Chapter **43**

Air and Water Pollution: Burden and Strategies for Control

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Environmental pollution has many facets, and the resultant health risks include diseases in almost all organ systems. Thus, a chapter on air and water pollution control links with chapters on, for instance, diarrheal diseases (chapter 19), respiratory diseases in children and adults (chapters 25 and 35), cancers (chapter 29), neurological disorders (chapter 32), and cardiovascular disease (chapter 33), as well as with a number of chapters dealing with health care issues.

NATURE, CAUSES, AND BURDEN OF AIR AND WATER POLLUTION

Each pollutant has its own health risk profile, which makes summarizing all relevant information into a short chapter difficult. Nevertheless, public health practitioners and decision makers in developing countries need to be aware of the potential health risks caused by air and water pollution and to know where to find the more detailed information required to handle a specific situation. This chapter will not repeat the discussion about indoor air pollution caused by biomass burning (chapter 42) and water pollution caused by poor sanitation at the household level (chapter 41), but it will focus on the problems caused by air and water pollution at the community, country, and global levels.

Estimates indicate that the proportion of the global burden of disease associated with environmental pollution hazards ranges from 23 percent (WHO 1997) to 30 percent (Smith, Corvalan, and Kjellstrom 1999). These estimates include infectious diseases related to drinking water, sanitation, and food hygiene; respiratory diseases related to severe indoor air pollution from biomass burning; and vectorborne diseases with a major environmental component, such as malaria. These three types of diseases each contribute approximately 6 percent to the updated estimate of the global burden of disease (WHO 2002).

As the World Health Organization (WHO) points out, outdoor air pollution contributes as much as 0.6 to 1.4 percent of the burden of disease in developing regions, and other pollution, such as lead in water, air, and soil, may contribute 0.9 percent (WHO 2002). These numbers may look small, but the contribution from most risk factors other than the "top 10" is within the 0.5 to 1.0 percent range (WHO 2002).

Because of space limitations, this chapter can give only selected examples of air and water pollution health concerns. Other information sources on environmental health include Yassi and others (2001) and the Web sites of or major reference works by WHO, the United Nations Environment Programme (UNEP), Division of Technology, Industry, and Economics (http://www.uneptie.org/); the International Labour Organization (ILO), the United Nations Industrial Development Organization (UNIDO; http://www.unido.org/), and other relevant agencies.

Table 43.1 indicates some of the industrial sectors that can pose significant environmental and occupational health risks to populations in developing countries. Clearly, disease control measures for people working in or living around a smelter may be quite different from those for people living near a tannery or a brewery. For detailed information about industry-specific

Table 43.1 Selected Industrial Sectors and Their Contribution to Air and Water Pollution and to Workplace Hazards

Industrial sector	Air	Water	Workplace[a]
Base metal and iron ore mining	PM	Toxic metal sludge	Silica
Cement manufacturing	PM	Sludge	Silica
Coalmining and production	PM, coal dust	Sludge	Coal dust, silica
Copper smelting	Arsenic	Arsenic	Arsenic, cadmium
Electricity generation	PM, SO_2	Hot water	SO_2
Foundries	PM	Solvents	Silica, solvents
Iron and steel smelting	PM	Sludge	Carbon monoxide, nickel
Lead and zinc smelting	PM, SO_2, lead, cadmium, arsenic	Lead, cadmium, arsenic	PM, SO_2, lead, cadmium, arsenic
Meat processing and rendering	Odor	High biological oxygen demand	Infections
Oil and gas development	SO_2, carcinogens	Oil	Hydrocarbons
Pesticide manufacturing	Pesticides and toxic intermediates	Pesticides and toxic intermediates	Pesticides and toxic intermediates
Petrochemicals manufacturing	SO_2	Oil	Hydrocarbons
Petroleum refining	SO_2	Sludge, hydrocarbons	Hydrocarbons
Phosphate fertilizer plants	PM	Nutrients	
Pulp and paper mills	Odor	High biological oxygen demand, mercury	Chlorine
Tanning and leather finishing	Odor	Chromium, acids	Chromium, acids
Textile manufacturing		Toxic dyes	

Source: World Bank 1999.
a. In all the cases, the workplaces are subject to risk of injury, noise, dust, and excessively hot or cold temperatures.

pollution control methods, see the Web sites of industry sector organizations, relevant international trade union organizations, and the organizations listed above.

Air Pollution

Air pollutants are usually classified into suspended particulate matter (PM) (dusts, fumes, mists, and smokes); gaseous pollutants (gases and vapors); and odors.

Suspended PM can be categorized according to total suspended particles: the finer fraction, PM_{10}, which can reach the alveoli, and the most hazardous, $PM_{2.5}$ (median aerodynamic diameters of less than 10.0 microns and 2.5 microns, respectively). Much of the $PM_{2.5}$ consists of secondary pollutants created by the condensation of gaseous pollutants—for example, sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). Types of suspended PM include diesel exhaust particles; coal fly ash; wood smoke; mineral dusts, such as coal, asbestos, limestone, and cement; metal dusts and fumes; acid mists (for example, sulfuric acid); and pesticide mists.

Gaseous pollutants include sulfur compounds such as SO_2 and sulfur trioxide; carbon monoxide; nitrogen compounds such as nitric oxide, NO_2, and ammonia; organic compounds such as hydrocarbons; volatile organic compounds; polycyclic aromatic hydrocarbons and halogen derivatives such as aldehydes; and odorous substances. Volatile organic compounds are released from burning fuel (gasoline, oil, coal, wood, charcoal, natural gas, and so on); solvents; paints; glues; and other products commonly used at work or at home. Volatile organic compounds include such chemicals as benzene, toluene, methylene chloride, and methyl chloroform. Emissions of nitrogen oxides and hydrocarbons react with sunlight to eventually form another secondary pollutant, ozone, at ground level. Ozone at this level creates health concerns, unlike ozone in the upper atmosphere, which occurs naturally and protects life by filtering out ultraviolet radiation from the sun.

Sources of Outdoor Air Pollution. Outdoor air pollution is caused mainly by the combustion of petroleum products or coal by motor vehicles, industry, and power stations. In some countries, the combustion of wood or agricultural waste is another major source. Pollution can also originate from industrial processes that involve dust formation (for example, from cement factories and metal smelters) or gas releases (for instance, from chemicals production). Indoor sources also contribute to outdoor air pollution, and in heavily populated areas, the contribution from indoor sources can create extremely high levels of outdoor air pollution.

Motor vehicles emit PM, nitric oxide and NO_2 (together referred to as NO_x), carbon monoxide, organic compounds, and lead. Lead is a gasoline additive that has been phased out in industrial countries, but some developing countries still use leaded gasoline. Mandating the use of lead-free gasoline is an important intervention in relation to health. It eliminates

Box 43.1

The Bhopal Catastrophe

The Bhopal plant, owned by the Union Carbide Corporation, produced methyl isocyanate, an intermediate in the production of the insecticide carbaryl. On December 2, 1984, a 150,000-gallon storage tank containing methyl isocyanate apparently became contaminated with water, initiating a violent reaction and the release of a cloud of toxic gas to which 200,000 people living near the plant were exposed. Low wind speed and the high vapor pressure of methyl isocyanate exacerbated the severity of toxic exposure, resulting in the immediate death of at least 6,000 people.

The dominating nonlethal effects of this emission were severe irritation of the eyes, lungs, and skin. Effects on the nervous system and reproductive organs were also reported. The reaction of methyl isocyanate with water had a corrosive effect on the respiratory tract, which resulted in extensive necrosis, bleeding, and edema. Treatment was impeded by the unknown and disputed composition of the gas cloud and a lack of knowledge about its health effects and about antidotes.

Source: Dhara and Dhara 2002.

vehicle-related lead pollution and permits the use of catalytic converters, which reduce emissions of other pollutants.

Catastrophic emissions of organic chemicals, as occurred in Bhopal, India, in 1984 (box 43.1), can also have major health consequences (McGranahan and Murray 2003; WHO 1999).

Another type of air pollution that can have disastrous consequences is radioactive pollution from a malfunctioning nuclear power station, as occurred in Chernobyl in 1986 (WHO 1996). Radioactive isotopes emitted from the burning reactor spread over large areas of what are now the countries of Belarus, the Russian Federation, and Ukraine, causing thousands of cases of thyroid cancer in children and threatening to cause many cancer cases in later decades.

Exposure to Air Pollutants. The extent of the health effects of air pollution depends on actual exposure. Total daily exposure is determined by people's time and activity patterns, and it combines indoor and outdoor exposures. Young children and elderly people may travel less during the day than working adults, and their exposure may therefore be closely correlated with air pollution levels in their homes. Children are particularly vulnerable to environmental toxicants because of their possibly greater relative exposure and the effects on their growth and physiological development.

Meteorological factors, such as wind speed and direction, are usually the strongest determinants of variations in air pollution, along with topography and temperature inversions. Therefore, weather reports can be a guide to likely air pollution levels on a specific day.

Workplace air is another important source of air pollution exposure (chapter 60). Resource extraction and processing industries, which are common in developing countries, emit dust or hazardous fumes at the worksite (table 43.1). Such industries include coalmining, mineral mining, quarrying, and cement production. Developed countries have shifted much of their hazardous production to developing countries (LaDou 1992). This shift creates jobs in the developing countries, but at the price of exposure to air pollution resulting from outdated technology. In addition, specific hazardous compounds, such as asbestos, have been banned in developed countries (Kazan-Allen 2004), but their use may still be common in developing countries.

Impacts on Health. Epidemiological analysis is needed to quantify the health impact in an exposed population. The major pollutants emitted by combustion have all been associated with increased respiratory and cardiovascular morbidity and mortality (Brunekreef and Holgate 2002). The most famous disease outbreak of this type occurred in London in 1952 (U.K. Ministry of Health 1954), when 4,000 people died prematurely in a single week because of severe air pollution, followed by another 8,000 deaths during the next few months (Bell and Davis 2001).

In the 1970s and 1980s, new statistical methods and improved computer technology allowed investigators to study mortality increases at much lower concentrations of pollutants. A key question is the extent to which life has been shortened. Early loss of life in elderly people, who would have died soon regardless of the air pollution, has been labeled *mortality displacement,* because it contributes little to the overall burden of disease (McMichael and others 1998).

Long-term studies have documented the increased cardiovascular and respiratory mortality associated with exposure to PM (Dockery and others 1993; Pope and others 1995).

A 16-year follow-up of a cohort of 500,000 Americans living in different cities found that the associations were strongest with $PM_{2.5}$ and also established an association with lung cancer mortality (Pope and others 2002). Another approach is ecological studies of small areas based on census data, air pollution information, and health events data (Scoggins and others 2004), with adjustments for potential confounding factors, including socioeconomic status. Such studies indicate that the mortality increase for every 10 micrograms per cubic meter (μg per m^3) of $PM_{2.5}$ ranges from 4 to 8 percent for cities in developed countries where average annual $PM_{2.5}$ levels are 10 to 30 $\mu g/m^3$. Many urban areas of developing countries have similar or greater levels of air pollution.

The major urban air pollutants can also give rise to significant respiratory morbidity (WHO 2000). For instance, Romieu and others (1996) report an exacerbation of asthma among children in Mexico City, and Xu and Wang (1993) note an increased risk of respiratory symptoms in middle-aged nonsmokers in Beijing.

In relation to the very young, Wang and others (1997) find that PM exposure, SO_2 exposure, or both increased the risk of low birthweight in Beijing, and Pereira and others (1998) find that air pollution increased intrauterine mortality in São Paulo.

Other effects of ambient air pollution are postneonatal mortality and mortality caused by acute respiratory infections, as well as effects on children's lung function, cardiovascular and respiratory hospital admissions in the elderly, and markers for functional damage of the heart muscle (WHO 2000). Asthma is another disease that researchers have linked to urban air pollution (McConnell and others 2002; Rios and others 2004). Ozone exposure as a trigger of asthma attacks is of particular concern. The mechanism behind an air pollution and asthma link is not fully known, but early childhood NO_2 exposure may be important (see, for example, Ponsonby and others 2000).

Leaded gasoline creates high lead exposure conditions in urban areas, with a risk for lead poisoning, primarily in young children. The main concern is effects on the brain from low-level exposure leading to behavioral aberrations and reduced or delayed development of intellectual or motoric ability (WHO 1995). Lead exposure has been implicated in hypertension in adults, and this effect may be the most important for the lead burden of disease at a population level (WHO 2002). Other pollutants of concern are the carcinogenic volatile organic compounds, which may be related to an increase in lung cancer, as reported by two recent epidemiological studies (Nyberg and others 2000; Pope and others 2002).

Urban air pollution and lead exposure are two of the environmental hazards that WHO (2002) assessed as part of its burden-of-disease calculations for the *World Health Report 2002*. The report estimates that pollution by urban PM causes as much as 5 percent of the global cases of lung cancer, 2 percent of deaths from cardiovascular and respiratory conditions, and 1 percent of respiratory infections, adding up to 7.9 million disability-adjusted life years based on mortality only. This burden of disease occurs primarily in developing countries, with China and India contributing the most to the global burden. Eastern Europe also has major air pollution problems, and in some countries, air pollution accounts for 0.6 to 1.4 percent of the total disability-adjusted life years from mortality.

The global burden of disease caused by lead exposure includes subtle changes in learning ability and behavior and other signs of central nervous system damage (Fewthrell, Kaufmann, and Preuss 2003). WHO (2002) concludes that 0.4 percent of deaths and 0.9 percent (12.9 million) of all disability-adjusted life years may be due to lead exposure.

Water Pollution

Chemical pollution of surface water can create health risks, because such waterways are often used directly as drinking water sources or connected with shallow wells used for drinking water. In addition, waterways have important roles for washing and cleaning, for fishing and fish farming, and for recreation.

Another major source of drinking water is groundwater, which often has low concentrations of pathogens because the water is filtered during its transit through underground layers of sand, clay, or rocks. However, toxic chemicals such as arsenic and fluoride can be dissolved from the soil or rock layers into groundwater. Direct contamination can also occur from badly designed hazardous waste sites or from industrial sites. In the United States in the 1980s, the government set in motion the Superfund Program, a major investigation and cleanup program to deal with such sites (U.S. Environmental Protection Agency 2000).

Coastal pollution of seawater may give rise to health hazards because of local contamination of fish or shellfish—for instance, the mercury contamination of fish in the infamous Minamata disease outbreak in Japan in 1956 (WHO 1976). Seawater pollution with persistent chemicals, such as polychlorinated biphenyls (PCBs) and dioxins, can also be a significant health hazard even at extremely low concentrations (Yassi and others 2001).

Sources of Chemical Water Pollution. Chemicals can enter waterways from a point source or a nonpoint source. Point-source pollution is due to discharges from a single source, such as an industrial site. Nonpoint-source pollution involves many small sources that combine to cause significant pollution. For instance, the movement of rain or irrigation water over land picks up pollutants such as fertilizers, herbicides, and insecticides and carries them into rivers, lakes, reservoirs, coastal waters, or groundwater. Another nonpoint source is stormwater that collects on roads and eventually reaches rivers or lakes. Table 43.1 shows examples of point-source industrial chemical pollution.

Paper and pulp mills consume large volumes of water and discharge liquid and solid waste products into the environment. The liquid waste is usually high in biological oxygen demand, suspended solids, and chlorinated organic compounds such as dioxins (World Bank 1999). The storage and transport of the resulting solid waste (wastewater treatment sludge, lime sludge, and ash) may also contaminate surface waters. Sugar mills are associated with effluent characterized by biological oxygen demand and suspended solids, and the effluent is high in ammonium content. In addition, the sugarcane rinse liquid may contain pesticide residues. Leather tanneries produce a significant amount of solid waste, including hide, hair, and sludge. The wastewater contains chromium, acids, sulfides, and chlorides. Textile and dye industries emit a liquid effluent that contains toxic residues from the cleaning of equipment. Waste from petrochemical manufacturing plants contains suspended solids, oils and grease, phenols, and benzene. Solid waste generated by petrochemical processes contains spent caustic and other hazardous chemicals implicated in cancer.

Another major source of industrial water pollution is mining. The grinding of ores and the subsequent processing with water lead to discharges of fine silt with toxic metals into waterways unless proper precautions are taken, such as the use of sedimentation ponds. Lead and zinc ores usually contain the much more toxic cadmium as a minor component. If the cadmium is not retrieved, major water pollution can occur. Mining was the source of most of the widespread cadmium poisoning (Itai-Itai disease) in Japan in 1940–50 (Kjellstrom 1986).

Other metals, such as copper, nickel, and chromium, are essential micronutrients, but in high levels these metals can be harmful to health. Wastewater from mines or stainless steel production can be a source of exposure to these metals. The presence of copper in water can also be due to corrosion of drinking water pipes. Soft water or low pH makes corrosion more likely. High levels of copper may make water appear bluish green and give it a metallic taste. Flushing the first water out of the tap can minimize exposure to copper. The use of lead pipes and plumbing fixtures may result in high levels of lead in piped water.

Mercury can enter waterways from mining and industrial premises. Incineration of medical waste containing broken medical equipment is a source of environmental contamination with mercury. Metallic mercury is also easily transported through the atmosphere because of its highly volatile nature. Sulfate-reducing bacteria and certain other micro-organisms in lake, river, or coastal underwater sediments can methylate mercury, increasing its toxicity. Methylmercury accumulates and concentrates in the food chain and can lead to serious neurological disease or more subtle functional damage to the nervous system (Murata and others 2004).

Runoff from farmland, in addition to carrying soil and sediments that contribute to increased turbidity, also carries nutrients such as nitrogen and phosphates, which are often added in the form of animal manure or fertilizers. These chemicals cause eutrophication (excessive nutrient levels in water), which increases the growth of algae and plants in waterways, leading to an increase in cyanobacteria (blue-green algae). The toxics released during their decay are harmful to humans.

The use of nitrogen fertilizers can be a problem in areas where agriculture is becoming increasingly intensified. These fertilizers increase the concentration of nitrates in groundwater, leading to high nitrate levels in underground drinking water sources, which can cause methemoglobinemia, the life-threatening “blue baby” syndrome, in very young children, which is a significant problem in parts of rural Eastern Europe (Yassi and others 2001).

Some pesticides are applied directly on soil to kill pests in the soil or on the ground. This practice can create seepage to groundwater or runoff to surface waters. Some pesticides are applied to plants by spraying from a distance—even from airplanes. This practice can create spray drift when the wind carries the materials to nearby waterways. Efforts to reduce the use of the most toxic and long-lasting pesticides in industrial countries have largely been successful, but the rules for their use in developing countries may be more permissive, and the rules of application may not be known or enforced. Hence, health risks from pesticide water pollution are higher in such countries (WHO 1990).

Naturally occurring toxic chemicals can also contaminate groundwater, such as the high metal concentrations in underground water sources in mining areas. The most extensive problem of this type is the arsenic contamination of groundwater in Argentina, Bangladesh (box 43.2), Chile, China, India, Mexico, Nepal, Taiwan (China), and parts of Eastern Europe and the United States (WHO 2001). Fluoride is another substance that may occur naturally at high concentrations in parts of China, India, Sri Lanka, Africa, and the eastern Mediterranean. Although fluoride helps prevent dental decay, exposure to levels greater than 1.5 milligrams per liter in drinking water can cause pitting of tooth enamel and deposits in bones. Exposure to levels greater than 10 milligrams per liter can cause crippling skeletal fluorosis (Smith 2003).

Water disinfection using chemicals is another source of chemical contamination of water. Chlorination is currently the most widely practiced and most cost-effective method of disinfecting large community water supplies. This success in disinfecting water supplies has contributed significantly to public health by reducing the transmission of waterborne disease. However, chlorine reacts with naturally occurring organic matter in water to form potentially toxic chemical compounds,

Box 43.2

Arsenic in Bangladesh

The presence of arsenic in tube wells in Bangladesh because of natural contamination from underground geological layers was first confirmed in 1993. Ironically, the United Nations Children's Fund had introduced the wells in the 1960s and 1970s as a safe alternative to water contaminated with microbes, which contributed to a heavy diarrheal disease burden. Estimates indicate that 28 million to 35 million people of Bangladesh's population of 130 million are exposed to arsenic levels exceeding 50 micrograms per liter, the prescribed limit for drinking water in Bangladesh (Kinniburgh and Smedley 2001). This number increases to 46 million to 57 million if the WHO guideline level of 10 micrograms per liter is used. The most common sign of arsenic poisoning in Bangladesh is skin lesions characterized by hyperkeratosis and melanosis. Other effects reported, but not epidemiologically confirmed, include cancer (particularly of the skin, lungs, and bladder); liver damage; diabetes; hypertension; and reproductive effects (spontaneous abortions and stillbirths). Cancer and vascular effects are the dominating effects in other arsenic-polluted areas (WHO 2001).

Source: Authors.

known collectively as disinfection by-products (International Agency for Research on Cancer 2004).

Exposure to Chemical Water Pollution. Drinking contaminated water is the most direct route of exposure to pollutants in water. The actual exposure via drinking water depends on the amount of water consumed, usually 2 to 3 liters per day for an adult, with higher amounts for people living in hot areas or people engaged in heavy physical work. Use of contaminated water in food preparation can result in contaminated food, because high cooking temperatures do not affect the toxicity of most chemical contaminants.

Inhalation exposure to volatile compounds during hot showers and skin exposure while bathing or using water for recreation are also potential routes of exposure to water pollutants. Toxic chemicals in water can affect unborn or young children by crossing the placenta or being ingested through breast milk.

Estimating actual exposure via water involves analyzing the level of the contaminant in the water consumed and assessing daily water intake (WHO 2003). Biological monitoring using blood or urine samples can be a precise tool for measuring total exposure from water, food, and air (Yassi and others 2001).

Health Effects. No published estimates are available of the global burden of disease resulting from the overall effects of chemical pollutants in water. The burden in specific local areas may be large, as in the example cited in box 43.2 of arsenic in drinking water in Bangladesh. Other examples of a high local burden of disease are the nervous system diseases of methylmercury poisoning (Minamata disease), the kidney and bone diseases of chronic cadmium poisoning (Itai-Itai disease), and the circulatory system diseases of nitrate exposure (methemoglobinemia) and lead exposure (anemia and hypertension).

Acute exposure to contaminants in drinking water can cause irritation or inflammation of the eyes and nose, skin, and gastrointestinal system; however, the most important health effects are due to chronic exposure (for example, liver toxicity) to copper, arsenic, or chromium in drinking water. Excretion of chemicals through the kidney targets the kidney for toxic effects, as seen with chemicals such as cadmium, copper, mercury, and chlorobenzene (WHO 2003).

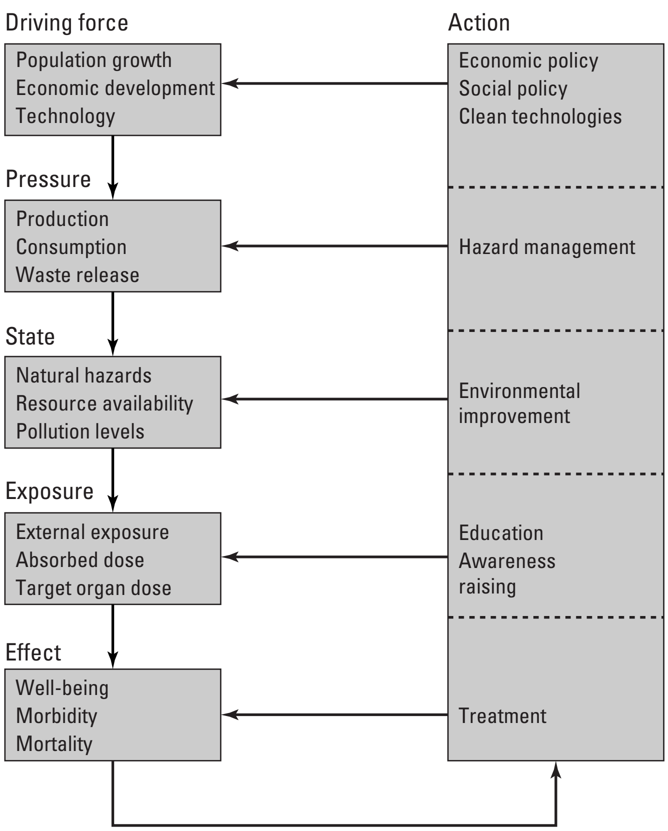
Pesticides and other chemical contaminants that enter waterways through agricultural runoff, stormwater drains, and industrial discharges may persist in the environment for long periods and be transported by water or air over long distances. They may disrupt the function of the endocrine system, resulting in reproductive, developmental, and behavioral problems. The endocrine disruptors can reduce fertility and increase the occurrence of stillbirths, birth defects, and hormonally dependent cancers such as breast, testicular, and prostate cancers. The effects on the developing nervous system can include impaired mental and psychomotor development, as well as cognitive impairment and behavior abnormalities (WHO and International Programme on Chemical Safety 2002). Examples of endocrine disruptors include organochlorines, PCBs, alkylphenols, phytoestrogens (natural estrogens in plants), and pharmaceuticals such as antibiotics and synthetic sex hormones from contraceptives. Chemicals in drinking water can also be carcinogenic. Disinfection by-products and arsenic have been a particular concern (International Agency for Research on Cancer 2004).

INTERVENTIONS

The variety of hazardous pollutants that can occur in air or water also leads to many different interventions. Interventions pertaining to environmental hazards are often more sustainable if they address the driving forces behind the pollution at the community level rather than attempt to deal with specific exposures at the individual level. In addition, effective methods to prevent exposure to chemical hazards in the air or water may not exist at the individual level, and the only feasible individual-level intervention may be treating cases of illness.

Figure 43.1 shows five levels at which actions can be taken to prevent the health effects of environmental hazards. Some would label interventions at the driving force level as policy instruments. These include legal restrictions on the use of a toxic substance, such as banning the use of lead in gasoline, or community-level policies, such as boosting public transportation and reducing individual use of motor vehicles.

Interventions to reduce pressures on environmental quality include those that limit hazardous waste disposal by recycling hazardous substances at their site of use or replacing them with less hazardous materials. Interventions at the level of the state of the environment would include air quality monitoring linked to local actions to reduce pollution during especially polluted periods (for example, banning vehicle use when pollution levels reach predetermined thresholds). Interventions at the exposure level include using household water filters to reduce arsenic in drinking water as done in Bangladesh. Finally, interventions at the effect level would include actions by health services to protect or restore the health of people already showing signs of an adverse effect.



Source: Kjellstrom and Corvalan 1995.

Figure 43.1 Framework for Environmental Health Interventions

Interventions to Reduce Air Pollution

Reducing air pollution exposure is largely a technical issue. Technologies to reduce pollution at its source are plentiful, as are technologies that reduce pollution by filtering it away from the emission source (end-of-pipe solutions; see, for example, Gwilliam, Kojima, and Johnson 2004). Getting these technologies applied in practice requires government or corporate policies that guide technical decision making in the right direction. Such policies could involve outright bans (such as requiring lead-free gasoline or asbestos-free vehicle brake linings or building materials); guidance on desirable technologies (for example, providing best-practice manuals); or economic instruments that make using more polluting technologies more expensive than using less polluting technologies (an example of the polluter pays principle).

Examples of technologies to reduce air pollution include the use of lead-free gasoline, which allows the use of catalytic converters on vehicles' exhaust systems. Such technologies significantly reduce the emissions of several air pollutants from vehicles (box 43.3). For trucks, buses, and an increasing number of smaller vehicles that use diesel fuel, improving the quality of the diesel itself by lowering its sulfur content is another way to reduce air pollution at the source. More fuel-efficient vehicles, such as hybrid gas-electric vehicles, are another way forward. These vehicles can reduce gasoline consumption by about 50 percent during city driving. Policies that reduce "unnecessary" driving, or traffic demand management, can also reduce air pollution in urban areas. A system of congestion fees, in which drivers have to pay before entering central urban areas, was introduced in Singapore, Oslo, and London and has been effective in this respect.

Power plants and industrial plants that burn fossil fuels use a variety of filtering methods to reduce particles and scrubbing methods to reduce gases, although no effective method is currently available for the greenhouse gas carbon dioxide. High chimneys dilute pollutants, but the combined input of pollutants from a number of smokestacks can still lead to an overload of pollutants. An important example is acid rain, which is caused by SO_2 and NO_x emissions that make water vapor in the

Box 43.3

Air Pollution Reduction in Mexico City

Mexico City is one of the world's largest megacities, with nearly 20 million inhabitants. Local authorities have acknowledged its air quality problems since the 1970s. The emissions from several million motor vehicles and thousands of industries created major concerns about health effects. Annual average particulate matter (PM_{10}) levels of 50 to 100 $\mu g/m^3$ have been measured in the worst-polluted central area and can be associated with annual mortality excess of 15 to 30 percent. Even if only 20 percent of the population were exposed to such high levels, that exposure would account for 6,000 to 12,000 additional deaths per year. To tackle the problem, Mexico City started air quality monitoring and health studies in the 1980s. High-risk groups were the 2.2 million children, 250,000 street vendors, and 250,000 commercial drivers. After 20 years of policies and actions, interventions for better health have borne fruit.

The first intervention was lead-free gasoline in 1990, which enabled the government to require catalytic converters on new cars, thus dramatically reducing carbon monoxide, NO_x, and hydrocarbon emissions. In 1997, leaded gasoline was completely phased out. The annual average concentration of lead in the air in the worst-polluted area was reduced from 1.2 $\mu g/m^3$ in 1990 to less than 0.1 $\mu g/m^3$ in 2000. Surveys of blood lead levels in children showed reductions from 200 to 100 μg/liter during the same period, implying that the intervention had protected thousands of children from lead poisoning. Another key concern was SO_2 emissions from industry and diesel vehicles. Heavy fuel oil was phased out in the mid 1990s, and the sulfur content of diesel was reduced. In addition, power plants and some industry shifted to natural gas in the early 1990s. The result was a 90 percent reduction of SO_2 in ambient air in five years.

Air quality standards, emission standards for vehicles, and other technical actions to reduce air emissions were tightened during the 1990s, contributing to downward trends of carbon monoxide, NO_x, and ozone levels. Levels of emissions were reduced by half at some sites, resulting in an estimated reduction of 3,000 to 6,000 excess deaths.

Sources: Fernandez 2002; McMichael, Kjellstrom, and Smith 2001; WHO 2000.

atmosphere acidic (WHO 2000). Large combined emissions from industry and power stations in the eastern United States drift north with the winds and cause damage to Canadian ecosystems. In Europe, emissions from the industrial belt across Belgium, Germany, and Poland drift north to Sweden and have damaged many lakes there. The convergence of air pollutants from many sources and the associated health effects have also been documented in relation to the multiple fires in Indonesia's rain forest in 1997 (Brauer and Hisham-Hashim 1998); the brown cloud over large areas of Asia, which is mainly related to coal burning; and a similar brown cloud over central Europe in the summer, which is caused primarily by vehicle emissions.

Managing air pollution interventions involves monitoring air quality, which may focus on exceedances of air quality guidelines in specific hotspots or on attempts to establish a specific population's average exposure to pollution. Sophisticated modeling in combination with monitoring has made it possible to start producing detailed estimates and maps of air pollution levels in key urban areas (World Bank 2004), thus providing a powerful tool for assessing current health impacts and estimated changes in the health impacts brought about by defined air pollution interventions.

Interventions to Reduce Water Pollution

Water pollution control requires action at all levels of the hierarchical framework shown in figure 43.1. The ideal method to abate diffuse chemical pollution of waterways is to minimize or avoid the use of chemicals for industrial, agricultural, and domestic purposes. Adapting practices such as organic farming and integrated pest management could help protect waterways (Scheierling 1995). Chemical contamination of waterways from industrial emissions could be reduced by cleaner production processes (UNEP 2002). Box 43.4 describes one project aimed at effectively reducing pollution.

Other interventions include proper treatment of hazardous waste and recycling of chemical containers and discarded products containing chemicals to reduce solid waste buildup and leaching of toxic chemicals into waterways. A variety of technical solutions are available to filter out chemical waste from industrial processes or otherwise render them harmless. Changing the pH of wastewater or adding chemicals that flocculate the toxic chemicals so that they settle in sedimentation ponds are common methods. The same principle can be used at the individual household level. One example is the use of iron chips to filter out arsenic from contaminated well water in Bangladeshi households (Kinniburgh and Smedley 2001).

Box 43.4

Water Pollution Control in India

In 1993, the Demonstration in Small Industries for Reducing Wastes Project was started in India with support from the United Nations Industrial Development Organization. International and local experts initiated waste reduction audits in four pulp and paper plants, four textile dyeing and finishing factories, and four pesticide production units. The experts identified priority areas, estimated the likely reduction in the pollutant load, and came up with more than 500 pollution prevention options. The 12 companies spent a total of US$300,000 to implement pollution prevention options and saved US$3 million in raw materials and wastewater treatment costs.

The most impressive savings were in the pulp and paper sector. For instance, the Ashoka Pulp and Paper Company participated in the project with the dual objectives of reducing production costs and complying with environmental regulations in a cost-effective manner. Pressure from the public to improve environmental performance and the need to conserve water, especially during the summer, added urgency to the project. The company implemented 24 waste minimization options, with 13 additional options under consideration, resulting in net annual savings of about US$160,000. The payback period for the implemented options was less than seven months, and the annual savings will continue.

The project demonstrated that waste minimization can cut pollution and business costs at the same time, especially when the environmental protection effort is directed toward the production process itself rather than to end-of-pipe treatment. The key to success lies in the sustained involvement of local experts and committed factory managers.

Source: United Nations 1997.

INTERVENTION COSTS AND COST-EFFECTIVENESS

This chapter cannot follow the detailed format for the economic analysis of different preventive interventions devised for the disease-specific chapters, because the exposures, health effects, and interventions are too varied and because of the lack of overarching examples of economic assessments. Nevertheless, it does present a few examples of the types of analyses available.

Comparison of Interventions

A review of more than 1,000 reports on cost per life year saved in the United States for 587 interventions in the environment and other fields (table 43.2) evaluated costs from a societal perspective. The net costs included only direct costs and savings. Indirect costs, such as forgone earnings, were excluded. Future costs and life years saved were discounted at 5 percent per year. Interventions with a cost per life year saved of less than or equal to zero cost less to implement than the value of the lives saved. Each of three categories of interventions (toxin control, fatal injury reduction, and medicine) presented in table 43.2 includes several extremely cost-effective interventions.

The cost-effective interventions in the air pollution area could be of value in developing countries as their industrial and transportation pollution situations become similar to the United States in the 1960s. The review by Tengs and others (1995) does not report the extent to which the various interventions were implemented in existing pollution control or public health programs, and many of the most cost-effective interventions are probably already in wide use. The review did create a good deal of controversy in the United States, because professionals and nongovernmental organizations active in the environmental field accused the authors of overestimating the costs and underestimating the benefits of controls over chemicals (see, for example, U.S. Congress 1999).

Costs and Savings in Relation to Pollution Control

A number of publications review and discuss the evidence on the costs and benefits of different pollution control interventions in industrial countries (see, for example, U.S. Environmental Protection Agency 1999). For developing countries, specific data on this topic are found primarily in the so-called gray literature: government reports, consultant reports, or reports by the international banks.

Air Pollution. Examples of cost-effectiveness analysis for assessing air quality policy include studies carried out in Jakarta, Kathmandu, Manila, and Mumbai under the World Bank's Urban Air Quality Management Strategy in Asia (Grønskei and others 1996a, 1996b; Larssen and others 1996a, 1996b; Shah, Nagpal, and Brandon 1997). In each city, an emissions inventory was established, and rudimentary dispersion modeling was carried out. Various mitigation measures for

Table 43.2 Median Cost Per Life Year Saved, Selected Relatively Low-Cost Interventions
(1993 U.S. dollars)

Intervention	Cost per life year saved
Toxin control	
Control coal-fired power plant emissions through high chimneys and other means	≤ 0
Reduce lead in gasoline from 1.1 to 0.1 grams per gallon	≤ 0
Ban amitraz pesticide on apples	≤ 0
Introduce a chloroform emission standard at selected pulp mills	≤ 0
Control SO_2 by desulfuring residual fuel oil	≤ 0
Initiate sedimentation, filtration, and chlorination of drinking water	4,200
Introduce radon remediation in homes with levels greater than 21.6 picocuries per liter	6,100
Ban asbestos in brake linings	29,000
Set arsenic emission standards at selected copper smelters	36,000
Fatal injury reduction	
Make motorcycle helmet laws mandatory	≤ 0
Install automatic seat belts in cars	≤ 0
Require bad drivers to attend driving improvement schools	≤ 0
Pass a law requiring smoke detectors in homes	≤ 0
Improve standards for concrete construction	≤ 0
Ban residential growth in tsunami-prone areas	≤ 0
Make seat belt use in cars mandatory	69
Install smoke detectors in airplane lavatories	30,000
Medicine	
Require all common types of early childhood vaccinations	≤ 0
Implement annual stool colon cancer screening for people age 55 and older	≤ 0
Introduce detoxification or methadone maintenance for heroin addicts	≤ 0
Screen newborns for phenylketonuria	≤ 0
Recommend cervical cancer screening every three years for women age 65 and older	≤ 0
Introduce universal prenatal care for expectant mothers	≤ 0
Vaccinate all citizens against influenza	140
Screen men age 45–54 for hypertension	5,200
Institute annual mammography and breast examinations for women age 40–64	17,000
Perform three-vessel coronary artery bypass surgery for severe angina	23,000

Source: Based on Tengs and others 1995.
Note: The fatal injury reduction and medicine categories are included for comparison purposes.

reducing PM_{10} and health impacts were examined in terms of reductions in tons of PM_{10} emitted, cost of implementation, time frame for implementation, and health benefits and their associated cost savings. Some of the abatement measures that have been implemented include introducing unleaded gasoline, tightening standards, introducing low-smoke lubricants for two-stroke engine vehicles, implementing inspections of vehicle exhaust emissions to address gross polluters, and reducing garbage burning.

Transportation policies and industrial development do not usually have air quality considerations as their primary objective, but the World Bank has developed a method to take these considerations into account. The costs of different air quality improvement policies are explored in relation to a baseline investment and the estimated health effects of air pollution. A comparison will indicate the cost-effectiveness of each policy. The World Bank has worked out this "overlay" approach in some detail for the energy and forestry sectors in the analogous case of greenhouse gas reduction strategies (World Bank 2004).

Water Pollution. The costs and benefits associated with interventions to remove chemical contaminants from water need to be assessed on a local or national basis to determine specific needs, available resources, environmental conditions (including climate), and sustainability. A developing country for which substantial economic analysis of interventions has been carried out is China (Dasgupta, Wang, and Wheeler 1997; Zhang and others 1996).

Another country with major concerns about chemicals (arsenic) in water is Bangladesh. The arsenic mitigation programs have applied various arsenic removal technologies, but the costs and benefits are not well established. Bangladesh has adopted a drinking water standard of 50 μg/L (micrograms per liter) for arsenic in drinking water. The cost of achieving the lower WHO guideline value of 10 μg/L would be significant. An evaluation of the cost of lowering arsenic levels in drinking water in the United States predicts that a reduction from 50 to 10 μg/L would prevent a limited number of deaths from bladder and lung cancer at a cost of several million dollars per death prevented (Frost and others 2002).

Alternative water supplies need to be considered when the costs of improving existing water sources outweigh the benefits. Harvesting rainwater may provide communities with safe drinking water, free of chemicals and micro-organisms, but contamination from roofs and storage tanks needs to be considered. Rainwater collection is relatively inexpensive.

ECONOMIC BENEFITS OF INTERVENTIONS

One of the early examples of cost-benefit analysis for chemical pollution control is the Japan Environment Agency's (1991) study of three Japanese classical pollution diseases: Yokkaichi asthma, Minamata disease, and Itai-Itai disease (table 43.3). This analysis was intended to highlight the economic aspects of pollution control and to encourage governments in developing countries to consider both the costs and the benefits of industrial development. The calculations take into account the 20 or 30 years that have elapsed since the disease outbreaks occurred and annualize the costs and benefits over a 30-year period. The pollution damage costs are the actual payments for victims' compensation and the cost of environmental remediation. The compensation costs are based on court cases or government decisions and can be seen as a valid representation of the economic value of the health damage in each case. As table 43.3 shows, controlling the relevant pollutants would have cost far less than paying for damage caused by the pollution.

A few studies have analyzed cost-benefit aspects of air pollution control in specific cities. Those analyses are based mainly on modeling health impacts from exposure and relationships between doses and responses. Voorhees and others (2001) find that most studies that analyzed the situation in specific urban areas used health impact assessment to estimate impacts avoided by interventions. Investigators have used different methods for valuing the economic benefits of health improvements, including market valuation, stated preference methods, and revealed preference methods. The choice of assumptions and inputs substantially affected the resulting cost and benefit valuations.

One of the few detailed studies of the costs and benefits of air pollution control in a specific urban area (Voorhees and others 2000) used changing nitric oxide and NO_2 emissions in Tokyo during 1973–94 as a basis for the calculations. The study did not use actual health improvement data but calculated likely health improvements from estimated reductions in NO_2 levels and published dose-response curves. The health effects included respiratory morbidity (as determined by hospital admissions and medical expenses), and working days lost for sick adults, and maternal working days lost in the case of a child's illness. The results indicated an average cost-benefit ratio of 1 to 6, with a large range from a lower limit of 3 to 1 to an upper limit of 1 to 44. The estimated economic benefits of reductions in nitric oxide and NO_2 emissions between 1973 and 1994 were considerable: US$6.78 billion for avoided medical costs, US$6.33 billion for avoided lost wages of sick adults, and US$0.83 billion for avoided lost wages of mothers with sick children.

Blackman and others' (2000) cost-benefit analysis of four practical strategies for reducing PM_{10} emissions from

Table 43.3 Comparison of Actual Pollution Damage Costs and the Pollution Control Costs That Would Have Prevented the Damage, for Three Pollution-Related Disease Outbreaks, Japan
(¥ millions, 1989 equivalents)

			Pollution damage costs			
Pollution disease	Main pollutant	Pollution control costs	Health damage	Livelihood damage	Environmental remediation	Total
Yokkaichi asthma	SO_2, air pollution	14,800	21,000 (1,300)[a]	Not estimated	Not estimated	21,000
Minamata disease	Mercury, water pollution	125	7,670	4,270	690	12,630
Itai-Itai disease	Cadmium, water and soil pollution	600	740	880	890	2,510

Source: Japan Environment Agency 1991.
Note: US$1 = ¥150.
a. Based on actual compensation payments to a fraction of the population. The larger figure is what it would have cost to compensate all those who were affected.

traditional brick kilns in Ciudad Juárez in Mexico suggests that, given a wide range of modeling assumptions, the benefits of three control strategies would be considerably higher than the costs. Reduced mortality was by far the largest component of benefits, accounting for more than 80 percent of the total.

Pandey and Nathwani (2003) applied cost-benefit analysis to a pollution control program in Canada. Their study proposed using the life quality index as a tool for quantifying the level of public expenditure beyond which the use of resources is not justified. The study estimated total pollution control costs at US$2.5 billion per year against a monetary benefit of US$7.5 billion per year, using 1996 as the base year for all cost and benefit estimates. The benefit estimated in terms of avoided mortality was about 1,800 deaths per year.

El-Fadel and Massoud's (2000) study of urban areas in Lebanon shows that the health benefits and economic benefits of reducing PM concentration in the air can range from US$4.53 million to US$172.50 million per year using a willingness-to-pay approach. In that study, the major monetized benefits resulted from reduced mortality costs.

Aunan and others (1998) assessed the costs and benefits of implementing an energy saving and air pollution control program in Hungary. They based their monetary evaluation of benefits on local monitoring and population data and took exposure-response functions and valuation estimates from Canadian, U.S., and European studies. The authors valued the average total benefits of the interventions at US$1.56 billion per year (with 1994 as the base year), with high and low bounds at US$7.6, billion and US$0.4 billion, respectively. They estimated the cost-benefit ratio at 1 to 3.4, given a total cost of interventions of US$0.46 billion per year. Many of the benefits resulted from reduced mortality in the elderly population and from reduced asthma morbidity costs.

Misra (2002) examined the costs and benefits of water pollution abatement for a cluster of 250 small-scale industries in Gujarat, India. Misra's assessment looked at command-and-control, market-based solutions and at effluent treatment as alternatives. In a cost-benefit analysis, Misra estimated the net present social benefits from water pollution abatement at the Nandesari Industrial Estate at Rs 0.550 billion at 1995–96 market prices using a 12 percent social discount rate. After making corrections for the prices of foreign exchange, unskilled labor, and investment, the figure rose to Rs 0.62 billion. It rose still further to about Rs 3.1 billion when distributional effects were taken into account.

IMPLEMENTATION OF CONTROL STRATEGIES: LESSONS OF EXPERIENCE

The foregoing examples demonstrate that interventions to protect health that use chemical pollution control can have an attractive cost-benefit ratio. The Japan Environment Agency (1991) estimates the national economic impact of pollution control legislation and associated interventions. During the 1960s and early 1970s, when the government made many of the major decisions about intensified pollution control interventions, Japan's gross domestic product (GDP) per capita was growing at an annual rate of about 10 percent, similar to that of the rapidly industrializing countries in the early 21st century. At that time, Japan's economic policies aimed at eliminating bottlenecks to high economic growth, and in the mid 1960s, industry was spending less than ¥50 billion per year on pollution control equipment. By 1976, this spending had increased to almost ¥1 trillion per year. The ¥5 trillion invested in pollution control between 1965 and 1975 accounted for about 0.9 percent of the increase in GDP per capita during this period. The Japan Environment Agency concluded that the stricter environmental protection legislation and associated major investment in pollution control had little effect on the overall economy, but that the resulting health benefits are likely cumulative.

Air

The broadest analysis of the implementation of control strategies for air pollution was conducted by the U.S. Environmental Protection Agency in the late 1990s (Krupnick and Morgenstern 2002). The analysis developed a hypothetical scenario for 1970 to 1990, assuming that the real costs for pollution control during this period could be compared with the benefits of reduced mortality and morbidity and avoided damage to agricultural crops brought about by the reduction of major air pollutant levels across the country during this period. The study estimated reduced mortality from dose-response relationships for the major air pollutants, assigning the cost of each death at the value of statistical life and the cost of morbidity in relation to estimated health service utilization. The study used a variety of costing methods to reach the range of likely present values presented in table 43.4. It assumed that the reduction of air pollution resulted from the implementation of the federal Clean Air Act of 1970 and associated state-level regulations and air pollution limits.

The analysis showed a dramatically high cost-benefit ratio and inspired debate about the methodologies used and the results. One major criticism was of the use of the value of statistical life for each death potentially avoided by the reduced air pollution. A recalculation using the life-years-lost method reduced the benefits for deaths caused by PM from US$16,632 billion to US$9,100 billion (Krupnick and Morgenstern 2002). The recalculated figure is still well above the fifth percentile estimate of benefits and does not undermine the positive cost-benefit ratio reported. Thus, if a developing country were to implement an appropriate control strategy for urban air pollution, it might derive significant

Table 43.4 Present Value of Monetary Benefits and Costs Associated with Implementation of the U.S. Clean Air Act, 1970–90 *(1990 US$ billions)*

Category	Pollutant	Present value, 5th percentile	Present value, mean	Present value, 95th percentile
Mortality	PM	2,369	16,632	40,957
Mortality	Lead	121	1,339	3,910
Chronic bronchitis	PM	409	3,313	10,401
IQ reduction	Lead	271	399	551
Other morbidity	Several	227	337	501
Soil damage	PM	6	74	192
Visibility reduction	PM	38	54	71
Agricultural damage	Ozone	11	23	35
Total benefits	All	3,452	22,171	56,618
Total costs	All	Not estimated	523	Not estimated
Net benefits (total benefits − total costs)	All	Not estimated	21,648	Not estimated

Source: Krupnick and Morgenstern 2002.

economic benefits over the subsequent decades. The country's level of economic development, local costs, and local benefit valuations will be important for any cost-benefit assessment. WHO's (2000) air quality guidelines are among the documents that provide advice on analytical approaches.

Water

We were unable to find an analysis for water similar to the broad analysis presented for air, but the examples of water pollution with mercury, cadmium, and arsenic described earlier indicate the economic benefits that can be reaped from effective interventions against chemical water pollution. Since the pollution disease outbreaks of mercury and cadmium poisoning in Japan, serious mercury pollution situations have been identified in Brazil, China, and the Philippines, and serious cadmium pollution has occurred in Cambodia, China, the Lao People's Democratic Republic, and Thailand. Arsenic in groundwater is an ongoing, serious problem in Bangladesh, India, and Nepal and a less serious problem in a number of other countries.

WHO has analyzed control strategies for biological water pollution and water and sanitation improvements in relation to the Millennium Development Goals (Hutton and Haller 2004). The analysis demonstrated the considerable benefits of water and sanitation improvements: for every US$1 invested, the economic return was in the range of US$5 to US$28 for a number of intervention options. Careful analysis of the same type is required for populations particularly vulnerable to chemical water pollution to assess whether control of chemical pollution can also yield significant benefits.

RESEARCH AND DEVELOPMENT AGENDA

Even though a good deal of information is available about the health risks of common air and water pollutants, further research is needed to guide regulations and interventions. The pollutants that were most common in developed countries in the past are still major problems in developing countries; however, direct application of the experiences of developed countries may not be appropriate, because exposed populations in developing countries may have a different burden of preexisting diseases, malnutrition, and other factors related to poverty. Research on specific vulnerabilities and on relevant dose-response relationships for different levels of economic development and for various geographic conditions would therefore be valuable for assessing risks and targeting interventions. In addition, global chemical exposure concerns, such as endocrine disruptors in air, water, and food, require urgent research to establish the need for interventions in both industrial and developing countries.

An important research topic is to clearly describe and quantify the long-term health effects of exposure to air pollution. The existing literature indicates that long-term exposure may have more adverse health effects than short-term exposure and, hence, have higher cost implications. Another topic is to assess the health issue pertaining to greenhouse gases and climate change, which are related to the same sources as urban air pollution (Intergovernmental Panel on Climate Change 2001). Research and policy analysis on how best to develop interventions to reduce health risks related to climate change need to be considered together with the analysis of other air pollutants.

In addition, to improve analysis of the economic costs of health impacts, better estimates are needed of the burden of disease related to chemical air and water pollution at local, national, and global levels. Cost-effectiveness analysis of air and water pollution control measures in developing countries needs to be supported by further research, as cost levels and benefit valuations will vary from country to country, and solutions that are valid in industrial countries may not work as well in developing countries. Strategies for effective air and water resource management should include research on the potential side effects of an intervention, such as in Bangladesh, where tube wells drilled to supply water turned out to be contaminated with arsenic (see box 43.2). Research is also needed that would link methodologies for assessing adverse health effects with exposure and epidemiological studies in different settings to permit the development of more precise forecasting of the health and economic benefits of interventions.

The variety of health effects of urban air pollution and the variety of sources create opportunities for ancillary effects that need to be taken into account in economic cost-effectiveness and cost-benefit analysis. These are the beneficial effects of reducing air pollution on other health risks associated with the sources of air pollution. For example, if the air pollution from transportation emissions is reduced by actions that reduce the use of private motor vehicles by, say, providing public transportation, not only are carbon dioxide levels reduced; traffic crash injuries, noise, and physical inactivity related to the widespread use of motor vehicles also decline (Kjellstrom and others 2003).

One of the key challenges for policies and actions is to find ways to avoid a rapid buildup of urban air pollution in countries that do not yet have a major problem. The health sector needs to be involved in assessing urban planning, the location of industries, and the development of transportation systems and needs to encourage those designing public transportation and housing to ensure that new sources of air pollution are not being built into cities.

Decades of economic and industrial growth have resulted in lifestyles that increase the demands on water resources simultaneous with increases in water pollution levels. Conflicts between household, industrial, and agricultural water use are a common public health problem (UNESCO 2003). The developing countries need to avoid the experiences of water pollution and associated disease outbreaks in industrial countries. Strategies to ensure sufficient pollution control must be identified at the same time as strategies to reduce water consumption. High water use depletes supplies and increases salinity in groundwater aquifers, particularly in coastal regions. The impact of climate change must also be taken into consideration (Vorosmarty and others 2000).

CONCLUSION: PROMISES AND PITFALLS

Evidence shows that a number of chemicals that may be released into the air or water can cause adverse health effects. The associated burden of disease can be substantial, and investment in research on health effects and interventions in specific populations and exposure situations is important for the development of control strategies. Pollution control is therefore an important component of disease control, and health professionals and authorities need to develop partnerships with other sectors to identify and implement priority interventions.

Developing countries face major water quantity and quality challenges, compounded by the effects of rapid industrialization. Concerted actions are needed to safely manage the use of toxic chemicals and to develop monitoring and regulatory guidelines. Recycling and the use of biodegradable products must be encouraged. Technologies to reduce air pollution at the source are well established and should be used in all new industrial development. Retrofitting of existing industries and power plants is also worthwhile. The growing number of private motor vehicles in developing countries brings certain benefits, but alternative means of transportation, particularly in rapidly growing urban areas, need to be considered at an early stage, as the negative health and economic impacts of high concentrations of motor vehicles are well established. The principles and practices of sustainable development, coupled with local research, will help contain or eliminate health risks resulting from chemical pollution. International collaboration involving both governmental and nongovernmental organizations can guide this highly interdisciplinary and intersectoral area of disease control.

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