Chapter 1

Injury Prevention and Environmental Health: Key Messages from *Disease Control Priorities,* Third Edition

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VOLUME SUMMARY

Injury Prevention and Environmental Health identifies essential prevention strategies and related policies that address substantial population health needs, are cost-effective, and are feasible to implement. This chapter summarizes and critically assesses the volume's four key findings.

- There is a large burden of death and disability from injuries and environmental health conditions. Worldwide, injuries result in more than 5 million premature deaths per year out of a global total of 56 million deaths (based on widely used estimates). There are also large numbers of deaths attributable to risk factors related to noninjury occupational exposures (560,000); inadequate access to clean water, sanitation, and hygiene (1.4 million); and air pollution (5.5 million). The vast majority of these deaths are in low- and middle-income countries.
- Risk factors for deaths from these diseases vary with stages of national development in ways that can be understood and used in designing prevention strategies.
- A range of interventions could effectively address these problems; many of these interventions are among the most cost-effective and cost-beneficial of all interventions used to prevent disease.
- This chapter synthesizes the volume's prevention strategies to identify an effective essential package of interventions and policies, most of which have been inadequately applied on a global scale. Better implementation of these interventions and policies would help bring down the high rates of death and disability

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from injury and environmental and occupational risks in low- and middle-income countries (LMICs) toward the lower rates in high-income countries. Doing so could avert more than 7 million deaths annually from environmental and occupational exposures and injuries.

INTRODUCTION

Injury Prevention and Environmental Health identifies essential prevention strategies and related policies that address substantial population health needs and that are cost-effective and feasible to implement. This volume addresses diverse conditions that arise from exposure to outside forces, such as chemicals and toxins, kinetic energy, or thermal energy. These conditions require similar policy approaches to reducing risk and mandate involvement of multiple sectors. Included in this group of conditions are injuries attributable to unintentional mechanisms (road traffic crashes, falls, burns, and drowning); injuries attributable to intentional mechanisms (interpersonal violence); disorders caused by or aggravated by exposure to airborne toxins (air pollution); occupational issues (injuries and disorders caused by or aggravated by toxins in the workplace); and waterborne infectious diseases. This volume focuses exclusively on interventions to prevent these conditions. Treatment for health conditions resulting from injury and environmental risk factors is covered in other volumes of the third edition of *Disease Control Priorities* (*DCP3*), as are immunizations and prevention of suicide (Black, Laxminarayan, and others 2016; Black, Levin, and others 2016; Bundy and others 2017; Debas and others 2015; Mock and others 2015; Patel and others 2015; Patel and others 2016; Prabhakaran and others 2017).

In this review, we identify several key messages. First, there is a large health burden from injury, occupational risk factors, air pollution, unclean water, and poor sanitation. These conditions are major global health problems to which inadequate attention has been directed. Second, these disorders and the risk factors that cause them have predictable patterns across stages of national development. Understanding these patterns can assist with the planning of prevention efforts. Third, cost-effective and cost-beneficial interventions that can address these conditions already exist and are in established use in most high-income countries (HICs). In most low- and middle-income countries (LMICs), these interventions have been implemented only to a modest extent or not at all. On the basis of these interventions' cost-effectiveness and their potential to lower the disease burden, we propose a package of policy interventions (box 1.1).

Box 1.1

From the Series Editors of *Disease Control Priorities,* Third Edition

Budgets constrain choices. Policy analysis helps decision makers achieve the greatest value from limited resources. In 1993, the World Bank published *Disease Control Priorities in Developing Countries* (*DCP1*), which sought to assess systematically the cost-effectiveness (value for money) of interventions addressing the major sources of disease burden in low- and middle-income countries (Jamison and others 1993). The World Bank's *World Development Report* 1993 drew heavily on *DCP1*'s findings to conclude that specific interventions to combat noncommunicable diseases were cost-effective, even in environments with substantial burdens of infection and undernutrition (World Bank 1993).

Disease Control Priorities in Developing Countries, second edition *(DCP2)* published in 2006, updated and extended *DCP1* in several respects, giving explicit consideration to the implications for health systems of expanded intervention coverage (Jamison and others 2006). One way to expand coverage of health interventions is through platforms for interventions that require similar logistics but that address heterogeneous health problems. Platforms often provide a more natural unit for investment than do individual interventions, but conventional health economics has offered little understanding of how to make choices across platforms. Analysis of the costs of packages and platforms—and of the

box continues next page

Box 1.1 (continued)

health improvements they can generate in given epidemiological environments—can help guide health system investments and development.

DCP3 introduces the notion of packages of interventions. Whereas platforms contain logistically related sets of interventions, packages contain conceptually related ones. The 21 packages developed in the nine volumes of *DCP3* include those for surgery and cardiovascular disease, for example. In addition, *DCP3* explicitly considers health systems' objective of financial risk protection. In populations lacking access to health insurance or prepaid care, medical expenses that are high relative to income can be impoverishing. Where incomes are low, seemingly inexpensive medical procedures can have catastrophic financial effects. *DCP3* considers financial protection and the distribution across income groups as outcomes resulting from policies (for example, public finance) to increase intervention uptake and improve delivery quality. All of the volumes seek to combine the available science about interventions implemented in specific locales and conditions with informed judgment to reach reasonable conclusions about the impact of intervention mixes in diverse environments. *DCP3*'s broad aim is to delineate essential intervention packages—such as those for injury prevention and environmental health in this volume—and their related delivery platforms. This information is intended to assist decision makers in allocating often tightly constrained budgets and in achieving health system objectives.

Four of *DCP3*'s nine volumes were published in 2015 and 2016, and the remaining five will appear in 2017 and 2018. The volumes appear in an environment in which serious discussion continues about quantifying and achieving the Sustainable Development Goal (SDG) for health (United Nations 2015). *DCP3*'s analyses are well placed to assist in choosing the means with which to attain the health SDG and assessing the related costs. These volumes, and the analytic efforts on which they are based, will enable researchers to explore SDG-related and other broad policy conclusions and generalizations. The final volume will report those conclusions. Each individual volume provides specific policy analyses on the full range of interventions, packages, and policies relevant to its health topic.

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KEY MESSAGES

Disease Burden Addressable by Injury Prevention and Environmental Health

The different topics examined take advantage of one or more widely used data sources, such as the World Health Organization (WHO) Global Health Estimates or the Global Burden of Disease (GBD) study.

Other global datasets may show slightly different relationships, but the patterns would be similar.[1]

Injury

Injuries include those arising from unintentional causes (such as road traffic crashes, falls, and burns) and intentional causes (such as suicide and violence). In 2012, injuries altogether caused more than 5 million premature deaths globally (table 1.1).[2]

The vast majority (85 percent) of these deaths were in LMICs. The annual incidence of mortality from injury is considerably higher in LMICs (76 per 100,000) compared with HICs (58 per 100,000) (WHO 2016). In most LMICs, half or more of road traffic crash deaths happen to vulnerable road users, such as motorcyclists, bicyclists, and especially pedestrians. Injuries to vehicle occupants predominate in most HICs. Other leading causes of unintentional injury are falls, drowning, and burns. The leading cause of intentional injury deaths is suicide. Homicide is the next leading cause, followed at a distant third by deaths directly due to war and other forms of collective violence (Watkins, Dabestani, Mock, and others 2017; WHO 2016). Interpersonal violence is also an important yet under-recognized risk factor for high-risk behaviors, such as unsafe sex, smoking, and substance abuse, and, through these behaviors, for some

Table 1.1 Injuries: Deaths by Cause, All Ages, Both Sexes, 2012

	Low- and Middle-Income Countries 2012		High-Income Countries 2012	
	Total deaths (thousands)	Percent of all deaths	Total deaths (thousands)	Percent of all deaths
All causes	44,200	100	11,700	100
Injuries (unintentional and intentional)	4,400	10	750	6
Unintentional injuries	**3,220**	**7**	**510**	**4**
Road traffic injuries	1,140	3	120	1
Other unintentional injuries	750	2	180	2
Falls	580	1	120	1
Drowning	340	1	40	0
Fire, heat, and hot substances	250	1	20	0
Poisoning	160	0	30	0
Exposure to forces of nature	2	0	0	0
Intentional injuries	**1,190**	**3**	**240**	**2**
Self-harm	610	1	200	2
Interpersonal violence	460	1	40	0
Collective violence and legal intervention	120	0	0	0

Source: WHO Global Health Estimates 2012 (WHO 2016).
Note: Not all totals are exact due to rounding.

communicable and noncommunicable diseases, as well as for mental health conditions, including anxiety disorders, depression, and suicidal ideation.

Occupational Risks

Occupational and environmental (water and air) risks lead to a substantial health burden. In the usual estimates of global disease burden, this burden is reflected in disease-specific estimates; for example, unsafe water leads to deaths from diarrhea, which are reported in the main global disease burden estimates (Watkins, Dabestani, Mock, and others 2017; WHO 2016). Additional analyses discussed later show the burden from the risk factors themselves.

Occupationally related deaths and disabilities include on-the-job injuries and exposure to chemicals (such as pesticides, solvents, and heavy metals); heat; and noise; among other risk factors. An estimated 720,000 deaths occur annually from occupational exposures globally, 79 percent of which are in LMICs. The largest contributors to this burden are injuries and exposure to particulate matter, gases, and fumes (which contribute to respiratory and cardiovascular disease and cancers) (table 1.2). Occupational ergonomic factors and exposure to noise do not cause mortality, but they contribute significantly to disability.

Notwithstanding the global estimates in table 1.2, estimates and sources of overall burden of occupational deaths and disabilities are not well known for many countries. Part of the problem is lack of reporting on occupational issues, which is aggravated by the fact that most people in LMICs work in the informal sector, for which accurate, or sometimes any, statistics are not kept. Occupational health problems encompass some that are long-standing, such as agricultural injuries. Others arise or are aggravated by changes in manufacturing and supply chain practices globally as more dangerous jobs are transferred to LMICs, especially to locations with limited environmental and safety safeguards, and are performed by people with lower levels of training and who usually have limited or no access to protective equipment (Watkins, Dabestani, Mock, and others 2017).

Water, Sanitation, and Hygiene

Inadequate access to safe water, sanitation, and hygiene (WASH) was estimated to result in about 1.4 million deaths globally in 2013, virtually all (more than 99 percent) in LMICs (table 1.3). WASH-related deaths account for a large proportion of diarrheal disease and intestinal infectious diseases, almost all among children. The major attributal factors are unsafe water sources (1,240,000 deaths globally), unsafe sanitation (820,000 deaths), and lack of hygiene (especially availability of handwashing with soap: 520,000 deaths), with an uncertain degree of overlap in attributable deaths among

Table 1.2 Occupational Risks: Attributable Deaths by Cause, All Ages, Both Sexes, 2013

	Deaths (Thousands)	
	Low- and middle-income countries 2013	High-income countries 2013
Total attributable deaths	**23,800**	**7,000**
Total environmental and occupational risks	7,420	760
Occupational risks	**570**	**140**
Occupational asthmagens	50	0
Occupational carcinogens	190	110
Occupational ergonomic factors	0	0
Occupational injuries	140	20
Occupational noise	0	0
Occupational particulate matter, gases, and fumes	200	10

Source: Global Burden of Disease (GBD) 2013 Study (IHME 2016).
Note: Each of the six major occupational hazards is listed as a subcategory of "occupational risks," which are a subset of "total environmental and occupational risks," which are a subset of "total attributable deaths." Data from GBD 2013 were used because similar data were unavailable from the WHO Global Health Estimates. GBD 2010 and GBD 2015 estimates are somewhat different from GBD 2013. Not all totals are exact due to rounding.

Table 1.3 Environmental Risks: Attributable Deaths by Cause, All Ages, Both Sexes, 2013

	Deaths (Thousands)	
	Low- and middle-income countries 2013	High-income countries 2013
Total attributable deaths	**23,800**	**7,000**
Total environmental and occupational risks	7,420	760
Unsafe water, sanitation, and handwashing	**1,390**	**10**
No handwashing with soap	510	10
Unsafe sanitation	820	0
Unsafe water source	1,240	10
Air pollution	**4,990**	**540**
Ambient ozone pollution	180	40
Ambient particulate matter pollution	2,430	500
Household air pollution from solid fuels	2,880	10

Source: Global Burden of Disease (GBD) 2013 Study (IHME 2016).
Note: Each of the major environmental hazards is listed as a subcategory of the bolded categories. Data from GBD 2013 were used because similar data were unavailable from the WHO Global Health Estimates. There is an unknown degree of overlap between the impacts across the air pollution and unsafe water categories, which is not addressed here.

these causes. Water and sanitation were the topics of Millennium Development Goal 7 and have received considerable attention over the past several decades. As a result, there have been significant advances in access to clean water and improved sanitation, with related decreases in burden. In addition, better nutrition and rehydration therapy have reduced case fatality substantially. The total number of deaths estimated as attributable to inadequate WASH has declined by 49 percent, from 2.7 million deaths in 1990 to 1.4 million deaths in 2013 (Watkins, Dabestani, Mock, and others 2017). Despite these improvements, inadequate access to WASH remains a major health problem, accounting for approximately 43 percent of under-five mortality in South and South-East Asia and Sub-Saharan Africa (Humphrey 2009; Petri and Miller 2008).

Air Pollution

Exposure to airborne pollutants in ambient and household settings was estimated to result in more than

5 million deaths globally in 2013 (table 1.3). In disease burden estimates, air pollution contributes a significant proportion of deaths attributable to respiratory infections; chronic obstructive pulmonary disease; cerebrovascular disease; ischemic heart disease; and cancers of the trachea, bronchus, and lung. The forms of air pollution evaluated were ambient particulate matter pollution (approximately 2.9 million deaths globally) and household air pollution from solid fuels (approximately 2.9 million deaths globally) in the form of particle and ozone pollution, although there are other categories that have not yet been assessed globally. Overall, 90 percent of air pollution deaths are in LMICs. However, because use of solid cooking fuels in households is confined almost entirely to LMICs, essentially all impacts occur there. Ambient particulate matter air pollution occurs in rural and urban areas and is related to a variety of emissions sources, including motorized transport, power plants, industry, road and construction dust, brick kilns, and garbage burning. Household air pollution occurs primarily in less urbanized areas and is related to use of solid fuels for cooking and heating. It also is a major source of ambient pollution, causing at least a quarter of ambient pollution exposures in India and China, for example (Chafe and others 2014; Lelieveld and others 2015). Thus, perhaps 16 to 31 percent of the burden attributed to ambient pollution actually started in households, although this burden is not yet well characterized. Ambient air pollution is estimated to account for a larger proportion of cardiovascular and cerebrovascular diseases, while household air pollution accounts for a larger proportion of chronic and acute respiratory disease, the latter affecting children (Watkins, Dabestani, Mock, and others 2017).

Taken together, the conditions and risks covered in this review comprise more than 12 million deaths per year, not accounting for possible overlaps among different categories of attributable causes. Climate change contributes a small portion of the current burden of climate-sensitive health outcomes but, given its trajectory, will become increasingly important in future decades.

Environmental and Injury Risk Transitions

All comparisons in this section rely on the widely used GBD 2015 dataset—other global datasets may show slightly different absolute levels and relationships, but the patterns will be similar.[3,4] A classic portrayal of mortality trends during the national development process is the "mortality transition" that documents shifts over time in causes of death (figure 1.1) (Omran 1971).

This portrayal gives the false impression, however, that the impact of noncommunicable disease increases with development, which is not the case at large scale. For comparisons of the health status of populations, the correct calculation is the age-standardized version. The age-standardized version is the true *epidemiological transition*, which takes account of the younger age structure in poor countries, as shown in figure 1.2 (Smith and Ezzati 2005). Age-standardized data provide a more accurate illustration of the comparative health of someone going through the life course in each region, what most people consider the important comparison of health status across populations. In contrast to what is shown in the mortality transition (figure 1.1), in figure 1.2 all general disease categories—communicable (category I), noncommunicable (category II), and injuries (category III)—actually decline across income groups after age standardization, substantially so in categories I and III (communicable and injuries), but definitively for noncommunicable as well. Thus, as is uncomfortably true for many of life's conditions, it is generally better to live in a richer rather than a poorer society.

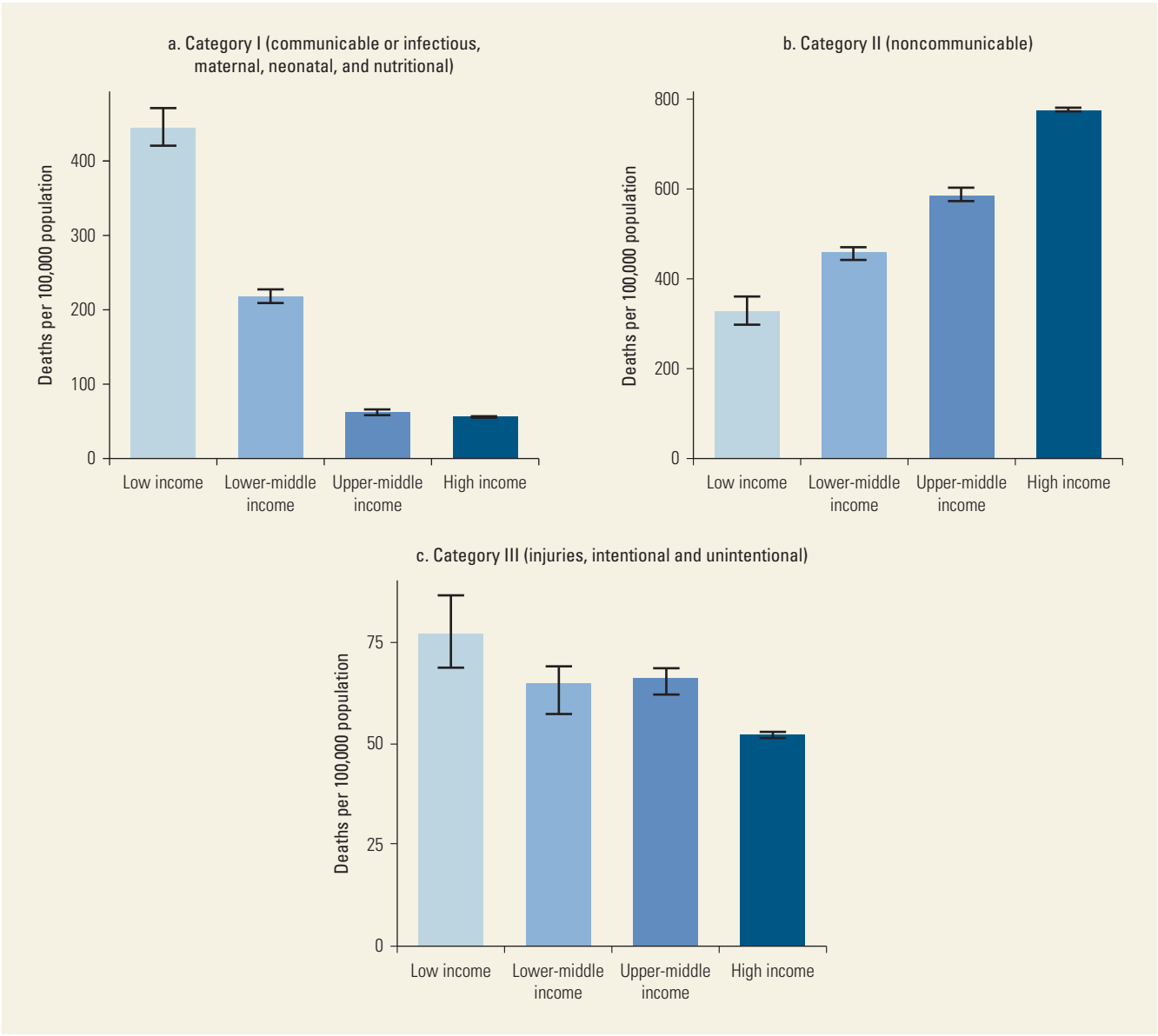
Many factors other than income affect health, and many of these are amenable to policy. Policy, in turn, is affected by factors other than income, although income remains one primary determinant. All analyses in this section use age-standardized deaths per capita to normalize across the four World Bank income regions and aggregate large categories of disease and risk that tend to obfuscate individual differences. It should be noted that higher resolution by more subregions, specific diseases, or even by country might show subtleties not revealed by comparison across only four income regions. Mortality trends are not reflective of the entire picture of health because nonfatal injury and illness also affect health status. The aggregated patterns shown in this section, however, show similar trends when disability-adjusted life years (DALYs) are used.

As shown in figure 1.3, the overall health impacts from environmental and occupational exposures and from injuries tend to decline across country income groups after age standardization. Examined in more detail, however, the trends for environmental risks can be divided into three categories in what has been termed the *environmental risk transition* (Smith 1990).

Traditional Environmental Health Risks

Traditional environmental health risks (poor food, air, water, and sanitation at the household level) tend to decline with economic development, but they do so at varying rates depending on policy and the degree of income and education equity in societies. This link to income is observed in figure 1.4, which shows the

Figure 1.1 Crude Death Rates across Income Categories for All Category I, II, and III Diseases, All Ages, 2015



burden from household air pollution and from poor water, sanitation, and hygiene steadily declining across income groups. Although much diminished in rich countries, these risks still dominate global environmental health burdens today.

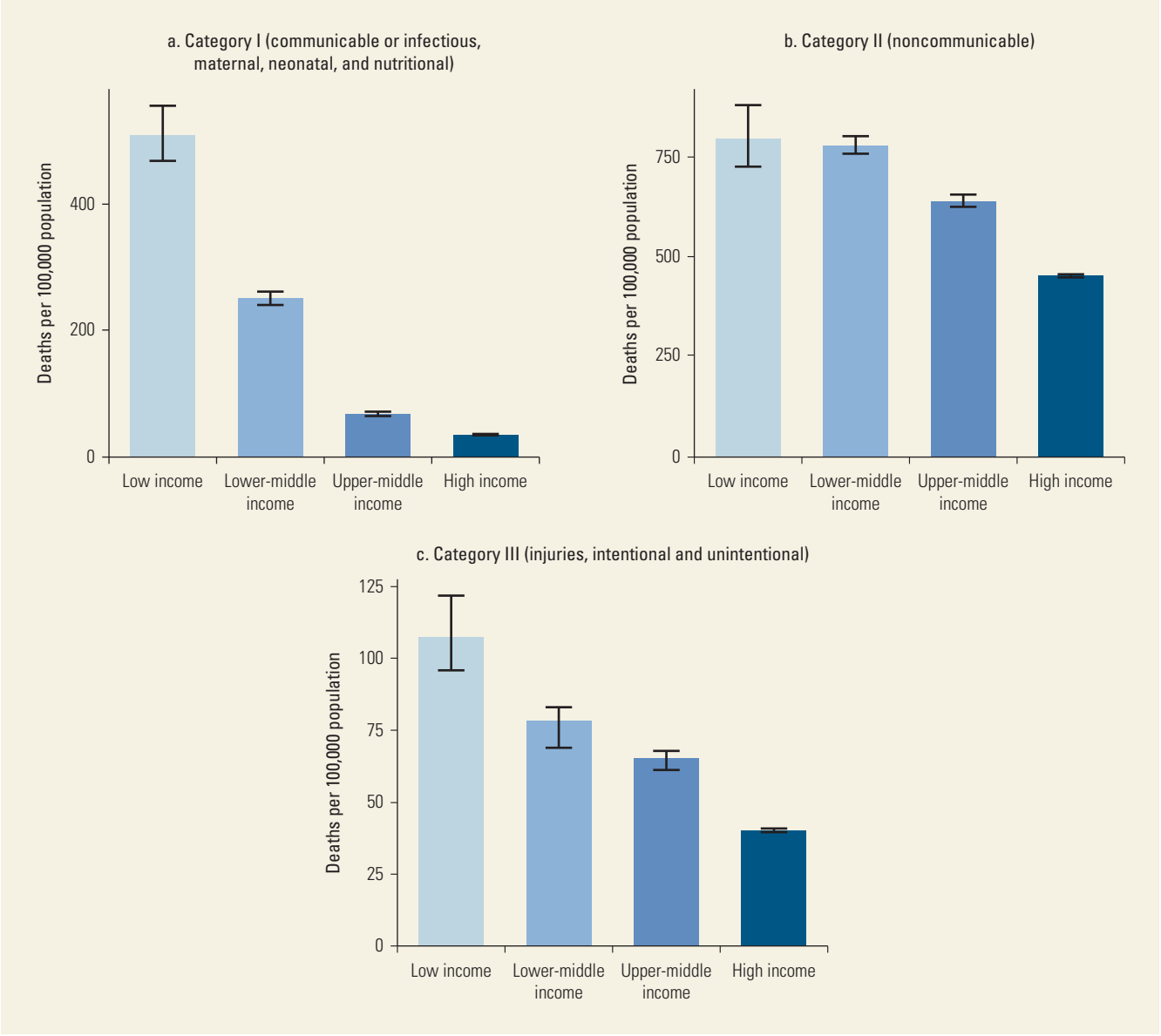
Modern Environmental Health Risks

Modern environmental health risks from industrialization, urbanization, vehicularization, and agricultural modernization tend to rise at first during the development process, then peak and fall at higher levels of income and education. Again, the height these risks reach and the point at which they turn downward are strongly determined by preventive policy. Figure 1.5 illustrates how the burdens from ambient particle pollution, environmental tobacco smoke, and ambient ozone air pollution rise and then fall with development.

Global Environmental Health Risks

The imposition of a set of global environmental risks—exemplified by release of greenhouse pollutants and including other global environmental stressors, such as biodiversity loss—has risen with development. The notable exception is reductions of stratospheric

Figure 1.2 Age-Standardized Trends in Mortality Risk for Category I, II, and III Diseases by Income, 2015



ozone–depleting pollutants under the Montreal Protocol, which is one of the major examples of successful international policy. Such global hazards do not dominate current environmental health burdens, but as these threats continue to rise, they may dominate health burdens later in the century unless strong actions are implemented. The trends for risks from greenhouse gas emissions are illustrated in figure 1.6 for the two most important gases, carbon dioxide and methane (Smith, Desai, and others 2013).

In summary, as shown in figure 1.7, all environmental risk factors taken together declined over the development spectrum because of the strong decline in traditional risks. In general, traditional risks are faced mostly at the household level in lower-income countries, where required behavioral changes and low access to resources are barriers to interventions. Modern risks are commonly seen at the community level because they derive from larger-scale social organization, including industrialization and urban design. Global risks arise at larger

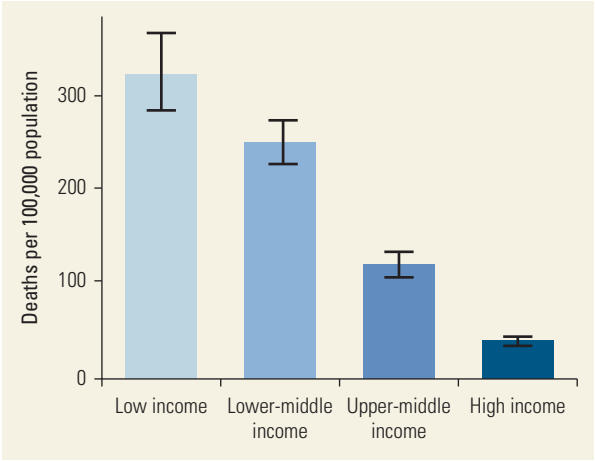
geographic and organizational scales, with most health impacts generally occurring in populations that have contributed little to concentrations of greenhouse gases in the atmosphere.

Is there an injury risk transition? Panel c of figure 1.2 illustrates that the impact of all forms of injuries declines with development. A question, however, is whether examination of individual injury categories reveals different patterns, recognizing that reporting bias is present for many types of injury. Mortality from, in declining number, road traffic injuries, falls, drowning, fires, occupational injuries, and snakebites (surprisingly prevalent in poor areas) appears generally to follow the classic traditional risk form, declining steadily with development (figure 1.8). Mortality from interpersonal violence and poisoning may also follow the traditional form, but trends are not clear at this resolution (four income groups only; figure 1.9). Thus, there is no clear transition from one to another type of injury with development, but rather a steady decline across essentially all categories examined here as protective policies and infrastructure are put in place and daily work and living environments evolve.

Transition frameworks are common in development discussion (for example, demographic, nutrition, and inequality transitions) but should primarily be considered tools for parsing observed patterns rather than generating normative predictions of what will happen. They provide a structure for categorizing changes that occur during development and for designing policies that avoid the worst trends and enhance the best ones. They are not destiny but analytic tools.

It is important to be aware that the relationships in this chapter are cross-sectional and thus cannot take into account the different world situation in place when currently developed regions were developing as compared with poor countries today. Nevertheless, they provide instructive ways to understand and organize current risk patterns.

Figure 1.3 Age-Standardized Mortality, 2015, from All Occupational and Environmental Risk Factors Examined in the Global Burden of Disease Study 2015



Note: This figure is based on summed impacts from estimates of the impacts of separate risk factors. It thus includes contributions from communicable diseases (category I), noncommunicable diseases (category II), and injuries (category III). This figure contains no contribution from global risks, but as shown in the vertical axis of figure 1.6, global risks are relatively small at present.

Figure 1.4 Age-Standardized Trends in Mortality Risk for Household Air Pollution and for Poor Water, Sanitation, and Hygiene, 2015

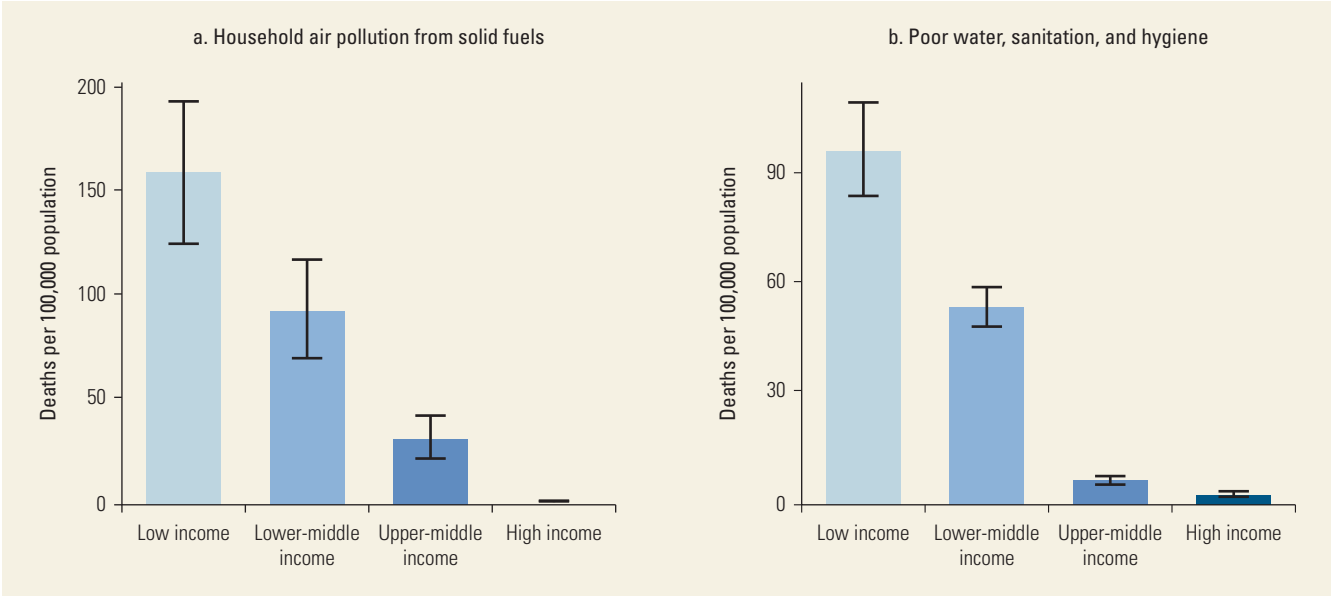
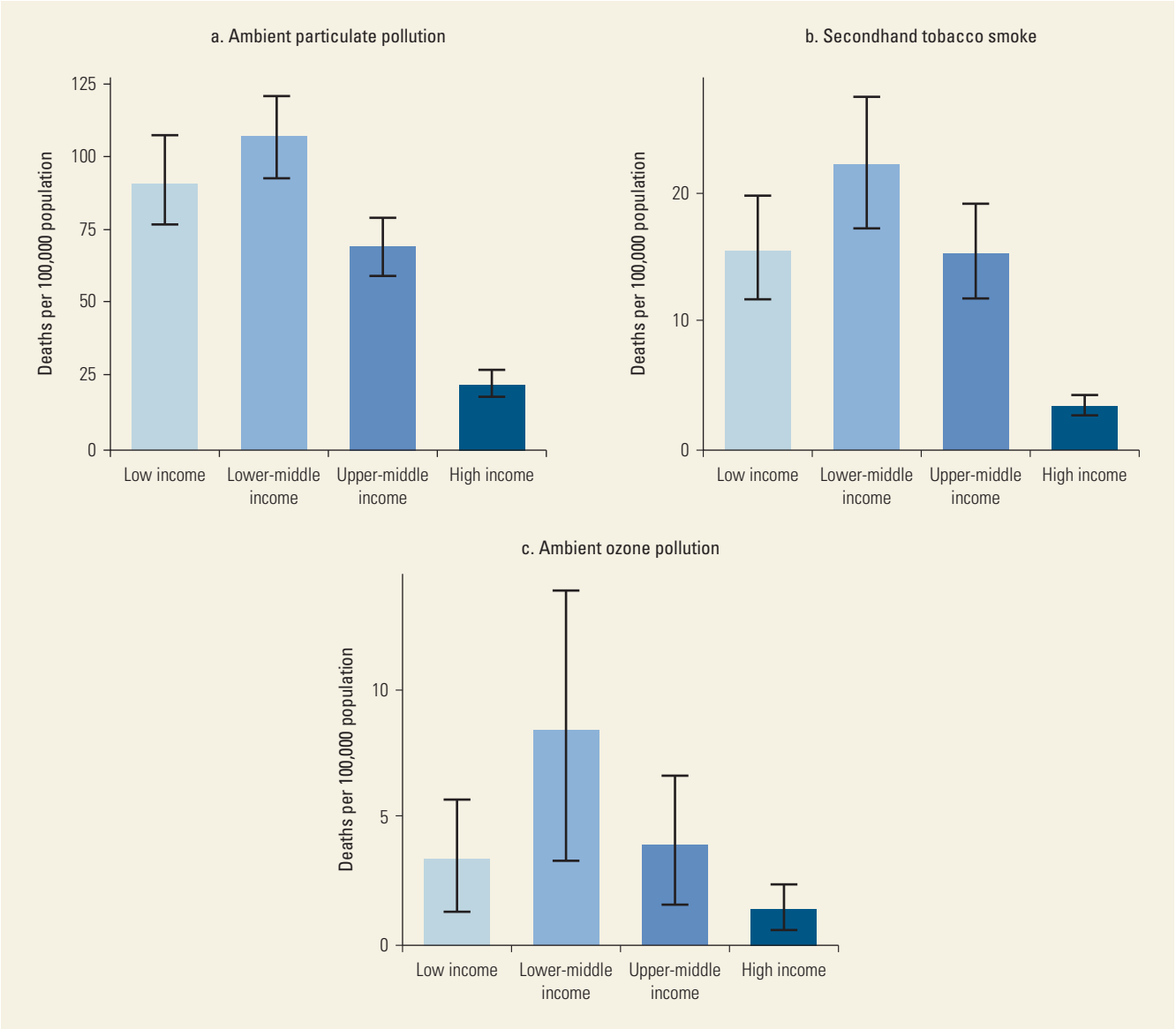


Figure 1.5 Age-Standardized Trends in Mortality Risk for Ambient Particle Pollution, Environmental (Secondhand) Tobacco Smoke, and Ambient Ozone Pollution, 2015



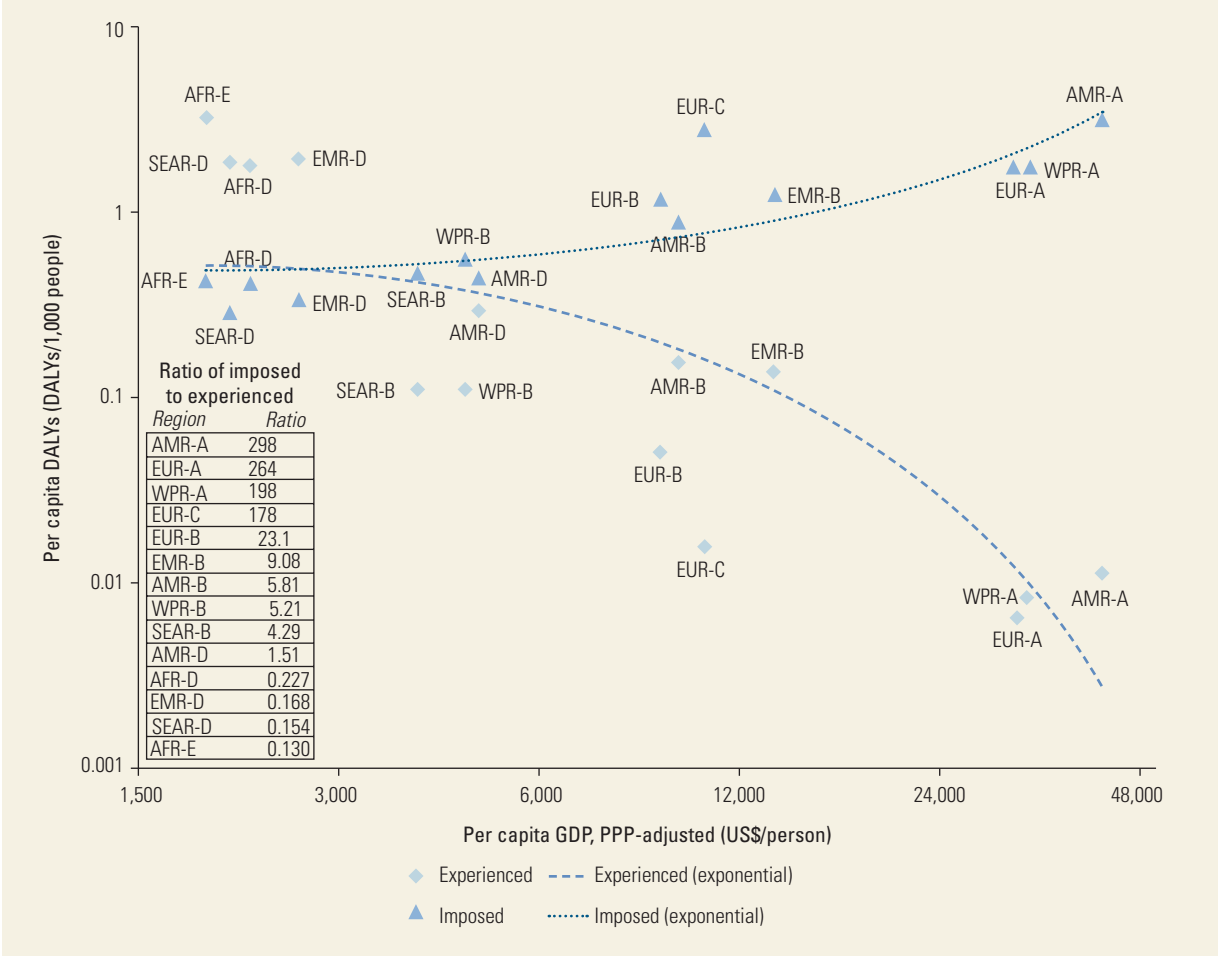
ECONOMIC EVALUATION OF INJURY PREVENTION AND ENVIRONMENTAL INTERVENTIONS

Economic evaluation aims to inform decision making by quantifying tradeoffs between resource inputs required for alternative strategies and resulting outcomes. Four main approaches are discussed in box 1.2.

Economic evaluation of the interventions that address the conditions in this review has not been conducted to the same extent as for many other health problems (Watkins, Dabestani, Nugent, and Levin 2017), in part because many of the interventions are population-based policies and regulations that use multisectoral approaches, which are inherently less straightforward to study using economic methods that are more readily applied to individual-level health interventions. In addition, several of the environmental interventions have notable non-health outcomes that are often difficult to cost, such as time savings, reduction in black carbon emissions, and lower pressure on forests from shifts in household fuels.

Nevertheless, there is an accumulating body of evidence that many of the interventions addressing injury and environmental health are very cost-effective

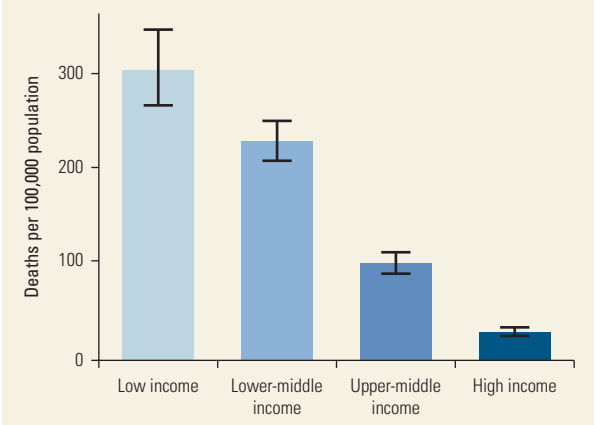
Figure 1.6 Trends of Global Environmental Health Risk by Income Using WHO Regions



Region	Ratio
AMR-A	298
EUR-A	264
WPR-A	198
EUR-C	178
EUR-B	23.1
EMR-B	9.08
AMR-B	5.81
WPR-B	5.21
SEAR-B	4.29
AMR-D	1.51
AFR-D	0.227
EMR-D	0.168
SEAR-D	0.154
AFR-E	0.130

Source: Smith, Desai, and others 2013.
Note: DALY = disability-adjusted life year; GDP = gross domestic product; PPP = purchasing power parity. In key, AFR = African Region; AMR = American Region; EMR = Eastern Mediterranean Region; EUR = European Region; SEAR = South-East Asia Region; WPR = Western Pacific Region. A–E refer to specific groupings of countries by mortality strata within each region. The trend for "experiencing" the risk is inverse to the trend for "imposing the risk." The latter is based on parsing the total estimated global burden from climate change according to each region's contribution to emissions of carbon dioxide and methane over time—its natural debt.

Figure 1.7 Deaths from All Environmental Risk Factors, Age Standardized, 2015



in LMICs. For example, studies in LMICs have shown that speed bumps at high-risk junctions cost US$12 per DALY averted (in 2012 US$), improved enforcement of traffic laws costs US$84 per DALY averted, and enforcing motorcycle helmet use costs US$615 per DALY averted (Bishai and Hyder 2006; Ditsuwan and others 2013; Watkins, Dabestani, Nugent, and Levin 2017). Swimming lessons and improved supervision of children to prevent drowning cost US$27 and US$256 per DALY averted, respectively (Rahman and others 2012; Watkins, Dabestani, Nugent, and Levin 2017).

In general, an intervention with a cost-effectiveness ratio of one to three times the per capita gross domestic product of a country is considered cost-effective (Newall, Jit, and Hutubessy 2014; Watkins, Dabestani, Nugent, and Levin 2017). Thus, for almost all countries, the examples

Figure 1.8 Age-Standardized Trends in Mortality Risk for Types of Unintentional Injury, 2015

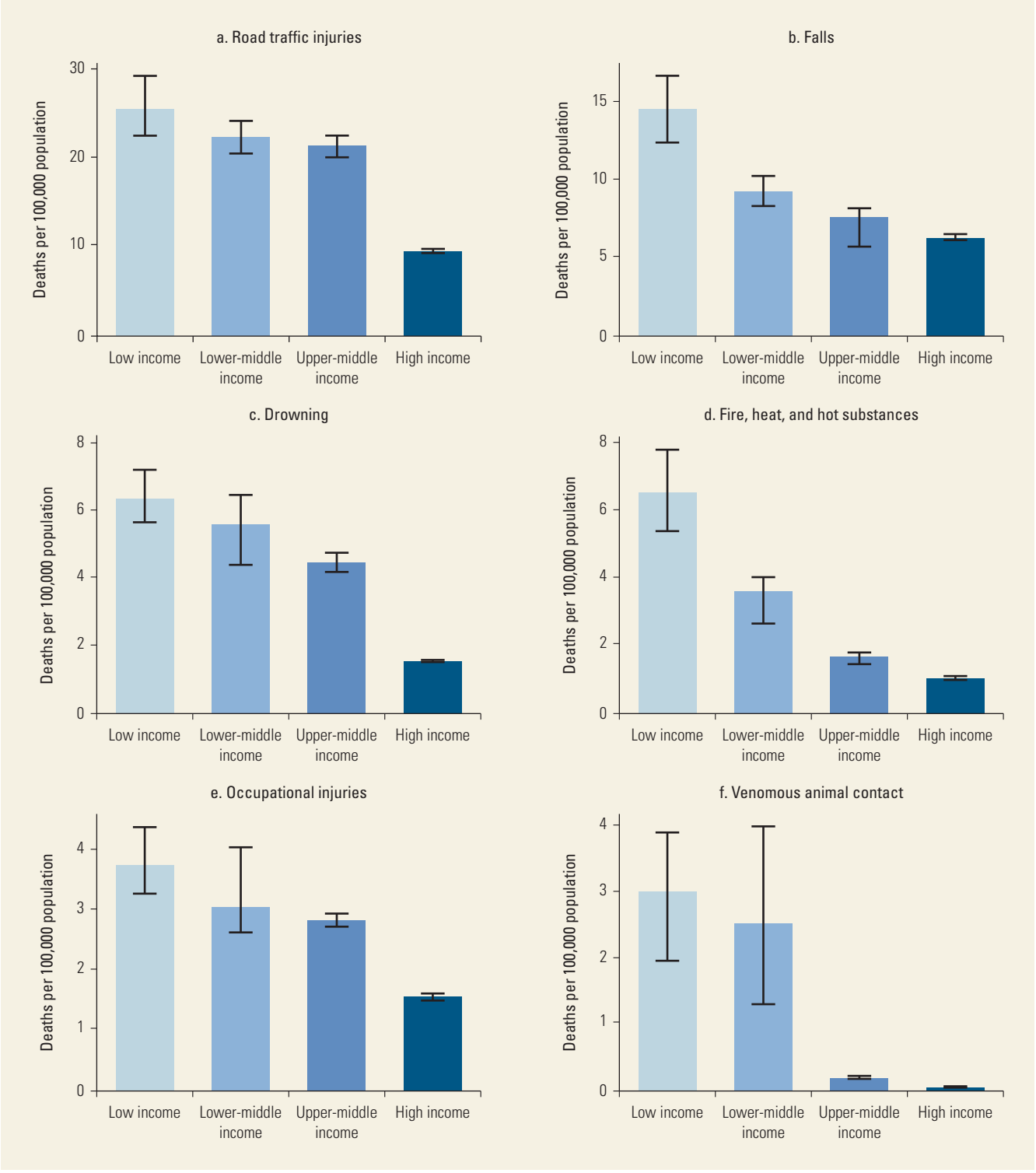
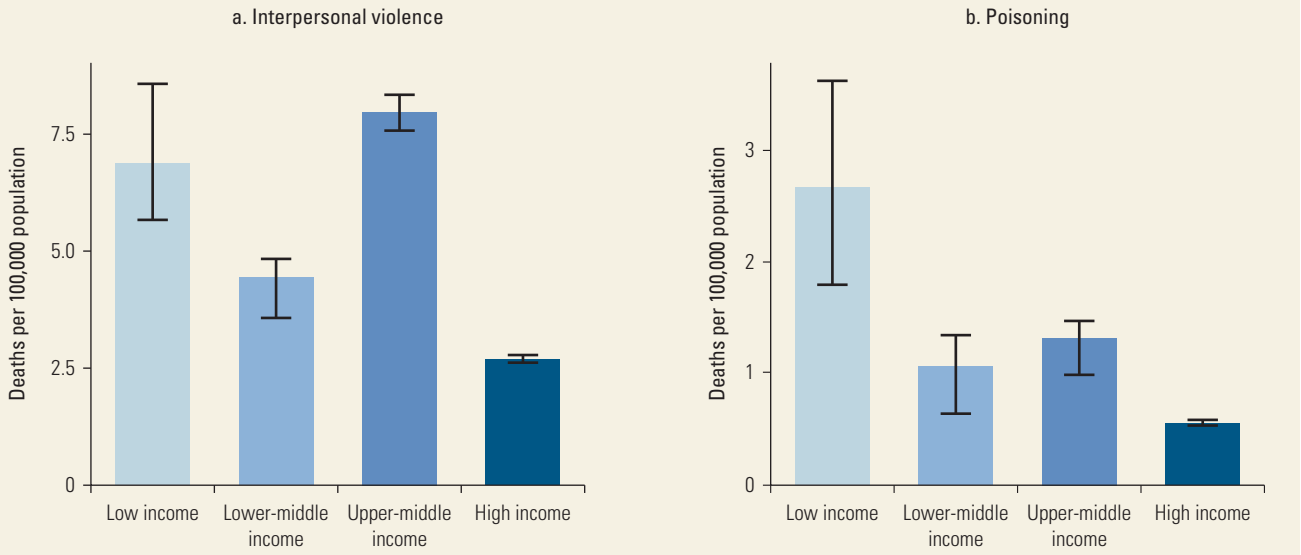


Figure 1.9 Age-Standardized Trends in Mortality Risk for Interpersonal Violence and Poisoning, 2015



Box 1.2

Economic Evaluation of Investments in Injury Prevention and Environmental Health

Economic evaluation aims to inform decision making by quantifying tradeoffs between resource inputs required for alternative investments and resulting outcomes. Four main approaches are relevant to this chapter:

- Assessing how much of a *specific health outcome*—for example, serious injuries averted—can be attained for a given level of resource input.
- Assessing how much of an *aggregate measure of health*—such as deaths or disabilities or disability-adjusted life years (DALYs) averted—can be attained from a given level of resource inputs applied to alternative interventions. This approach (cost-effectiveness analysis, or CEA) allows comparisons of the attractiveness of interventions addressing different health outcomes (for example, motorcycle helmet use versus cesarean section) to be made.
- Assessing how much *health and financial risk protection* and its distribution across population subgroups can be attained for a given policy (for example, public sector finance of a given intervention, such as regulation of helmets for motorcyclists). This approach, extended cost-effectiveness analysis (ECEA), enables assessment not only of efficiency in improving the health of a population but also of efficiency in achieving the other major goal of a health system—protecting the population from financial risk of medical impoverishment—along with the distributional consequences of the given policy, such as equity.
- Assessing the *economic benefits*, measured in monetary terms, from investment in a health intervention and weighing that benefit against its cost (benefit-cost analysis, or BCA). BCA enables comparison of the attractiveness of interventions in the same sector and across different sectors. Benefit-cost ratios greater than 1 identify interventions that represent net positive returns on investment.

CEAs predominate among economic evaluations in injury prevention. Three recent overviews of CEA findings for injury prevention in low- and

box continues next page

Box 1.2 (continued)

middle-income countries (one in this volume) have especially focused on road safety and drowning prevention. These studies underpin this chapter's conclusion that many injury prevention modalities are highly cost-effective even in resource-constrained environments (Ditsuwan and others 2013; Rahman and others 2012; Watkins, Dabestani, Nugent, and Levin 2017).

BCAs predominate among economic evaluations in environmental health, especially for air pollution and for water, sanitation, and hygiene. BCAs are especially suitable for these topics because they are able to consider the benefits of nonhealth outcomes, such as time savings in procuring water or fuels. These BCAs have consistently identified interventions with benefit-cost ratios greater than 1, and many greater than 10 (Hutton and Chase 2017; Watkins, Dabestani, Nugent, and Levin 2017).

ECEAs are still a relatively new evaluation approach. This volume presents two new ECEAs. One is on the impact of motorcycle helmet regulation on health, equity, and medical impoverishment in Vietnam (Olson and others 2017). The other found that a public-private subsidy for poor Indian households to receive clean fuels could avert 44,000 deaths for US$825 each and about 1.5 million DALYs for US$25 each. This result was far cheaper than cookstove alternatives, and the subsidy for clean fuels provided greater health benefits to all income groups. The greatest health benefit is achieved when the clean fuel subsidy is targeted to the poor (Pillarisetti, Jamison, and Smith 2017).

cited earlier for injury prevention would be considered cost-effective. Likewise, the cost-effectiveness of the interventions is similar to that of many widely implemented health interventions, for example, treatment of severe malaria (US$5–US$220 per DALY averted), micronutrient supplementation (US$20–US$100 per DALY averted), oral rehydration solution (US$150 per DALY averted), and treatment of pneumonia (US$300–US$500 per DALY averted) (Black, Laxminarayan, and others 2016).

The area of WASH has undergone extensive economic analysis, primarily using benefit-cost analysis. A benefit-cost ratio (BCR) greater than 1 is generally considered a good investment. Favorable BCRs (1.9–5.1) have been identified for a range of interventions: filters, piped water, boreholes, and private latrines. Combinations of interventions have shown even higher BCRs (2–45) for improved water, sanitation, and universal basic access (Hutton 2013; Hutton and Chase 2016; Hutton and Chase 2017; Watkins, Dabestani, Nugent, and Levin 2017).

Air pollution control has been subjected to limited economic analysis in LMICs. Two studies on ambient air pollution in Mexico found that retrofitting vehicles to reduce emissions produced net benefits of US$100–US$11,000 per vehicle, corresponding to BCRs of 1.1–7.0. Measures to decrease pollution from brick kilns, including filtration systems, switching to natural gas, and relocating kilns to less densely populated areas, produced net benefits corresponding to BCRs of 38 and higher (Blackman and others 2000; Stevens, Wilson, and Hammitt 2005; Watkins, Dabestani, Nugent, and Levin 2017). For household air pollution control, a limited but growing literature evaluates cost-effectiveness and BCRs associated with transitions to cleaner cooking. Hutton and others performed global cost-benefit analyses of scenarios in which households made the transition away from solid fuels to either clean fuels or clean biomass stoves and found the transition to clean fuel and the transition to improved stoves had BCRs of 4.3 and approximately 60, respectively (Hutton and others 2006; Hutton, Rehfuess, and Tediosi 2007). Benefit-cost analysis has been applied in other specific geographies, including in Nepal (Malla and others 2011; Pant 2011), China (Aunan and others 2013), the Western Pacific Region (Arcenas and others 2010), and in Kenya and Sudan (Malla and others 2011).

Similarly, the few occupational safety and health interventions that have been studied in LMICs do appear cost-effective or cost-beneficial. Simulation studies using the WHO-CHOICE methodology found engineering controls that decrease the release of silica into the air at the workplace to be a cost-effective method for preventing silicosis in several industries in LMICs; these were found to be more cost-effective than the use of masks and respirators (but all with cost-effectiveness ratios in the range of several hundred U.S. dollars per DALY averted) (Lahiri and others 2005). Similar methodology identified training programs to prevent back injury to be a cost-effective method for preventing back pain in LMICs globally; these training programs were found to be more cost-effective than

engineering controls (but all with cost-effectiveness ratios of less than US$1,000) (Lahiri, Markkanen, and Levenstein 2005). Ergonomic changes in footwear manufacturing in Brazil had a BCR of 7.2 (Guimarães, Ribeiro, and Renner 2012; Watkins, Dabestani, Nugent, and Levin 2017).

In summary, although the literature on economic evaluation of injury prevention and environmental health in LMICs is small, consistent evidence is emerging that a range of interventions are cost-effective, cost-beneficial, or both. One particular environmental issue will likely become increasingly preeminent in the twenty-first century: climate change. The economic consequences of the resulting health problems and food and water insecurity will potentially rival those of other major risk factors. In addition to lowering greenhouse gas emissions, a range of countermeasures have been considered, such as establishing occupational heat exposure standards and enhancing surveillance for water- and vector-borne infections. Economic analyses of such measures are in their infancy but have nonetheless suggested that not addressing climate change will be very costly to health systems in less than two decades (Ebi, Hess, and Watkiss 2017).

Essential Interventions to Address Injury and Environmental Health

On the basis of their cost-effectiveness or cost-benefit, feasibility, and potential to lower the burden of these conditions, a package of policy interventions can be recommended (tables 1.4 and 1.5). These interventions include policies in the health sector and in other sectors, including taxes and regulations that affect infrastructure and the built environment—especially interventions that have proven cost-effectiveness in LMICs.

Table 1.4 Essential Injury and Occupational Health Policies

	Fiscal and Intersectoral Policy			
Domain of action	**Taxes and subsidies**	**Infrastructure, built environment, and product design**	**Regulation**	**Information, education, and communication**
Road safety				
Overall	Subsidized public transportation	Mass transport infrastructure and land use (bus rapid transit, rail)	Adoption and enforcement of harmonized motor vehicle safety standards	
Pedestrian safety		Increased visibility, areas for pedestrians separate from fast motorized traffic		Increased supervision of children walking to school
Motorcycle safety		Exclusive motorcycle lanes	Mandatory use of daytime running lights for motorcycles	
			Mandatory motorcycle helmet laws	
Bicycle safety		Increased visibility, lanes for cyclists separate from fast motorized traffic		Social marketing to promote helmet use by child bicyclists
Child passenger safety			Legislation for and enforcement of child restraints (including seats)	
Speed control		Traffic-calming infrastructure (for example, speed bumps), especially at dangerous road segments	Setting and enforcement of speed limits appropriate to function of roads	
Driving under the influence of alcohol			Setting and enforcement of blood alcohol concentration limits	
Seatbelt use			Mandatory seatbelt use laws for all occupants	Social marketing to promote seatbelt use

table continues next page

Table 1.4 Essential Injury and Occupational Health Policies (continued)

	Fiscal and Intersectoral Policy			
Domain of action	**Taxes and subsidies**	**Infrastructure, built environment, and product design**	**Regulation**	**Information, education, and communication**
Other unintentional injury				
Drowning			Legislation and enforcement of use of personal flotation devices for recreational and other high-risk boaters	Parental or other adult supervision (for example, use of crèches) in high-risk areas Swimming lessons for children
Burns		Safer stove design		
Poisoning		Child-resistant containers		Information, education, and communication for safe storage of hazardous substances
Violence				
Child maltreatment			Corporal punishment ban	Parent training, including nurse home visitation, for high-risk families
Youth violence				Social development programs that teach social skills and incorporate training for parents Information sharing between police and hospital emergency departments
Gender-based violence and intimate partner violence	Microfinance combined with gender equity training			School-based programs to address gender norms and attitudes Interventions for problem drinkers (who are also abusive partners) Advocacy support programs (for example, to increase availability and use of shelters for at-risk women)
Cross cutting for multiple types of injury	Reducing availability and harmful use of alcohol through increased taxation and decreased availability of outlets	Dispensing alcohol in plastic rather than glass that could be used as a weapon	Stricter licensing laws and reduced availability of firearms	
Occupational safety and health				
		Engineering controls to decrease release of silica and other toxins Safe injection devices, such as blunt-tip suture needles	Enforcement of safety standards Formalization of large informal sectors in low- and middle-income countries	Training in hazard recognition and control relevant to the work performed (for example, task-based training for hazardous tasks) Effective use of available personal protective equipment Occupational health workforce development

Note: Interventions for treatment—for example, trauma care for injured people—are covered in other *DCP3* volumes and are not addressed here.

Table 1.5 Essential Environmental Policies

Domain of action	Fiscal and Intersectoral Policy			Information, education, and communication
	Taxes and subsidies	Infrastructure and built environment	Regulation	
Water and sanitation	Targeted subsidies to poor and vulnerable groups Incentives for private sector to become more involved with WASH for supply chain and service provision	Quality WASH facilities in schools, workplaces, public spaces, and health care facilities	Defined WASH standards per setting (household, outside household)	National awareness campaigns (for example, on handwashing) WASH behavior-change interventions, such as community-led total sanitation
Outdoor air pollution	Fuel taxes Fines for residential trash burning Fines for not controlling construction dust Tax polluters Cap and trade policies for specific pollutants (for example, SO_2) No more subsidies for coal	Relocation of industrial sources, such as brick kilns Municipal trash collection Diesel to CNG transition for fleets Movement toward banning solid fuels in cities Regular street cleaning to control dust	Diesel retrofits Coal to natural gas transition Brick kiln retrofits for emissions control PM, SO_2, and NO_2 emissions control Acceleration of Euro standards for vehicles National regulation to reduce household emissions to outdoors Construction and road dust controls Adoption of European Union fuel standards	Updated health information systems to include vulnerability, adaptation, and capacity assessment
Household air pollution	Advanced biomass stove subsidies Targeted and expanded LPG and other clean fuel subsidies to the poor Subsidies for clean alternatives to kerosene Campaigns for middle class to give up subsidies intended for poor	Improved ventilation as part of building codes and norms Enhanced clean fuel distribution networks Electrification as a health measure Application of modern digital technology to enhance access to household clean fuel	Lower barriers and expanded licensure requirements for clean fuel distribution Kerosene ban National regulation on clean household fuels to match UN SE4ALL goals Smoke-free communities	Ventilation HAP health effects education Promotion of kitchen retrofits to encourage HAP-reducing interventions and behaviors
Chemical contamination		Regulations on hazardous waste disposal covering land, air, and water	Arsenic: monitoring of groundwater supplies and provision of alternatives if needed Asbestos: banning of import, export, mining, manufacture, and sale Mercury: monitoring and reduction or elimination of use in artisanal mining, large-scale smelting, and cosmetics Established and enforced toxic element emissions limits for air and water Restricted access to contaminated sites Strict control and movement to selective bans of highly hazardous pesticides	Notification of public of locations of contaminated sites

table continues next page

Table 1.5 Essential Environmental Policies (continued)

Domain of action	Fiscal and Intersectoral Policy			Information, education, and communication
	Taxes and subsidies	Infrastructure and built environment	Regulation	
Lead exposure	Concessionary financing for remediation of worst conditions	Minimization of occupational and environmental exposures in maintaining, renovating, and demolishing buildings and other structures with lead paint	Ban on lead paint and leaded fuels Ban on lead in water pipes, cookware, drugs, food supplements, and cosmetics Reduction in corrosiveness of drinking water National take-back requirements for collecting used lead batteries Regulations governing land-based waste disposal Risk-based limits for lead in air, water, soil, and dust	Lead poisoning training for health care providers
Global climate change	Carbon tax or cap and trade (mitigation) Subsidies to renewable energy	Mitigation policies and incentives, including land-use plans, building design, transportation, to reduce GHGs Resilient design in buildings and infrastructure (adaptation) Consideration of climate change in public health infrastructure (mitigation and adaptation)	Energy efficiency and fuel efficient vehicles (mitigation) Mainstreaming of climate change into public health planning and programs, and into health system policies and plans Methane control regulations	Early warning and emergency response systems

Note: CNG = compressed natural gas; GHG = greenhouse gas; HAP = household air pollution; LPG = liquefied petroleum gas; NO_2 = nitrogen dioxide; PM = particulate matter; SO_2 = sulfur dioxide; UN SE4ALL = United Nations Sustainable Energy for All program; WASH = water, sanitation, and hygiene. Interventions for treatment (for example, oral rehydration solution for diarrhea) or other individual-level medical services (for example, deworming, growth monitoring) are covered in other *DCP3* volumes and are not addressed here. Interventions in this table include those that have been shown to be cost-effective or cost-beneficial in low- and middle-income countries or for which such cost-effectiveness or cost-benefit can be logically concluded from high-income or other data. For water and sanitation, many of the policy-level interventions mentioned do not have such evidence; however, the individual items promoted by these policies (for example, filters, piped water, boreholes, private latrines) do have a strong evidence base. Unlike interventions with only health benefits, however, many if not most interventions in environmental health bring a range of other benefits lying outside the health sector, for example, time savings, property values, IQ enhancement, and so on. Cost-effectiveness measured solely in health terms, therefore, can be misleading with regard to total social benefit-cost relationships.

The package also includes interventions with proven cost-effectiveness in HICs with high likelihood of transferability to LMICs. Finally, the package also includes interventions that are logical and feasible, but for which there is currently little empirical evidence on cost-effectiveness. Details of these policies, including the evidence for them, are addressed in the chapters of this volume.

We acknowledge that the list is not exhaustive. Other policies might be considered essential. For many countries, tables 1.4 and 1.5 provide a reasonable starting point for an essential policy package to comprehensively address injury prevention and environmental health, although there will be country-specific variations.

Examples from injury prevention include promoting safer forms of transportation. In general, the individual automobile (especially two- and three-wheeled motorized vehicles) is one of the least safe modes of transportation. The overall field of transport safety would be considerably advanced by government policies (including taxes and subsidies) that promote alternative safer and more energy-efficient forms of transportation, such as mass transport, especially rail, as well as by promoting and ensuring the safety of walking and cycling. For road traffic crashes themselves, promoting safer infrastructure is a key intervention. For example, traffic-calming infrastructure such as speed bumps, especially at dangerous intersections, is a very cost-effective method for protecting pedestrians. In similar fashion, safety-related product design, such as child-resistant containers for poisons and medicines, has played a major role in injury prevention. Safety-related product design encompasses engineering (as do infrastructure and the built environment) as well as regulation because safer products are often best promoted by mandating them in legislation. Other key injury prevention regulations include mandating the use of restraints for automobile occupants and helmets for motorcycle riders.

Within the public health sector, information and communication strategies can be successfully delivered through mass media, as with strategies to promote safe driving behaviors such as seatbelt and helmet use. Such strategies usually do not work well in isolation but are best combined with legislation and effective enforcement. Information and communication strategies can also be delivered in smaller group settings and individually, as with many of the violence prevention strategies. For example, home visiting programs using skills training to promote better parenting skills, especially to high-risk groups such as young first-time parents from lower socioeconomic status, have been found to be very effective in preventing child maltreatment in HICs.

Occupational safety and health overlap with injury prevention. However, interventions in this field primarily target the worksite and thus are distinct from those described earlier that target the general population. Key strategies in promoting occupational safety and health include regulations such as setting appropriate limits on work hours. Given higher risks faced by those in the informal work sector, formalizing this sector, including encompassing it within appropriate and context-specific regulatory and organized labor systems, is a key measure that needs to be promoted globally. On an individual basis, better application of known safe practices and known effective personal protective equipment, such as masks and respirators to prevent inhalation of silica and other airborne toxins, is needed.

Many of the individual WASH interventions, such as filters, piped water, boreholes, and private latrines, have been documented to be very cost-effective and cost-beneficial (table 1.5). However, access to these interventions can be difficult for the poor, especially in rural areas. Policies to ensure that these interventions reach everyone include financing strategies (such as targeted subsidies to poor and vulnerable groups), strengthening supply chains for water and sanitation products and services, and developing national standards on universal access.

Pollution-related interventions include those addressing air pollution (household and ambient, both of which are primarily related to combustion-derived particulate matter) as well as a number of chemical contaminants, such as lead, asbestos, arsenic, and pesticides. The range of policy levers can be used for these issues: taxes and subsidies (such as targeting clean fuel subsidies to the poor); infrastructure and built environment (such as relocating industrial sources such as brick kilns); regulation and international agreements (such as banning the import, export, mining, manufacture, and sale of asbestos); and actions within the health sector (such as establishing environmental lead surveillance). Among these, awareness of the health impacts of household air pollution is relatively recent, and understanding of the true scale of the impact of other issues, such as lead, has recently been greatly enhanced. Thus, actions in the health sector have lagged the knowledge of potential benefits.

Some of the interventions, although listed for one condition, have beneficial effects for other conditions. For example, promoting alternatives to private automobiles decreases both injury rates and pollutant emissions. Improved stoves and fuels decrease air pollution and rates of household burns. Violence prevention strategies (such as home visiting and life and social skills training) reduce substance abuse, mental health problems, and subsequent crime and violence, and increase positive outcomes, including academic attainment and employment.

A set of policies for a specific subset of pollution, climate change, is presented in table 1.5. Many of these policies have been widely considered and are straightforward and logical (such as promoting active transport and early warning and emergency response systems). As noted above, economic analysis of their impact has just recently begun.

Implementation of many of the interventions requires intersectoral collaboration. For example, road safety involves law enforcement, ministries of transport, government agencies that regulate manufacturing, and public health agencies. Likewise, surveillance plays a key role. Surveillance includes not only monitoring of trends for disease burden, but also surveillance for risk factors. For example, a key element for managing air pollution is monitoring of air quality. Such monitoring, which is especially important for lead control, includes such activities as examining sample surveys of blood in children and monitoring of levels from hot spots such as lead battery manufacturing and recycling sites. Similarly, a key component of improving WASH is a strengthened monitoring and rapid feedback system for the coverage and quality of water and sanitation services.

CONCLUSIONS

Injury and occupational and environmental risks result in a large health burden. Some of this burden tends to decrease with economic development (for example, risks from unsafe water and sanitation), whereas some tends to initially increase with economic development before declining at high-income levels (for example, ambient air pollution and transport injuries). A range of interventions can speed the decrease in burden for the former or mitigate the rises for the latter. Many of these interventions have been shown to be among the most cost-effective or cost-beneficial of all interventions used to

prevent or treat disease. The interventions summarized in this chapter include these as well as other similar interventions that are reasonable but have not yet been subjected to sufficient economic analysis. Given their potential to lower this significant health burden, these interventions are high priorities for future population, policy, and implementation research.

Implementation of most of the interventions that address the conditions in this volume (tables 1.4 and 1.5) has been far less than optimal, especially in LMICs. For example, the WHO's *Global Status Report on Road Safety* (WHO 2015) assessed 180 countries for the status of key road safety interventions. Although the majority of countries (105) implemented best practice standards for seatbelt laws (such as mandatory seatbelts for all occupants), far fewer had best practice standards for laws on speed control (47), mandatory motorcycle helmet use (44), and drunk driving (34) (WHO 2015). Formal health-based intervention programs for household air pollution have not shown major worldwide implementation success to date, although local progress during the relatively short period that they have been implemented is occasionally seen. Nevertheless, clean fuels, through nonhealth actions and economic growth, have brought major health benefits to hundreds of millions of people. Finding ways to expand the rate of these improvements to cover populations that would not benefit otherwise is clearly a high priority.

Many of the interventions considered herein need to be better applied in HICs, but most have been implemented to a lesser extent in LMICs, which has contributed to the higher health burden from injury and from occupational and environmental risk factors in LMICs. To assess the potential gains from more widespread implementation of these interventions, we estimated the deaths that could be averted if the age-adjusted mortality rates for these conditions in HICs pertained in LMICs. This assessment was straightforward for injury deaths. However, for deaths from occupational and environmental exposures, we considered "attributable deaths" (tables 1.2 and 1.3). These are not mutually exclusive, with overlap of some of the categories. For example, deaths from unsafe water and lack of handwashing partly overlap. Hence, differences in mortality rates were considered for the overall categories of WASH, air pollution, and occupational health, not by subcategory. There is likely minimal overlap between air pollution and unsafe WASH. For simplicity and lack of systematic analysis of these overlaps, they are ignored in this analysis.

Within these caveats, it can be estimated that more widespread implementation of the package of interventions and policies covered in this review could avert about 2 million deaths from injury (not including suicide, which is not addressed in this volume); 200,000 deaths from occupational risk factors (not including injury); 1.4 million deaths from unsafe water and sanitation; and about 4 million deaths from air pollution (the larger component of which is attributable to household fuels). A total of more than 7 million deaths could be averted (table 1.6).

Several factors might cause the real number of potentially avertable deaths to be lower or higher. For example, the differences in death rates between countries at different economic levels is in part attributable to better prevention, but also to better medical treatment, which is not addressed in the policy package considered in this volume. Therefore, the estimates of deaths averted by improved prevention alone might be overstated. However, these estimates do not take into account the lives that could be saved by addressing some of the other nonoccupational toxins, such as lead and arsenic. Finally, the interventions considered here have not been fully applied in many HICs, and many deaths could be averted there as well. Even within these caveats and limitations, it is apparent that a large number of deaths could be

Table 1.6 Disease Burden Avertable by Improved Injury Prevention, Occupational Safety and Health, and Environmental Policy in Low- and Middle-Income Countries

	Total Deaths (Thousands)		
	Current scenario	Hypothetical scenario	Avertable
Injury (excluding suicide)	3,790	1,730	2,060
Occupational risks (excluding injury)	430	220	210
Unsafe water, sanitation, and handwashing	1,390	20	1,370
Air pollution	4,990	950	4,040
Total			**7,680**

Source: Global Burden of Disease (GBD) 2013 Study (IHME 2016); WHO Global Health Estimates 2012 (WHO 2016).
Note: Hypothetical scenario is the disease burden that would occur if age-specific rates for these conditions in high-income countries applied in low- and middle-income countries. Avertable burden is the difference between current and hypothetical scenarios. Three levels of significance are kept to reduce rounding errors, but true uncertainty is possibly higher. Even so, totals may not add due to rounding.

averted by better implementation of the low-cost and feasible interventions considered in this volume.

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NOTES

World Bank Income Classifications as of July 2014 are as follows, based on estimates of gross national income (GNI) per capita for 2013:

- Low-income countries (LICs) = US$1,045 or less
- Middle-income countries (MICs) are subdivided:
  a) lower-middle-income = US$1,046 to US$4,125
  b) upper-middle-income (UMICs) = US$4,126 to US$12,745
- High-income countries (HICs) = US$12,746 or more.

1. This chapter cites the source of burden estimates at each use, but these estimates change regularly as new data become available and modeling tools improve. There are some discrepancies between the estimates done by different organizations, namely, the Institute for Health Metrics and Evaluation and the WHO, because of different assumptions and methods. The precision is generally kept at three places of significance to avoid rounding errors, but in reality true uncertainties are much larger.
2. Note on terminology: Some definitions of *premature deaths* involve those deaths below a certain age, for example, younger than age 70 years. This table and the other tables in this chapter consider all of the deaths to be premature but not relative to a specific threshold for age.
3. Except for figure 1.1, all analyses in this section are presented with age-standardized deaths per capita to normalize across the four World Bank income regions using GBD 2015 data. Results are similar if using age-standardized DALYs, however. Only environmental risks examined in the GBD 2015 were included. It should be noted that conducting the analysis using more subregions or by country might show subtleties not revealed by comparison across only four income regions.
4. Like the environmental risk factors, the occupational injury category was examined in a comparative risk assessment framework, that is, with a nonzero counterfactual based on what is considered feasible to obtain. The estimates shown for all the other injury categories, however, here assume that 100 percent of the impact can be avoided.

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