2001c. Role of urbanization and air pollution in adolescent asthma: A mass screening in Taiwan. J Formos Med Assoc 100:649–655.

Lipfert FW, Perry HM Jr, Miller JP, Baty JD, Wyzga RE, Carmody SE. 2003. Air pollution, blood pressure, and their long-term associations with mortality. Inhalation Toxicol 15:493–512.

Ma HB, Hong CJ. 1992. The impact of air particulate matter on chronic respiratory illness in Shanghai residents [in Chinese]. Chin J Public Health 11:229–232.

Maclure M. 1991. The case-crossover design: A method for studying transient effects on the risk of acute events. Am J Epidemiol 133:144–153.

Maeda K, Nitta H, Nakai S. 1991-1992. Exposure to nitrogen oxides and other air pollutants from automobiles. Public Health Rev 19:61–72.

Mahoney MJ. 1977. Publication prejudices: An experimental study of confirmatory bias in the peer review system. Cognit Ther Res 1:161–175.

Makino K. 2000. Association of school absence with air pollution in areas around arterial roads. J Epidemiol 10:292–299.

McCullagh P, Nelder JA. 1983. Generalized Linear Models. Chapman & Hall, London, England.

McDonnell WF, Nishino-Ishikawa N, Petersen FF, Chen LH, Abbey DE. 2000. Relationships of mortality with the fine and coarse fractions of long-term ambient PM_{10} concentrations in nonsmokers. J Expos Anal Environ Epidemiol 10:427–436.

McGhee SM, Hedley AJ, Ho LM. 2002. Passive smoking and its impact on employers and employees in Hong Kong. Occup Environ Med 59:842–846.

Mumford JL, He XZ, Chapman RS, Cao SR, Harris DB, Li XM, Xian YL, Jiang WZ, Xu CW, Chuang JC, et al. 1987. Lung cancer and indoor air pollution in Xuan Wei, China. Science 235:217–220.

Mumford JL, Helmes CT, Lee XM, Seidenberg J, Nesnow S. 1990. Mouse skin tumorigenicity studies of indoor coal and wood combustion emissions from homes of residents in Xuan Wei, China with high lung cancer mortality. Carcinogenesis 11:397–403.

Murray CJL, Lopez AD, eds. 1996. The Global Burden of Disease: A Comprehensive Assessment of Mortality and Disability from Diseases, Injuries, and Risk Factors in 1990 and Projected to 2020. Global Burden of Disease and Injury Series, Vol 1. Harvard University Press, Cambridge MA.

Murray CJL, Lopez AD. 1997a. Alternative projections of mortality and disability by cause 1990–2020: Global Burden of Disease Study. Lancet 349:1498–1504.

Murray CJL, Lopez AD. 1997b. Global mortality, disability, and the contribution of risk factors: Global Burden of Disease Study. Lancet 349:1436–1442.

Neas LM, Schwartz J, Dockery D. 1999. A case-crossover analysis of air pollution and mortality in Philadelphia. Environ Health Perspect 107:629–631.

Nishtar S. 2002. Prevention of coronary heart disease in south Asia. Lancet 360:1015–1018.

Oberdörster G, Finkelstein JN, Johnston C, Gelein R, Cox C, Baggs R, Elder ACP. 2000. Acute Pulmonary Effects of Ultrafine Particles in Rats and Mice. Research Report 96. Health Effects Institute, Cambridge MA.

O'Neill MS, Jerrett M, Kawachi I, Levy JI, Cohen AJ, Gouveia N, Wilkinson P, Fletcher T, Cifuentes L, Schwartz J; Workshop on Air Pollution and Socioeconomic Conditions. 2003. Health, wealth, and air pollution: Advancing theory and methods. Environ Health Perspect 111:1861–1870.

Ong SG, Liu J, Wong CM, Lam TH, Tam AYC, Daniel L, Hedley AJ. 1991. Studies on the respiratory health of primary school children in urban communities of Hong Kong. Sci Total Environ 106:121–135.

Ono M, Murakami M, Nitta H, Nakai S, Maeda K. 1990. Epidemiological studies of air pollution and health effects in areas near roadways with heavy traffic in Tokyo [in Japanese]. Nippon Koshu Eisei Zasshi 37:321–332.

Ostro B, Chestnut L, Vichit-Vadakan N, Laixuthai A. 1999. The impact of particulate matter on daily mortality in Bangkok, Thailand. J Air Waste Manage Assoc 49:PM100–PM107.

Pan BJ, Hong YJ, Chang GC, Wang MT, Cinkotai FF, Ko YC. 1994. Excess cancer mortality among children and adolescents in residential districts polluted by petrochemical manufacturing plants in Taiwan. J Toxicol Environ Health 43:117–129.

Pande JN, Bhatta N, Biswas D, Pandey RM, Ahluwalia G, Siddaramaiah NH, Khilnani GC. 2002. Outdoor air pollution and emergency room visits at a hospital in Delhi. Indian J Chest Dis Allied Sci 44:13–19.

Park H, Lee B, Ha E-H, Lee J-T, Kim H, Hong Y-C. 2002. Association of air pollution with school absenteeism due to illness. Arch Pediatr Adolesc Med 156:1235–1239.

Peacock JL, Anderson HR, Atkinson RW, Sweeting M. 2004. Publication bias in studies of PM_{10} and children's lung function. Epidemiology. In press.

Peters J, Hedley AJ, Wong CM, Lam TH, Ong SG, Liu J, Spiegelhalter DJ. 1996. Effects of an ambient air pollution intervention and environmental tobacco smoke on children's respiratory health in Hong Kong. Int J Epidemiol 25:821–828.

Piver WT, Ando M, Ye F, Portier CJ. 1999. Temperature and air pollution as risk factors for heat stroke in Tokyo, July and August 1980–1995. Environ Health Perspect 107:911–916.

Pope CA III, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, Thurston GD. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287:1132–1141.

Pope CA III, Dockery DW. 1999. Epidemiology of particle effects. In: Air Pollution and Health (Holgate ST, Samet JM, Koren HS, Maynard R, eds). Academic Press, London, England.

Pothikamjorn SL, Ruxrungtham K, Thampanitchawong P, Fuangthong R, Srasuebkul P, Sangahsapaviriyah A, Suttithavil W, Klaewsongkram J, Parisuthikul V, Viravan T, Rumsaeng V, Kana K, Direkwattanachai C, Kamchaisathien V, Phanupak P. 2002. Impact of particulate air pollutants on allergic diseases, allergic skin reactivity and lung function. Asian Pac J Allergy Immunol 20:77–83.

Qian Z, Chapman RS, Tian Q, Chen Y, Lioy PJ, Zhang J. 2000. Effects of air pollution on children's respiratory health in three Chinese cities. Arch Environ Health 55:126–133.

Qian Z, Zhang J, Korn LR, Wei F, Chapman RS. 2004. Exposure–response relationships between lifetime exposure to residential coal smoke and respiratory symptoms and illnesses in Chinese children. J Expos Anal Environ Epidemiol 14:S78–S84.

Raiyani CV, Shah SH, Desai NM, Venkaiah K, Patel JS, Parikh DJ, Kashyap SK. 1993. Characterization and problems of indoor pollution due to cooking stove smoke. Atmos Environ 27A:1643–1655.

Ramachandran A, Snehalatha C, Satyavani K, Sivasankari S, Vijay V. 2003. Metabolic syndrome in urban Asian Indian adults: A population study using modified ATP III criteria. Diabetes Res Clin Pract 60:199–204.

Regional COPD Working Group. 2003. COPD prevalence in 12 Asia-Pacific countries and regions: Projections based on the COPD prevalence estimation model. Respirology 8:192–198.

Registrar General and Census Commissioner. 2001. Census of India 2001, Series 1: Tables on Houses, Household Amenities, and Assets. Office of the Registrar General, New Delhi, India. Available at *www.censusindia.net/2001housing/housing_tables_main.html*.

Roemer W, Clench-Aas J, Englert N, Hoek G, Katsouyanni K, Pekkanen J, Brunekreef B. 1999. Inhomogeneity in response to air pollution in European children (PEACE project). Occup Environ Med 56:86–92.

Romieu I, Samet JM, Smith KR, Bruce N. 2002. Outdoor air pollution and acute respiratory infections among children in developing countries. J Occup Environ Med 44:640–649.

Rudan I, Tomaskovic L, Boschi-Pinto C, Campbell H. 2004. Estimating the incidence of acute lower respiratory infections (ALRI) in children under five years in developing countries: 1 global estimate. Bull World Health Organ. In press.

Saksena S, Singh PB, Prasad RK, Prasad R, Malhotra P, Joshi V, Patil RS. 2003. Exposure of infants to outdoor and indoor air pollution in low-income urban areas: A case study of Delhi. J Expos Anal Environ Epidemiol 13:219–230.

Samet JM, Dominici F, Zeger SL, Schwartz J, Dockery DW. 2000a. The National Morbidity, Mortality, and Air Pollution Study, Part I: Methods and Methodologic Issues. Research Report 94. Health Effects Institute, Cambridge MA.

Samet JM, Zeger SL, Dominici F, Curriero F, Coursac I, Dockery DW, Schwartz J, Zanobetti A. 2000b. The National Morbidity, Mortality, and Air Pollution Study, Part II: Morbidity and Mortality from Air Pollution in the United States. Research Report 94. Health Effects Institute, Cambridge MA.

Sastry N. 2002. Forest fires, air pollution, and mortality in Southeast Asia. Demography 39:1–23.

Sawaguchi T, Toro K, Sawaguchi A. 1997. Sudden infant death syndrome in relation to climatic temperature, climatic humidity and air pollution in Japan. Rom J Leg Med 5:21–24.

Schipper L, Marie-Lilliu C, Lewis-Davis G. 2000. Rapid motorization in the largest countries in Asia: Implication of oil, CO_2 and transportation. Pac Asian J Energy 10: 153–169.

Schwartz J. 2001. Is there harvesting in the association of airborne particles with daily deaths and hospital admissions? Epidemiology 12:55–61.

Schwartz J, Zanobetti A. 2000. Using meta-smoothing to estimate dose-response trends across multiple studies, with application to air pollution and daily death. Epidemiology 11:666–672.

Setiani O. 1996. Trend of air pollution and its effect on human health in Hiroshima Prefecture: A retrospective study in the cities of Otake, Kure, Mihara, Takehara, Fukuyama and Kaita Town, 1977–1992. Hiroshima J Med Sci 45:43–50.

Shanghai Municipal Statistics Bureau. 1991–1999. Shanghai Statistical Yearbook (1991–1999) [in Chinese]. China Statistics Publishing House, Beijing, China.

Sheth T, Nair C, Nargundkar M, Anand S, Yusuf S. 1999. Cardiovascular and cancer mortality among Canadians of European, south Asian and Chinese origin from 1979 to 1993: An analysis of 1.2 million deaths. Can Med Assoc J 161:132–138.

Shima M, Adachi M. 2000. Effect of outdoor and indoor nitrogen dioxide on respiratory symptoms in schoolchildren. Int J Epidemiol 29:862–870.

Shima M, Adachi M, Tanaka T, Tsunetoshi Y. 1999. Serum complement levels in children in communities with different levels of air pollution in Japan. Arch Environ Health 54:264–270.

Shima M, Nitta Y, Adachi M. 2003. Traffic-related air pollution and respiratory symptoms in children living along trunk roads in Chiba Prefecture, Japan. J Epidemiol 13:108–119.

Shima M, Nitta Y, Ando M, Adachi M. 2002. Effects of air pollution on the prevalence and incidence of asthma in children. Arch Environ Health 57:529–535.

Shimizu S, Kagawa J, Ishiguro M. 2001. The association between emergency clinic visits for asthmatic attacks and fluctuating environmental factors [in Japanese]. Arerugi 50:612–620.

Simes RJ. 1986. Publication bias: The case for an international registry of clinical trials. J Clin Oncol 4: 1529–1541.

Smith KR. 1990. The risk transition. Int Environ Aff 2:227–251.

Smith KR. 1996. The natural debt: north and south. Chapter 16 in: Climate Change: Developing Southern Hemisphere Perspectives (Giambelluca TW, Henderson-Sellers A, eds), pp 423–448. Wiley & Sons, New York NY.

Smith KR. 1997. Development, health, and the environmental risk transition. Chapter 3 in: International Perspectives in Environment, Development, and Health: Toward a Sustainable World. A Collaborative Initiative of the World Health Organization, the United Nations Development Programme, and the Rockefeller Foundation (Shahi G, Levy BS, Binger A, Kjellstrom T, Lawrence R, eds), pp 51–62. Springer, New York NY.

Smith KR. 2000. National burden of disease in India from indoor air pollution. Proc Natl Acad Sci U S A 97:13286–13293.

Smith KR, Apte MG, Yuqing M, Wongsekiarttirat W, Kulkarni A. 1994. Air pollution and the energy ladder in Asian cities. Energy 19:587–600.

Smith KR, Corvalán CF, Kjellström T. 1999. How much global ill health is attributable to environmental factors? Epidemiology 10:573–584.

Smith KR, Mehta S, Feuz M. 2004. Indoor air pollution from solid fuel use. In: Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors (Ezzati M, Lopez AD, Rodgers A, Murray CJL, eds), vol 2. World Health Organization, Geneva, Switzerland. In press.

Smith KR, Samet JM, Romieu I, Bruce N. 2000. Indoor air pollution in developing countries and acute lower respiratory infections in children. Thorax 55:518–532.

Srivastava A, Kumar R. 2002. Economic valuation of health impacts of air pollution in Mumbai. Environ Monit Assess 75:135–143.

Sterling TD. 1959. Publication decisions and their possible effects on inferences drawn from tests of significance—or vice versa. J Am Stat Assoc 54:30–34.

Stieb DM, Judek S, Burnett RT. 2002. Meta-analysis of time-series studies of air pollution and mortality: Effects of gases and particles and the influence of cause of death, age, and season. J Air Waste Manage Assoc 52:470–484.

Tam AYC, Wong CM, Lam TH, Ong SG, Peters J, Hedley AJ. 1994. Bronchial responsiveness in children exposed to atmospheric pollution in Hong Kong. Chest 106:1056–1060.

Tan WC, Qiu D, Liam BL, Ng TP, Lee SH, van Eeden SF, D'Yachkova Y, Hogg JC. 2000. The human bone marrow response to acute air pollution caused by forest fires. Am J Respir Crit Care Med 161:1213–1217.

Tanaka H, Honma S, Nishi M, Igarashi T, Teramoto S, Nishio F, Abe S. 1998. Acid fog and hospital visits for asthma: An epidemiological study. Eur Respir J 11:1301–1306.

Tang F-C, Chen P-C, Chan C-C, Yau K-IT, Wang J-D. 1997. Predictive pulmonary function of school children in an area of low air pollution in Taiwan. J Formos Med Assoc 96:397–404.

Tango T. 1994. Effect of air pollution on lung cancer: A Poisson regression model based on vital statistics. Environ Health Perspect 102(Suppl 8):41–45.

Tao X, Hong CJ, Yu S, Chen B, Zhu H, Yang M. 1992. Priority among air pollution factors for preventing chronic obstructive pulmonary disease in Shanghai. Sci Total Environ 127:57–67.

Thorvaldsen P, Asplund K, Kuulasmaa K, Rajakangas A-M, Schroll M, for the WHO MONICA project. 1995. Stroke incidence, case fatality, and mortality in the WHO MONICA project: World Health Organization Monitoring Trends and Determinants in Cardiovascular Disease. Stroke 26:361–367.

Tri-Tugaswati A, Yasuo K. 1996. Effect of air pollution on respiratory symptoms of junior high school students in Indonesia. Southeast Asian J Trop Med Public Health 27:792–800.

Tsai FC, Smith KR, Vichit-Vadakan N, Ostro BD, Chestnut LG, Kungskulniti N. 2000. Indoor/outdoor PM_{10} and $PM_{2.5}$ in Bangkok, Thailand. J Expos Anal Environ Epidemiol 10:15–26.

Tsai S-S, Huang C-H, Goggins WB, Wu, T-N, Yang CY. 2003. Relationship between air pollution and daily mortality in a tropical city: Kaohsiung, Taiwan. J Toxicol Environ Health 66:1341–1349.

Tseng RYM, Li CK. 1990. Low level atmospheric sulfur dioxide pollution and childhood asthma. Ann Allergy 65:379–383.

Tseng RYM, Li CK, Spinks JA. 1992. Particulate air pollution and hospitalization for asthma. Ann Allergy 68:425–432.

United Nations. 1995. World Urbanization Prospects: The 1994 Revision. Population Division, Department of Economic and Social Affairs, New York NY.

United Nations. 2001. World Urbanization Prospects: The 1999 Revision. ST/ESA/SER.A/194. Population Division, Department of Economic and Social Affairs, New York NY.

United Nations. 2002. World Urbanization Prospects: The 2001 Revision. ST/ESA/SER.A/216. Population Division, Department of Economic and Social Affairs, New York NY.

United Nations Centre for Human Settlements (Habitat). 1996. An Urbanizing World: Global Report on Human Settlements, 1996. Oxford University Press, New York NY.

United Nations Department of Economic and Social Affairs. 2004. World Economic Situation and Prospects 2004. ISBN:9211091462. United Nations, New York NY. Available at *www.un.org/esa/policy/wess/wesp2004.pdf*.

United Nations Development Programme. 2002. Human Development Report 2002: Deepening Democracy in a Fragmented World. Oxford University Press, New York NY.

United Nations Environment Programme. 1996. International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management. IETC Technical Publication Series 6. International Environmental Technology Centre, Osaka/Shiga, Japan.

Venners SA, Wang B, Peng Z, Xu Y, Wang L, Xu X. 2003. Particulate matter, sulfur dioxide, and daily mortality in Chongqing, China. Environ Health Perspect 111:562–567.

Vichit-Vadakan N. 2003. Measuring the Health Effects of Cleaning the Air: A Case Study on the Health Benefits of Reducing Lead in Petrol in Bangkok. Presentation at the Better Air Quality 2003 Workshop, Manila, Philippines, December 17–19, 2003. Available at *www.cleanairnet.org/baq2003/1496/article-58066.html*.

Vichit-Vadakan N, Ostro BD, Chestnut LG, Mills DM, Aekplakorn W, Wangwongwatana S, Panich N. 2001. Air pollution and respiratory symptoms: Results from three panel studies in Bangkok, Thailand. Environ Health Perspect 109(Suppl 3):381–387.

Wang B, Peng Z, Zhang X, Xu Y, Wang H, Allen G, Wang L, Xu X. 1999a. Particulate matter, sulfur dioxide, and pulmonary function in never- smoking adults in Chongqing, China. Int J Occup Environ Health 5:14–19.

Wang J. 1992. Study of the effects of air pollution on human health in Beijing [in Chinese]. Zhonghua Liu Xing Bing Xue Za Zhi 13:89–92.

Wang JN, Cao SR, Li Z, Zhang Y, Li SM. 1988. Human exposure to carbon monoxide and inhalable particulate in Beijing, China. Biomed Environ Sci 1:5–12.

Wang T-N, Ko Y-C, Chao Y-Y, Huang C-C, Lin R-S. 1999b. Association between indoor and outdoor air pollution and adolescent asthma from 1995 to 1996 in Taiwan. Environ Res 81:239–247.

Wang X, Ding H, Ryan L, Xu X. 1997. Association between air pollution and low birth weight: A community-based study. Environ Health Perspect 105:514–520.

Wichmann HE, Mueller W, Allhoff P, Beckmann M, Bocter N, Csicsaky MJ, Jung M, Molik B, Schoeneberg G. 1989. Health effects during a smog episode in West Germany in 1985. Environ Health Perspect 79:89–99.

Wilhelm M, Ritz B. 2003. Residential proximity to traffic and adverse birth outcomes in Los Angeles County, California, 1994–1996. Environ Health Perspect 111:207–216.

Wong CM, Atkinson RW, Anderson HR, Hedley AJ, Ma S, Chau PYK, Lam T-H. 2002a. A tale of two cities: Effects of air pollution on hospital admissions in Hong Kong and London compared. Environ Health Perspect 110:67–77.

Wong CM, Hu ZG, Lam TH, Hedley AJ, Peters J. 1999a. Effects of ambient air pollution and environmental tobacco smoke on respiratory health of non-smoking women in Hong Kong. Int J Epidemiol 28:859–864.

Wong CM, Lam TH, Peters J, Hedley AJ, Ong SG, Tam AYC, Liu J, Spiegelhalter DJ. 1998. Comparison between two districts of the effects of an air pollution intervention on bronchial responsiveness in primary school children in Hong Kong. J Epidemiol Community Health 52:571–578.

Wong CM, Ma S, Hedley AJ, Lam T-H. 1999c. Does ozone have any effect on daily hospital admissions for circulatory diseases? J Epidemiol Community Health 53:580–581.

Wong CM, Ma S, Hedley AJ, Lam T-H. 2001b. Effect of air pollution on daily mortality in Hong Kong. Environ Health Perspect 109:335–340.

Wong GWK, Ko FWS, Lau TS, Li ST, Hui D, Pang SW, Leung R, Fok TF, Lai CKW. 2001a. Temporal relationship between air pollution and hospital admissions for asthmatic children in Hong Kong. Clin Exp Allergy 31:565–569.

Wong TW, Lau TS, Yu TS, Neller A, Wong SL, Tam W, Pang SW. 1999b. Air pollution and hospital admissions for respiratory and cardiovascular diseases in Hong Kong. Occup Environ Med 56:679–683.

Wong TW, Tam WS, Yu TS, Wong AHS. 2002b. Associations between daily mortalities from respiratory and cardiovascular diseases and air pollution in Hong Kong, China. Occup Environ Med 59:30–35.

Wong TW, Wun YT, Yu TS, Tam W, Wong CM, Wong AHS. 2002c. Air pollution and general practice consultations for respiratory illnesses. J Epidemiol Community Health 56:949–950.

Wongsurakiat P, Maranetra KN, Nana A, Naruman C, Aksornint M, Chalermsanyakorn T. 1999. Respiratory symptoms and pulmonary function of traffic policemen in Thonburi. J Med Assoc Thai 82:435–443.

Woo KS, Donnan SP. 1989. Epidemiology of coronary arterial disease in the Chinese. Int J Cardiol 24:83–93.

Woodruff TJ, Grillo J, Schoendorf KC. 1997. The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States. Environ Health Perspect 105:608–612.

World Health Organization. 1979. Guidelines for Air Quality. WHO, Geneva, Switzerland.

World Health Organization. 1997. Health and Environment in Sustainable Development: Five Years After the Earth Summit. WHO/EHG/97.8, p 86. WHO, Geneva, Switzerland.

World Health Organization. 1998. Report on the Bi-Regional Workshop on Health Impacts of Haze-Related Air Pollution. Report RS/98/GE/17 (MAA). WHO Regional Office for the Western Pacific, Manila, Philippines.

World Health Organization. 1999. Guidelines for Air Quality. WHO, Geneva, Switzerland.

World Health Organization. 2000a. Guidelines for Air Quality. WHO, Geneva, Switzerland.

World Health Organization. 2000b. World Health Statistics Annual. WHO, Geneva, Switzerland.

World Health Organization. 2001a. GBD 2000 Version 1 Estimates by Region: Mortality (last updated 10/3/01). *www3.who.int/whosis/menu.cfm?path=whosis,burden,burden_estimates,burden_estimates_2000V1,burden_estimates_2000V1_region&language=english.* Accessed 04/04.

World Health Organization. 2001b. GBD 2000 Version 1 Estimates by Region: DALYs (last updated 10/3/01). *www3.who.int/whosis/menu.cfm?path=whosis,burden,burden_estimates,burden_estimates_2000V1,burden_estimates_2000V1_region&language=english.* Accessed 04/04.

World Health Organization. 2002. The World Health Report 2002: Reducing Risks, Promoting Healthy Life. WHO, Geneva, Switzerland.

World Health Organization. 2003. Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide. EUR/03/5042688. Report of a WHO Working Group. WHO, Bonn, Germany. Available at *www.euro.who.int/document/e79097.pdf.*

World Health Organization United Nations Environment Programme. 1992. Urban Air Pollution in Megacities of the World. Earthwatch: Global Environment Monitoring System. Blackwell Publishers, Cambridge MA.

Wu AH, Henderson BE, Pike MC, Yu MC. 1985. Smoking and other risk factors for lung cancer in women. JNCI 74:747–751.

Wu-Williams AH, Dai XD, Blot W, Xu ZY, Sun XW, Xiao HP, Stone BJ, Yu SF, Feng YP, Ershow AG, et al. 1990. Lung cancer among women in north-east China. Br J Cancer 62:982–987.

Xiao H-P, Xu Z-Y. 1985. Air pollution and lung cancer in Liaoning Province, People's Republic of China. JNCI Monogr 69:53–58.

Xu X, Ding H, Wang X. 1995a. Acute effects of total suspended particles and sulfur dioxides on preterm delivery: A community-based cohort study. Arch Environ Health 50:407–415.

Xu X, Dockery DW, Christiani DC, Li B, Huang H. 1995b. Association of air pollution with hospital outpatient visits in Beijing. Arch Environ Health 50:214–220.

Xu X, Gao J, Dockery DW, Chen Y. 1994. Air pollution and daily mortality in residential areas of Beijing, China. Arch Environ Health 49:216–222.

Xu X, Li B, Huang H. 1995c. Air pollution and unscheduled hospital outpatient and emergency room visits. Environ Health Perspect 103:286–289.

Xu XP, Dockery DW, Wang L. 1991. Effects of air pollution on adult pulmonary function. Arch Environ Health 46:198–206.

Xu X, Wang L. 1993. Association of indoor and outdoor particulate level with chronic respiratory illness. Am Rev Respir Dis 148:1516–1522.

Xu Z, Yu D, Jing L, Xu X. 2000. Air pollution and daily mortality in Shenyang, China. Arch Environ Health 55:115–120.

Xu ZY, Blot WJ, Fraumeni JF Jr. 1986. Geographic variation of female lung cancer in China. Am J Public Health 76:1249–1250.

Xu Z-Y, Blot WJ, Xiao H-P, Wu A, Feng Y-P, Stone BJ, Sun J, Ershow AG, Henderson BE, Fraumeni JF Jr. 1989. Smoking, air pollution, and the high rates of lung cancer in Shenyang, China. JNCI 81:1800–1806.

Xu ZY, Brown L, Pan GW, Li G, Feng YP, Guan DX, Liu TF, Liu LM, Chao RM, Sheng JH, Gao GC. 1996a. Lifestyle, environmental pollution and lung cancer in cities of Liaoning in northeastern China. Lung Cancer 14(Suppl 1):S149–S160.

Xu ZY, Liu Y, Yu D, Chen B, Xu X, Jin L, Yu G, Zhang S, Zhang J. 1996b. Effect of air pollution on mortalities in Shenyang city [in Chinese]. Chin J Public Health 15:61–64.

Yan CH, Wu SH, Shen XM, Zhang Y, Jiang F, Yin J, Zhou J, He J, Ao L, Zhang Y, Li R. 2002. The trends of changes in children's blood lead levels since the introduction of lead free gasoline in Shanghai [in Chinese]. Zhonghua Liu Xing Bing Xue Za Zhi 23:172–174.

Yanagisawa Y, Nishimura H, Matsuki H, Osaka F, Kasuga H. 1986. Personal exposure and health effect relationship for NO_2 with urinary hydroxyproline to creatinine ratio as indicator. Arch Environ Health 41:41–48.

Yang C-Y, Cheng B-H, Hsu T-Y, Chuang H-Y, Wu T-N, Chen P-C. 2002a. Association between petrochemical air pollution and adverse pregnancy outcomes in Taiwan. Arch Environ Health 57:461–465.

Yang C-Y, Cheng M-F, Chiu J-F, Tsai S-S. 1999a. Female lung cancer and petrochemical air pollution in Taiwan. Arch Environ Health 54:180–185.

Yang C-Y, Chiu H-F, Tsai S-S, Chang C-C, Chuang H-Y. 2002b. Increased risk of preterm delivery in areas with

cancer mortality problems from petrochemical complexes. Environ Res 89:195–200.

Yang CY, Tsai SS, Cheng BH, Hsu TY, Wu TN. 2000. Female lung cancer mortality and sex ratios at birth near a petroleum refinery plant. Environ Res 83:33–40.

Yang C-Y, Tseng Y-T, Chang C-C. 2003. Effects of air pollution on birth weight among children born between 1995 and 1997 in Kaohsiung, Taiwan. J Toxicol Environ Health A66:807–816.

Yang C-Y, Wang J-D, Chan C-C, Chen P-C, Huang J-S, Cheng M-F. 1997. Respiratory and irritant health effects of a population living in a petrochemical-polluted area in Taiwan. Environ Res 74:145–149.

Yang C-Y, Wang J-D, Chan C-C, Hwang J-S, Chen P-C. 1998. Respiratory symptoms of primary school children living in a petrochemical polluted area in Taiwan. Pediatr Pulmonol 25:299–303.

Yang C-Y, Yu S-T, Chang C-C. 2002c. Respiratory symptoms in primary schoolchildren living near a freeway in Taiwan. J Toxicol Environ Health A 65:747–755.

Yang G, Fan L, Tan J, Qi G, Zhang Y, Samet JM, Taylor CE, Becker K, Xu J. 1999b. Smoking in China: Findings of the 1996 National Prevalence Survey. JAMA 282:1247–1253.

Yau K-IT, Fang L-J, Shieh K-H. 1999. Factors predisposing infants to lower respiratory infection with wheezing in the first two years of life. Ann Allergy Asthma Immunol 82:165–170.

Ye F, Piver WT, Ando M, Portier CJ. 2001. Effects of temperature and air pollutants on cardiovascular and respiratory diseases for males and females older than 65 years of age in Tokyo, July and August 1980–1995. Environ Health Perspect 109:355–359.

Yu T-SI, Wong TW, Wang XR, Song H, Wong SL, Tang JL. 2001. Adverse effects of low-level air pollution on the respiratory health of schoolchildren in Hong Kong. J Occup Environ Med 43:310–316.

Yusuf S, Reddy S, Ounpuu S, Anand S. 2001a. Global burden of cardiovascular diseases. Part I: General considerations, the epidemiologic transition, risk factors, and impact of urbanization. Circulation 104:2746–2753.

Yusuf S, Reddy S, Ounpuu S, Anand S. 2001b. Global burden of cardiovascular diseases. Part II: Variations in cardiovascular disease by specific ethnic groups and geographic regions and prevention strategies. Circulation 104:2855–2864.

Zanobetti A, Wand MP, Schwartz J, Ryan LM. 2000. Generalized additive distributed lag models: Quantifying mortality displacement. Biostatistics 1:279–292.

Zanobetti A, Schwartz J, Samoli E, Gryparis A, Touloumi G, Atkinson R, Le Tertre A, Bobros J, Celko M, Goren A, Forsberg B, Michelozzi P, Rabczenko D, Aranguez Ruiz E, Katsouyanni K. 2002. The temporal pattern of mortality responses to air pollution: A multicity assessment of mortality displacement. Epidemiology 13:87–93.

Zanobetti A, Schwartz J, Samoli E, Gryparis A, Touloumi G, Peacock J, Anderson RH, Le Tertre A, Bobros J, Celko M, Goren A, Forsberg B, Michelozzi P, Rabczenko D, Hoyos SP, Wichmann HE, Katsouyanni K. 2003. The temporal pattern of respiratory and heart disease mortality in response to air pollution. Environ Health Perspect 111:1188–1193.

Zeger SL, Dominici F, Samet J. 1999. Harvesting-resistant estimates of air pollution effects on mortality. Epidemiology 10:171–175.

Zhang H, Cai B. 2003. The impact of tobacco on lung health in China. Respirology 8:17–21.

Zhang J, Hu W, Wei F, Wu G, Korn LR, Chapman RS. 2002. Children's respiratory morbidity prevalence in relation to air pollution in four Chinese cities. Environ Health Perspect 110:961–967.

Zhang J, Qian Z, Kong L, Zhou L, Yan L, Chapman RS. 1999. Effects of air pollution on respiratory health of adults in three Chinese cities. Arch Environ Health 54:373–381.

Zhang J, Smith KR. 2003. Indoor air pollution: A global health concern. Brit Med Bull 68:209–225.

Zhang J, Song H, Tong S, Li L, Liu B, Wang L. 2000. Ambient sulfate concentration and chronic disease mortality in Beijing. Sci Total Environ 262:63–71.

Zhou W, Yuan D, Ye S, Qi P, Fu C, Christiani DC. 2001. Health effects of occupational exposures to vehicle emissions in Shanghai. Int J Occup Environ Health 7:23–30.

Zhou YR, Zhen Q, Xu F. 1996. Impact of air pollution on human respiratory system in Chongqing [in Chinese]. Acta Universitas Scientiae Medicinae Chongqing 21(Suppl):118–122.

Zhu ZH, Tau ZQ, Yi ZK, Zhang Y, Deng YK. 1987. The effect of air pollution on lymphocyte transformation rate in children [in Chinese]. Hua Xi Yi Ke Da Xue Bao 18:157–159.

Appendices A–H. Summaries of Epidemiologic Studies of Air Quality and Health in Asia (1980–2003)

Appendix A. China

Appendix B. India

Appendix C. Indonesia

Appendix D. Japan

Appendix E. Malaysia

Appendix F. Singapore

Appendix G. South Korea

Appendix H. Thailand

Appendix A. China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Mainland China[b]					
Chang et al 2003a Beijing	Time series	1998–2000 All cause-specific deaths	TSP, SO_2, CO, NO_x, PM_{10}	Daily cause-specific mortality (RespD, CVD, CBVD, CHD, COPD)	Airborne levels of CO, SO_2, NO_x, and PM_{10} each correlated significantly with mortality, especially from RespD, CVD, CBVD, CHD, and COPD. TSP levels were associated with RespD.
Chang et al 2003b Beijing	Time series	1998–2000 Children	TSP, PM_{10}, SO_2, NO_x, CO	Daily unscheduled hospital outpatient and ER visits for colds, pneumonia, and bronchitis	When CO, SO_2, NO_x or PM_{10} increased by 100 μg/m^3, visits for colds, bronchitis and pneumonia also increased by 1–8%.
Chen et al 1995 Guangzhou	Case control	1985–1992 7695 delivered infants (325 adverse outcomes and 390 controls)	Petrochemical air pollution	Pregnancy outcomes (congenital malformation, stillbirth, low birth weight, preterm birth)	Adverse pregnancy outcomes were significantly higher among women living near a petrochemical plant.
Dong et al 1996 Beijing	Time series	1991 All unscheduled patient visits	TSP, SO_2	Unscheduled outpatient and surgery visits	Airborne TSP level was significantly related to the number of unscheduled nonsurgical outpatient visits but not to the number of unscheduled surgical visits. SO_2 was significantly associated with pediatric visits only.
Gao et al 1993 Beijing	**Time series**	**1989 All deaths**	**TSP, SO_2**	**Total mortality, RespD mortality**	**Logarithmic levels of airborne SO_2 were significantly associated with daily number of deaths (especially from bronchitis, COPD, and cor pulmonale).**
Han et al 1995 Datong	Ecologic	1985–1989	TSP, B*a*P	Tumor mortality, serum copper and zinc levels	Greater levels of nitrate and nitrite in drinking water and airborne levels of B*a*P were associated with significantly higher levels of serum copper and zinc and significantly higher incidence of malignant tumor mortality compared with a control group.
Han et al 1997 Datong	Cross section	35,561 subjects in polluted area; 35,110 in nonpolluted areas	TSP, B*a*P	Cytogenetic damage	The micronuclei and aberration nucleus rates as well as the cpm values of cultured lymphocytes among residents strongly correlated with B*a*P, TSP, nitrate, and nitrite in air and drinking water.

Table continues next page

[a] Entries in bold type were included in the meta-analysis.

[b] One panel study published in China was not available for review: Zhu ZH, Tau ZQ, Yi ZK, Deng YK. 1987. The effect of air pollution on lymphocyte transformation rate in children [in Chinese]. Hua Xi Yi Ke Da Zue Zue Bao 18(2):157–159.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Mainland China (*continued*)					
He et al 1993 Wuhan	Cross section	1981–1988 604 children	TSP, NO_x, SO_2, CO	Pulmonary function (FVC, FEV_1), clinical exam of upper respiratory tract (nasal mucosa, concha, nasal passages, pharynx, tonsils)	Higher airborne TSP, SO_2, and NO_x values were associated with significantly slower growth of respiratory function and respiratory irritation in children but not with FEV_1.
Kan and Chen 2003 Shanghai	Case crossover	2000–2001	PM_{10}, NO_2, SO_2	Mortality (total, COPD, and CVD)	Conditional logistic regression identified increases in relative risk of death from COPD and CVD for each 10 μg/m^3 increase in NO_2, SO_2 and PM_{10} (in decreasing intensity of impact). The study also provides information on the applicability of case-crossover study design.
Jin et al 1999 Benxi	Ecologic	1993–1994 667,553 people	TSP, SO_2	All-cause mortality, COPD, CVD, CBVD	Annual daily mean TSP concentrations varied from medium to high in three districts of Benxi, a major base of the iron and steel industry. With each 100 μg/m^3 increase in TSP, mortality from all causes, COPD, CVD, and CBVD were estimated to increase by 8% to 24%.
Li et al 1994 Shandong Province	Ecologic	1985–1989 All deaths	Air pollution	Lung cancer mortality	Compared with 1970–1974, deaths from lung cancer were higher in 1985–1989. Correlational analyses attributed rate of lung cancer to air pollution.
Ma and Hong 1992 Shanghai	Cross section	Residents	TSP	Chronic respiratory illness	A 100 μg/m^3 increase in TSP levels was associated with odds ratios of 1.1% to 1.6% for incidence of respiratory symptoms and diseases.
Qian et al 2000 Lanzhou, Wuhan, Guangzhou	Cross section	1985–1988 1784 city children	TSP, NO_x, SO_2	Wheeze, asthma, bronchitis, hospitalization due to RespD, cough, phlegm, pneumonia	In all 3 urban districts, TSP levels were significantly associated with the adjusted odds ratios for cough, phlegm, hospitalization, and pneumonia. Parental smoking was associated with cough and phlegm, and coal use in the home was associated only with cough.
Tao et al 1992 Shanghai	Cross section	1978–1987 All deaths	SO_2, inhalable particles (<10 nm), indoor coal use	Mortality and morbidity (COPD, lung function, nonspecific immunologic function)	Among ambient SO_2, inhalable particles, and indoor use of coal, COPD mortality and morbidity as well as nonspecific immunologic compromise correlated most strongly with indoor use of coal.

Table continues next page

[a] Entries in bold type were included in the meta-analysis.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Mainland China (*continued*)					
Venners et al 2003 Chongqing	**Time series**	**1995 576,000 residents**	**SO_2, $PM_{2.5}$**	**Daily mortality (RespD, CVD, cancers, other)**	**When SO_2 increased by 100 μg/m^3, relative risks of mortality (lags 2 and 3), RespD mortality (lag 2), and CVD mortality (lag 3) also increased. The association of $PM_{2.5}$ and daily mortality was negative and nonsignificant. Rates of mortality due to cancer and other causes did not change. Estimated RespD and CVD mortality correlated with SO_2 even after control for $PM_{2.5}$.**
Wang 1992 Beijing	Cross section	1989–1990 1500 adults, 1500 children	Urban, suburban, rural pollution	Health status, respiratory symptoms	The effects of air pollution on human health in cities were more severe than in the suburban and rural areas. Respiratory complaints correlated with the level of pollution.
Wang et al 1988 Beijing	Panel	20 nonsmokers	Indoor, outdoor, and personal exposure levels of CO, PM	Serum CO	Average outdoor CO concentration was 1.5 ppm in summer and 3.9 ppm in winter; indoor CO averaged 2.8 ppm in summer and 20.1 ppm in winter. Personal exposure fluctuated between these values. Serum CO was 0.2% in summer and 1.9% in winter.
Wang et al 1997 Beijing	Cohort	1988–1991 parity1 live births	TSP, SO_2	Birth weight	Maternal exposure to airborne SO_2 and TSP during the third trimester of pregnancy was significantly related to reduced infant birth weight.
Wang et al 1999a Chongqing	Cross section	1989 1075 adults 35–60 yr	SO_2, $PM_{2.5}$	Lung function	Mean urban SO_2 (213 μg/m^3) was double suburban SO_2 (103 μg/m^3). Urban and suburban $PM_{2.5}$ were high (143 and 139 μg/m^3, respectively). After removal of 104 subjects with confounding occupation exposures, the estimated difference between urban and suburban FEV_1, and FEV_1/FVC% were significant for men and women.
Xiao and Xu 1985 Liaoning Province	Ecologic	1976–1978	TSP, industrial pollution (including Cu, Zn)	Lung cancer mortality	Neighborhood air pollution indices correlated significantly with mortality rates in one city, and lung cancer rates were higher near point sources of industrial pollution. Little correlation was found between TSP levels and lung cancer in 10 cities.

Table continues next page

[a] Entries in bold type were included in the meta-analysis.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Mainland China (*continued*)					
Xu and Wang 1993 Beijing	Cross section	1982 1576 never-smokers (40–69 yr)	Airborne particulates	Respiratory illness	Particulate levels were highest to lowest in the industrial, residential, and suburban areas. Subjects residing in the industrial and residential areas had an excess risk of respiratory symptoms and showed an increased prevalence of symptoms with increased outdoor particulate levels.
Xu et al 1989 Shenyang	Case control	1985–1987 1249 patients, 1345 controls	Industrial pollution	Lung cancer	After adjustment for smoking (the principal cause of lung cancer in this cohort), increased lung cancer risk was significantly associated with several measures of exposure to air pollutants.
Xu et al 1991 Beijing	Cohort	1986 1440 adults (40–69 yr)	TSP, SO_2	Pulmonary function	Outdoor SO_2 had an inverse linear relation to lung capacity with or without coal stove heating.
Xu et al 1994 Beijing	**Time series**	**1989 1.5 million residents in two areas**	**SO_2, TSP**	**Daily mortality (all causes, CVD, cardiopulmonary disease, cancer)**	**SO_2 was significantly associated with total mortality (at levels below WHO recommendations) and with COPD, CHD, cardiopulmonary, and CVD mortality. TSP was significantly associated only with COPD mortality. SO_2 and TSP were significant predictors of total mortality in summer, but in winter only SO_2 was a significant predictor.**
Xu et al 1995a Beijing	Cohort	1988 (25,370 deliveries)	TSP, SO_2	Preterm delivery (at < 37 weeks)	Preterm delivery showed a significant dose-dependent association with levels of SO_2 and TSP (mean SO_2, 102 μg/m^3; mean TSP, 375 μg/m^3).
Xu et al 1995b Beijing	**Time series**	**1990**	**TSP, SO_2**	**Hospital outpatient visits**	**The number of daily nonsurgical outpatient visits was significantly associated with SO_2 and TSP levels, especially in summer. This was true even though the mean SO_2 concentration in summer was only 17 μg/m^3.**

Table continues next page

[a] Entries in bold type were included in the meta-analysis.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Mainland China (*continued*)					
Xu et al 1995c Beijing	**Time series**	**1990**	**TSP, SO_2**	**Daily hospital outpatient and ER visits**	**Results suggested an exposure–response relation between TSP and SO_2 and hospital outpatient visits both at high air pollution levels and at levels well below WHO air quality standards.**
Xu et al 1996a Shenyang	Case control	1985–1988 1249 lung cancer patients, 1345 controls	Industrial pollution	Lung cancer mortality	Risk was increased for all occupations in which there was exposure to dusts, with the highest risk seen among coke oven workers and fire-resistant brick makers. Significant dose–response patterns were observed among cumulative total dust, cumulative total B*a*P, and lung cancer.
Xu et al 1996b Shenyang	Ecologic	438,600 people	TSP, SO_2	All-cause mortality, COPD, CBVD, CVD, cancer, tuberculosis	Annual daily TSP means in three neighborhoods of low, medium, or high pollution were 361, 477, and 518 μg/m^3. The means for SO_2 were 64, 128, and 235 μg/m^3. The three neighborhoods differed in rates of mortality from all causes, COPD, CBVD, CVD, cancer, and tuberculosis.
Xu et al 2000 Shenyang	**Time series**	**1992 3.1 million residents**	**SO_2, TSP**	**Daily mortality (all causes, CVD, cardiopulmonary disease, COPD, cancer)**	**High mean TSP (430 μg/m^3) and SO_2 (197 μg/m^3) levels were each positively associated with total daily mortality. TSP was also significantly associated with CVD mortality, and SO_2 was positively associated with COPD mortality.**
Yan et al 2002 Shanghai	Ecologic	2001–2002 Children	Lead	Blood lead levels	Unleaded gasoline became available throughout China in 2000. One year later, the average blood level of lead among children in Shanghai had dropped from 3 μg/dL to 80 μg/dL. Two years later, 2002, the average level was 76 μg/dL.
Zhang et al 1999 Lanzhou, Wuhan, Guangzhou	Cross section	1985–1988 4108 adults	TSP, SO_2, NO_x	Respiratory morbidity (cough, phlegm, wheeze, persistent cough & phlegm, asthma, bronchitis)	Standardized questionnaires revealed increased rates of cough, phlegm, persistent cough and phlegm, and wheeze associated with increasing TSP levels. Findings in adults were compared to their children. Tobacco smoking was a confounder.
Zhang et al 2000 Beijing	Cohort	1980–1992 4108 adults	SO_4^{2-}, TSP, SO_2, NO_x, CO, B*a*P	Cause-specific mortality (total, RespD, CBVD and CVD, malignant tumor)	Both current SO_4^{2-} level and the level 12 yr prior to death were significantly correlated with total mortality and mortality due to CVD, malignant tumor, and lung cancer. SO_4^{2-} levels did not correlate with mortality from RespD or CBVD.

Table continues next page

[a] Entries in bold type were included in the meta-analysis.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Mainland China (*continued*)					
Zhang et al 2002 Guangzhou, Wuhan, Lanzhou, Chongqing	Cross section	1993–1996 7557 elementary school students	NO_x, SO_2, TSP, $PM_{(2.5,\ 10–2.5,\ 10)}$	Wheeze, asthma, bronchitis, hospitalization due to respiratory diseases, persistent cough, persistent phlegm	Standardized questionnaires revealed positive associations between respiratory morbidity and all outdoor PM levels, especially $PM_{10–2.5}$. A weaker but still positive association was found with NO_x and SO_2.
Zhou et al 1996 Chongqing	Cross section		Air pollution unspecified	Upper respiratory symptoms	An attributable risk of 20% was reported for upper respiratory symptoms from exposure to air pollution.
Zhou et al 2001 Shanghai	Cross section	1998 745 bus and taxi drivers, 532 controls	Vehicle emissions	Respiratory symptoms	The prevalence of some respiratory symptoms and chronic respiratory diseases was significantly higher in the exposed group compared with controls. Pulmonary function and serum lead levels did not significantly correlate with exposure.
Hong Kong					
Hedley et al 2002 Hong Kong	Time series	1985–1995 ~75% of Hong Kong residents	NO_2, SO_2, PM_{10}, O_3	Monthly mortality (all, RespD, CVD)	A one-weekend restriction to < 0.5% sulfur content in fuel oil for power plants and motor vehicles in Hong Kong led to an immediate fall in SO_2 levels. In the following year, seasonal mortality was substantially reduced for total deaths, RespD, and CVD causes, resulting in a gain in life expectancy. By 3–5 years later, the pattern had returned to expected.
Ong et al 1991 Hong Kong	Cross section	1989 3846 school children	Emissions from factories	Respiratory morbidity (sore throat, evening cough, cough for longer than 3 months, morning phlegm, wheezing)	In a district with high levels of exhaust emissions from factories, primary school children had significantly higher levels of sore throat, cough, morning phlegm, and wheezing compared with a control group. The study was intended to provide a baseline for evaluating the impact of low sulfur regulations to be introduced subsequently.
Peters et al 1996 Hong Kong	Cross section	1989–1991 3521 children	RSP, NO_x, SO_2, TSP	Respiratory symptoms	After regulation, ambient SO_2 levels in a polluted district of Hong Kong fell by up to 80% and sulfate in respiratory particles fell by 38%. Reports of cough, sore throat, phlegm and wheezing among children declined. Tobacco smoke in the home increased the risk for RespD before and after the regulation.

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[a] Entries in bold type were included in the meta-analysis.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Hong Kong (*continued*)					
Tam et al 1994 Hong Kong	Cross section	1989–1990 423 children (mean age, 10.85 yr)	NO_2, O_3, SO_2, RSP, TSP	Bronchial responsiveness (FEV_1, FVC)	Bronchial hyperreactivity after histamine challenge was more common among children living in a more polluted district even when results were controlled for wheeze, asthma, home tobacco smoke, and socioeconomic factors.
Tseng and Li 1990 Hong Kong	Time series	1983–1987 13,620 childhood hospitalizations	SO_2, NO_2, NO, O_3, TSP, RSP	Asthma episodes	Hospitalizations of children for asthma compared with levels of SO_2, NO_2, NO, O_3, TSP, and RSP identified an inverse correlation of SO_2 with hospitalization.
Tseng et al 1992 Hong Kong	Time series	1983–1989 hospital patients	TSP, RSP, NO_2, NO_x, SO_2, O_3	Hospital discharges for asthma	Quarterly mean TSP and hospital discharge rates were strongly correlated for children 1–4 yr, were inversely correlated for children 5–14 yr, and were uncorrelated for adults. No correlation was found for SO_2, O_3, RSP, NO_2, or NO_x.
Wong et al 1998 Hong Kong	Cohort	1990–1991 School children 9–12 yr	Ambient air pollution before and after intervention	Bronchial reactivity and hyperreactivity	At 1 and 2 years after government restriction of sulfur content in fuels to 0.5%, children were challenged with histamine. Those in a highly polluted district and those in a less polluted district showed significant differences in bronchial hyperreactivity but not in bronchial reactivity 1 year later. Children in the more polluted area showed a further significant decrease in hyperreactivity and reactivity in the second year.
Wong et al 1999a Hong Kong	Cohort	1989–1991 3405 nonsmoking women (mean age, 36.5 yr)	TSP, SO_2, NO_x	Respiratory symptoms (sore throat, morning cough, evening cough, phlegm in the morning, phlegm day or night, and phlegm for 3 months)	Assessments before and 1 and 2 yr after governmental restriction of sulfur in fuel oil showed that air pollution and tobacco smoke had adverse effects.

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[a] Entries in bold type were included in the meta-analysis.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Hong Kong (*continued*)					
Wong et al 1999b Hong Kong	**Time series**	**1994–1995**	**PM_{10}, NO_2, SO_2, O_3**	**Hospital admissions for RespD and CVD**	**Levels of NO_2, SO_2, O_3 and PM_{10} were significantly associated with admissions for RespD, CVD, COPD and heart failure. NO_2, O_3 and PM_{10} were significantly associated with admissions for asthma, pneumonia, and influenza. Significant positive interactions were found between NO_2, O_3, and PM_{10} and between O_3 and winter months. Patients $\geq$ 65 yr were at greater risk.**
Wong et al 1999c Hong Kong	**Time series**	**1995–1997 629,196 people $\geq$ 65 yr**	**O_3**	**Hospital admissions for CVD or CBVD**	**Daily hospital admissions for all causes of circulatory disease were associated with increased ozone with the strongest effect on patients with arrhythmias and heart failure.**
Wong et al 2001a Hong Kong	**Time series**	**1993–1994 1217 children <15 yr**	**PM_{10}, NO_2, SO_2**	**Hospital admissions for asthma**	**Daily admissions for asthma increased significantly with increases in ambient NO_2, SO_2, and inhalable particles**
Wong et al 2001b Hong Kong	**Time series**	**1995–1997 All residents**	**NO_2, SO_2, PM_{10}, O_3**	**Daily mortality (nonaccidental, CVD, RespD)**	**Ambient concentrations of NO_2, SO_2 and O_3 were associated with mortality from all nonaccidental causes, CVD, and RespD during the cool season but not the warm season. PM_{10} was associated with RespD mortality only.**
Wong et al 2002a Hong Kong, London	**Time series**	**1995–1997 (Hong Kong) 1992–1994 (London)**	**PM_{10}, NO_2, SO_2, O_3**	**Hospital admissions for asthma (15–64 yr), RespD (60 yr only), cardiac disease (all ages), IHD (all ages)**	**For respiratory admissions, both cities showed positive associations with PM_{10}, NO_2, SO_2, and O_3 with slightly different lags. For cardiac admissions, both cities showed positive associations with PM_{10}, NO_2, and SO_2. Associations between NO_2 and O_3 were negative in London but positive in Hong Kong.**

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[a] Entries in bold type were included in the meta-analysis.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Hong Kong (*continued*)					
Wong et al 2002b Hong Kong	**Time series**	**1995–1998 Hong Kong residents**	**NO_2, SO_2, PM_{10}, O_3**	**Daily mortality (RespD; CVD and CBVD)**	**Levels of NO_2, SO_2, O_3 and PM_{10} were significantly associated with mortality from RespD and from IHD. In multipollutant analyses, PM_{10} was not associated with RespD or CVD mortality.**
Yu et al 2001 Hong Kong	Cross section	1994–1995 1294 children (8–12 yr)	SO_2, NO_2, RSP	Respiratory symptoms, spirometry	Children living in a more polluted district had higher odds ratios for frequent cough, frequent sputum, chronic sputum, and doctor-diagnosed asthma and had poorer measured lung function.
Taipei,China					
Chen et al 1998 Taiksi, Keelung, Sanchung, Toufen, Jenwu, Linyuan	Cross section	1994–1995 5072 primary school children	PM_{10}, O_3, NO_x, NO_2, NO, SO_2, CO, THC, NMHC	Respiratory symptoms or disease (morning cough, day or night cough, chronic cough, shortness of breath, nasal symptoms, sinusitis, wheezing or asthma, allergic rhinitis, bronchitis, pneumonia)	Urban children had significantly more respiratory symptoms (cough, shortness of breath, nasal symptoms) and diseases (sinusitis, wheezing or asthma, allergic rhinitis, bronchitis) compared with rural children. The authors considered their findings to be suggestive but did not confirm a causal relation.
Chen et al 1999 Sanchung, Taiksi, Linyan	Panel	1995 941 school children	PM_{10}, SO_2, O_3, NO_2, CO	Pulmonary function	Using data from a questionnaire, peak O_3 was significantly negatively associated with FVC and FEV_1. Lung function decreased 1 mL/ppb at peak hourly O_3 exposure.
Guo et al 1999 Taipei,China	Cross section	1994–1996 331,686 middle school children	SO_2, NO_x, O_3, CO, PM_{10}	Asthma prevalence	A nationwide survey of asthma linked to local air pollution revealed that nonsummer temperature, winter humidity and traffic-related air pollution (especially CO and NO_x) were positively associated with asthma prevalence.
Huang et al 1991 Taipei,China	Panel (chamber)	6 mite-sensitive children with asthma (5 boys, 1 girl; 10–14 yr)	SO_2, NO_x	Pulmonary function	Spirometry was used to measure pulmonary function after short-term exposures to breathing low levels of compressed polluted air. After polluted air was inhaled, neither pulmonary function nor methacholine and allergen sensitivities of airways increased.

Table continues next page

[a] Entries in bold type were included in the meta-analysis.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Taipei,China (*continued*)					
Hwang et al 2000 Taipei,China	Cohort	1994–1995	NO_2, NO_x	Illness-related school absence	Subject-domain models showed a significant association between absences due to illness and acute NO_2–NO_x exposures at levels below WHO guidelines. Time-domain models showed no such association.
Hwang and Chan 2002 50 townships and city districts	**Time series**	**1998**	**NO_2, CO, SO_2, O_3, PM_{10}**	**Daily clinic visits for lower respiratory tract illness**	**The number of daily clinic visits were associated with current day levels of NO_2, CO, SO_2, and PM_{10}. People over 65 yr were most susceptible, and estimated pollution effects decreased as exposure lag increased.**
Knöbel et al 1995 Kaohsiung area	Time series	1981–1991 Infants (1 wk –1 yr)	PSI, PM_{10}, SO_2, CO	Daily mortality from sudden infant death syndrome or suffocation	Mortality from sudden infant death syndrome was 3.3 times greater in lowest category of visibility on day of death than in the highest category; rate ratio was 3.4 for the average visibility during 9 days before death. Adjusting for covariates increased rate ratios to 3.8 and 5.1, respectively.
Ko et al 1997 Taipei,China	Case control	1992–1993 117 women		Morbidity: lung cancer	Risk of lung cancer for nonsmoking women was associated with certain cooking practices, especially preparing meals in kitchens not equipped with fume extractor at age of 20–40 yr.
Kuo et al 2002 Taipei,China	Cross section	1996 12,926 junior high school students	O_3, PM_{10}, NO_2, SO_2	Morbidity: asthma prevalence, hospital admissions (for respiratory illness), pulmonary function	Asthma prevalence significantly correlated with NO_2 and O_3 concentrations. Levels of NO_2 and PM_{10} significantly correlated with monthly hospital admissions. FVC, FEV_1, and PEF for asthmatics were 6–11% lower than normal predicted values.
Lee et al 2003 Taipei,China	Cross section	1995–1996 331,686 middle school children	SO_2, NO_x, O_3, CO, PM_{10}	Morbidity: allergic rhinitis	Physician-diagnosed allergic rhinitis associated with higher nonsummer temperatures and traffic-related air pollutants, including CO, NO_x, O_3.
Lin et al 2001a Kaohsiung, Nan-Tzu, Tso-Ying	Case control	1993–1996 51,700 births	Petrochemical air pollution	Preterm delivery	Compared to controls, preterm births occurred significantly more frequently among mothers living in a petroleum refinery area.

Table continues next page

[a] Entries in bold type were included in the meta-analysis.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Taipei,China (*continued*)					
Lin et al 2001b Lin-Yuan, Taicei	Case control	1993–1996 2545 births	Petrochemical air pollution	Full term birth weight	The prevalences of low birth weight in a petrochemical community and a control community were 3.22% and 1.84%, respectively.
Lin et al 2001c Taipei,China	Cross section	1995–1996 school children	Urban ambient pollution	Prevalence of asthma	On the basis of questionnaire data, adolescents living in highly polluted areas were more likely to have asthma than those in an area with no or light pollution. Boys were more likely to be affected than girls.
Pan et al 1994 Taipei,China	Ecologic	1971–1990 Children and adolescents (0–19 yr)	Petrochemical air pollution	Cancer death	Review of death certificates of children (0–19 yr) living near petrochemical and petroleum complexes revealed statistically significant excess deaths due to cancers at all sites when compared with national and local reference groups. Excess cancer deaths of bone, brain, and bladder were clustered in the 10–19 year age group, who had been possibly exposed for a longer period.
Tang et al 1997 Chang-Hwa, Yunlin	Cross section	Elementary school children (423 boys and 413 girls)	Ambient air pollution	Respiratory symptoms, FVC/FEV_1	Data from a parental questionnaire and spirometry tests were used to quantify lung function among children living in an area of low air pollution.
Tsai et al 2003 Kaohsiung	Case crossover	1994–2000 All nonaccidental deaths	PM_{10}, SO_2, O_3, NO_2, CO	RespD and circulatory mortality	No significant effects were found between PM_{10} and SO_2 levels and respiratory mortality.
Wang et al 1999b Kaohsiung, Pintong	Cross section	1995–1996 165,173 people (11–16 yr)	NO_2, O_3, CO, PM_{10}, SO_2, TSP, HC	Morbidity: asthma prevalence, respiratory and allergic illness (wheeze, nocturnal dry cough, wheezing after exercise, sneeze, conjunctivitis symptoms, atopic dermatitis, and rhinitis)	Using questionnaire data, TSP, NO_2, CO, O_3, and airborne dust particles were all found to display independent associations with asthma with an 8–29% increased risk of asthma among these adolescents.
Yang et al 1997 Sanwei, Taicei	Cross section	1995 Adults 30–64 yr	SO_2, NO_2, PM_{10}	Morbidity: chronic respiratory symptoms and irritative symptoms	Among residents of a petrochemical-polluted area, cough, wheezing, and chronic bronchitis, reported by questionnaire, were not significantly more prevalent than among the control population. Eye irritation, nausea, throat irritation, and chemical odor perception were significantly more common.

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[a] Entries in bold type were included in the meta-analysis.

Appendix A. (*continued*) China[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Taipei,China (*continued*)					
Yang et al 1998 Linyuan, Taihsi	Cross section	1994–1995 1071 primary school children (460 in polluted area, 611 in control area)	Petrochemical air pollution (PM, SO_2, NO_2, acid aerosols)	Respiratory symptoms among primary school children	Primary school children living in a petrochemical area were exposed to significantly higher levels of PM, SO_2, NO_2, and acid aerosols than children in a control area. The exposed children had significantly more upper respiratory symptoms and asthma. A causal relation could not be confirmed.
Yang et al 1999a Taipei,China	Case control	1991–1994 All deaths	Petrochemical air pollution	Female lung cancer mortality	Women living in areas with a high level of petrochemical air pollution had a significantly higher risk of developing lung cancer than a group living in an area with low petrochemical air pollution.
Yang et al 2000 Tso-Ying, Nan-Tzu	Cohort	1971–1996	Petrochemical air pollution	Sex ratio at birth, female lung cancer mortality	Standardized mortality ratios for female lung cancer revealed that lung cancer deaths rose gradually 30–37 years after introduction of the local petroleum refinery camp. The sex ratio was not affected.
Yang et al 2002a Taipei, China	Cohort	1993–1996 39,750 singleton births	Petrochemical air pollution	Lower birth weight (< 2500 g) and preterm delivery (< 37 gestational week)	The prevalences of preterm delivery and of low birth weight were higher among women living near petrochemical industrial complexes but were not significantly different when compared with a control group.
Yang et al 2002b Kaohsiung	Cohort	1993–1996 57,127 single births	Petrochemical air pollution	Preterm delivery (< 37 weeks)	The prevalence of preterm delivery was significantly higher among women living near petrochemical industrial complexes than in a control group.
Yang et al 2002c Kaohsiung	Cross section	1999 3221 primary school children	NO_2	Chronic respiratory symptoms (asthma, cough, wheeze, dyspnea, bronchitis, and upper respiratory symptoms: sneezing, nose irritation, running and stuffy nose)	Data from a parental questionnaire indicate that a freeway surrounding a child's school may not be associated with an increased risk of respiratory symptoms.
Yang et al 2003 Kaohsiung	Cohort	1995–1997 Full-term single live births	Daily PM_{10}, SO_2	Birth weight	Birth weight was estimated to be reduced 0.52 g for 1 $\mu g/m^3$ increase in either SO_2 or PM_{10} in the first trimester of pregnancy.
Yau et al 1999 Taipei	Cross section	1992–1994 71 full-term infants	Environmental and demographic features that might contribute to lower respiratory illness	Acute lower respiratory illness	Lung function tests on 71 healthy infants chosen randomly failed to identify any differences that predicted the 18 infants who developed a lower respiratory infection within the first 2 years of life.

[a] Entries in bold type were included in the meta-analysis.

Appendix B. India[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Agarwal et al 2002 Delhi	Cross section	2000 34 infants 9–24 months	Haze (visible atmospheric pollution)	Vitamin D status (serum calcium, alkaline phosphatase, parathyroid hormone, hydroxyvitamin D, dihydroxy-vitamin D)	Children living in areas of high atmospheric pollution (haze) had significantly lower serum vitamin D indicators and significantly higher parathyroid hormone and alkaline phosphatase levels when compared with age-matched children from a low pollution area.
Awasthi et al 1996 Lucknow	Cross section	1993–1994 664 children 1 mo–4.5 yr	SO_2, NO_x, suspended PM	Respiratory symptoms complex (RSC), morbidity due to pneumonia (having cough and difficulty breathing)	Airborne PM and SO_2 and cooking-heating fuels and indoor cooking were associated with increased respiratory symptoms, increased duration of symptoms, or both.
Bladen 1983 Bombay	Time series	1979 2980 patient records of respiratory illness	SO_2, PM, HC, CO	Acute respiratory illness	Air pollution from SO_2, PM, CO, and HC were markedly associated with acute respiratory illness. This finding was especially strong in November–February when pollution concentrations were higher due to thermal inversions.
Chhabra et al 1999 Delhi	Cross section	21,367 children 5–17 yr	TSP	Asthma	Questionnaires completed by parents showed male sex, a family history of atopic disorders, and smokers in the family were significantly associated with asthma whereas economic class, ambient TSP, and type of kitchen fuel were not.
Chhabra et al 2001 Delhi	Cross section	1988–1998 4171 adult residents in 2 areas of differing pollution levels	TSP, SO_2, NO_x	Chronic respiratory morbidity (chronic respiratory symptoms, prevalence of chronic respiratory airways disease, and lung function)	Smoking, male sex, increasing age and socioeconomic status were strong independent risk factors for chronic respiratory symptoms. Prevalence of bronchial asthma, COPD, and chronic bronchitis was not significantly different among residents of the two zones. Lung function of asymptomatic nonsmokers was consistently and significantly better among both male and female residents of the lower-pollution area.

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[a] Entries in bold type were included in the meta-analysis.

Appendix B (*continued*). India[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Cropper et al 1997 Delhi	**Time series**	**1991–1994**	**TSP, SO_2, NO_x**	**Mortality (nontraumatic deaths; RespD and CVD deaths)**	**Mortality for ages 5 to 64 yr was significantly associated with TSP. The authors note, however, that reducing TSP by 100 μg/m^3 led to a 2.3% increase in deaths compared with a 6% increase reported for other countries. They attributed the difference to differences in expected life span.**
Deb 1998 Tripura	Ecologic	1992–1993 Children < 5 yr	Ambient pollution	Acute respiratory infection–related morbidity and mortality	Air pollution in the urban area was responsible for the higher incidence of acute respiratory illness in all age groups when compared with children in the relatively unpolluted rural area.
Gupta et al 2001 Chandigarh	Case control	1995–1997 235 cases and 525 controls matched for sex and age	Urban air pollution, indoor pollution, tobacco smoking, occupational exposure	Lung cancer	Questionnaire data on smoking and daily pollution levels indicated that urban residence (ie, exposure to higher air pollution) did not increase the risk of developing lung cancer.
Joseph et al 2003 Mumbai	Impact assessment	1995–2000 General population	RSP	Mortality	The authors conclude that transfer of results from epidemiologic studies in developed countries can underestimate health effects in developing countries and should not be used for this purpose.
Kamat and Doshi 1987 Mumbai	Cross section	1977–1979 4129 subjects	SPM, SO_2, NO_2	Respiratory morbidity; mortality (cardiac, respiratory, cancer)	Air pollution was related to several respiratory symptoms as well as an increase in mortality due to cardiac, respiratory, and malignant diseases.
Kamat et al 1980 Mumbai	Cross section	1977–1979 4129 subjects	SPM, SO_2, NO_2	Prevalence of cardiac diseases, dermatitis, stuffy nose, chest pain, and eye irritation; respiratory symptoms; lung function	In the 3 urban areas of low, medium, and high air pollution levels, low pollution was associated with higher lung function at all ages. In the rural area, however, lung function was significantly lower despite lower pollution. Other factors possibly contributed to this difference.
Kamat et al 1992 Mumbai	Cross section	1988–1989 1545 matched subjects	SPM, SO_2, NO_2	Respiratory and cardiac symptoms	Respiratory symptoms and cardiac diseases appeared to occur more commonly in more polluted areas.

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[a] Entries in bold type were included in the meta-analysis.

Appendix B (*continued*). India[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Kumar et al 2000 Hyderabad	Cross section	1991 216 male adults	SPM, SO_2, NO_x	Prevalence of respiratory problems, lung function	A respiratory questionnaire and lung function spirometry tests revealed a higher prevalence of respiratory problems associated with higher levels of SO_2 and NO_x.
Pande et al 2002 New Delhi	Time series	1997–1998 Over 10 million people	TSP, CO, SO_2, NO_x	Morbidity (COPD, asthma, acute coronary event)	ER visits for acute asthma, COPD, and coronary events increased by 21%, 25%, and 24%, respectively, on days with higher levels of pollution (CO, NO_x, SO_2).
Srivastava and Kumar 2002 Mumbai	Impact assessment	1997	Ambient air pollution	Health damage cost	A dose–response relation of air pollution to human health was based on time spent by an individual in different microenvironments during one day. Economic valuation of morbidity and mortality was estimated through lost salary. Results showed that avoidance cost was 29% of total health damage cost.

[a] Entries in bold type were included in the meta-analysis.

Appendix C. Indonesia

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Aditama 2000 8 provinces	Episode	1997–1998 General population	Haze disaster	Respiratory health	Data collected from pulmonologists, health offices and hospitals indicated a "significant" increase in respiratory conditions that the authors attributed to air pollution haze.
Browne et al 1999 Semarang	Impact assessment	1996–1997 Adults/children	Airborne lead and TSP	Mortality (total, RespD)	Increased TSP near major roads resulted in an estimated 1.6% increase in total mortality and a 7.9% increase in RespD mortality.
Kunii et al 2002 Jakarta, Jambi	Cross section	1997 543 adults	Haze disaster (PM_{10}, CO, O_3, PAHs, NO_2)	Respiratory symptoms, lung function	Questionnaire interviews and lung function spirometry tests indicated respiratory symptoms in over 90% of participants in the presence of PM_{10} and CO levels at very low or hazardous levels and PAH levels 6–14 times higher than an unaffected area. Gender, asthma, and wearing a mask were associated with severity of symptoms.
Ostro 1994 Jakarta	Impact assessment				This report proposes a method for quantifying the benefits of reduced air pollution and applies the method to data from Jakarta.
Tri-Tugaswati and Yasuo 1996 Jakarta	Cross section	1994 16,187 junior high school students	NO_2	Respiratory symptoms (cough, phlegm, wheeze, etc)	In a self-administered questionnaire, the prevalence of persistent cough was 7.3–10.8% and of persistent phlegm was 4.5–5.0%. A significant relation was found between NO_2 exposure and the prevalence of cough, phlegm, and wheeze.

Appendix D. Japan[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Choi et al 1997 47 prefectures	Ecologic	1970–1990 All deaths	NO_2, SO_2, traffic pollution	Lung cancer mortality every 5 years	Regional differences in age-adjusted lung cancer death rates were explained by NO_2 and temperature. Temperature increased the effect of NO_2 on lung cancer deaths compared with NO_2 alone in one region.
Kagamimori et al 1986 Awara-machi	Cross section	1970–1979 School children	SP, SO_2, NO_2	Prevalence of respiratory symptoms	Children were divided into those who did and those who did not have a positive response to a skin test for dust mites. The positive group showed a more significant correlation between air pollution concentrations (SO_2 and NO_2) and the prevalence of respiratory symptoms.
Maeda et al 1991–1992 Tokyo	Cross section	1987–1990 200 women	PM, NO_x, PAHs	Respiratory symptoms, pulmonary function, mutagenicity of SPM	Results suggest that exposure to automobile exhaust may be associated with respiratory symptoms but that pulmonary function did not show consistent variation overall.
Makino 2000 Tokyo	Cohort	1993–1997	SPM, NO_2	School absence	Results from annual correlation analyses did not identify common findings for the two schools or for five years. The prevalence of absence did correlate positively with SPM, NO_2, and relative humidity; absence correlated negatively with atmospheric temperature.
Ono et al 1990 Tokyo	Panel	1987 Adults/children (805 homes)	SPM, NO_2	Respiratory symptoms	Health questionnaires were obtained from 805 homes. An SPM sampler and NO_2 filter badge were used to measure pollution levels in and outside 200 homes for 4 consecutive days within a 4-week period. SPM and NO_2 varied widely depending on cigarette smoking, unventilated space heaters, and building air tightness. An association was observed between an increase in pollution levels and the distance from the roadway, but its effect was small compared to indoor source effects. Respiratory symptoms were more prevalent in areas nearest heavily trafficked roadways.

Table continues next page

[a] Entries in bold type were included in the meta-analysis.

Appendix D (*continued*). Japan[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Piver et al 1999 Tokyo	Time series	July–August 1980–1995	NO_2, O_3, PM_{10}	Heat stroke	Same day daily maximum temperature and NO_2 concentrations were the most significant risk factors for heat stroke in all age groups of men and women. Men over 65 yr were most at risk for heat stroke.
Sawaguchi et al 1997 47 prefectures	Time series	1988–1994	NO_2, SO_2	Sudden infant death syndrome	No correlation was found between the incidence of sudden infant death syndrome and temperature, humidity, NO_2 level, or SO_2 level.
Setiani 1996 6 cities	Cross section	1977–1992 13,836 adults 40–59 yr	Annual mean SPM, SO_2, NO_2, O_x	Health symptoms	Comparing questionnaire data and meterologic data identified a significant association between SO_2 and lacrimacy, runny nose, and cough, and between O_x and phlegm. NO_2 levels were negatively associated with phlegm.
Shima and Adachi 2000 Osaka	Cross section	1991–1993 842 children 9–10 yr	NO_2	Morbidity: respiratory symptoms	Questionnaire responses and other data revealed a significant association between wheeze and asthma and outdoor NO_2 levels but no such association with indoor NO_2 concentration. The data did suggest that girls may be more susceptible to indoor NO_2 than boys are.
Shima et al 1999 Osaka	Panel	1994 1037 children 8–11 yr	PM_{10}, NO_2, NO, SO_2 (stationary & mobile)	Serum concentration of complement components C3c and C4	In boys, serum levels of both C3c and C4 significantly increased as concentrations of air pollution increased in this urban population. In girls, the relation was not significant. C3c and C4 serum levels did not differ with respect to asthma or wheezing.
Shima et al 2002 8 communities	Cross section	1989–1992 4114 children 6 yr	PM_{10}, NO_2, SO_2	Respiratory symptoms	The prevalence of asthma among urban first graders was not associated with air pollution concentrations in this prospective annual questionnaire study. In the followup period (second to sixth grades), however, asthma incidence was significantly associated with NO_2 levels. PM_{10} was associated with a higher incidence of asthma but not significantly.

Table continues next page

[a] Entries in bold type were included in the meta-analysis.

Appendix D (*continued*). Japan[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Shima et al 2003 Chiba Prefecture	Cross section	1991–1995 2506 school children (6–13 yr)	NO_2, SO_2, SPM	Asthma	For girls, the prevalence of asthma was higher among those living less than 50 m from trunk roads and increased significantly with increases in the concentration of air pollution in each area. For boys, the prevalence of asthma did not differ in relation to distance from roads although the rate was higher in urban areas than in rural areas.
Shimizu et al 2001 Yokohama	Time series	1990–1991	Daily SPM, SO_2, NO_2, NO, temperature, humidity	Nocturnal ER visits for asthmatic attack	The number of asthma attack visits positively correlated with increasing levels of pollutants. When both humidity and temperature decreased, the degree of correlation between attacks and pollution increased.
Tanaka et al 1998 Kushiro	Time series	1992–1993 102 people with asthma 15–79 yr	SPM, SO_2, NO, NO_2, NO_x, O_3, fog, meteorologic variables	Morbidity: asthma hospital visit	In nonatopic patients, fog, high O_3 and water vapor pressure, low day-to-day temperature differences, and low concentrations of atmospheric NO and NO_2 significantly contributed to increasing hospital visits. In atopic patients, fog, high water vapor pressure, low levels of atmospheric NO_2 and SO_2 contributed significantly to hospital visits.
Tango 1994 Tokyo	Cohort	1972–1988 (mortality) 1974–1988 (air pollutants) Women 40–79 yr	SO_2, NO_2	Mortality: lung cancer	NO_2 was positively associated with the rate of increase in lung cancer mortality. The association with SO_2 was weaker.
Yanagisawa et al 1986 Tokyo	Cross section	1982 800 women	NO_2 (personal monitors)	Hydroxyproline to creatine ratio (HOP:C) in urine	Urinary hydroxyproline to creatinine ratio (HOP:C) correlated significantly with personal exposure to NO_2 and active or passive cigarette smoking. NO_2 exposure had no correlation with intensity of smoking, but HOP:C increased proportionally to number of cigarettes.
Ye et al 2001 Tokyo	**Time series**	**July–August 1980–1995 Emergency transports > 65 yr**	**NO_2, O_3, PM_{10}, CO, SO_2**	**CVD (angina, cardiac insufficiency, hypertension, MI) and RespD (asthma, acute and chronic bronchitis, pneumonia)**	**Concentrations of NO_2 or PM_{10} were associated with daily hospital emergency transports for angina, cardiac insufficiency, MI, asthma, acute and chronic bronchitis, and pneumonia among men and women.**

[a] Entries in bold type were included in the meta-analysis.

Appendix E. Malaysia

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Sastry 2002 Multiple cities	Episode	1997 All deaths	Air pollution from forest fire	Mortality	Smoke haze from widespread forest fires had a deleterious effect on the health of population.

Appendix F. Singapore[a]

Citation	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Chew et al 1999a	Cross section	1994 School children (2030, 6–7 yr; 4208, 12–15 yr)		Asthma and allergies	In data from an ISAAC questionnaire, outcomes were associated with demographic and socioeconomic differences but not with air pollution or environmental factors.
Chew et al 1999b	**Time series**	**1990–1994 Children (3–21 yr)**	**SO_2, NO_2, O_3, TSP**	**Morbidity: acute asthma, ER visits**	**Although overall levels of air pollution were generally within WHO quality guidelines, higher levels of SO_2 and TSP were associated with more frequent ER visits for children 3–12 yr but not those 13–21 yr.**
Emmanuel 2000	Episode	1997	Haze, PM_{10}, SO_2, NO_2, O_3, CO	Outpatient visits and mortality for RespD, accident, and emergency visit	During several months of haze from forest fires, an increase of PM_{10} from 50 to 150 $\mu g/m^3$ was significantly associated with increases in outpatient visits for upper respiratory illness (12%), asthma (19%), and rhinitis (26%). Neither hospital admissions nor mortality increased significantly.
Tan et al 2000	Episode	1997 30 adult male workers	SO_2, NO_2, O_3, PM_{10}, CO	FEV_1 and FVC, bone marrow and blood cell response (PMNs)	During the 1997 haze from forest fires, serial WBC counts showed that elevated band neutophil counts were significantly associated with elevated PM_{10} and SO_2 compared with a period after the haze had cleared.

[a] Entries in bold type were included in the meta-analysis.

Appendix G. South Korea[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Cho et al 2000 Ulsan, Daejeon, Suwon	**Time series**	**1996 3.6 million people**	**TSP, CO, NO_2, SO_2, O_3**	**Morbidity: hospitalizations for RespD (bronchial asthma, COPD, bronchitis)**	**In a single-pollutant model, respiratory admissions were highly correlated with CO in a residential area and with NO_2 and CO in a mixed residential-industrial area. In a multipollutant model, TSP and CO were significantly associated in the residential area, but CO alone was significantly associated in the industrial area.**
Ha et al 2001 Seoul	Cohort	1996–1997 276,763 births	CO, NO_2, SO_2, O_3, TSP	Birth weight (first and third trimester only)	CO, NO_2, SO_2 and TSP during first trimester of pregnancy were risk factors for low birth weight. O_3 during the last trimester was a risk factor but other pollutants were not. Third trimester correlations were not significant.
Ha et al 2003 Seoul	**Time series**	**1995–1999 Postneonates; 1 mo–1 yr (1045); 2–64 yr (67,597); > 65 yr (100,316)**	**TSP, CO, NO_2, SO_2, O_3, PM_{10}**	**Daily total and respiratory mortality (excluding accidental deaths)**	**CO level was significantly associated with respiratory mortality, especially for postneonates.**
Hong et al 1999a Inchon	**Time series**	**1995**	**TSP, PM_{10}, SO_2, NO_2, O_3, CO**	**Daily mortality (total)**	**Total daily mortality increased 1.2% for each 10 $\mu g/m^3$ increase in 6-day moving average of TSP and 1.2% for each 10 $\mu g/m^3$ increase in 5-day moving average of PM_{10}. Associations between gaseous pollutants and total mortality were not significant. The relative risk of death increased at particulate levels well below the Korean Air Quality Standard at that time.**
Hong et al 1999b Inchon	**Time series**	**1995–1996 2.4 million residents**	**TSP, PM_{10}, SO_2, NO_2, O_3, CO**	**Mortality: CVD, RespD, and total deaths not due to accidents or violence**	**PM_{10} was significantly associated with total, CVD and RespD mortality. SO_2 and CO were significantly associated with RespD mortality. O_3 was not significantly or linearly associated with mortality of any cause. The combined index of PM_{10}, NO_2, SO_2, and CO seemed to better explain exposure–response relation.**

Table continues next page

[a] Entries in bold type were included in the meta-analysis.

Appendix G (*continued*). South Korea[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Hong et al 2002a Seoul	**Time series**	**1995–1998 10.6 million people**	**PM_{10}, SO_2, NO_2, O_3, CO**	**Mortality: stroke**	**Estimated increase in stroke mortality was 1.5% for each interquartile increase in PM_{10} and ozone in the same day. Stroke mortality increased 3.1% for NO_2, 2.9% for SO_2, and 4.1% for CO in a 2-day lag for each interquartile increase in single pollutant models. The elderly and women were more susceptible to particulate pollutants.**
Hong et al 2002b Seoul	**Time series**	**1991–1997**	**TSP, SO_2, NO_2, CO, O_3**	**Daily stroke mortality (both hemorrhagic and ischemic)**	**TSP, SO_2, NO_2, CO, and O_3 levels were significantly associated with ischemic, but not hemorrhagic, stroke mortality.**
Kwon et al 2001 Seoul	**Time series**	**1994–1998 1800 people**	**PM_{10}, CO, NO_2, SO_2, O_3**	**Mortality (nonaccidental)**	**An increase in PM_{10} was associated with an increase in mortality from congestive heart failure. CO, NO_2, SO_2, and O_3 were also associated with mortality from congestive heart failure.**
Lee and Schwartz 1999 Seoul	Case crossover	1991–1995 12 million people	TSP, SO_2, O_3	Mortality (nonaccidental)	Increases in atmospheric SO_2 level were associated with increases in daily mortality across different analysis methods.
Lee et al 1999 Seoul, Ulsan	**Time series**	**1991–1995**	**SO_2, O_3, TSP**	**Mortality (nonaccidental)**	**Increase of 50 ppb of SO_2 significantly increased all cause mortality by 12–13%. A 50 ppb increase of O_3 increased all cause mortality by 14% and 4.6% in the two study cities.**
Lee et al 2000 7 cities	**Time series**	**1991–1997 22.8 million people**	**SO_2, O_3, TSP**	**Mortality (nonaccidental)**	**Increase of 50 ppb of SO_2 corresponded to 1–12% more deaths depending on the city assessed. Estimated risk of death by SO_2 was unaffected by adding TSP and O_3 to the model. All ambient levels were below Korea's standards at that time.**
Lee et al 2002 Seoul	**Time series**	**1997–1999 6436 children < 15 yr**	**PM_{10}, SO_2, NO_2, O_3, CO**	**Hospitalization due to asthma attack**	**Estimated relative risk of asthma hospitalization was 1.07 for PM_{10}, 1.11–1.16 for SO_2, NO_2, O_3, and CO. In the multipollutant models, control for other pollutants did not change the estimated effect for O_3 or NO_2.**
Park et al 2002 Seoul	**Time series**	**1996–1999 1264 school children**	**PM_{10}, SO_2, O_3, NO_2, CO**	**Illness-related school absenteeism**	**Exposures to PM_{10}, SO_2, and O_3 but not NO_2 were associated with illness-related absenteeism from elementary school.**

[a] Entries in bold type were included in the meta-analysis.

Appendix H. Thailand[a]

Citation, Study Location	Design	Period, Sample	Exposure	Health Outcome	Summary of Published Findings
Karita et al 2001 Bangkok, Ayutthaya	Cross section	1998–1999 78 traffic and 60 nontraffic urban policemen; 68 rural policemen	Vehicle exhaust	Lung function, respiratory symptoms	Results of lung function spirometry and respiratory questionnaires showed no consistent decrease in pulmonary function in urban traffic police. Mean FEV_1 and FVC were significantly lower in all urban police than in rural police. Respiratory symptoms were slightly more prevalent among urban police.
Ostro et al 1999 Bangkok	**Time series**	**1992–1995 6+ million people**	**PM_{10}**	**Mortality (all except accidental, homicidal, suicidal)**	**PM_{10} was significantly associated with alternative measures of daily mortality. The results suggest relative risks consistent with or greater than those reported in most US studies: A 10 μg/m^3 change in daily PM_{10} was associated with 1–2% increases in natural and CVD mortality and a 3–6% increase in RespD mortality.**
Pothikamjorn et al 2002 Bangkok	Cross section	1998–1999 290 high school students exposed to a 24-hr average of 170 μg/m^3 PM_{10}	PM_{10}	Allergic symptoms, allergic skin sensitivity, lung function	A significant increase in school absence and medical expenses was associated with high PM_{10} exposure.
Vichit-Vadakan et al 2001 Bangkok	Panel	1996 172 adults, 83 school children	PM_{10} (limited $PM_{2.5}$ data)	Respiratory symptom	Daily upper and lower respiratory symptoms were generally associated with daily PM_{10} and $PM_{2.5}$ concentrations. Estimated odds ratios were consistent with or slightly higher than those reported in US studies. Time trends in data make the effect magnitude uncertain.
Wongsurakiat et al 1999 Bangkok	Cross section	1996–1997 629 traffic policemen and 303 control subjects		Respiratory symptoms, lung function	Nonsmoker traffic policemen had significantly higher prevalence of cough, phlegm, rhinitis symptoms, and abnormal air flow than nonsmoker controls. Mean FEV_1 and FVC values were also significantly lower for the policemen. Policemen who did not wear protective masks had significantly increased prevalence of abnormal FVC compared with controls and abnormal FEV_1 and FVC compared with mask-wearing policemen.

[a] Entries in bold type were included in the meta-analysis.

Abbreviations and Other Terms

acute MI	acute myocardial infarction
AIC	Akaike information criterion
ALRI	acute lower respiratory infection
APHEA	Air Pollution and Health: A European Approach
B*a*P	benzo[*a*]pyrene
CBVD	cerebrovascular disease
CH_3	methane
CHD	coronary heart disease
CI	confidence interval
CO	carbon monoxide
CO_2	carbon dioxide
COPD	chronic obstructive pulmonary disease
CRA	comparative risk assessment
CVD	cardiovascular disease
DALY	disability-adjusted life year
EPA	Environmental Protection Agency (US)
ER	emergency room
FEV_1	forced expiratory volume in 1 second
FVC	forced vital capacity
GAM	generalized additive model
GDP	gross domestic product
HC	hydrocarbon
HKAQO	Hong Kong Air Quality Objective
IHD	ischemic heart disease
ISAAC	International Study of Asthma and Allergies in Children
LPG	liquefied petroleum gas
MMEF	maximal mid expiratory flow
NAAQS	National Ambient Air Quality Standards (China)
NMHC	nonmethane hydrocarbon
NMMAPS	National Morbidity and Mortality Air Pollution Study (US)
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_3	ozone
O_x	photochemical oxidants
PAH	polycyclic aromatic hydrocarbon
PAPA	Public Health and Air Pollution in Asia
PEF	peak expiratory flow
PM	particulate matter
PM_{10}	PM less than 10 µm in aerodynamic diameter
$PM_{10–2.5}$	PM 10–2.5 µm in aerodynamic diameter
$PM_{2.5}$	PM less than 2.5 µm in aerodynamic diameter
PMN	polymorphonuclear leukocyte
PSI	pollutants standard index
RespD	respiratory disease
RSP	respirable suspended particulates
SO_2	sulfur dioxide
SO_4^{2-}	sulfate
SO_x	sulfur oxides
SP	suspended particles
TEOM	tapered element oscillating microbalance
THC	total hydrocarbons
TSP	total suspended particles (equivalent to suspended PM)
WBC	white blood cells
WHO	World Health Organization

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