HEI

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EXECUTIVE SUMMARY

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Health Effects of Outdoor Air Pollution in Developing Countries of Asia

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The Health Effects Institute, established in 1980, is an independent and unbiased source of information on the health effects of pollutants from motor vehicles and other sources in the environment. Supported jointly by the US Environmental Protection Agency and industry, HEI provides science to inform decisions that are directly relevant to regulation. Other public and private organizations periodically support HEI special projects or research programs and activities in other parts of the world. HEI science includes:

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Special Reviews of an entire area of scientific literature on key topics including asbestos, diesel exhaust, oxygenates in fuel, and the health effects of air pollution in developing countries in Asia, the subject of this Executive Summary.

Reanalysis of studies central to regulatory proceedings, such as the Harvard Six Cities Study and the American Cancer Society Study of the health effects of air pollution.

HEI's research priorities are guided by its five-year Strategic Plan and developed through extensive consultation with sponsors, stakeholders, and members of the scientific community. HEI exercises autonomy in adopting and implementing its research priorities and in reaching its conclusions. It is governed by an independent *Board of Directors* consisting of leaders in science and policy with a commitment to the public–private partnership that is central to the HEI approach. The scientific work of the institute is overseen by two independent committees. The *Health Research Committee* develops and manages HEI's research program. The *Health Review Committee*, which has no role in selecting or overseeing studies, uses stringent peer review to evaluate and interpret the results of HEI's studies. Together with staff, these bodies act to ensure the ongoing quality, relevance, and impartiality of HEI-funded science.

In implementing its Strategic Plan, HEI has taken an increasingly international perspective, both to use global science to better inform US decisions and to improve science in other parts of the world. In this context, the *Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review*, is published as part of HEI's Public Health and Air Pollution in Asia (PAPA) program. The PAPA program is part of the Clean Air Initiative for Asian Cities, a partnership of the Asian Development Bank and the World Bank to inform measures taken to improve Asian air quality.

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

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 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.

This Executive Summary of HEI Special Report 15, *Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review*, was prepared on behalf of the International Scientific Oversight Committee of HEI's Public Health and Air Pollution in Asia program. The entire Special Report 15 is available from *www.healtheffects.org* or from HEI.

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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 the 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. In addition to 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 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

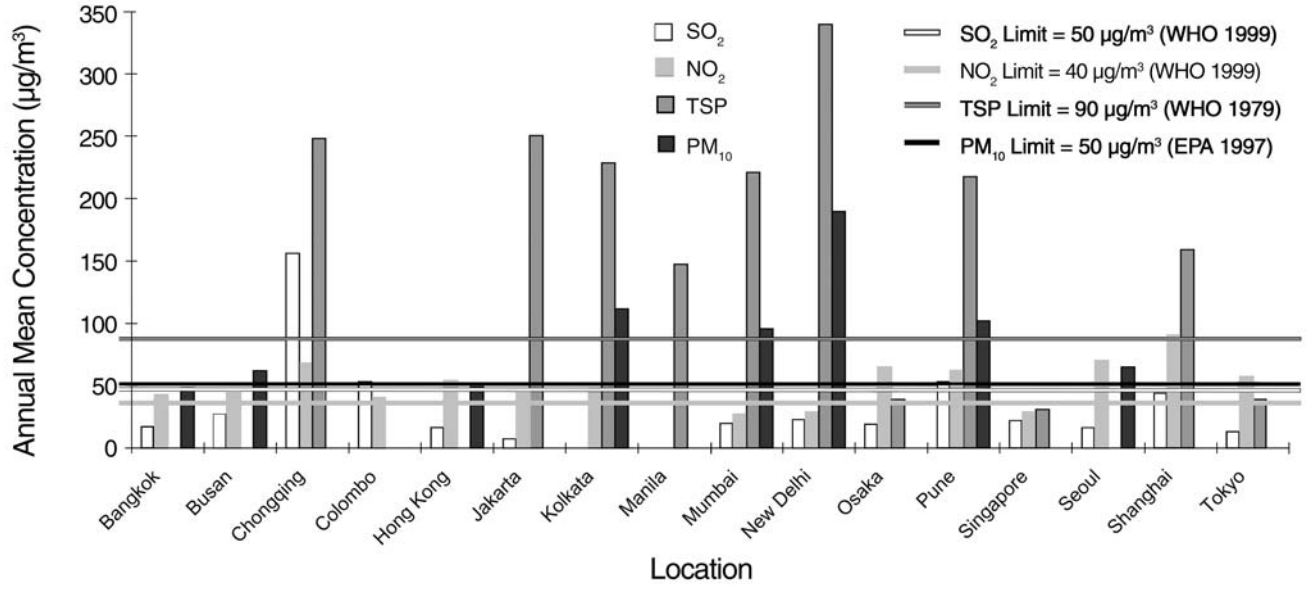

Figure 1. Annual mean concentrations of pollutants compared with their guidelines and standards in Asian cities, 2000 and 2001. Data from Air Pollution in Megacities of Asia 2004.

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 on a daily basis), 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 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.

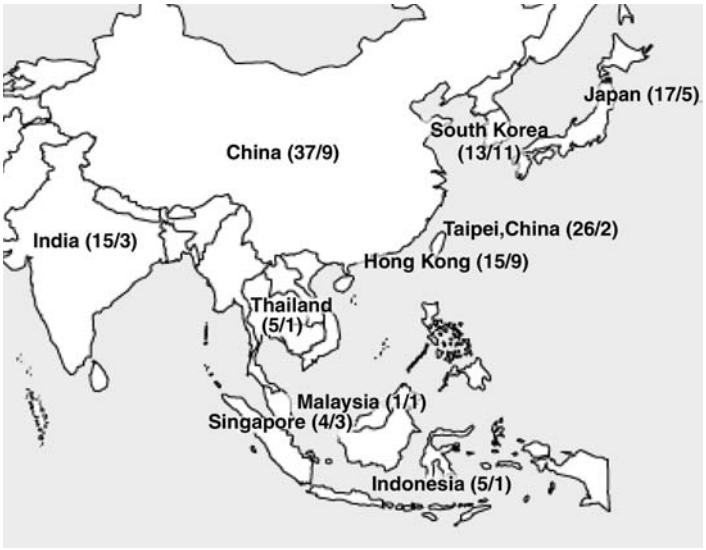

Figure 2. Epidemiologic studies of air pollution in Asia published from 1980 to 2003. Numbers in parentheses are total studies/time-series studies conducted.

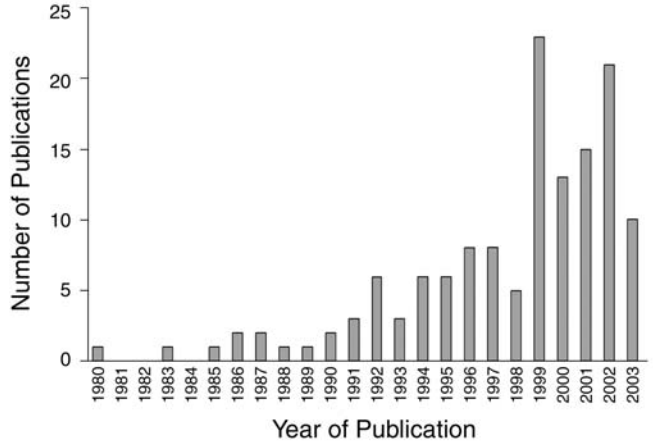

Figure 3. Number of publications of epidemiologic studies of air pollution in Asia by year. In 2003, published papers were collected only through June.

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).

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

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.

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 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.

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

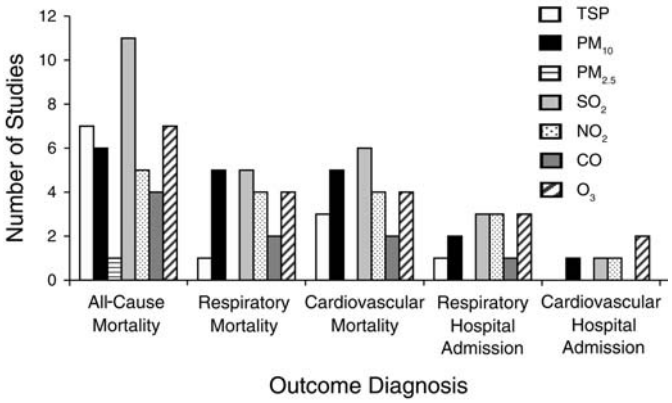

Figure 4. Outcome diagnosis by pollutant in the 28 Asian daily time-series studies.

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

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).

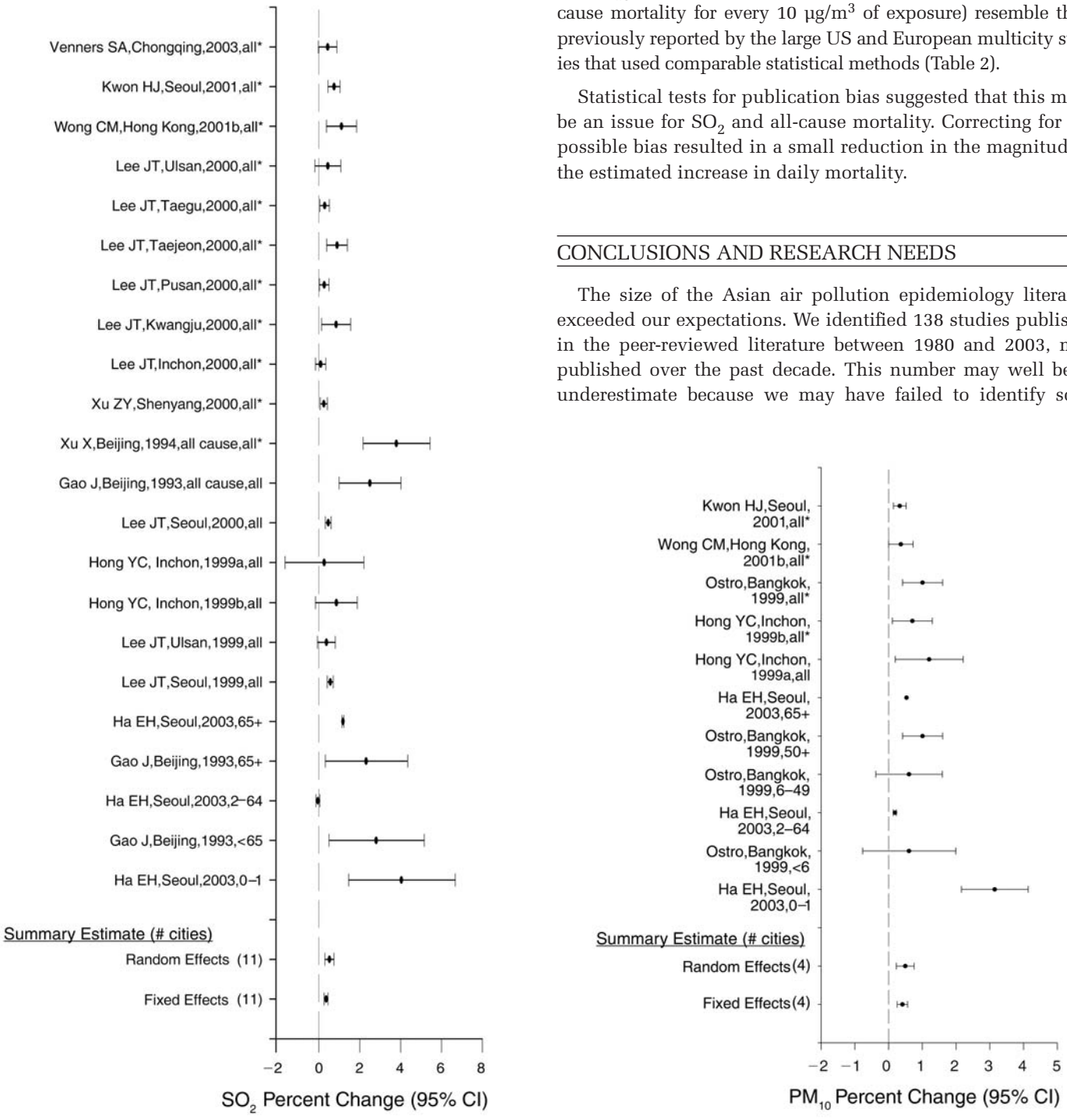

Figure 5. Percent change in mean number of daily deaths from all causes per 10 μg/m^3 increase in 24-hour mean level of SO_2 (left) and PM_{10} (right). Note the difference between x-axis scales. Y-axis labels give study information in the following sequence: first author name, study location, publication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

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 μg/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 μg/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

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 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).

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, 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. One 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 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.

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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

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