Chapter 10

Interventions to Prevent Injuries and Reduce Environmental and Occupational Hazards: A Review of Economic Evaluations from Low- and Middle-Income Countries

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INTRODUCTION

Collectively, unintentional injuries and interpersonal violence accounted for at least 8 percent of deaths and 9 percent of disability-adjusted life years (DALYs) in low- and middle-income countries (LMICs) in 2012 (WHO 2016). Diseases related to air pollution and inadequate water and sanitation measures accounted for 15 percent of attributable deaths and 10 percent of attributable DALYs in LMICs in 2013 (IHME 2015). Millennium Development Goal 7 has inspired steady progress on water- and sanitation-related indicators, although many countries have not yet reached target levels of coverage (Luh and Bartram 2016) or the newer targets for Sustainable Development Goal 6 (UN 2016). Health losses from road traffic injuries (RTIs), interpersonal violence, and outdoor air pollution continue to rise (WHO 2016).

A common feature of the seemingly disparate conditions covered in this volume is that they can be addressed largely through population-based policies and regulations using intersectoral approaches. For example, risks related to most types of injuries can be substantially reduced through educational programs and legal regulations (Ditsuwan and others 2013). The regulation of air pollution usually occurs within the purview of the public sector environmental agency, as does the provision of clean water and basic sanitation services that are then implemented by public works agencies (Pattanayak and others 2010). Reducing the health risks associated with these environmental hazards involves partnerships between ministries of health and ministries responsible for environment, transportation, and public works. As another example, reduction of occupational hazards is considered the responsibility of employers and employees alike, but it is often monitored and regulated by ministries responsible for labor.

This chapter summarizes the evidence of the costs and benefits of interventions to prevent injuries and reduce occupational and environmental risks in LMICs. Although the interventions reviewed reflect a set of conditions and risk factors more narrow than those covered in this volume, they are the major drivers of disease burden in these cause and risk factor groups in LMICs. The overarching objective of this chapter is to summarize the evidence on value for money to reduce the burden of injuries and environmental and occupational risks in these settings. Evidence on the costs and cost-effectiveness of treating the medical consequences

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of injury, trauma, and environmental exposures can be found in other volumes of this series.

Although externalities and their policy solutions, such as tradable emissions, that are associated with air and water pollution are critical for human health, this chapter does not review these economic issues as they relate to environmental health. Readers are referred to environmental economics textbooks and manuals for discussions of these issues (Maler and Vincent 2005). This chapter focuses exclusively on studies of costs and cost-effectiveness (including benefit-cost studies) that have been conducted in LMICs.

The economic evidence is modest for injury and ambient environment interventions compared to other conditions, but important lessons can be learned about the types of interventions to receive the highest priority for public investment. Benefit-cost analysis (BCA) is the standard approach in environmental economics. Cost-effectiveness analysis (CEA) is typically applied to health sector interventions, but environmental and other intersectoral interventions—such as development and education—are more suited to BCA because many of the costs and benefits are likely to accrue outside the health sector, and many of these direct benefits can be more easily valued in monetary terms. For example, improved water reduces the risk of morbidity and mortality from diarrheal disease, but it also has many nonhealth benefits, such as its intrinsic value to the consumer and positive effect on tourism. Further, these benefits may even be worth more in monetary terms than the health benefits. This chapter presents CEA and BCA evidence side-by-side with some comments on differences in methods and results.

METHODS

During July 2015, we systematically searched the literature on costs and cost-effectiveness of interventions to prevent injury and reduce risks in the ambient environment. The search combined terms for the specific injuries and occupational and environmental hazards addressed in this volume, together with economic terms and names of specific LMICs and regions containing LMICs. Our search did not include studies on self-harm, which is treated in volume 4 of this series (Patel and others 2015). Annex 10A contains the search terms and strategy used to identify relevant articles. We were interested in CEAs regardless of perspective. However, we present program costs from the health system or government perspective. The BCAs presented here were conducted from a societal perspective, which is standard in the field.

Our search yielded 4,539 titles through database searches and 31 additional studies through expert consultation. After screening titles and abstracts, we reviewed 161 full-text studies. We included 42 of those studies in the final review on the basis of criteria related to evaluation methods used and quality of the data. Additionally, we considered only those studies published on or after January 1, 2000 (including costs that were collected on or after that date) and pertaining to LMICs (annex 10A). We assessed the quality of included studies using a checklist developed by Drummond and others (2015). Annex 10B provides a flow diagram of the review process.

Among the 42 studies, we identified 16 higher-quality studies. The majority of those studies addressed water, sanitation, and hygiene (WASH); one to two studies were found in each category of injury; and no studies were available on occupational injury. We extracted 41 estimates of intervention costs and 59 estimates of intervention cost-effectiveness, including incremental cost-effectiveness ratios (ICERs), net benefits, and benefit-cost ratios (BCRs). All ICERs, net benefits, and program costs were converted to 2012 U.S. dollars. Costs were first converted to local currency units based on midyear exchange rates in the year that the data were collected. Then they were inflated to 2012 values using the World Bank consumer price index series for the country of the study. Finally, they were converted to U.S. dollars using midyear exchange rates for 2012.

We qualitatively summarized the remaining 26 studies that were of lower quality or used older data sources, but we did not extract quantitative estimates of ICERs or BCRs. In general, an intervention with an ICER less than 1–3 times the per capita gross domestic product of a country was considered cost-effective. An intervention with positive net benefits or a benefit-cost ratio greater than 1 was considered a good investment. Annex 10C provides costs, cost-effectiveness ratios, and descriptive information for each study and a quality assessment score.

COST-EFFECTIVENESS OF INTERVENTIONS

Injuries and Occupational Hazards

Economic analyses on injury prevention suggest that interventions to prevent RTIs, drowning, and interpersonal violence are cost-effective and may even be cost saving (table 10.1). A quasi-experimental study by Bishai and others (2008) assessed a traffic enforcement program in Uganda. This program, which focused on reducing speeding, demonstrated a reduction in fatal crashes at a cost of US$944 per death averted (Bishai and others 2008).

Table 10.1 Results from Economic Evaluations of Injury Prevention Interventions

Study author (year)	Intervention	Location, perspective[a]	Cost per outcome as presented	Unit of outcome	Currency as presented (year)	Cost per outcome (2012 US$)
Bishai and others (2008)	Traffic enforcement	Uganda, government	603	Death averted	U.S. dollar (2005)	944
Ditsuwan and others (2013)	Checkpoint and media campaign	Thailand, government	10,400	DALY averted	Thai baht (2004)	400
Ditsuwan and others (2013)	Breath testing (selective)	Thailand, government	13,000	DALY averted	Thail baht (2004)	600
Ditsuwan and others (2013)	Breath testing (random)	Thailand, government	14,300	DALY averted	Thail baht (2004)	600
Ditsuwan and others (2013)	Media campaign	Thailand, government	10,300	DALY averted	Thail baht (2004)	400
Ditsuwan and others (2013)	Breath testing (selective) and media campaign	Thailand, government	12,700	DALY averted	Thail baht (2004)	500
Ditsuwan and others (2013)	Breath testing (random) and media campaign	Thailand, government	13,500	DALY averted	Thail baht (2004)	600
Rahman and others (2012)	Anchal drowning prevention program	Bangladesh, societal	812	DALY averted	International dollar (2010)	256
Rahman and others (2012)	SwimSafe drowning prevention program	Bangladesh, societal	85	DALY averted	International dollar (2010)	27
Rahman and others (2012)	Anchal–SwimSafe drowning prevention program (combined)	Bangladesh, societal	362	DALY averted	International dollar (2010)	114
Jan and others (2011)	Microfinance and gender training (trial period)	South Africa, government	7,688	DALY averted	U.S. dollar (2004)	9,826
Jan and others (2011)	Microfinance and gender training (scale-up period)	South Africa, government	2,307	DALY averted	U.S. dollar (2004)	2,948

Note: DALY = disability-adjusted life year.
a. "Perspective" refers to the perspective from which costs were estimated.

A study in Thailand modeled the cost-effectiveness of several hypothetical interventions for RTIs, including checkpoints, media campaigns, and breath testing, alone or in combination. Compared to the null set, all interventions were very cost-effective; all interventions were cost saving when treatment costs averted were included in the ICER calculations (Ditsuwan and others 2013).

A quasi-experimental study (Rahman and others 2012) addressed drowning prevention in rural Bangladesh. The intervention had two components. The first program, Anchal, focused on direct supervision of children ages 1–5 years at child care centers near bodies of water. The second program, SwimSafe, focused on teaching children ages 4–12 years about basic swimming, safety, and rescue of others from drowning. Both Anchal and SwimSafe were very cost-effective; when their results were combined and extrapolated to a program that would apply to the entire population of rural Bangladesh, they cost approximately US$114 per DALY averted (Rahman and others 2012).

Interpersonal violence is the intentional use of physical force or power against other persons by an individual or small group of individuals (chapter 5 in this volume, Mercy and others 2017). A modeling study by Elliot and Harris (2001) estimated the costs and benefits of landmine clearance in postconflict Mozambique. They found negative net benefits and recommended against landmine clearance. Despite ongoing calls for and guidance on conducting economic evaluations for intimate partner violence (IPV) (Duvvury and others 2013), only a single study included in this review focused on IPV. This study, by Jan and others (2011), evaluated a trial of microfinance to reduce IPV in South Africa. In the South African economic context, ICERs for this program were favorable in both the trial and a subsequent scale-up period (Jan and others 2011).

Additional global and regional studies and modeling approaches using a set of assumptions and secondary data sources provide insights into the potential economic costs and benefits of injury prevention. Bishai and Hyder (2006) found that increased enforcement, speed bumps, bicycle helmets, motorcycle helmets, and childproof containers to prevent poisoning were cost-effective in most world regions. Chisholm and others (2012) conducted an RTI prevention study using the World Health Organization–Choosing Interventions That Are Cost-Effective (WHO-CHOICE) approach. Focusing on WHO regions, the authors found that (1) bicycle helmets; (2) a combination of speed limits, drunk-driving laws, and motorcycle helmet use; and (3) a combination of speed limits, drunk-driving laws, seatbelt laws, bicycle helmet use, and motorcycle helmet use were cost-effective in high-mortality Sub-Saharan African countries, such as Kenya and Tanzania. They also found that a combination of speed limits, impaired driving laws, seatbelt laws, and motorcycle helmet use—with or without bicycle helmet use—were cost-effective in high-mortality Asian countries, such as India and Nepal. Finally, using a preevaluation–postevaluation strategy, Stevenson and others (2008) found that a seatbelt use program was cost-effective in Guangzhou City, China.

Additionally, two regional analyses using the WHO-CHOICE model provide evidence on the cost-effectiveness of measures to prevent occupational injury. In the first study, training programs were more cost-effective than engineering and ergonomics programs in all WHO regions (Lahiri, Markkanen, and Levenstein 2005). In the second study, engineering controls were more cost-effective than masks and respirators to prevent silicosis (a frequent cause of occupational lung injury) in the Western Pacific, including China (Lahiri and others 2005). Finally, a study by Guimaraes, Ribeiro, and Renner (2012) looked at ergonomic changes in footwear manufacturing facilities in Brazil; their intervention had a BCR of 7.2.

Environmental Hazards

The limited evidence on economic evaluation for improved air quality comes from Mexico and focuses on reducing pollution from small-scale industry and automobiles (table 10.2). Blackman and others (2000) investigated different ways of reducing pollution from brick kilns, which are a significant contributor to industrial pollution by the small-scale informal sector. Their analysis used an air dispersion model for pollution and assumed a linear relationship between particulate concentration and health outcomes. Net benefits, measured in total dollars per population, were greatest for the strategies focused on retrofitting kilns or using natural gas. Relocating kilns to less densely populated areas or instituting no-burn days had lower net benefits (Blackman and others 2000). In another study, Stevens, Wilson, and Hammitt (2005) assessed a variety of methods for retrofitting vehicles to reduce air pollution. They used a box model with

Table 10.2 Results from Economic Evaluations of Ambient Environment Interventions: Benefit-Cost Analyses

Study author (year)	Intervention	Location	Net benefit as presented	Currency as presented (year)	Net benefit (2012 US$)
Blackman and others (2000)	NMSU kiln	Mexico	46,810,286	U.S. dollar (1999)	73,761,533
Blackman and others (2000)	Natural gas	Mexico	47,063,087	U.S. dollar (1999)	74,159,885
Blackman and others (2000)	Relocation	Mexico	26,759,571	U.S. dollar (1999)	42,166,522
Blackman and others (2000)	No-burn days	Mexico	905,308	U.S. dollar (1999)	1,426,543
Stevens, Wilson, and Hammitt (2005)	Catalyzed DPF	Mexico	400–1,700	U.S. dollar (2000)	500–2,300
Stevens, Wilson, and Hammitt (2005)	Active regeneration DPF	Mexico	100–8,100	U.S. dollar (2000)	100–10,800
Stevens, Wilson, and Hammitt (2005)	Diesel oxidation catalyst	Mexico	100–2,600	U.S. dollar (2000)	100–3,500

Note: DPF = diesel particulate filter; NMSU = New Mexico State University.

health outcomes informed by concentration-response coefficients from cohort studies in the United States. Despite the cost of the retrofit, all interventions had impressive net benefits that ranged from US$100 to nearly US$11,000 per vehicle retrofitted.

The largest number of economic evaluations of environmental health interventions address water and sanitation and highlight a range of interventions at the population, community, and household levels (tables 10.3 and 10.4). One quasi-experimental study that assessed a hygiene education initiative in Burkina Faso (Borghi and others 2002) found this program to be modestly cost-effective at approximately US$1,100 per death averted. A randomized, controlled trial looked at home-based education and provision of filters, specifically targeting households affected by human immunodeficiency virus/acquired immune deficiency syndrome (HIV/AIDS) in Uganda. The ICER for this program was more than US$2,000 per DALY averted, which is not considered cost-effective in the Ugandan context by Shrestha and others (2006).

The nine remaining water and sanitation evaluations are derived from public works programs affecting environmental health. Günther and Fink (2011) developed a model using Demographic and Health Survey data from 38 countries that demonstrated the relative cost-effectiveness of both basic improved water and sanitation and privately piped water and toilets. Three benefit-cost analyses of improved water and sanitation in different settings demonstrated favorable BCRs (ranging from 1.9 to 5.1) for a variety of interventions, including filters, piped water, and boreholes, as well as private latrines and community-based sanitation practices (Cameron and others 2011; Hutton and others 2014; Whittington and others 2009). The study by Cameron and others (2011) used preintervention and postintervention data from their study site to estimate health outcomes, whereas the other two studies used static (equation-based) models of health outcomes. Another study (World Bank 2013) used a water quality simulation model to assess wastewater treatment strategies in Indonesia. This study demonstrated favorable BCRs for all approaches except one that focused only on large industries. Finally, two multicountry studies that used static (equation-based) models of health outcomes demonstrated wide variation in BCRs by country. However, all the water and sanitation strategies—alone or in combination—were generally a good return on investment (Hutton 2012; Hutton, Haller, and Bartram 2007).

Further findings based on the WHO-CHOICE and other models compare cost-effectiveness of various community-wide and household prevention approaches for water treatment and reduction of indoor air pollution. One study found that household water treatments were generally more cost-effective than piped water supply and sewage connections in

Table 10.3 Results from Economic Evaluations of Ambient Environment Interventions: Cost-Effectiveness Analyses

Study author (year)	Intervention	Location, perspective[a]	Cost per outcome as presented	Unit of outcome	Currency as presented (year)	Cost per outcome (2012 US$)
Borghi and others (2002)	Hygiene promotion	Burkina Faso, government	657	Death averted	U.S. dollar (1999)	1,113
Shrestha and others (2006)	Improved water among households affected by HIV/AIDS	Uganda, government	1,252	DALY averted	U.S. dollar (2004)	2,066
Günther and Fink (2011)	Basic improved water and sanitation in Sub-Saharan African countries	Multiple, government	1,104	LY saved	U.S. dollar (2007)	n.a.
Günther and Fink (2011)	Privately piped water and flush toilets	Multiple, government	995	LY saved	U.S. dollar (2007)	n.a.
Günther and Fink (2011)	Improved water and sanitation	Multiple, government	3,281	LY saved	U.S. dollar (2007)	n.a.
Günther and Fink (2011)	Privately piped water and flush toilets in other LMICs	Multiple, government	3,188	LY saved	U.S. dollar (2007)	n.a.

Note: HIV/AIDS = human immunodeficiency virus/acquired immune deficiency syndrome; DALY = disability-adjusted life year; LMICs = low- and middle-income countries; LY = life year; n.a. = not applicable. Costs were estimated for multiple countries and then aggregated; no cost deflator is available for this grouping.
a. “Perspective” refers to the perspective from which costs were estimated.

Table 10.4 Results from Economic Evaluations of Ambient Environment Interventions: Benefit-Cost Analyses

Study author (year)	Intervention	Location	Benefit-cost ratio[a]	Currency used (year)
Cameron and others (2011)	Improved water	South Africa	3.1	South African rand (2008)
Hutton and others (2014)	Community sewage system (urban)	East Asia and Pacific	1.9	U.S. dollar (2008)
Hutton and others (2014)	Private wet pit latrine (rural)	East Asia and Pacific	5.1	U.S. dollar (2008)
Whittington and others (2009)	Borehole and public hand pump	Multiple	3.3	U.S. dollar (2007)
Whittington and others (2009)	Community-led total sanitation program	Multiple	3.0	U.S. dollar (2007)
Whittington and others (2009)	Biosand filter	Multiple	3.0	U.S. dollar (2007)
Whittington and others (2009)	Large dam	Multiple	3.7	U.S. dollar (2007)
World Bank (2013)	Treatment of domestic wastewater	Indonesia	2.3	Indonesian rupiah (2010)
World Bank (2013)	Treatment of industrial wastewater, differentiating all industries or large industries only	Indonesia	0.6	Indonesian rupiah (2010)
World Bank (2013)	Treatment of domestic and industrial wastewater	Indonesia	2.0	Indonesian rupiah (2010)
World Bank (2013)	Treatment of domestic and industrial wastewater and recycling of industrial wastewater	Indonesia	2.3	Indonesian rupiah (2010)
Hutton, Haller, and Bartram (2007)	Improved water	Multiple	4.4–31.6	n.a.
Hutton, Haller, and Bartram (2007)	Improved water and sanitation	Multiple	5.5–45.5	n.a.
Hutton, Haller, and Bartram (2007)	Improved water and sanitation and universal basic access	Multiple	5.2–45.0	n.a.
Hutton, Haller, and Bartram (2007)	Universal basic access and point-of-use treatment	Multiple	5.7–40.7	n.a.
Hutton, Haller, and Bartram (2007)	Regulated piped water supply and sewer connection	Multiple	2.1–11.8	n.a.
Hutton (2012)	Universal access to improved sanitation	Multiple	2.8–8.0	n.a.
Hutton (2012)	Universal access to improved drinking water sources	Multiple	0.6–3.7	n.a.
Hutton (2012)	Universal access to improved sanitation and improved drinking water sources	Multiple	2.0–5.3	n.a.

Note: n.a. = not applicable. Costs were estimated for multiple countries and then aggregated; no cost deflator is available for this grouping. Net benefits and benefit-cost ratios are presented from a societal perspective.

a. Benefit-cost ratios are presented as given in the article because they are independent of currency inflation and exchange rates.

different world regions (Haller, Hutton, and Bartram 2007). Within the household, two studies found that using home-based water filter techniques was ultimately more cost-effective than boiling water (Clasen and others 2007; Clasen and others 2008). A study by Larsen (2003) found that providing safe sanitation facilities was more cost-effective than providing safe water supplies, which was more cost-effective than hygiene improvement strategies. Finally, Jeuland and Pattanayak (2012) developed a model for use in conducting multiple sensitivity analyses related to cookstove interventions. A major finding is that uptake levels of interventions and other assumptions greatly alter the estimated net benefits to households; in some cases, households are worse off with improved cookstoves (Jeuland and Pattanayak 2012).

PROGRAM COSTS

Injuries and Occupational Hazards

The estimated costs of the injury prevention program derived from the cost-effectiveness and benefit-cost studies are presented in table 10.5. The RTI prevention interventions in Thailand and Uganda cost less than US$1 per capita. However, the combined drowning prevention program in Bangladesh and the IPV prevention program cost more than US$20 per capita per participant, owing to the higher resource needs and training required to conduct these programs. Mine clearance was very expensive, at more than US$14,000 per hectare, which is part of the reason the program had net negative benefits.

Environmental Hazards

Table 10.6 summarizes the costs of programs to reduce environmental risks. Air pollution control, despite being cost-effective, was relatively expensive in Mexico. Water and sanitation programs also required large investments over a long time horizon, with the exception of personal point-of-use technologies. Special attention was paid in these studies to the recurrent costs of WASH infrastructure, which in many cases were a substantial contributor to overall costs and might be borne by households. However, these large costs appeared to be outweighed by the economic benefits. A collection of studies on water and sanitation demand not included in this

Table 10.5 Program Costs of Injury Prevention Interventions

Study author (year)	Intervention	Location, perspective[a]	Cost as presented	Unit of cost	Currency as presented (year)	Cost (2012 US$)
Bishai and others (2008)	Traffic enforcement	Uganda, government	0.45	Per vehicle per year	U.S. dollar (2005)	0.70
Ditsuwan and others (2013)	Sobriety checkpoints by metropolitan police	Thailand, government	0.27	Per capita per year	Thai baht (2004)	0.01
Ditsuwan and others (2013)	Sobriety checkpoints by traffic police	Thailand, government	5.29	Per capita per year	Thai baht (2004)	0.23
Ditsuwan and others (2013)	Media campaign on drink-driving	Thailand, government	2.86	Per capita per year	Thai baht (2004)	0.12
Rahman and others (2012)	Anchal drowning prevention program	Bangladesh, societal	60.50	Per capita first year	International dollar (2010)	19.07
Rahman and others (2012)	Anchal drowning prevention program	Bangladesh, societal	50.74	Per capita second year onward	International dollar (2010)	16.00
Rahman and others (2012)	SwimSafe drowning prevention program	Bangladesh, societal	13.46	Per capita per year	International dollar (2010)	4.24
Elliot and Harris (2001)	Mine clearance	Mozambique, societal	6,176.50	Per hectare	U.S. dollar (1996)	14,249.00
Jan and others (2011)	Microfinance and gender training (trial period)	South Africa, government	42.93	Per capita per 2 years	U.S. dollar (2004)	54.87
Jan and others (2011)	Microfinance and gender training (scale-up)	South Africa, government	12.88	Per capita per 2 years	U.S. dollar (2004)	16.46

a. "Perspective" refers to the perspective from which costs were estimated.

Table 10.6 Program Costs of Ambient Environment Interventions

Study author (year)	Intervention	Location, perspective[a]	Cost as presented	Unit of cost	Currency as presented (year)	Cost (2012 US$)
Air pollution						
Blackman and others (2000)	NMSU kiln	Mexico, societal	175,214.00	Per year	U.S. dollar (1999)	276,094.00
Blackman and others (2000)	Natural gas	Mexico, societal	249,553.00	Per year	U.S. dollar (1999)	393,234.00
Blackman and others (2000)	Relocation	Mexico, societal	350,429.00	Per year	U.S. dollar (1999)	552,190.00
Blackman and others (2000)	No-burn days	Mexico, societal	24,692.00	Per year	U.S. dollar (1999)	38,909.00
Stevens, Wilson, and Hammitt (2005)	Catalyzed DPF	Mexico, societal	270.00	Per vehicle per year	U.S. dollar (2000)	360.00
Stevens, Wilson, and Hammitt (2005)	Active regeneration DPF	Mexico, societal	600.00	Per vehicle per year	U.S. dollar (2000)	800.00
Stevens, Wilson, and Hammitt (2005)	Diesel oxidation catalyst	Mexico, societal	90.00	Per vehicle per year	U.S. dollar (2000)	120.00
Water, Sanitation, and Hygiene						
Borghi and others (2002)	Hygiene promotion	Burkina Faso, government	8.11	Per capita	U.S. dollar (1999)	13.73
Cameron and others (2011)	Improved water	South Africa, societal	153.31	Per capita per year	South African rand (2008)	2.58
Shrestha and others (2006)	Improved water among households affected by HIV/AIDS	Uganda, government	2.19	Per capita per year	U.S. dollar (2004)	3.61
Whittington and others (2009)	Borehole and public hand pump	Multiple, societal	2.00	Per house per month	U.S. dollar (2007)	n. a.
Whittington and others (2009)	Community-led total sanitation program	Multiple, societal	0.39	Per house per month	U.S. dollar (2007)	n. a.
Whittington and others (2009)	Biosand filter	Multiple, societal	1.25	Per house per month	U.S. dollar (2007)	n. a.
Whittington and others (2009)	Large dam	Multiple, societal	3,743,000.00	Per 75 years	U.S. dollar (2007)	n. a.
World Bank (2013)	Treatment of domestic wastewater	Indonesia, societal	888,000,000,000.00	Per 20 years	Indonesian rupiah (2010)	109,000,000.00
World Bank (2013)	Treatment of industrial wastewater, differentiating all industries or large industries only	Indonesia, societal	172,000,000,000.00	Per 20 years	Indonesian rupiah (2010)	21,000,000.00

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Table 10.6 Program Costs of Ambient Environment Interventions (continued)

Study author (year)	Intervention	Location, perspective[a]	Cost as presented	Unit of cost	Currency as presented (year)	Cost (2012 US$)
World Bank (2013)	Treatment of domestic and industrial wastewater	Indonesia, societal	1,059,000,000,000.00	Per 20 years	Indonesian rupiah (2010)	130,000,000.00
World Bank (2013)	Treatment of domestic and industrial wastewater and recycling of industrial wastewater	Indonesia, societal	1,164,000,000,000.00	Per 20 years	Indonesian rupiah (2010)	143,000,000.00
Günther and Fink (2011)	Basic sanitation (latrines)	Multiple, government	600.00–965.00	Per house per lifetime	U.S. dollar (2007)	n.a.
Günther and Fink (2011)	Basic improved water	Multiple, government	309.00–545.00	Per house per lifetime	U.S. dollar (2007)	n.a.
Günther and Fink (2011)	Flush toilets	Multiple, government	2,099.00–2,400.00	Per house per lifetime	U.S. dollar (2007)	n.a.
Günther and Fink (2011)	Privately piped water	Multiple, government	1,623.00–2,509.00	Per house per lifetime	U.S. dollar (2007)	n.a.

Note: HIV/AIDS = human immunodeficiency virus/acquired immune deficiency syndrome; DPF = diesel particulate filter; NMSU = New Mexico State University; n.a. = not applicable. Costs were estimated for multiple countries and then aggregated; no cost deflator is available for this grouping.
a. "Perspective" refers to the perspective from which costs were estimated.

review suggests that despite the high cost of water and sanitation infrastructure, households in LMICs are generally willing to pay a substantial amount for these goods and services (Dutta and Tiwari 2005; Pattanayak and others 2010).

Some recent studies can inform the costs of these programs, although data may be incomplete or out of date. For example, a study by Banerjee and others (2007) found that social marketing of safe water systems resulted in economies of scale and greater financial sustainability. A study by Crocker and Bartram (2014) looked at the cost of routine water quality testing in seven countries. They documented great heterogeneity and economic inefficiencies in existing monitoring practices and proposed ways of optimizing monitoring. A study by Dodane and others (2012) demonstrated that in urban Senegal, sewer-based systems were more expensive, less feasible, and no more effective than more commonly used on-site waste management systems.

OTHER ECONOMIC ASPECTS OF INJURIES AND ENVIRONMENTAL HEALTH

Prevention of injury is likely to have more economic benefits than those described in the cost-effectiveness studies here. Injury often leads to disability, which can be permanent. From a human capital perspective, injury leads to foregone wages and hinders economic growth and development (Nguyen and others 2016). Gender-based violence, in particular, can hinder women's economic opportunities and impede gender equity, leading to consequences for overall economic growth (Duvvury and others 2013). Occupational injury may have deleterious effects on both employees and employers, but in practice, costs often fall exclusively on employees. In countries where trauma care is financed predominantly by out-of-pocket funds, injuries can have catastrophic or impoverishing effects on households (Nguyen and others 2016). Preventing injury in these settings can reduce the risk of medical impoverishment (Olson and others 2016).

The rationale for government intervention to prevent environmental exposures stems from the concept of internalizing externalities or reducing the social costs associated with private decisions. Such social costs include negative effects on the environment. The BCA approach used in most environmental health evaluations reviewed should, in principle, include an estimate of the environmental (nonhealth) benefits of scaling up WASH and addressing air pollution. In practice, however, many of these benefits are undervalued. For example, households appear to place a high intrinsic value (willingness-to-pay) on WASH services, but when these services are not present, households face high coping costs related to unreliable water supply (Dutta and Tiwari 2005). In such cases, public sector regulation can improve economic efficiency. Empirical evidence suggests that in most settings, people are willing to pay substantial amounts to mitigate negative externalities in the injury and environmental health domains (Ortuzar, Cifuentes, and Williams 2000).

LIMITATIONS IN EVIDENCE

Our review has summarized the recent economic evaluations that focus on preventing injuries and reducing environmental hazards in LMICs. The absolute number of studies on such hazards in LMICs published since 2000 is small in comparison to other areas of health. However, there are a few additional studies from LMICs published before 2000; these were reviewed in chapters 42 and 43 of *Disease Control Priorities in Developing Countries* (second edition) (Bruce and others 2006; Kjellstrom and others 2006).

Despite broad recognition of the problem and many effective interventions, there is surprisingly little economic literature on the prevention of RTIs in LMICs. Evidence from high-income countries shows that investments in promoting or establishing helmet laws, vehicle inspections, seatbelt use, and, to a lesser extent, speed limits appear to be good value for money (Waters, Hyder, and Phillips 2004). Many of these approaches would likely be effective in LMICs. However, the costs, affordability, and cost-effectiveness may vary, depending on country context and the amount of government and regulatory infrastructure in place to implement and scale up these interventions.

Similarly, there are few economic analyses on prevention of falls, burns, poisoning, or injuries from forces of nature in LMICs. Given the increasing burden of injuries (in particular, falls) and of interpersonal violence in LMICs, this area will be important for future research. Studies in high-income countries have demonstrated that regulatory and legal interventions are cost-effective, but the social and legal differences compared to LMICs make these studies difficult to generalize (Waters and others 2004). Further, the most neglected area for economic analysis by far is occupational injury. We found no high-quality studies in LMICs in this area, but we anticipate that the productivity benefits of addressing occupational hazards in these settings will be impressive and warrant further investigation.

With respect to environmental risks, the evidence is compelling for scaling up WASH interventions, particularly basic sanitation measures and point-of-use water quality interventions. Piped water and other large-scale infrastructure projects can be good value for money from a societal standpoint (that is, including the intrinsic value individuals place on having piped water independent of its health effect). However, these projects require more substantial up-front investments and may be infeasible as a first step for low-income countries. Whether WASH infrastructure should be a high priority for other sectoral reasons (that is, besides the health benefits) for governments of low-income countries is unclear.

Unfortunately, little economic evidence exists on control of outdoor air pollution in LMICs outside of Mexico, and there are essentially no economic studies published after 2000 on control of indoor air pollution. In contrast, outdoor air pollution—which, in the near future, is expected to supplant the burden of indoor air pollution in LMICs—has been the focus of many epidemiological studies and economic evaluations in high-income countries. These analyses can serve as a first step to informing policy in LMICs. (See, for example, the economic evaluations conducted by the U.S. Environmental Protection Agency [2011].) Analyses of outdoor air pollution policies in LMICs will be of utmost importance given trends in urbanization and the potential for mitigating climate change. We note that a discussion of the economics of climate change is particularly challenging and is outside the scope of this review. See chapter 8 in this volume (Ebi, Hess, and Watkiss 2017) for a discussion of potential global costs and benefits of mitigating climate change.

Even more difficult than evaluating health sector interventions, economic evaluations of cross-sectoral interventions with multiple types of costs and benefits face serious methodological challenges, given the difficulty of valuing and combining the direct and indirect benefits of reducing personal injury and promoting environmental health. The literature is concentrated in several areas, especially RTI interventions and structural WASH interventions. Both areas suggest quite positive results, but do not fully account for social benefits. For RTIs, an accounting for downstream health effects of injury is lacking. For environmental exposures, the key issue is the difficulty of capturing and measuring benefits across sectors. In these cases, we are likely to be underestimating the benefits of such interventions and therefore underinvesting in environmental health protection.

CONCLUSIONS

We have identified several areas in injury prevention and environmental and occupational health where a good economic case might be made for action. Yet important methodological challenges remain, as well as unanswered questions and conditions for which no literature exists. If one considers the human capital and other social costs associated with these diseases and risk factors, more research in this area is urgently needed to inform the design and implementation of intersectoral policies.

ANNEXES

The annexes to this chapter are as follows. They are available at http://www.dcp-3.org/environment.

- Annex 10A. Search Terms Used to Identify Relevant Literature
- Annex 10B. Flow Chart of Identification, Screening, and Eligibility of Included Studies
- Annex 10C. List of Included Studies, Main Findings, and Quality Assessment

NOTE

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.

All intervention costs in this chapter have been converted into 2012 US$, using the World Bank consumer price index or regional inflation rates, unless otherwise noted.

REFERENCES

Banerjee, A., D. McFarland, R. Sinh, and R. Quick. 2007. "Cost and Financial Sustainability of a Household-Based Water Treatment and Storage Intervention in Zambia." *Journal of Water and Health* 5 (3): 385–95.

Bishai, D., B. Asiimwe, S. Abbas, A. Hyder, and W. Bazeyo. 2008. "Cost-Effectiveness of Traffic Enforcement: Case Study from Uganda." *Injury Prevention* 14: 223–27.

Bishai, D., and A. Hyder. 2006. "Modeling the Cost Effectiveness of Injury Interventions in Lower and Middle Income Countries: Opportunities and Challenges." *Cost Effectiveness and Resource Allocation* 4 (2): 1–11.

Blackman, A., S. Newbold, J. Shih, and J. Cook. 2000. "The Benefits and Costs of Informal Sector Pollution Control: Mexican Brick Kilns." Discussion Paper 00-46, Resources for the Future, Washington, DC.

Borghi, J., L. Guinness, J. Ouedraogo, and V. Curtis. 2002. "Is Hygiene Promotion Cost-Effective? A Case Study in Burkina Faso." *Tropical Medicine and International Health* 7 (11): 960–69.

Bruce, N., E. Rehfuess, S. Mehta, G. Hutton, and K. Smith. 2006. "Indoor Air Pollution." In *Disease Control Priorities in Developing Countries* (second edition), edited by D. T. Jamison, J. G. Bremen, A. R. Measham, G. Alleyne, M. Claeson, D. B. Evans, P. Jha, A. Mills, and P. Musgrove. Washington, DC: World Bank.

Cameron, J., P. Jagals, P. Hunter, S. Pedley, and K. Pond. 2011. "Economic Assessments of Small-Scale Drinking-Water Interventions in Pursuit of MDG Target 7C." *Science of the Total Environment* 410–11: 8–15.

Chisholm, D., H. Naci, A. Hyder, N. Tran, and M. Peden. 2012. "Cost Effectiveness of Strategies to Combat Road Traffic Injuries in Sub-Saharan Africa and South East Asia: Mathematical Modelling Study." *BMJ* 344: e612.

Clasen, T., C. McLaughlin, N. Nayaar, S. Boisson, R. Gupta, and others. 2008. "Microbiological Effectiveness and Cost of Disinfecting Water by Boiling in Semi-Urban India." *American Society of Tropical Medicine and Hygiene* 79 (3): 407–13.

Clasen, T., D. Thao, S. Boisson, and O. Shipin. 2007. "Microbiological Effectiveness and Cost of Boiling to Disinfect Drinking Water in Rural Vietnam." *Environmental Science and Technology* 42 (12): 4255–61.

Crocker, J., and J. Bartram. 2014. "Comparison and Cost Analysis of Drinking Water Quality Monitoring Requirements versus Practice in Seven Developing Countries." *International Journal of Environmental Research and Public Health* 11: 7333–46.

Ditsuwan, V., J. Veerman, M. Bertram, and T. Vos. 2013. "Cost-Effectiveness of Interventions for Reducing Road Traffic Injuries Related to Driving under the Influence of Alcohol." *Value in Health* 16: 23–30.

Dodane, P., M. Mbeguere, O. Sow, and L. Strande. 2012. "Capital and Operating Costs of Full-Scale Fecal Sludge Management and Wastewater Treatment Systems in Dakar, Senegal." *Environmental Science and Technology* 46: 3705–11.

Drummond, M. F., M. J. Schulpher, K. Claxton, G. L. Stoddart, and G. W. Torrance. 2015. *Methods for the Economic Evaluation of Health Care Programmes*, fourth edition. Oxford, U.K.: Oxford University Press.

Dutta, V., and A. Tiwari. 2005. "Cost of Services and Willingness to Pay for Reliable Urban Water Supply: A Study from Delhi, India." *Journal of Water Science and Technology* 5 (6): 135–44.

Duvvury, N., A. Callan, P. Carney, and S. Raghavendra. 2013. "Intimate Partner Violence: Economic Costs and Implications for Growth and Development." Working Paper 82532, World Bank, Washington, DC.

Ebi, K. L., J. J. Hess, and P. Watkiss. 2017. "Health Risks and Costs of Climate Variability and Change." In *Disease Control Priorities* (third edition): Volume 7, *Injury Prevention and Environmental Health*, edited by C. N. Mock, R. Nugent, O. Kobusingye, and K. R. Smith. Washington, DC: World Bank.

Elliot, G., and G. Harris. 2001. "A Cost-Benefit Analysis of Landmine Clearance in Mozambique." *Development Southern Africa* 18 (5): 625–33.

Guimaraes, L., J. Ribeiro, and J. Renner. 2012. "Cost-Benefit Analysis of a Socio-Technical Intervention in a Brazilian Footwear Company." *Applied Ergonomics* 43: 948–57.

Günther, I., and G. Fink. 2011. "Water and Sanitation to Reduce Child Mortality: The Impact and Cost of Water and Sanitation Infrastructure." Policy Research Working Paper 5618, World Bank, Washington, DC.

Haller, L., G. Hutton, and J. Bartram. 2007. "Estimating the Costs and Health Benefits of Water and Sanitation Improvements at Global Level." *Journal of Water and Health* 5 (4): 467–81.

Hutton, G. 2012. *Global Costs and Benefits of Drinking-Water Supply and Sanitation Interventions to Reach the MDG Target and Universal Coverage*. Geneva: World Health Organization.

Hutton, G., L. Haller, and J. Bartram. 2007. "Global Cost-Benefit Analysis of Water Supply and Sanitation Interventions." *Journal of Water and Health* 5 (4): 481–502.

Hutton, G., U. Rodriguez, A. Winara, N. Anh, K. Phyrum, and others. 2014. "Economic Efficiency of Sanitation Interventions in Southeast Asia." *Journal of Water, Sanitation and Hygiene for Development* 4 (1): 23–36.

IHME (Institute for Health Metrics and Evaluation). 2015. "Global Burden of Disease Study 2013 (GBD 2013) Data Downloads." IHME, Seattle. http://ghdx.healthdata.org/global-burden-disease-study-2013-gbd-2013-data-downloads.

Jan, S., G. Ferrari, C. Watts, J. Hargreaves, J. Kim, and others. 2011. "Economic Evaluation of a Combined Microfinance and Gender Training Intervention for the Prevention of Intimate Partner Violence in Rural South Africa." *Health Policy and Planning* 26: 366–72.

Jeuland, M., and S. K. Pattanayak. 2012. "Benefits and Costs of Improved Cookstoves: Assessing the Implications of Variability in Health, Forest and Climate Impacts." *Plos One* 7 (2): e30338.

Kjellstrom, T., M. Lodh, T. McMichael, G. Ranmuthugala, R. Shrestha, and others. 2006. "Air and Water Pollution: Burden and Strategies for Control." In *Disease Control Priorities in Developing Countries* (second edition), edited by D. T. Jamison, J. G. Bremen, A. R. Measham, G. Alleyne, M. Claeson, D. B. Evans, P. Jha, A. Mills, and P. Musgrove. Washington, DC: World Bank.

Lahiri, S., C. Levenstein, D. Nelson, and B. Rosenberg. 2005. "The Cost Effectiveness of Occupational Health Interventions: Prevention of Silicosis." *American Journal of Industrial Medicine* 48: 503–14.

Lahiri, S., P. Markkanen, and C. Levenstein. 2005. "The Cost Effectiveness of Occupational Health Interventions: Preventing Occupational Back Pain." *American Journal of Industrial Medicine* 48: 515–29.

Larsen, B. 2003. "Hygiene and Health in Developing Countries: Defining Priorities through Cost-Benefit Assessments." *International Journal of Environmental Health Research* 13: S37–46.

Luh, J., and J. Bartram. 2016. "Drinking Water and Sanitation: Progress in 73 Countries in Relation to Socioeconomic Indicators." *Bulletin of the World Health Organization* 94: 111–21.

Maler, K. G., and J. R. Vincent, eds. 2005. *Handbook of Environmental Economics: Economywide and International Environmental Issues*, third edition. Amsterdam: North Holland.

Mercy, J. A., S. D. Hillis, A. Butchart, M. A. Bellis, C. L. Ward, and others. 2017. "Interpersonal Violence: Global Impact and Paths to Prevention." In *Disease Control Priorities* (third edition): Volume 7, *Injury Prevention and Environmental Health*, edited by C. N. Mock, R. Nugent, O. Kobusingye, and K. R. Smith. Washington, DC: World Bank.

Nguyen, H., R. Ivers, S. Jan, A. Martiniuk, L. Segal, and others. 2016. "Cost and Impoverishment 1 Year after Hospitalisation due to Injuries: A Cohort Study in Thai Binh, Vietnam." *Injury Prevention* 22 (1): 33–39.

Olson, Z., J. A. Staples, C. N. Mock, N. P. Nguyen, A. M. Bachani, and others. 2016. "Helmet Regulation in Vietnam: Impact on Health, Equity, and Medical Impoverishment." *Injury Prevention* 22 (4): 233–38.

Ortuzar, J. D., L. A. Cifuentes, and H. C. W. L. Williams. 2000. "Application of Willingness-to-Pay Methods to Value Transport Externalities in Less Developed Countries." *Environment and Planning A* 32 (11): 2007–18.

Patel, V., D. Chisholm, T. Dua, R. Laxminarayan, and M. E. Medina-Mora, eds. 2015. *Disease Control Priorities* (third edition): Volume 4, *Mental, Neurological, and Substance Use Disorders*. Washington, DC: World Bank.

Pattanayak, S., C. Poulos, J. Yang, and S. Patil. 2010. "How Valuable Are Environmental Health Interventions? Evaluation of Water and Sanitation Programmes in India." *Bulletin of the World Health Organization* 88: 535–42.

Rahman, F., S. Bose, M. Linnqn, A. Rahman, S. Mashreky, and others. 2012. "Cost-Effectiveness of an Injury and Drowning Prevention Program in Bangladesh." *Pediatrics* 130 (6): 1–10.

Shrestha, R., E. Marseille, J. Kahn, J. Lule, C. Pitter, and others. 2006. "Cost-Effectiveness of Home-Based Chlorination and Safe Water Storage in Reducing Diarrhea among HIV-Affected Households in Rural Uganda." *American Journal of Tropical Medicine and Hygiene* 74 (5): 884–90.

Stevens, G., A. Wilson, and J. Hammitt. 2005. "A Benefit-Cost Analysis of Retrofitting Diesel Vehicles with Particulate Filters in the Mexico City Metropolitan Area." *Risk Analysis* 25 (4): 1–17.

Stevenson, M., D. Hendrie, R. Ivers, Z. Su, and R. Norton. 2008. "Reducing the Burden of Road Traffic Injury: Translating High-Income Country Interventions to Middle-Income and Low-Income Countries." *Injury Prevention* 14: 2848–49.

UN (United Nations). 2016. *Sustainable Development Goals: 17 Goals to Transform Our World. Goal 6: Ensure Access to Water and Sanitation for All.* New York: UN. http://www.un.org/sustainabledevelopment/water-and-sanitation.

U.S. EPA (United States Environmental Protection Agency). 2011. "The Benefits and Costs of the Clean Air Act from 1990 to 2010: Final Report–Rev. A." Office of Air and Radiation, U.S. EPA, Washington, DC.

Waters, H. R., A. A. Hyder, and T. L. Phillips. 2004. "Economic Evaluation of Interventions to Reduce Road Traffic Injuries: A Review of the Literature with Applications to Low and Middle-Income Countries." *Asia-Pacific Journal of Public Health* 16 (1): 23–31.

Waters, H. R., A. A. Hyder, Y. Rajkotia, S. Basu, and J. A. Rehwinkel. 2004. *The Economic Dimensions of Interpersonal Violence*. Geneva: World Health Organization.

Whittington, D., M. Shanemann, C. Sadoff, and M. Jeuland. 2009. "The Challenge of Improving Water and Sanitation Services in Less Developed Countries." *Foundations and Trends in Microeconomics* 4 (6–7): 469–609.

WHO (World Health Organization). 2016. *Global Health Estimates 2012*. Geneva: WHO. http://www.who.int/healthinfo/global_burden_disease/en/.

World Bank. 2013. "Downstream Impacts of Water Pollution in the Upper Citarum River, West Java, Indonesia: Economic Assessment of Interventions to Improve Water Quality." Technical Paper 85194, World Bank, Washington, DC.