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Environmental Equity in Air Quality Management: Local and International Implications for Human Health and Climate Change

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The health burden of environmental exposures, including ambient air pollution and climate-change-related health impacts, is not equally distributed between or within regions and countries. These inequalities are currently receiving increased attention in environmental research as well as enhanced appreciation in environmental policy, where calls for environmental equity are more frequently heard. The World Health Organization (WHO) 2006 Global Update of the Air Quality Guidelines attempted to address the global-scale inequalities in exposures to air pollution and the burden of diseases due to air pollution. The guidelines stop short, however, of addressing explicitly the inequalities in exposure and adverse health effects within countries and urban areas due to differential distribution of sources of air pollution such as motor vehicles and local industry, and differences in susceptibility to the adverse health effects attributed to air pollution. These inequalities, may, however, be addressed in local air quality and land use management decisions. Locally, community-based participatory research can play an important role in documenting potential inequities and fostering corrective action. Research on environmental inequities will also benefit from current efforts to (1) better understand social determinants of health and (2) apply research evidence to reduce health disparities. Similarly, future research and policy action will benefit from stronger linkages between equity concerns related to health consequences of both air pollution exposure and climate change, since combustion products are important contributors to both of these environmental problems.

The epidemiology of the adverse health effects attributed to environmental exposures such as air pollution reflects variations in patterns of human exposure and susceptibility. The role played by social and economic inequality in determining these variations, both between and within regions and countries, has received increasing attention of late (O'Neill et al., 2003). The World Health Organization (WHO) recently updated its air quality guidelines (AQGs), which serve as an international reference on the health consequences of exposure to air pollution and are intended to reduce these consequences worldwide (WHO, 2006a). An important feature of the new guidelines was a focus on their relevance and applicability in all nations, especially those that experience extremely high levels of pollution.

Other important developments in the research and policy realms suggest that environmental equity is taking a new and more prominent place in air quality management. In particular, appreciation is growing that the adverse impacts of climate change likely will fall disproportionately upon the most vulnerable societies and population groups (Woodward, 2002). Using as a springboard the WHO AQGs (Kinney & O'Neill, 2006), this article provides selected examples of evidence and action related to environmental equity at the international and local scales, including (1) links with climate change; (2) discussions on new research frontiers and needs and connections with research on social determinants of health; (3) comments on implications of environmental equity research for policy; and (4) conclusions with views of future directions in this arena.

ENVIRONMENTAL AND HEALTH INEQUALITIES

International variations in air pollution exposure and its health effects reflect interrelated dynamic processes that themselves are the result of economic and political development. Smith and Ezzati (2005) described these processes in terms of environmental risk and epidemiologic transitions. In its simplest form, the environmental risk transition postulates that as countries become wealthier, or "develop," the pattern of environmental health risks faced by the population changes,

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due to (1) the use of cleaner fuels, (2) changes in pollution sources with mobile sources playing an increasingly role, and (3) shifts in the geographic scale of emissions and human exposure from the household to community and global scales. Similarly, the epidemiologic transition theory, originally proposed by Omran (1971), postulates that increasing wealth is associated with a changing population health profile in which chronic diseases, such as cancer and cardiovascular diseases, displace infectious disease and diseases of childhood as the leading causes of morbidity and death. The ongoing environmental and epidemiologic transitions in many countries have important implications for the patterns of health risk associated with air pollution exposure. Developing countries such as China and India must simultaneously contend with significant environmental risk due to household-level pollution, e.g., from the burning of solid fuels indoors, while at the same time facing an increasing environmental risk from community-level pollution from industry and mobile sources. Household-level air pollution exacerbates infectious diseases in young children (Smith et al., 2000), and community-level pollution is associated with increased morbidity and mortality from chronic diseases in adults.

These transitions are not expressions of immutable natural laws. Rather, the ways in which they play out in the real world reflect political and economic decision making at different levels. One model, based on the historical experience of the United States and Western Europe, postulated that development entails rising levels of environmental pollution (resulting in an increased burden of disease), which improves after some level of income growth has occurred (Kuznets, 1955). This model was challenged by academics (de Bruyn et al., 1998) and by environmental advocates (Center for Science and Environment, 2006) who argue that environmental degradation and its associated adverse health effects are "leapfrogged" by poor countries if the appropriate policies are pursued. The deleterious effects on the environment and human health of international lending policies of the World Bank and International Monetary Fund are documented (Kim et al., 2000; Bello, 1994), but others (McMichael, 2001; Stiglitz, 2003) also noted that international agencies, including the World Bank and the United Nations, can and need to play important roles in addressing environmental and health inequalities.

Monitoring networks for air pollution and other environmental exposures are often either entirely absent or not highly reliable in less developed countries (Ezzati et al., 2005), so data on ambient concentrations are incomplete. For example, such data are virtually nonexistent for the growing urban centers of Sub-Saharan Africa. Nonetheless, estimated annual outdoor particle (particulate matter, PM) concentrations in cities across the globe show a wide range, and many of the most polluted cities are located in the developing countries of Asia, Africa, and Latin America (Figure 1). Since particles measured at ambient stations were shown to be broadly reflective of personal exposure to the entire pollutant mix (Sarnat et al., 2006), particle level may be a good overall indicator of outdoor pollution exposure for cross-national comparisons. However, this relationship may vary substantially for developing world cities, where air pollution exposures may have much larger local source than regional source components than is the case in the eastern United States—e.g., intra-urban patterns of high-emission traffic, refuse burning, and biomass fuel use for cooking in congested slums. Because of the lack of air pollution monitoring

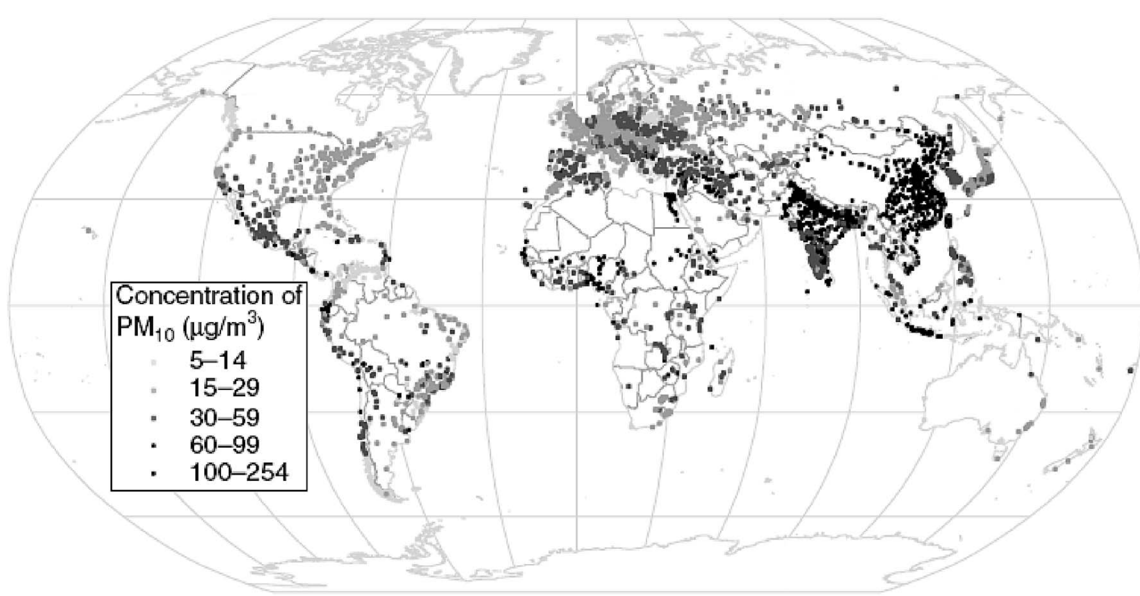

FIG. 1. Estimated annual average concentrations of PM_{10} in cities with populations over 100,000 and in national capital cities. Source: (Cohen et al., 2005).

infrastructure, especially in developing countries, an ongoing research and policy need is to improve such networks. In certain locales, airport visibility was used as a surrogate for PM air pollution or to aid in predicting missing values from networks that do not provide daily measures (Vajanapoom et al., 2001; O'Neill et al., 2002; A. L. F. Braga, personal communication to M. S. O'Neill on use of visibility data for Brazilian cities without monitoring, Paris, September 2006). This approach is likely to be of continued value, especially as evidence emerges suggesting that long-term exposure to fine-fraction PM, which correlates well with horizontal visibility, may exert greater adverse health effects than coarse PM fraction exposure (Pope et al., 2002a; WHO, 2006a).

ENVIRONMENTAL EQUITY

Clearly, inequalities in exposure, susceptibility, and population health exist both locally and internationally. However, the discussion about these patterns and the appropriate public health and policy response commonly uses the term "equity," which has an ethical component, implying more than simply the absence of "inequality" in exposure to an environmental agent and/or a difference in health outcome given the same exposure (Neufeld & Johnson, 2001; Dahlgren & Whitehead, 1991). Rather, this concept, similar to "environmental justice," reflects an implicit moral judgment that environmental inequalities are unfair ("avoidable, undeserved and remediable"; Levy et al., 2006) and need to be rectified as a moral imperative. Frequently, research in environmental equity is outcome based, and does not address the processes that led to the observed differences, or "disparities," across population groups (Carter-Pokras & Baquet, 2002; Ikeme, 2003; O'Neill et al., 2003). This is appropriate, as different methods and disciplinary approaches would be required to determine the process leading up to an observed difference. Environmental equity research and policy can have a very broad scope, encompassing equity within and between nations and communities, as well as across generations. Equity concerns are made explicit in some policy contexts, in which fairness is articulated as a goal of environmental management, as in the South African constitution and state and federal laws in the United States (CARB, 2001; NYDEC, 2003; U.S. EPA, 1999; South Africa, 1996). For policy on an international scale, environmental equity concerns can be best addressed through recognition of the international heterogeneity in the scope and scale of environmental contamination and capacity to address the problem.

INTERNATIONAL ENVIRONMENTAL EQUITY

The update of the AQG by WHO was specifically intended to make the guidelines more relevant to countries where pollution levels are high, and where a tiered set of target concentrations of pollution to reduce health impacts may be a more useful regulatory tool than a dose-response function (WHO, 2006a). The working group's discussions about these guidelines addressed the extremely high burden that indoor pollutant exposures pose in developing countries, but the focus of the update, and this article, dealt with outdoor pollutants (WHO, 2006a).

The sulfur dioxide (SO_2) AQG was chosen, among a total of 4 pollutants included in the update, in part due to the rise in the use of high-sulfur coal and fuel oil in China and India, which is expected to continue increasing in the next 20–30 yr (HEI, 2004). Although levels of SO_2 in wealthy countries have fallen to such low levels that any associations with adverse health effects may actually reflect the effects of correlated pollutants, such as PM, a stronger SO_2 AQG would continue to keep the focus on reducing emissions from high-sulfur fuels such as coal used in these populous countries, and would have health benefits regardless of which component of their emissions was responsible for adverse health effects.

The form of the new PM AQG, i.e., the specification of a guideline value and interim targets, was adopted largely in response to the needs of developing countries, whose representatives argued that the previous guidelines were ineffective in situations, such as low-income countries in Asia and Africa, where existing ambient levels were high. Both PM_{10} and $PM_{2.5}$ AQGs were adopted, in part due to the fact that more monitoring networks in developing countries have the capacity to monitor PM_{10} than $PM_{2.5}$. Although the fine (and ultrafine) PM may be of greater relevance for health, the practical ability to monitor compliance with standards among less wealthy nations motivated this decision. Finally, the PM AQG is explicitly stated to apply both indoors and outdoors, addressing the huge burden of disease among the rural poor (largely women and children) in Asia, Africa, and Latin America due to the burning of solid fuels indoors. This statement reflects how the AQGs address equity both within and among countries.

CLIMATE EQUITY

Ambient air pollution and climate change are linked in several ways. For example, PM air pollution itself exerts climate forcing effects (Hansen et al., 2000), and there is evidence that increased stagnation of air masses due to global warming contributed to accumulation of air pollution in local areas (Mickley et al., 2004; Hogrefe et al., 2004). With regard to equity, the Intergovernmental Panel on Climate Change (IPCC) noted, "The impacts of climate change will fall disproportionately upon developing countries and the poor persons within all countries" (IPCC, 2001) For example, small island nations such as the Maldives contribute little to global greenhouse gas concentrations but are especially vulnerable to climate change outcomes with potentially devastating health consequences, including sea-level rise, floods (Ahern et al., 2005), and weather and precipitation changes (Ebi et al., 2006). Heat waves and hot weather also have different effects on the population, within and between countries, according to socioeconomic status, race/ethnicity, and age (Curriero et al., 2002;

O'Neill et al., 2005; Klinenberg, 2002; Wilkinson et al., 2002). Shifting patterns of rainfall and drought have the most direct impacts on populations whose health and well-being is most closely dependent on local agriculture. In part due to this accumulating research evidence, climate change has been framed as an environmental justice issue (EJCC, 2006), complementing similar efforts to address air pollution health effects through an equity lens (ALA, 2001).

Complex equity issues immediately arise when considering the health "co-benefits" that would result from reduced air pollution concentrations as greenhouse gas emissions are curtailed under climate change mitigation policies (Bell et al., 2006). An early co-benefits analysis estimated that 700,000 deaths could be avoided by reducing PM concentrations worldwide in accordance with the proposed Kyoto protocols (Anonymous, 1997). These estimates entailed assumptions about which emission sources would need to be controlled and in which regions the reductions in PM should occur: largely sources that predominate in the developed countries. These assumptions, and their impacts on the estimated co-benefits, were subsequently questioned by other scientists who argued that the estimates did not consider sources such as biomass burning and indoor exposures to PM from indoor sources, issues more relevant to developing countries, and arguably contributors to both climate change and human health at least on a par with the sources and effects considered in the 1997 analysis (K. R. Smith and X. Wang, personal communication to A. J. Cohen, January 31, 2007). Smith and Wang (personal communication, 2007) noted:

> Simplified models are appropriate and necessary for analyzing complex phenomena, but, if not done carefully, can be misleading. In this case, simplifications have meant that the most important policy lesson is lost: which is that the near-term health benefits from greenhouse gas control can be substantial, but will be large only if a pathway of greenhouse gas control is followed that implements certain technologies in certain sectors and regions.

LOCAL ENVIRONMENTAL EQUITY

Research evidence suggests that, due to local sources, certain populations within urban areas receive consistently and persistently higher exposures to outdoor pollution, and that these populations are frequently of lower socioeconomic circumstances and lower baseline health status (Kinney & O'Neill, 2006). Strong intra-urban spatial gradients in air pollution were reported, especially from motor vehicle sources within cities (Kinney et al., 2000; Hitchins et al., 2000; Zhu et al., 2002; Janssen et al., 2003; Lena et al., 2002; Fischer et al., 2000). These gradients may also coincide with socioeconomic gradients, since settlement and activity patterns tend to be patterned by material resources, race/ethnicity, and other factors. A detailed review of the literature examining these gradients was provided by Kinney and O'Neill (2006). In summary, these gradients depend on the pollutant examined, but in general, the body of research in developed countries suggests that twofold differences may occur for primary traffic pollutants, and less (approximately 20%) for pollutants that are secondary or regionally distributed. Though few data exist, local exposure gradients are likely to be greater in developing world cities, where freshly generated combustion pollutants are emitted by motor vehicles, as well as by burning of biomass and refuse, and other sources. As a result, the primary sources of local inequity in exposure are intra-urban combustion emissions, which may be especially toxic to human health (Hoek et al., 2002; Janssen et al., 2003; Venn et al., 2001; Garshick et al., 2003; Roemer & van Wijnen, 2001; Nicolai et al., 2003).

Urban hot spots are regions within a city with relatively higher concentrations of air pollution than other areas of the same city. These areas of stable, persistent higher air pollution may coincide with certain settlement patterns, and pollution levels may be driven even higher during particular weather conditions, such as thermal inversions, that impede dispersal of locally generated pollution. Inequities related to hot spots are illustrated by black carbon data collected recently in two communities in the New York City metropolitan area with different traffic emission densities and socioeconomic characteristics (Figure 2). The lower income, city location showed higher average concentrations than the higher income, suburban location. Both sites experienced similar temporal patterns in pollutant fluctuations due to weather, but these variations were of greater magnitude in the lower income, urban location.

Evidence such as this, documenting different exposures among different groups, defined by characteristics such as race and class, is what fostered the environmental justice movement in the 1970s (Bullard & Wright, 1993). This movement motivated, in part, a growing emphasis on community-based participatory research (CBPR) (Israel et al., 1998). This approach, which has its roots in Latin America, Asia, and Africa (Wallerstein & Duran, 2003), involves partnerships between affected communities and investigators who design and conduct research intended to be translated into policy action. Such a CBPR approach was applied in the Detroit area, in the Community Action Against Asthma partnership (Parker et al., 2003) that addressed, through research and policy action, the impacts of indoor and outdoor air quality on childhood asthma among lower-income children.

Some CBPR research utilized new molecular tools in environmental health research that shed light on individual susceptibilities due to genetic variability, and documented exposures to environmental contaminants. Shostak (2004) interviewed environmental justice activists who were concerned that these tools had the potential to create a focus on individual genetic susceptibility and divert efforts to reduce unequal environmental exposures at the population level. However, these activists also acknowledged the potential value of new techniques, including biomarkers and indicators of genetic damage, for providing evidence to support legal actions and policies to reduce unfair burdens of exposure (Shostak, 2004).

In addition to CBPR, local policy action on air pollution was initiated by activists organizing for this express purpose.

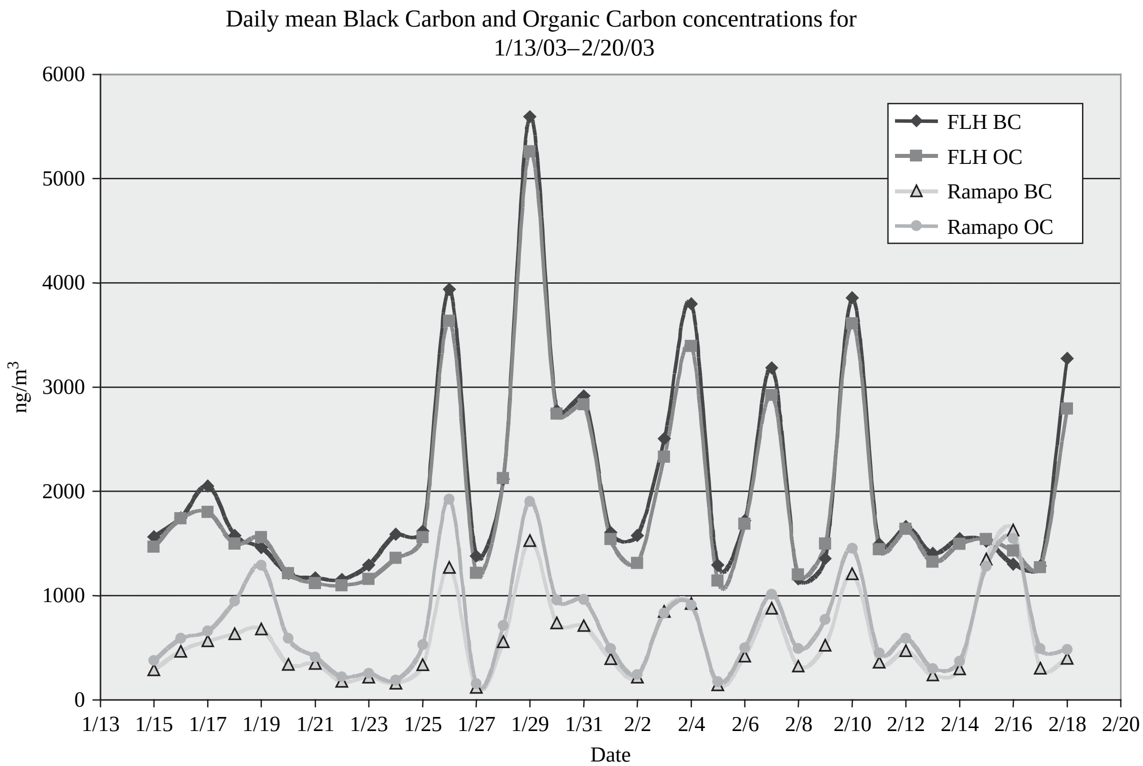

FIG. 2. Daily mean black carbon and organic carbon concentrations at an urban high-traffic site and a suburban low-traffic site in the New York City metropolitan area from13 January to 20 February 2003. FLH = urban site; Ramapo = suburban site; BC = black carbon measured by aethalometry; OC = organic carbon measured by aethalometry. (Kinney personal communication, 2006).

In Los Angeles, for example, the Bus Riders Union, a multiracial environmental justice organization, called for drastic reductions in air pollution and greenhouse gas emissions, and other improvements in transportation, in light of the disproportionate impacts on people of color and lower income residents of the Los Angeles metropolitan area (Bus Riders Union, 2006).

NEW RESEARCH FRONTIERS

Social Determinants

The WHO formed a Commission on the Social Determinants of Health in 2005, in response to a concern about the "unfair gaps" in health and well-being among "vulnerable and socially disadvantaged people" across the globe (WHO, 2006b). These widely recognized social gradients in health may be influenced by environmental exposures (Evans & Kantrowitz, 2002). Indoor biomass burning, infectious and vector-borne diseases, poor sanitation, and other environmentally linked exposures were among many reasons that poor people have greater health vulnerability in general. The commission, chaired by Sir Michael Marmot, was constituted to last through March of 2008 and had the following goals:

> The Commission aims to lever policy change by turning existing public health knowledge into actionable global and national policy agendas. It will: Compile evidence on successful interventions and formulate policies that address key social determinants, particularly for low-income countries; Raise societal debate and advocate for implementation by Member States, civil society, and global health actors of policies that address social determinants; Define a medium- and long-term action agenda for incorporating social determinants of health interventions/approaches into planning, policy, and technical work within WHO (2006b).

This new initiative, which includes one publication calling for a commitment to the value of equity, and taking an "evidence-based approach" (Kelly et al., 2006), is occurring concurrently with other calls to integrate and promote equitable environmental health policy along with research and action on other related issues, including social, economic and political disparities (Schulz & Northridge, 2004) This approach requires addressing environmental health concerns in an integrated way with "urban planning, housing, transportation and social welfare initiatives" (Schulz & Northridge, 2004, pp. 467–468). In a similar fashion, U.S. federal agencies and researchers called for a framework for considering environmental health concerns along with the social determinants of health (Payne-Sturges, 2006), and the U.S. Environmental Protection Agency incorporated social context in its cumulative risk assessment framework (US EPA, 2003). These trends toward more integration and cross-disciplinary action in addressing environmental equity concerns are promising and consistent with recommendations made at a 2002 international workshop (O'Neill et al., 2003).

A new area of research is to (1) address both air pollution and temperature in health models together, evaluating how season and weather may affect estimates (Touloumi et al., 2006; Ren et al., 2006); (2) conduct integrated assessments evaluating climate, air quality and health (Knowlton et al., 2004); and (3) determine co-benefits for health of reducing greenhouse gas emissions (Cifuentes et al., 2001). Another research frontier is incorporating equity concerns into air pollution risk assessments. For example, the health benefits from air pollution reduction may be greater for lower socioeconomic population subgroups when differential susceptibility and baseline health status are explicitly taken into account (Levy et al., 2002). Site-specific evaluations of air pollution source impacts, such as incinerators, also address equity considerations.

IMPLICATIONS OF SCIENCE FOR POLICY

Research in environmental equity, especially with regard to air pollution, has become more visible at international conferences, such as the International Society for Environmental Epidemiology (ISEE, 2006). However, the translation of environmental equity research results into concrete policy poses challenges. Two studies on long-term exposure to air pollution and mortality, from the United States and Europe, provide evidence for a strong gradient in air-pollution-associated mortality risk by educational attainment, with a monotonic rise in risk with decreasing levels of schooling (HEI, 2000; Pope et al., 2002a; Hoek et al., 2002). Short-term effects of air pollution were also evaluated in Hong Kong, where similar patterns were observed (Ou et al., 2006), but in preliminary analyses of data from Mexico City, Mexico, Sao Paulo, Brazil, and Santiago, Chile, no consistent pattern of mortality risk by education emerged (O'Neill et al., 2006).

Even if all these studies showed consistent results, the study designs do not enable identification of the responsible mechanisms for the gradients (Finkelstein, 2002; Pope et al., 2002b). Since it is not yet clear in all the study settings whether the observed patterns, if any, are attributable to differences in susceptibility, due to different prevalence of certain diseases among those with less schooling, or higher exposures among the less educated, the policy implications of this research are not self-evident. Reducing pollution levels within certain communities characterized by lower education (and probably other correlated socioeconomic characteristics), and implementing programs to improve the overall socioeconomic well-being and health status of the population (perhaps including improved access to education) might both be policies that would reduce inequitable health consequences due to air pollution exposure.

An additional challenge in considering the implications of research results for air pollution policy is that these policies are made across many sectors, and include activities such as (1) permitting and regulating of pollution sources; (2) developing and enforcing air quality standards and management plans; (3) developing and enforcing zoning, transportation and land-use policies; and (4) assessing health impacts. As Schulz and Northridge (2004) noted, cooperative action across these sectors is needed to comprehensively address the environmental and other causes of social disparities in health.

Although there are examples of air pollution risk assessment addressing differences in population susceptibility (Levy et al., 2002), these are not the norm in air quality standard setting, as the guidelines and standards tend to select a single concentration, while acknowledging ranges of susceptibilities and evidence suggesting there is no threshold below which the populace is completely "safe." However, evidence concerning local inequities in population exposure and susceptibility may influence local policy on such issues as siting of truck-transfer depot or pollution-emitting facilities such as incinerators.

CONCLUSION

The Environmental Equity chapter of the AQG update outlined several research needs, which are duplicated here:

1. Document whether exposures to and/or health effects associated with air pollution exhibit gradients by demography and socioeconomic position (SEP) in a variety of settings; of particular relevance are studies that would aim at assessing the heterogeneity of exposure-response functions according to age, gender, health status, educational achievement, income, and other related factors, both at individual and at population levels.
2. Characterize patterns of population exposure resulting from local sources in a variety of settings, especially cities in the developing world.
3. Frame research questions in a way that is relevant to and responsive to identified needs of policymakers and affected communities.
4. Select indicators of SEP that are amenable to policy intervention.
5. Involve a range of actors, including representatives of local communities affected by pollution, in problem identification, research design, research practice, and translating findings into action to reduce air pollution levels and exposure (Kinney & O'Neill, 2006).

In addition to these recommendations, further integration of environmental health concerns with research on social determinants of health is also needed, along with a more holistic view that incorporates health consequences of both air pollution exposure and global climate change into the discussion of environmental equity and our societies' use of fossil-fuel based energy sources.

Challenges to achieving environmental equity in air quality management include: (1) an inherent lack of political/economic power and access to information among lower status groups most affected by air pollution and climate change; (2) environmental concerns may rank low on the priority list of the socioeconomically deprived; (3) pollution exposures/pollution–health associations are not always higher in lower socioeconomic groups, and thus, when research contradicts expectation, it may not support actions desired by activists; and (4) different sectors (transport, zoning, social welfare) are responsible for relevant policies, and coordination among them may be difficult. The new WHO AQG specifically address the challenges in preparing broadly applicable health-based standards for countries where pollution levels and scientific and regulatory capacities differ greatly, but many of the aforementioned challenges are inherent to the issue and remain a concern for future progress in this field.

In spite of these limitations and challenges, however, there is reason for optimism that the direction of research, policy, and dialogue on environmental equity in air quality management bodes well for a future in which the WHO goal of "the attainment by all peoples of the highest possible level of health" will be realized, along with more sustainable and environmentally responsible management of the world's resources. Inequitably elevated health risks due to air pollution emissions bring into clearer focus the fundamental inequity associated with treating the atmosphere as a free resource for waste disposal. Throughout history, benefits of such use have been enjoyed by certain population groups at the expense of others who bear the costs. Better research can help us move toward a fuller accounting of the health costs associated with pollution emissions and their distributions, and provide valuable input to policies aimed at redressing the inequitable distribution of benefits and costs.

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