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Environmental Health Costs in Colombia

The Changes from 2002 to 2010

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Environmental Health Costs in Colombia

The Changes from 2002 to 2010

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Foreword

The Latin America and Caribbean (LAC) Region has a unique mix of qualities and challenges when it comes to the environment. It is exceptionally endowed with natural assets—diverse ecosystems including the world's greatest carbon sink in the Amazon, globally significant biodiversity such as the Mesoamerican Barrier Reef, and valuable crops. At the same time, the Region registers the highest rates of urbanization in the developing world, water and natural resources overuse, and increased pollution, with detrimental consequence for the environment and the health of people, especially the poor.

Over the past twenty years, the LAC Region has made impressive gains in addressing these issues. It leads the developing world in biodiversity conservation, natural and water resource management, and is at the forefront in reducing urban pollution. The World Bank often has the privilege to partner with countries in the Region to pioneer innovative environmental policies and initiatives. Such initiatives include improvement of fuel and air quality standards in Peru, carbon emission reduction in Mexico, payment for ecosystem services in Costa Rica, participatory and integrated water resources management in Brazil, and new approaches to irrigation management in Mexico.

The *Environment & Water Resources Occasional Paper Series*, a publication of the Environment Unit of the Sustainable Development Department in Latin America and Caribbean Region (LCSEN) was launched in 2013. The objective of the Series is to contribute to global knowledge exchange on innovation in addressing environmental issues and the pursuit of greener and more inclusive growth. The papers seek to bring to a broader public—decision makers, development practitioners, academics and other partners—lessons learned from World Bank-financed projects, technical assistance and other knowledge activities jointly undertaken with our partners. The Series highlights issues relevant to the Region's environmental sustainability agenda such as biodiversity conservation, natural and water resources management, irrigation, ecosystem services, environmental health, environmental policy, pollution management, environmental institutions and governance, environmental financing, and climate change and their linkages to development, growth and shared prosperity.

In this particular paper, we present you the findings of an assessment of environmental health costs in Colombia carried out in 2012. The World Bank's 2005 Colombia Country Environmental Analysis "Environmental Priorities and Poverty Reduction" estimated the costs of environmental degradation for Colombia for the first time. The 2012 assessment was carried out as part of the broader program of technical assistance and analytical support by the World Bank at the request of the Ministry of Environment and Sustainable Development and the National Planning Department of Colombia in order to update and analyze the health impacts and the associated economic costs caused by urban air pollution, indoor air pollution from solid fuel use, and an inadequate supply of water and sanitation combined with poor hygiene practices. These three environmental problems consistently cause the highest health costs across Latin America and the Caribbean. The 2005 study concluded, among other things, that the most costly problems associated with environmental degradation are urban and indoor air pollution; inadequate water supply, sanitation, and hygiene; natural disasters and land degradation. The present study updates and completes some of the previous estimates, accounting for the much increased complexity and an improved availability of relevant data in Colombia. We hope that this paper along with other publications under the Series will make a contribution to knowledge sharing within the LAC Region and globally.

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Acronyms and Abbreviations

ACS	American Cancer Society
AF	Population-Attributable Fractions
ALRI	Acute Lower Respiratory Infections
AMVA	Valle de Aburrá Metropolitan Area
ARI	Acute Respiratory Infection
ARI	Acute Respiratory Illness
AURI	Acute Upper Respiratory Infections
BMI	Body Mass Index
BRT	Bus Rapid Transit
CB	Chronic Bronchitis
CEAs	Country Environmental Analyses
COED	Costs of Environmental Degradation
COI	Cost of Illness
COP	Colombian Peso
COPD	Chronic Obstructive Pulmonary Disease
DALYs	Disability Adjusted Life Years
DANE	Colombia's National Statistical Authority
ENDS	National Demographic and Health Survey
GBD	Global Burden of Disease
GDP	Gross Domestic Product
HC	Human Capital
HCA	Human Capital Approach
IAP	Indoor Air Pollution
ICU	Intensive Care Units
LAC	Latin America and the Caribbean
LC	Lung Cancer
LPG	Liquid Petroleum Gas
MPS	Ministry of Social Protection
NCHS	US National Center for Health Statistics
ORT	Oral Rehydration Therapy
PEM	Protein-Energy Malnutrition
PDDB	Bogotá Ten-Year Decontamination Plan
PM	Particulate Matter
RR	Relative Risk Ratios
SD	Standard Deviations
UAP	Urban Air Pollution
VCO	Volatile Organic Compounds
VSL	Value of a Statistical Life
WA	Weight-For-Age
WASH	Water Supply, Sanitation and Hygiene
WAZ	Weight-For-Age Z-Score
WHO	World Health Organization
WTP	Willingness to Pay
YLL	Years of Life Lost

Currency Equivalents

(Exchange Rate Effective December 31, 2010)

Currency Unit = Colombian Peso

1 USD = 1867.3927 COP

0.000536 USD = 1 COP

Acknowledgements

This report presents the results of the study "Environmental Health Costs in Colombia: Changes from 2002 to 2010." The study was carried out in 2012 as part of the program of analytical support and technical assistance "Colombia: Strengthening Environmental Policies and Institutions", implemented by the team led by Juan Carlos Belausteguigoitia (former Lead Environmental Economist, World Bank, and currently Executive Director, Centro Mario Molina) and Irina Klytchnikova (Senior Economist, World Bank). The estimates presented in this study were carried out by Elena Golub and Gerardo Sanchez (Consultants). The team would like to thank the Ministry of Environment and Sustainable Development of Colombia, especially Luz Helena Sarmiento (Minister of Environment), Pablo Vieira (Vice Minister of Environment), Adriana Soto (former Vice Minister of Environment), Francisco Gómez (Director of Urban and Sectorial Affairs), Marcela Bonilla (former Director of Urban and Sectorial Affairs), Sergio Hernandez, Paula Rodriguez and Olga Lucia Bautista; as well as Carolina Urrutia (former Deputy Director for Environment and Sustainable Development at the National Planning Department) for their support throughout the preparation of this study, their helpful comments and discussion, as well as the participants of the workshops held in Bogotá in the context of the implementation of this study, and helpful comments by peer reviewer Ernesto Sanchez-Triana (Lead Environmental Specialist, World Bank) and Daniel Sellen (Sector Leader, World Bank). Assistance by Diana Guzmán and Geise Santos, editing by Janice Molina, and translation by Camila Sepulveda are gratefully acknowledged. The study was completed under the overall guidance of Gloria Grandolini (Country Director), Ede Jorge Ijjasz-Vasquez (Sector Director), Karin Kemper (former Sector Manager, LCSEN), Daniel Sellen (Sector Leader), Geoffrey Bergen (former Country Manager) and Issam Abousleiman (Country Manager) of the World Bank. Financial support by the multi-donor Trust Fund for Environmentally and Socially Sustainable Development (TFESSD) is gratefully acknowledged.

Abstract

Despite considerable progress in the area of environmental management over the last decade, Colombia still faces significant impacts from population exposure to urban air pollution, inadequate access to water supply and sanitation, and indoor air pollution from solid fuel use. This study estimates that the total health cost attributable to these three factors amounts to about 10.2 trillion Colombian Pesos (COP) annually, or about 2% of GDP in 2010. In terms of mortality, about 7,600 annual premature deaths can be attributed to these environmental factors. This study updates some of the estimates of environmental health costs reported in the 2005 Colombia Country Environmental Analysis "Environmental Priorities and Poverty Reduction". Using an updated methodology to reflect income growth and better pollution monitoring data compared with the earlier study and accounting for population growth in cities, this assessment finds that health costs of urban air pollution have increased. Previously the second highest category of costs, they have now shifted to the first place, rising by about a quarter of a percentage point to 1.1% of GDP in 2010. An improvement in fuel quality and other policy measures implemented since 2002 to improve urban air quality have helped reduce the health damages. This study estimates that a reduction in PM_{10} levels from an average of 66 $\mu g/m^3$ in 2002 to 59 $\mu g/m^3$ observed in Bogotá in 2010 helped save an average of 200 lives per year, and around 252 billion COP per year of health costs were saved. Health costs associated with inadequate water supply, sanitation access and hygiene have fallen to less than 0.7% of GDP in 2010 but a large share of the costs still results from child mortality, requiring continued policy attention to improving environmental health conditions in this sector. The costs of indoor air pollution have fallen to less than a quarter of a percentage point of GDP in 2010, but they continue to weigh the most on vulnerable groups and disproportionately affect women and children, often perpetuating the cycle of poverty and predominantly bearing on the rural population. In an ideal setting, all the deaths and illnesses can be avoided but public expenditures and investment resources are constrained and need to be allocated efficiently. Specific policy recommendations and targeted interventions can be derived from future analysis of environmental health costs at subnational level, cost-benefit analysis of specific policy interventions, and an analysis of the burden of health costs disaggregated by population groups and poverty levels. Disaggregated statistics on health outcomes, fuel use, access to infrastructure services, epidemiological studies, and air quality models (urban and industrial areas) are required for such analysis. Disaggregated assessments and cost benefit analysis, recommended for future studies, will facilitate an evaluation of policy and investment outcomes in terms of their impacts on the most vulnerable groups and the extent to which they are well targeted and benefit the poor.

Environmental Health Costs in Colombia

1. Introduction and Context

This study estimates environmental health costs of pollution, updating an earlier assessment.

The World Bank's 2005 Colombia Country Environmental Analysis, *Environmental Priorities and Poverty Reduction,* estimated the costs of environmental degradation (CoED) in Colombia for the first time. The study concluded that the most costly problems associated with environmental degradation were urban and indoor air pollution; inadequate water supply, sanitation, and hygiene; natural disasters and land degradation. The present report updates the previous estimates of the costs stemming from urban and indoor air pollution and from inadequate water supply, sanitation and hygiene, taking into account the income and population growth and an improved availability of monitoring data in Colombia since 2002. This study presents an assessment of health costs as of 2010 and compares them with the earlier estimates.

Despite considerable progress in the area of environmental management in Colombia over the last decade, this assessment reveals that Colombia's population still faces significant adverse impacts from exposure to urban air pollution (UAP), inadequate water, sanitation and hygiene (WASH), and indoor air pollution from solid fuel use (IAP). The total health cost attributable to these three factors amounts to about 10.2 trillion COP annually, or about 2% of GDP in 2010. In terms of mortality, about 7,600 annual premature deaths can be attributed to these environmental factors. About 5,000 deaths are associated with UAP, around 1,600 with inadequate WASH and a further 1,000 with IAP. The overall burden of health costs from these three factors has remained at a similar level as in 2002 but the relative magnitude of the costs has changed, reflecting population and income growth, an improvement in access to improved sanitation, and growth in urban population in Colombia.

The analysis in this study relies on large sets of statistics and data from various ministerial departments, institutions, and institutes in Colombia. It also draws on Colombian and international research studies, and has benefited from various methodological approaches applied by international organizations such as the World Health Organization, and is in accordance with all previous related work within the World Bank's Country Environmental Analyses (CEAs). This study is aimed at deepening the understanding of the country's major health challenges associated with environmental pollution. Publicly available and easily traceable information and indicators were used as much as possible in order to facilitate contrast and future updates. All costs calculated in this report are expressed in monetary terms, and they include the cost to society due to premature mortality, as well as the cost of healthcare provision to individuals suffering from pollution-related illnesses and the value individuals place on avoiding resulting pain and discomfort. Time losses or savings are valued at the opportunity cost of time.

Policy makers and stakeholders can use the estimates of premature mortality and illness and the associated economic costs as an input in the process of setting environmental objectives and investment and policy priorities. The Government of Colombia can use this information to examine institutional capacity for sound environmental management within the country and strengthen institutions and governance to enhance environmental outcomes. The World Bank and other donors can use this study's results to help set priorities in the policy dialogue with the Government of Colombia. Because preferences and values are expressed in monetary terms, the results can provide additional guidance for the allocation of resources across the range of socio-economic development goals.

Lastly, this evidence base helps to track progress with earlier reforms, as well as advancing further on the environmental protection and environmental health agendas. Ambitious and relevant policies will find adequate justification based on the large health and economic cost of environmental degradation in Colombian society. Addressing these environmental risks should continue to be a priority in the environmental and public health policy agenda in Colombia.

2. Summary of the Technical Findings

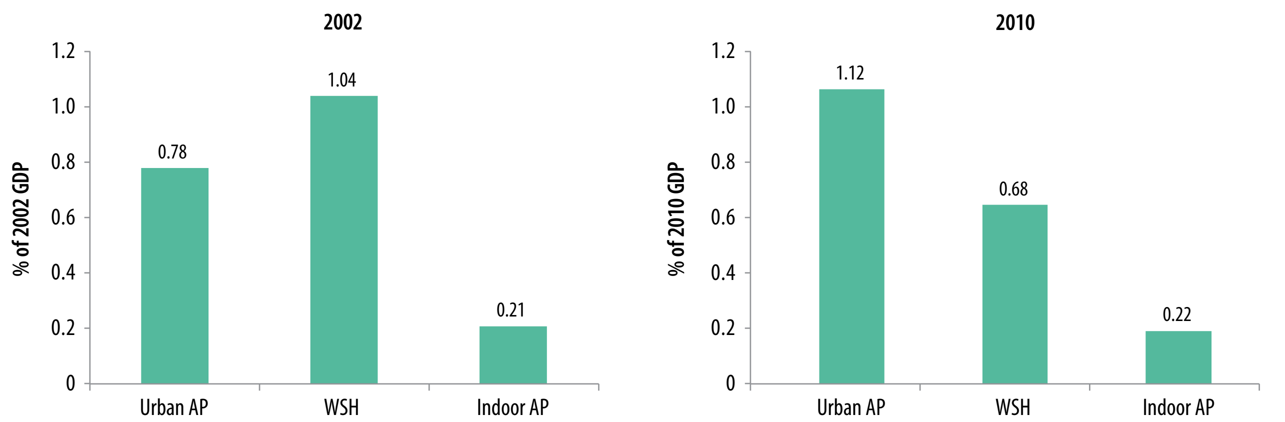
Health costs of environmental degradation, updated in this study, have increased at the same rate as the economy and population have grown.

This study estimates that the total health costs attributable to urban air pollution, inadequate water supply, sanitation and hygiene, and indoor air pollution from solid fuel use in Colombia amount to about 10.2 trillion COP (about 2% of GDP in 2010). The largest cost is attributable to urban air pollution, to which a large share of the population is exposed, followed by inadequate water supply, sanitation and hygiene. The third is the cost attributable to the indoor use of solid fuels, which is a common practice in rural areas of Colombia. The cost of these three environmental factors combined has remained unchanged as a proportion of the GDP—an earlier assessment also estimated them at 2% of GDP—although Colombia's GDP has more than doubled since. However, the ranking has shifted (Figure 1). The health costs associated with urban air pollution have increased as a percentage of GDP, rising to the first place, whereas the costs of indoor air pollution have remained unchanged and the costs of inadequate water, sanitation and hygiene have dropped markedly relative to GDP.

Health costs of urban air pollution have increased relative to other health costs, but better air quality in Bogotá helped temper that rise.

Urban air pollution was previously estimated as the third highest in terms of the associated costs, following water supply, sanitation and hygiene, and natural disasters. In this round of evaluation the

Figure 1 Health Costs of Selected Environmental Factors in Colombia in 2002 and 2010



Source: Authors' estimates for 2010 results; Larsen (2004) for 2002 results.
Note: The estimates of the costs of urban air pollution for 2002 and 2010 shown above are not directly comparable as a slightly different methodology was used in this study as is takes into account significant income growth in Colombia over the last decade and an expansion of the air quality monitoring network (and populations of cities with monitoring data are included in the 2010 analysis, whereas in 2002 an extrapolation was used for cities without monitoring networks). About half of the costs are due to population exposure to air pollution in Bogotá, and air quality has improved there since 2002. Sensitivity analysis reveals that, keeping all other factors constant, health costs due to air pollution in Bogotá alone would have been 7% higher in 2010 had air quality not improved.

mean annual cost of urban air pollution for Colombia is estimated at about 5.7 trillion COP, or 1.1% of 2009 GDP (Table 1). Mortality represents about 79% of the total estimated cost. Without considering the cost of natural disasters, this puts urban air pollution in first place, ahead of water supply, sanitation and hygiene.[1] An improvement in fuel quality and other policy measures implemented since 2002 to improve urban air quality in Bogotá alone have helped reduce the health damages that would have occurred in the absence of that improvement. This study estimates that a reduction in PM_{10} levels from an average of 66 μg/m^3 in 2002 to 59 μg/m^3 helped save an average of 200 lives in 2010; and around 252 billion COP per year of health costs were saved due to that improvement in air quality.

Indoor air pollution weighs the most on women and children, affecting the rural population and perpetuating the cycle of poverty.

The mean estimated annual cost of health impacts from indoor air pollution associated with the use of traditional fuels (mainly fuel wood) in rural areas of Colombia is 1.129 trillion COP (0.22% of GDP in 2010). This environmental factor weighs the most on the vulnerable groups and often perpetuates the poverty cycle: mortality in children under age five represents 6% of cost, and mortality in women over 30 years of age represents about 78% of cost. Acute respiratory illness (ARI) in children and adult females and Chronic Obstructive Pulmonary Disease (COPD) morbidity of adult females represent 16% of the cost.

Table 1 Summary of the Environmental Health Costs in 2010

Factor	Annual mortality	Annual morbidity	Associated monetary costs	
	Number of premature deaths	DALYs (million)	COP (billion)	Percentage of 2009 GDP
Urban Air Pollution (UAP)	5,000	65	5,700	1.12
Water, Sanitation and Hygiene (WASH)	1,600	20	3,450	0.68
Indoor Air Pollution (IAP)	1,000	12	1,129	0.22
Total	7,600	97	10,279	2.00

Source: Authors' estimates.
Note: 1 USD = 1,817 COP. DALYs are disability-adjusted life years.

[1] Direct comparison between estimates in 2002 and 2010 should be made with caution. Methodology of environmental health costs quantification significantly improved since 2002 in terms of capturing health impacts of pollution by $PM_{2.5}$ and valuation of mortality for middle-income countries. Furthermore, the air quality monitoring network expanded in Colombia, so it was possible to generate more accurate results in the current study using the revised methodology and more accurate estimates of population exposure to pollution based on monitored data instead of extrapolations in cities with no monitoring data, as was done in the earlier study for 2002. Lastly, recent literature concurs that Human Capital Approach (HCA)—the valuation method used in the earlier study for an adult mortality risk valuation—should not be used in a situation with a substantial GDP per capita growth, which has occurred in Colombia since then. To assess the benefits of an improvement in air quality observed in Bogotá since 2002, sensitivity analysis was carried out. It shows the changes in mortality and morbidity and the associated costs in Bogotá in two cases: a high concentration scenario with the average levels of PM_{10} measured in Bogotá in 2002, and a low concentration scenario with the levels measured in 2012. It is assumed that the ratio of $PM_{2.5}$ to PM_{10}, with the former being the pollutant due to which the health damages occur—is between 40 and 60%, and the midpoint of 50% is used in this calculation. It is estimated that 200 additional mortality cases would have occurred in Bogotá had the pollution level remained unchanged compared with the 2002 level; and 440 fewer mortality cases would have occurred, ceteris paribus, with a concentration level on average equal to 48 μg/m^3 (i.e., the level measured in 2012). Thus, the set of policy measures, including the introduction and enforcement of more stringent fuel quality standards in Bogotá and other measures, and which led to the lower measured levels of PM_{10} in Bogotá, resulted in a reduction of mortality cases in Bogotá by 7% in 2010 relative to what they would have been had air quality not improved. A further improvement in air quality in 2012 resulted in a reduction of mortality cases in Bogotá by 16% compared with the baseline scenario. For further details about the methodological differences between the 2002 and 2010 studies, see Annex 3.

Health costs of inadequate water supply, sanitation and hygiene have fallen but a large share of the costs still results from child mortality.

The mean estimated annual cost of health impacts from an inadequate supply of drinking water and sanitation and from poor hygiene in Colombia is 3.45 trillion COP (0.68% of GDP in 2010). Mortality in children under age five represents 17% of the cost, with morbidity accounting for the remaining 83%. Diarrheal mortality and morbidity represent about 89% of total cost and are estimated at about 3.05 trillion COP annually. Urban cost represents about 77% of the total diarrheal cost. The reduction of health costs in this sector is associated with an improvement of public health measures, a resulting reduction of background diarrheal mortality and morbidity burdens, and an increase of rural population with access to improved sanitation over the 2002–10 period.

Urban air pollution causes three times as many deaths as inadequate water supply, sanitation and hygiene, and 5 times as many deaths as indoor air pollution.

The health costs assessed in this study are derived from the estimates of premature mortality and morbidity linked with pollution.[2] As of 2010, about 7,600 premature deaths annually were attributable in Colombia to urban air pollution, indoor air pollution from solid fuel use, and an inadequate supply of water and sanitation combined with poor hygiene practices.

Of the total number of deaths due to these three factors, UAP caused about 65% of premature mortality, followed by WASH (around 20%) and IAP (about 15%). In terms of burden of disease (measured in terms of lost Disability Adjusted Life Years (DALYs)), the pattern is similar: nearly 70% of DALYs are attributable to UAP, around 20% to WASH, and around 10% to IAP.[3] The following levels of mortality and morbidity were estimated as attributable to UAP, IAP and WASH:

- About 5,000 premature deaths and almost 65 million DALYs can be attributed to urban air pollution each year in Colombia. Bogotá and the Valle de Aburrá Metropolitan Area (Área Metropolitana del Valle de Aburrá, AMVA) account for over 75% of the attributable mortality. Nearly 4,700 new cases of chronic bronchitis each year are also attributable to urban air pollution in Colombia. Mortality represents about half of the burden of disease attributable to air pollution, and morbidity (i.e., diseases) accounts for the other half.
- About 1,000 premature deaths and almost 12 million DALYs can be attributed to indoor air pollution caused by solid fuel use each year in Colombia. This burden of disease is almost completely restricted to rural areas, where nearly 50% of the population uses solid fuels for cooking and other household chores. An estimated 950 to 1,050 children and women died prematurely from respiratory illnesses associated with the use of wood and other biomass fuels for cooking in Colombia in 2010. About 200 of these deaths were among children under age five and 800 were among adult women.
- About 1,600 premature deaths and almost 20 million DALYs can be attributed to inadequate water supply, sanitation and poor hygiene each year in Colombia. About 1,000 of these premature deaths occur in children under age five due to infectious diseases amplified by malnourishment.

[2] These health impacts, in turn, must be interpreted cautiously. In the absence of relevant local epidemiological evidence, internationally accepted rapid assessment methods have been used for the calculations. Details about such calculations are explained in the report and technical annexes.
[3] DALYs are the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability.

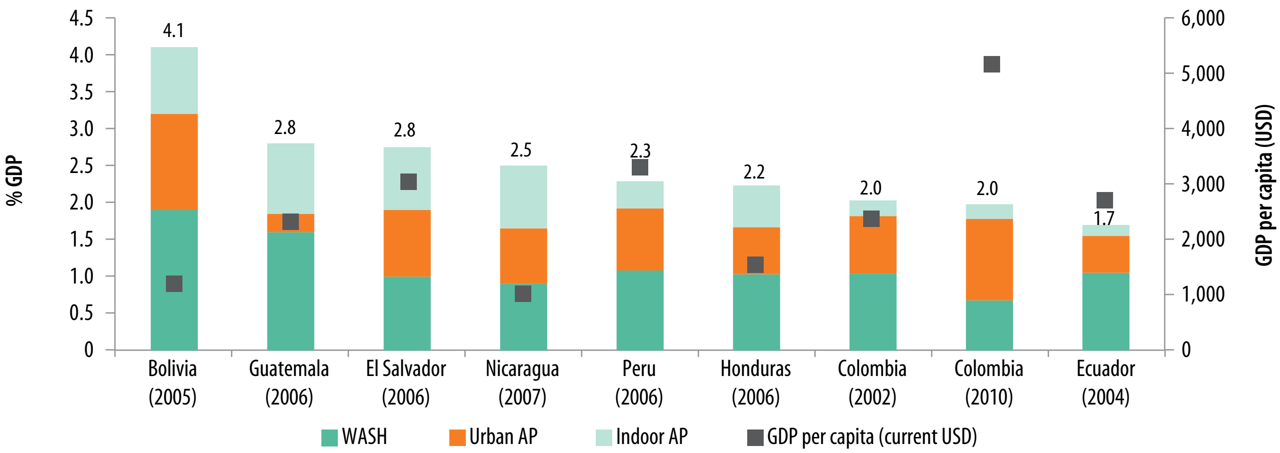
Environmental health costs in Colombia are at the lower end of the spectrum compared with other countries in the region.

Similar analyses were conducted in other countries in the LAC region over 2002–07 (Figure 2). The methodology in this report was shifted toward the application of value of statistical life (VSL) for the valuation of mortality due to urban air pollution (as opposed to the average between the human capital approach (HCA) and VSL in other studies). In practice, this means a higher value compared with the combined HCA-VSL approach. In spite of this, Colombia is on the lower end of the environmental pollution burden compared to other Latin American countries. Urban air pollution by far outweighs other environmental health problems. At the same time, the improvement of water supply, sanitation and hygiene and the reduction of indoor air pollution remain an important pending task that can effectively reduce mortality and morbidity in children in rural and urban areas, women and the rural population.

Recent efforts to strengthen air quality management have been effective at preventing a worsening in air pollution despite the growing vehicle fleet.

Significant progress has been made toward effective air pollution management in Colombia in the last decade. The 2010 Air Pollution Control and Prevention Policy notes some of the main areas of progress: air quality assessment, monitoring, standardization of air quality inventories, fuel quality improvement, and implementation of incentive programs for environmental control and monitoring. It is important to note that a strong effort in this regard helped generated an ample evidence base that revealed systemic weaknesses in air quality management and areas for improvement. The action plan for the implementation of the 2010 policy set ambitious goals to address policy and investment priorities. To illustrate specific improvements, in the last 10 years PM_{10} concentrations decreased slightly in Bogotá and more significantly in Cali and Bucaramanga. They increased 5% in the Aburrá Valley

Figure 2 Environmental Health Cost in Colombia and in the Region (% of GDP)



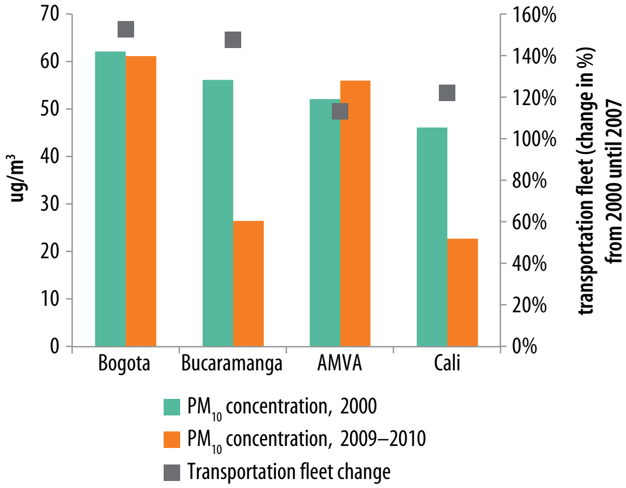
Source: Country Environmental Analyses for various years. For Colombia, this study for 2010 results and Larsen (2004) for 2002 results.
Note: For Colombia, the estimates of the costs of urban air pollution for 2002 and 2010 shown above are not directly comparable as a slightly different methodology was used in this study as is takes into account significant income growth in Colombia over the last decade and an expansion of the air quality monitoring network (and populations of cities with monitoring data are included in the 2010 analysis, whereas in 2002 an extrapolation was used for cities without monitoring networks). About half of the costs are due to population exposure to air pollution in Bogotá, and air quality has improved there since 2002. Sensitivity analysis reveals that, keeping all other factors constant, health costs due to air pollution in Bogotá alone would have been 7 percent higher in 2010 had air quality not improved.

Metropolitan Area (Area Metropolitana del Valle de Aburrá, which includes Medellin). At the same time, the number of registered vehicles per 1,000 inhabitants grew about 105 to 140% in these metropolitan areas (Molina et al. 2008). In total, the transportation fleet grew from 13 to 53% in 2000–07. Figure 3 presents the relative change in PM_{10} concentrations over 2000–10 and the rate of increase in transportation fleet over 2000–07 in these cities.

In the case of Bogotá, the concentration of particulate matter has decreased consistently: from a yearly average of about 70 µg/m³ in 2007 it fell to around 50 µg/m³ in 2011. Furthermore, seasonal variability and dangerous seasonal concentration peaks seem to be decreasing as well (Figure 4).

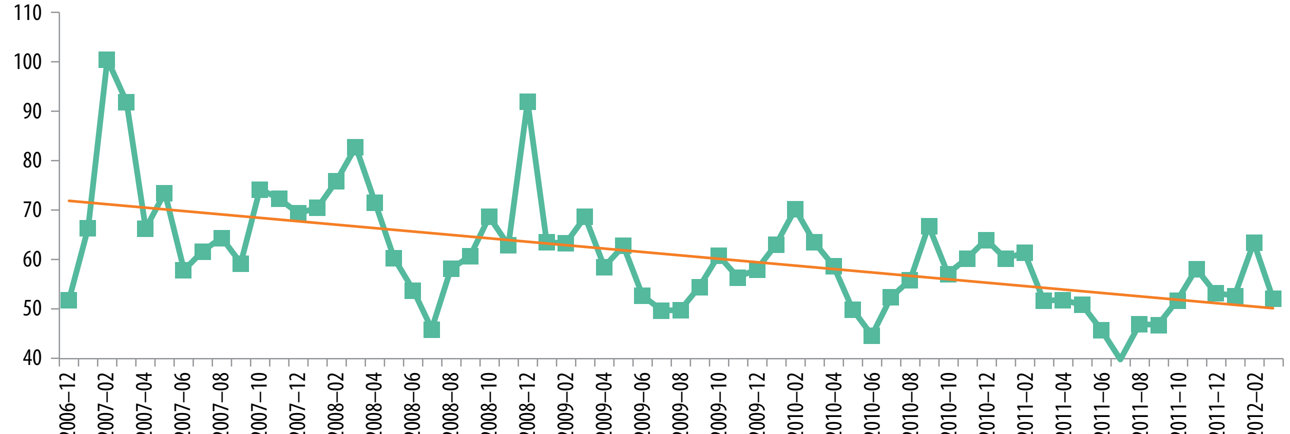
Other subnational and local governments have also strengthened efforts through sectoral measures with potential large benefits for air quality, such as urban transportation (Box 1). Following the example of Bogotá, car-free days, Bus Rapid Transit (BRT) systems and the promotion of non-motorized transport are extending to other large urban centers. The *"Pico y Placa"* (Peak and License Plate–a car-use restriction by the last digit of the license plate number at peak hours) schemes are also present now in major Colombian cities. A notable improvement is the expansion of the air quality monitoring network. The population covered by the network of monitoring stations as of 2010 was estimated at around 18 million people (up

Figure 3 Relative Change in PM_{10} Concentrations and Transportation Fleet



Source: Authors' estimates. PM_{10} concentrations are based on data from SISAIRE (http://www.sisaire.gov.co) for 2009–2010 and Larson (2002); transportation fleet estimated from Molina et al. (2008).

Figure 4 Monthly Average PM_{10} Concentration (Ug/M³) in Bogotá, 2006–12



Source: Bogotá Environmental Secretariat, pers. comm.

Box 1 Bogotá's Local Air Quality Management Policies

The local government in Bogotá has made significant efforts in the recent years to improve air quality in the metropolitan area. Short of a full policy impact assessment, we cannot establish a direct causality between air quality management policies implemented in Bogotá and the observed reductions in particulate matter. However, available indicators suggest that most measures and interventions adopted by the city government have likely had a large positive impact. These actions include, but are not limited to:

- *Diesel fuel quality improvement.* The maximum permissible sulfur content of diesel fuel sold in Bogotá in 2008 (500 parts per million) was reduced to 50 ppm in 2010, although real concentration of locally distributed fuel is around 30 ppm. As of the end of 2012, all diesel fuel in Colombia must be under 50 ppm.
- *Increased use of Bus Rapid Transit (BRT) system.* Increased occupancy levels in the Transmilenio system have entailed comparatively large emission reductions. Current BRT emissions are about 0.058 grams of $PM_{2.5}$ per passenger, compared with 0.311 grams in the rest of the current public transportation system in Bogotá (a comparative reduction of about 80%). Consequently, CO_2 emissions of the BRT system are much lower than for other means of transportation as well.
- *Restriction on sales of two-stroke engine motorbikes in Bogotá and a later ban on their circulation in Bogotá (subsequently overturned).* According to the emissions inventory in the city's ten-year decontamination plan (PDDB 2010) motorbikes contribute 25% of total mobile source emissions of PM in the city. Four-stroke engine motorbikes emit 40% less PM than two-stroke ones. The ban was only under application for two years, as a new mayor reversed the ban on two-stroke engines in 2012.

Further progress in these areas is part of an ambitious 10-year air quality management plan currently under implementation. One important planned city-wide intervention is the integration of the public transportation system; although not yet implemented, this integration is projected to have a major impact on the city's air quality. According to an ongoing study by the Universidad de los Andes, the reorganization has the potential to reduce $PM_{2.5}$ emissions from public transport by between 74 and 80%. That would entail health-related economic savings of 360 million USD over ten years (PDDB 2010).

Source: Clean Air Institute for Latin American Cities (pers. communication).

from 12.5 million in 2002, as reported in Larsen (2004)) whereas the population living in cities with greater than 100,000 inhabitants[4] not covered by air quality monitoring networks is close to 9 million (about the same as in 2002).

No systematic efforts have been made to reduce the burden of disease from indoor air pollution.

One area where little progress has been achieved over the last decade is in the management of indoor air pollution. There have been no focused efforts to decrease exposure to indoor air pollution, and the burden of diseases associated with indoor air pollution continues to be overwhelmingly concentrated in Colombia's rural households. There is no obvious decreasing trend, as 53% of rural households used solid fuels in 2005 compared to just over 50% in 2010 (ENDS 2010). In terms of a regional perspective, the Eastern and Caribbean regions have the highest incidence of solid fuel use: 17.7% and 20.1% respectively. The only region where solid fuel use for household uses is negligible is Bogotá.

Sanitation and diarrheal treatment have improved in rural areas, reducing the incidence of diarrheal illness.

General malnutrition (low weight for age) in Colombia decreased from 7% in 2005 to 4.5% in 2010.

[4] The cutoff point of 100,000 inhabitants is taken as an indicator that an urban setting is large enough to include substantial amounts of mobile and point sources of pollution to represent a health hazard.

Severe malnutrition has also decreased slightly, from 0.6 to 0.5% (ENDS 2010, p. 298). The use of some sort of oral rehydration therapy (ORT)—the main remedy used to treat diarrheal illness in children—increased from 61% in 2000 to 70% in 2005 and 74% in 2010 (ENDS 2010, p. 256). Although not proportional to GDP growth over the same period, these improvements are still notable. However, systematic differences remain between urban and rural areas as well as among regions in terms of the awareness and care of diarrheal diseases in children.

Rural-urban and regional differences still persist in the supply of safe drinking water and the provision of the appropriate means of sanitation. At the same time, the national demographic and health surveys reflect that in the last ten years the share of Colombian population without access to improved sanitation decreased by 13%. The share of rural population with improved sanitation reached 84%, and about 99% of urban households are connected to sewers. Inadequate WASH in rural areas is still a serious environmental health and health equity problem in Colombia that disproportionately affects the relatively more poor rural population.

Future studies should analyze environmental health costs and carry out cost-benefit analysis of investments and policy interventions at a disaggregated level.

This assessment has revealed the continuing importance and high costs of the environmental health problems in Colombia. Specific policy recommendations and targeted interventions can be derived from studies of environmental health costs at subnational level, cost-benefit analyses of specific policy interventions, and analyses of the burden of health costs disaggregated by population groups and poverty levels. Disaggregated statistics on health outcomes, fuel use, access to infrastructure services, and air quality models in urban areas are required for such analysis. Robust air quality models at metropolitan level are critically needed to enable an evaluation of alternative scenarios of emission reductions from fixed and mobile sources and the associated health benefits. Disaggregated assessments and cost-benefit analysis will facilitate an evaluation of policy and investment outcomes in terms of their impacts on the most vulnerable groups and the extent to which they are well targeted and benefit the poor.

3. Urban Air Pollution—Detailed Technical Findings

3.1 *Urban air pollution and health*

Worldwide evidence on the health effects of urban air pollution has been substantial for decades now, with extensive studies showing the association between certain air pollutants and respiratory and cardiovascular mortality, chronic bronchitis, respiratory infections, and several other related disorders. Most studies show the strongest association between pollutants and health effects for inhalable particulate matter, particularly $PM_{2.5}$ (smaller than 2.5 microns in diameter). To the comprehensive reviews in the late 1990s and early 2000s in European and North American countries, a growing body of evidence can be added from cities in developing countries of Asia (e.g., HEI 2008) and from cities in Latin American countries (Bell et al. 2006, O'Neill et al. 2008, Bell et al. 2011, among others).

The amount of information available in Colombia has also increased greatly. Air-pollution monitoring data, which in 2004 were available for four metropolitan areas in Colombia, are currently available for eleven large metropolitan areas comprising several municipalities (SISAIRE 2012). Monitoring of $PM_{2.5}$ has begun experimentally in some stations and there are now local estimates of the $PM_{10}/PM_{2.5}$ ratio. There is more accurate information on and better coverage of demographic and statistical information, and health indicators are better disaggregated. Thus, the uncertainty of the analysis has been reduced, but its complexity has increased in proportion to the amount of decisions and generalizations to be made in order to obtain nationwide estimates.

With these considerations in mind, the analytical approach to the estimation of the damage value of air pollution follows the same main steps used in Larsen (2004) as well as in most Country Environmental Analyses including air pollution: (i) identification of air pollutants and determination of concentrations; (ii) population exposed and its baseline vulnerability; (iii) calculation of the health impact of exposure to air pollution based on epidemiological techniques; and (iv) estimation of the value of this health impact.

3.2 *Baseline population, pollutant concentration and dose-response coefficients*

The proportion of the urban population was estimated at 74% in 2010 (DANE 2011). Nearly 60% of the Colombian population now lives in cities with over 100,000 inhabitants and almost 30% lives in cities with over 1 million inhabitants; Cartagena is quickly approaching this threshold as well. These figures are in line with a long-term increasing urbanization process in Colombia (see Table 2).

The population included in this analysis is the one nominally covered by air pollution measurement networks as of 2010. This coverage has increased greatly in the last decade, partly due to the governmental effort to establish environmental monitoring in areas surrounding ports and mining operations. In 2004, only four metropolitan areas (Bogotá, Bucaramanga, Valle de Aburrá, and Cali) measured

Table 2 Change in Selected Urban Demographic Indicators in Colombia, 2002 Versus 2010

Parameter	DANE 2002	DANE 2010
% of urban population	72	74
% living in cities with over 100,000 inhabitants	49	59
% living in cities with over 1,000,000 inhabitants	28	29

Source: National Administrative Department of Statistics (*Departamento Administrativo Nacional de Estadística*, DANE) http://www.dane.gov.co/.

PM_{10}. Today, most of Colombia's large metropolitan areas are covered by coordinated networks corresponding to environmental jurisdictions. We have organized the information in areas corresponding to eleven metropolitan areas of various sizes. Unlike previous studies (Larsen 2004), we did not feel that partitioning land use into categories could provide valuable insights on exposure differentials. A quick overview of land use in Bogotá and Medellín with a Geographical Information System showed a completely mixed pattern of land use, blurring any purported systematic differences. However, we weighted PM concentrations by the population of the main urban setting in which each monitoring station or separate network was embedded, assuming a relatively homogeneous dispersion of pollutants. Table 3 presents the population and population-weighted PM_{10} and $PM_{2.5}$ annual average concentrations for the metropolitan areas covered by one or more monitoring networks.

This evaluation only includes the urban population living in municipalities with real-time, constant monitoring of air pollution. Excluding a potentially exposed population of 9 million (nearly 25% of Colombia's urban population) is a suboptimal analytical choice, but the question remains about how to estimate exposure without information on the pollutants. The obvious option is to estimate their concentrations based on those observed in Colombian cities of comparable size. Such was the approach taken by Larsen (2004) in the absence of emissions inventories from which to derive concentrations (a method with its own drawbacks). However, there may be systematic differences between cities of comparable size according to their pollution

Table 3 Population and Weighted Average Concentration of PM_{10} and $PM_{2.5}$ in Colombian Cities with over 100,000 Inhabitants Covered by Air-Pollution Monitoring Networks

Urban area	Population in 2009 (million)	Annual average population weighted PM_{10} concentration ($\mu g/m^3$)*	Annual average population weighted $PM_{2.5}$ concentration ($\mu g/m^3$)**
Bogotá	7.26	60	30
AMVA[a]	3.25	56	28
Cali	2.22	22	11
Bucaramanga[b]	0.90	33	17
Cucuta	0.61	60	30
Pereira[c]	0.56	53	27
Ibague	0.52	32	16
Soacha	0.44	48	24
Manizales	0.39	34	17
Palmira	0.29	44	22
Sogamoso[d]	0.1	58	29
Yumbo	0.1	50	25

Source: Population figures are based on city specific estimates by DANE.
Note: *Based on data from SISAIRE (http://www.sisaire.gov.co) for 2009–2010.
**$PM_{2.5}/PM_{10}$ ratio of 0.50 is assumed.
[a] Includes 10 conurbated cities in the Valle de Aburrá.
[b] Includes Floridablanca and Girón.
[c] Includes Dos Quebradas.
[d] Includes Nobsa.

monitoring status (see Annex 2) that would render such an extrapolation highly uncertain. The force behind the establishment of air-quality monitoring networks—in Colombia and elsewhere—is precisely the presence of air-quality problems, which are in turn frequently linked to the size and density of urban settings.[5] Therefore, it is expected that municipalities with monitoring networks will be larger and more "urban" than those without networks. The likely presence of relevant systematic differences (beyond mere size) between cities with and without monitoring networks provides additional uncertainty to such a method for estimation. Furthermore, the urban population not covered by a monitoring network is shrinking rapidly in Colombia. Based on these considerations, we decided to drop altogether the estimation of mortality and morbidity effects of cities for which there were no data. Although we acknowledge that we are missing out on a potentially substantial proportion of the overall health impact of urban air pollution in Colombia, we believe this approach will provide more robust results for this and future updates. However, for comparison purposes, we also report overall results including mortality in non-monitored cities (see Annex 3).

Another divergence from previous studies on this matter is the $PM_{2.5}/PM_{10}$ ratio. The relative risks for mortality estimated in the literature most widely used in this type of calculations (Pope 2002) and in the previous Colombia Country Environmental Assessment relate to the concentration of $PM_{2.5}$. However, widespread monitoring of $PM_{2.5}$ is still uncommon. Colombia is no exception: as of today, only four measuring stations (all of them in Bogotá) measure $PM_{2.5}$ systematically. A recent study (PDDB 2009) for Bogotá places this ratio at 0.50. There is no reason to assume that other Colombian cities will have higher ratios than that; on the contrary, higher concentrations from mobile sources and industry typically account for higher ratios, so the ratios in cities smaller than Bogotá might reasonably be expected to be equal or lower. We used a $PM_{2.5}/PM_{10}$ ratio of 0.50.

Granted, inhalable particles are not the only health-relevant air pollutant. Many anthropogenic emissions have proved to be associated with adverse health outcomes, including (but not limited to) sulfur oxides, nitrogen oxides, volatile organic compounds (VCOs), carbon monoxide, lead, and especially ozone. Tropospheric (i.e., ground-level) ozone can trigger a large number of respiratory effects and aggravate certain chronic diseases, thus increasing outcomes, such as increased health care usage or absenteeism, with high costs to society (US EPA 2012). An association between ozone concentrations and long-term mortality has been found, but only when $PM_{2.5}$ concentrations were taken into account (Jerrett et al. 2009). In general, evidence shows that the strongest association and magnitude of effects in the interaction between air pollutants and premature mortality/health are related to particulate matter, particularly that with the smallest diameter fraction.

There has been a substantial improvement in available evidence on the links between air pollution and mortality in Latin America in the last decade, although most studies have dealt with short-term effects. A recent study (O'Neill et al. 2008) analyzed the effect of education on the association between PM_{10} concentrations and short-term mortality in Mexico City, São Paulo and Santiago de Chile, and found total non-accidental adult mortality 1-day lagged increases of 0.39%, 1.04% and 0.61%, respectively, for an increase of 10 $\mu g/m^3$ in concentration. In Brazil, studies have found associations

[5] Excluding cases where point sources contribute a large proportion of the pool of pollution.

between exposure to PM_{10} and low birth weight (Gouveia et al. 2004) and also with respiratory mortality in the elderly (Martins et al. 2004).

In Colombia, the evidence base for health risks of air pollution is still under development. Ibáñez (2003) reviewed three studies that assessed the relationship between urban air pollution and health effects in Bogotá, and provided dose-response coefficients for hospital respiratory admissions, child morbidity and respiratory mortality. A recent study (Aristizabal et al. 2009) studied the association between air pollution and acute respiratory infection (ARI) in three municipalities within Bogotá and found a higher incidence of objective symptoms in children living in areas with higher exposure to PM_{10}. That is, children living in more polluted areas of Bogotá are more likely to develop ARI; these differences are statistically significant when controlled for other factors, such as cigarette-smoke exposure. This study confirms previous observations (Arciniegas et al. 2006) and is contributing to a growing body of local evidence that will allow for ever more relevant assessments in Colombian urban areas.

Although these studies contribute to a greater understanding of the health effects of urban air pollution in Colombia, a larger body of evidence is required to provide reliable estimates of health effects applicable at the national level. For the association between exposure to inhalable particulate matter and mortality, the coefficients of Pope et al. (2002) continue to be the most solid results for long-term effects. Pope et al. (2002) utilized ambient air-quality data from metropolitan areas across the United States for 1979–1983 and 1999–2000, and information on certified causes of mortality of adults in the American Cancer Society (ACS) database over a period of 16 years. The details of the study (which confirms previous observations, such as those of Dockery et al. 1993, Pope et al. 1995) have been discussed extensively elsewhere, and the results still stand as the best available evidence for the association between exposure to inhalable particulate matter and mortality.

Likewise, the morbidity coefficients (Ostro 1994, Abbey 1995) presented in Table 4 still represent highly relevant indicators of increased risk for the considered categories. These are extracted directly from Larsen 2004, where the details of the studies are discussed extensively. Although the mortality effects are based on associations with concentrations of $PM_{2.5}$, the morbidity effects assessed in most worldwide studies are based on PM_{10}.

Table 4 Urban Air Pollution Dose-Response Coefficients

Annual health effect	Dose-response coefficient	Per 1 µg/m³ annual average ambient concentration of:
Mortality (% change in cardiopulmonary and lung cancer mortality)	0.8%	$PM_{2.5}$
Chronic bronchitis (% change in annual incidence)	0.9%	PM_{10}
Hospital respiratory admissions (per 100,000 population)	1.2	PM_{10}
Emergency room visits (per 100,000 population)	24	PM_{10}
Restricted activity days (per 100,000 adults)	5,750	PM_{10}
Lower respiratory illness in children (per 100,000 children)	169	PM_{10}
Respiratory symptoms (per 100,000 adults)	18,300	PM_{10}

Sources: Pope et al. (2002) for the mortality coefficient; Ostro (1994) and Abbey et al. (1995) for the morbidity coefficients.

3.3 Mortality and morbidity attributable to air pollution

In order to ascertain the share of mortality that is attributable to air pollution, baseline data on certain causes of mortality are required. These data are collected by Colombia's national statistical authority (DANE) and reported by department on an annual basis. The categories included are cardiopulmonary causes and lung cancer (DANE categories 206, 301–309, and 605–608). Crude total and cardiopulmonary mortality rates are listed in Table 5.

Regarding nonfatal outcomes with known air-pollution associations, perhaps the most burdensome for patients and health systems is chronic bronchitis (CB). Although there is a rather complete recent study on the prevalence of CB in Colombia (PREPOCOL: Caballero et al. 2008), there are still no good data on the annual incidence of the disease. The rates applied are those from the World Health Organization (WHO 2001) and Shibuya (2001) for the AMRO-B region[6] of WHO in which Colombia is a part, modified with the known data for clinical prevalence of COPD reported in the PREPOCOL study. The resulting incidence rate for the urban Colombian population over age 30 is 256 cases per 100,000 population in one year, compared to a value of 205 for AMRO-B.

For the calculation of an attributable fraction, we established a lower threshold level for $PM_{2.5}$, below which it is assumed there are no mortality effects. Although there is much debate about the usefulness of these lower limits (WHO recognizes

Table 5 Baseline Mortality and Morbidity Data for Cities with PM Monitoring Data

Cities with PMMN	Crude mortality rate (per 1,000 population)*	Cardiopulmonary and lung cancer deaths (% of all deaths)**
Bogotá	4.2	34
AMVA[a]	5.1	36
Cali	5.6	32
Bucaramanga[b]	4.8	34
Cucuta	5.0	37
Pereira[c]	5.8	36
Ibague	5.0	43
Manizales	5.4	39
Palmira	5.6	32
Sogamoso[d]	4.5	42
Yumbo	5.6	32
Average	5.2	36

Sources: Based on DANE statistics.
*Non-accidental based on departmental data.
**Based on departmental data.
[a] Includes 10 conurbated cities in the Valle de Aburrá.
[b] Includes Floridablanca and Girón.
[c] Includes Dos Quebradas.
[d] Includes Nobsa.

[6] Member states of WHO are divided into six geographical regions. this region is further subdivided into sub-regions according to child and adult mortality from A (lowest) to E (highest). The Americas conform one region (AMRO) and Colombia is one of the countries in the sub-region B.

that there is no safe threshold for inhalable particles), it is necessary for practical matters regarding air-quality management. WHO (2002) recommended this threshold to be 7.5 $\mu g/m^3$ in the World Health Report for mortality. However, a recent review by Krewski et al. (2009) lowers the threshold to 5 $\mu g/m^3$. We applied the 5 $\mu g/m^3$ threshold for mortality effects. No threshold was used for morbidity effects.

Aside from mortality, health end-points considered in this analysis are listed in Table 6. These specific health effects have become the standard health end-points considered in most of the worldwide studies on air pollution. In order to facilitate magnitude comparisons with other risk factors, health effects can be converted to disability adjusted life years (DALYs, a combination of years lost due to premature mortality and years lost due to disability). In order to do so, disability weights and average duration of each outcome are assigned to each health effect.[7] We use the weights determined by Larsen (2004) for the Latin America and the Caribbean (LAC) region. Years lost to premature mortality from air pollution were estimated from age-specific mortality data for cardiopulmonary and lung cancer deaths, discounted at 3% per year.

Once health effects of air pollution are converted to DALYs, quick comparisons can be made between different environmental risk factors. A calculation of DALYs lost per 10,000 cases of the considered health end-points is presented in Table 7.

The estimated health impact of urban air pollution in Colombia[8] is presented in Table 8. The values are calculated by applying relative risks and PM concentrations (minus thresholds, where applicable) to population exposed, adjusting for age groups when necessary and extracting the fraction of these health outcomes that is attributable to this specific exposure. DALYs are calculated simply by multiplying the number of cases by the factors in Table 7.

Table 6 Calculation of DALYs Per Case of Health Effects

Health effect	Disability weight	Average duration of illness
Mortality	1.0	(7.5 years lost)
Lower respiratory illness: children	0.28	10 days
Respiratory symptoms: adults	0.05	0.5 days
Restricted activity days: adults	0.1	1 day
Emergency room visits	0.30	5 days
Hospital admissions	0.40	14 days*
Chronic bronchitis	0.2	20 years

Source: Larsen (2004).
* Includes days of hospitalization and recovery period after hospitalization.

Table 7 DALYs Lost per Selected Health Effect Attributable to Air Pollution

Health effect	DALYs lost per 10,000 cases
Mortality	75,000
Chronic bronchitis (adults)	22,000
Hospital respiratory admissions	160
Emergency room visits	45
Restricted activity days: adults	3
Lower respiratory illness: children	65
Respiratory symptoms: adults	0.75

Source: Larsen 2004.

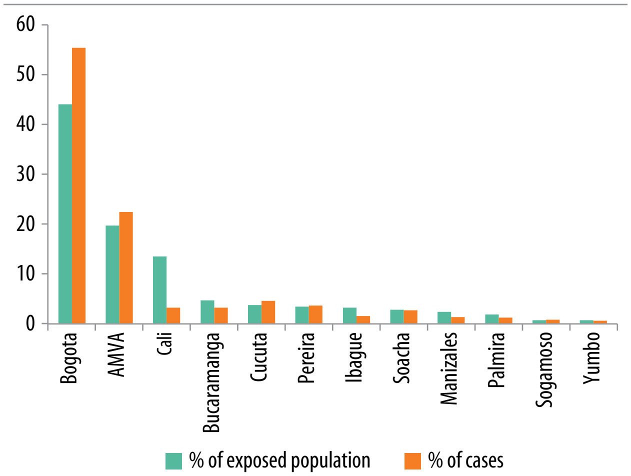
[7] This approach is not free from controversy, since there is considerable uncertainty about duration estimates, and weights include a substantial subjective component. However, it is widely used for convenience in this type of calculations.
[8] For cities covered by networks measuring concentrations of particulate matter.

Table 8 Estimated Health Impact of Urban Air Pollution in Cities with PM Monitoring Data

Health categories	Total cases	Total DALYs
Premature mortality	5,027	37,703
Chronic bronchitis	4,675	10,285
Hospital admissions	9,492	152
Emergency room/ outpatient hospital visits	186,208	838
Restricted activity days	32,748,479	9,825
Lower respiratory illness in children	374,314	2,433
Respiratory symptoms	104,225,594	7,817
	TOTAL	64,354

Source: Authors' estimates.

Figure 5 Percentage of Exposed Population and Attributable Mortality by City (With Monitoring Network)



Source: Authors' estimates.

The four largest urban centers (Bogotá, AMVA, Cali and Bucaramanga) account for more than 80% of the population exposed and attributable cases. There is good concordance between the exposed population and the concentration of cases (Figure 5), except in the case of Cali where lower pollutant concentrations result in fewer attributable cases. However, with only three monitoring stations in the Cali Metropolitan Area (SISAIRE 2012), this result should be interpreted cautiously.

An important health outcome attributable to air pollution (mortality in children under age 15 from respiratory causes) is not included in this analysis since we lacked age-specific mortality by cause and by city, but it should ideally be part of forthcoming updates. In order to properly link exposure to effects with high confidence, it is necessary to collect health statistics on relevant outcomes within each environmental jurisdiction. This will allow public health and environmental authorities to track real progress in reducing environmental health threats to local communities.

3.4 *Health cost of urban air pollution*

The estimated annual cost of health impacts from urban air pollution is presented in Table 9. The cost of mortality is based on the Value of a Statistical Life (VSL). We are not reporting a cost based on the Human Capital Approach (HCA), since we believe that an indicator based on foregone income due to premature mortality severely underestimates the true cost to society that excess mortality represents in a rapidly improving context such as that of urban Colombia. The total estimated annual health cost attributed to outdoor air pollution is about 5.7 trillion COP, or 1.1% of GDP in 2009. Mortality represents about 79% of the total estimated cost.

The estimated cost per case of premature mortality or specific health end-point is presented in Table 10. The VSL used in this assessment is that utilized by the government in Bogotá for the Bogotá Ten-Year Decontamination Plan (*Plan Decenal de Descontaminación de Bogotá,* PDDB 2009). In this report, the value of statistical life was derived

Table 9 Estimated Annual Cost of Health Impacts (Billion Pesos)

Health categories	Total annual cost (billion pesos)	Percent of total cost* (mean)
Mortality	4,519	79
Morbidity		
Chronic bronchitis	40	1
Hospital admissions	56	1
ER visits/outpatient hospital visits	58	1
Restricted activity days (adults)	839	15
Lower respiratory illness in children	84	1
Respiratory symptoms (adults)	113	2
Total cost of morbidity	1,189	21
TOTAL COST (mortality and morbidity)	5,708	100

Source: Authors' estimates.
*Annual cost is rounded to nearest billion, and percentages are rounded to nearest percent.

from: (i) Ortiz et al. (2009) in São Paulo, (ii) Hammit and Ibarraran (2002) in Mexico City, and (iii) Bowland and Beghin (2001) in Santiago de Chile. The PDDB does not specify which value is chosen or, in the case of a combination of the values from the three studies, which relative weight of pooling method was used. However, since the value is not far off from the most recent and most relevant reference (Ortiz et al. 2009; see Annex 1), we found it most appropriate to use a locally estimated value for VSL. Likewise, the WTP proxy applied is based on the ratio of Cost of Illness to Willingness to Pay (WTP) reported for Bogotá (PDDB 2009). The calculated cost of treatment was based on consultations with health authorities and the upper bound of the publicly listed prices that public insurers pay healthcare providers, which in turn are deemed the most adequate reflection of the true cost of treatment in Colombia (see Annex 3). The cost per case (comprising Cost of Illness plus the proxy for WTP) is the basis for the estimation of the annual costs in Table 9 and multiplying each cost for the cases in Table 8.

Table 11 details the baseline data that were used for the estimation of the cost of illness and the costs of time lost to illness. For comparability with previous estimates (see Annex 3) we kept most of

Table 10 Estimated Unit Cost by Health End-Point

Health categories	Total cost per case (000 pesos)	Cost of illness per case (000 pesos)	WTP proxy (000 pesos)
Mortality	1,008,000	N/A	N/A
Chronic bronchitis	8,597	2,629	5,968
Hospital admissions	5,853	1,790	4,063
Emergency room/outpatient hospital visits	312	95	216
Restricted activity days (adults)	26	7.8	18
Lower respiratory illness in children	224	68	155
Respiratory symptoms (adults)	1.08	0.33	0.75

Source: Authors' estimates.

the assumptions regarding duration of illness, rate and length of hospitalization, average time lost per health end-point, frequency of doctor visits, and discount rate. We also valued time lost to illness at 75% of average urban wage, and applied this cost both to working and nonworking individuals, based on the assumption of an equivalent opportunity cost for both categories.

Table 11 Baseline Data for Cost Estimation

	Baseline	Source
Cost Data for All Health End-Points:		
Cost of hospitalization (pesos per day)	246,000	Per consultations with medical service providers and health authorities (see Annex 3). Rounded to the nearest thousand pesos.
Cost of emergency visit (pesos): urban	95,000	
Cost of doctor visit (pesos) (mainly private doctors): urban	29,000	
Value of time lost to illness (pesos per day)	31,000	Based on urban wages in Colombia.
Chronic Bronchitis (CB):		
Average duration of illness (years)	20	Based on Shibuya et al. (2001).
Percent of CB patients hospitalized per year	1.5%	From Schulman et al. (2001) and Niederman et al. (1999).
Average length of hospitalization (days)	10	
Average number of doctor visits per CB patient per year	1	
Percent of CB patients with an emergency doctor/hospital outpatient visit per year	15%	
Estimated lost workdays (including household workdays) per year per CB patient	2.6	Estimated based on frequency of doctor visits, emergency visits, and hospitalization.
Annual real increases in economic cost of health services and value of time (real wages)	2%	Estimate.
Annual discount rate	3%	Applied by WHO for health effects.
Hospital Admissions:		
Average length of hospitalization (days)	6	Estimates based on Larsen (2004).
Average number of days lost to illness (after hospitalization)	4	
Emergency Room Visits:		
Average number of days lost to illness	2	
Restricted Activity Days:		
Average number of days of illness (per 10 cases)	2.5	
Lower Respiratory Illness in Children:		
Number of doctor visits	1	
Total time of caregiving by adult (days)	1	Estimated at 1–2 hours per day.

Source: Authors.

4. Inadequate Water Supply, Sanitation and Hygiene—Detailed Technical Findings

4.1 *Inadequate WASH and diarrheal illness*

Inadequate quantity and quality of potable water supply, sanitation facilities and practices, and hygiene conditions are associated with various illnesses both in adults and children, as discussed in Larsen (2003). Diarrheal illness in children under age five (mortality and morbidity) and adults (morbidity) is the major burden of disease associated with inadequate WASH. Although diarrheal illness is generally not as serious as some other waterborne illnesses, it is more common and affects a larger number of people. Table 12 presents the water supply and sanitation situation in Colombia in 2010. About 98% of the urban population and 73% of the rural population have access to improved water supply in Colombia.

In the last 10 years, the amount of the Colombian population with unimproved sanitation has decreased significantly. Figure 6 below presents the percentage of the population with improved sanitation in rural areas in 2000–2010.

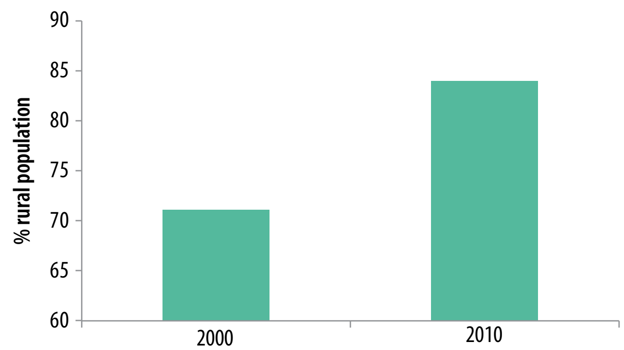
Improvements in sanitation were one of the reasons for substantial reductions in child mortality and diarrheal child mortality in Colombia. Reliable data on the health and nutritional status of the Colombian population are for the most part readily available. Public health information systems contain complete and reliable data on cause-specific adult and child mortality, child nutritional status, and incidence of infectious diseases. These data were applied for estimating the health effects or disease burden from environmental health risk factors. This report uses reported DANE (Ministry of Health) data, household surveys in Colombia (ENDS) and data reported by WHO that, combined, provide indications of several dimensions of health and nutrition in Colombia needed for this study of environmental health. The main household survey with relevant health statistics is Colombia's National Demographic and Health Survey *(Encuesta Nacional de Demografía y Salud* 2010 [ENDS 2010]) by the Association for the Well-being of the Colombian Family *(Asociación Probienestar de la Familia Colombiana,* Profamilia), the Ministry of Social Protection (*Ministerio de Protección Social*,

Table 12 Water Supply and Sanitation in Colombia in 2010 (percent)

	Urban	Rural
Piped water	91.7	59.6
Well water	0.7	10.8
Surface water	0.3	19.8
Rainwater	1.2	4.1
Tanker truck	0.1	0.5
Bottled water/demijohn	5.1	3
Other	0.9	2.2
Water within 15 minutes	99.7	93.6
Flush toilet	98.1	80.3
Pit latrine	0.5	3.8
No facility	1.3	15.8
Other	0	0.2

Source: ENDS 2010.

Figure 6 Percentage of Population with Access to Improved Sanitation



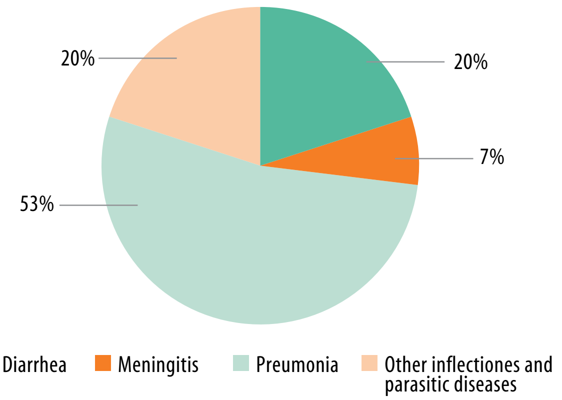
Source: ENDS 2000, ENDS 2010.

MPS) and the US Government through USAID. This survey includes information on child nutritional status, and estimates of the cause-specific structure of child and adult mortality in Colombia by WHO (2009). The reference year for this study is 2009.

4.2 *Child mortality and morbidity*

According to ENDS 2010, the under-five child mortality rate in Colombia was around 22 per 1,000 live births in 2010 (25 in rural areas and 21 in urban areas). It decreased about 9% from 2000. Based on statistics of the under-age-five population in Colombia (DANE 2009), from a population of 3 million children under age five in urban and 1.3 million in rural areas, an estimated 12,600 children under age five died in Colombia in urban areas and 6,400 in rural areas in 2009. WHO and DANE provide estimates of cause-specific child mortality in 2008–2009 for Colombia (WHO 2010; DANE 2010). According to these estimates, about 13 to 16% of mortality among children under five in Colombia was from infectious and parasitic diseases, and 84 to 87% was from other causes (Figure 7). For purposes of this report, it is assumed that the structure of child mortality in

Figure 7 Estimates of Cause-Specific Non-Accidental Mortality Among Children Under Age Five in Colombia from Infectious and Parasitic Diseases, 2008



Source: Produced from DANE estimates of mortality among children in Colombia in 2009 (DANE 2010).

urban and rural areas is the same as that estimated for Colombia as a whole.

The reported data suggest that diarrheal mortality decreased more than 50% in relative terms. At the same time, diarrheal prevalence decreased only 10%. The estimate of diarrheal cases per person is presented below. ENDS 2010 contains important information on the prevalence of diarrhea and symptoms of respiratory infections in children under age five. ENDS 2010 reports a two-week diarrheal prevalence rate of 11.6 to 15.2% in urban-rural areas of Colombia. The annual incidence of diarrhea per child per year is calculated based on the number of prevalence periods in a year and is adjusted for the duration of the diarrheal illness. The average duration of diarrhea is assumed to be 3 to 4 days. The incidence of diarrhea is therefore 2.4 to 3.6 cases per child per year in urban-rural areas, according to ENDS 2010.

Although diarrheal prevalence decreased in the last decade, it is still higher than average in children from lower-income households. Thus, the impact of inadequate WASH is higher in these income groups. For diarrhea, 88% of cases globally are attributed to water, sanitation and hygiene (Prüss et al. 2002; Prüss-Ustün et al. 2004). None of the surveys reports diarrheal disease among the population aged five years and older. Results from household surveys in other countries indicate that the incidence rate in children under age five is around 7 to 10 times higher than among the population aged five years and older. If this is also the case in Colombia, there are 2.4 to 3.2 cases of diarrhea per person/per year in the population aged five years and older, totaling over 13 million cases. Thus, in total there were over 24 million cases of diarrhea in Colombia in 2009. About 21 million of these cases are attributable to inadequate water supply; sanitation and hygiene, representing a loss of over 29,100 DALYs (see Table 14).

Table 13 Diarrheal Illness in Colombia among Children under Age Five in 2000–2009

	Urban	Rural	Total
Children under five mortality, 2000 (per 1,000 live births)	24	36	28
Children under five mortality, 2009 (per 1,000 live births)	21	25	22
Diarrheal mortality, 2000 (%)		7.3%	
Diarrheal mortality, 2009 (%)		3.5%	
Diarrheal morbidity, 2000 (prevalence last 2 weeks)	13.2%	15.6%	13.9%
By household wealth index			
Lowest			17.5%
Second			15.9%
Middle			12.9%
Fourth			10.4%
Highest			10.2%
Diarrheal morbidity, 2009 (prevalence last 2 weeks)	11.6%	15.2%	12.6%
By household wealth index			
Lowest			16.1%
Second			14.4%
Middle			11.3%
Fourth			10.6%
Highest			7.4%

Source: ENDS 2000, ENDS 2010.

Table 14 Estimated Annual Cases of Diarrheal Mortality and Morbidity from Water-Sanitation-Hygiene (WASH) in Colombia, 2009

	Annual cases of diarrhea		Attributable fraction from WASH	Annual cases from WASH		DALYs from WASH	
	Urban	Rural		Urban	Rural	Urban	Rural
Children under age 5: mortality	440	220	88%	400	200	13,500	6,800
Children under age 5: morbidity (million)	7.2	4.0		6.3	3.5	2,540	1,400
Population aged 5+: morbidity (million)	9.1	3.8		8.0	3.3	10,750	4,440
Total morbidity (million)	16.3	7.8		14.3	6.9	13,290*	5,840*

Source: Authors' estimates.
Note: *DALYs from diarrheal morbidity.

4.3 Child nutritional status and WASH health impact

Studies in different low-income countries with similar water supply, sanitation and hygiene problems suggest that measures to reduce environmental damages are justified in a number of areas on cost-benefit grounds as well on grounds of benefiting the poor. For water supply and sanitation, improvements in facilities in rural areas yield benefits in excess of costs under most assumptions. In urban areas, the focus should be on the monitoring of drinking-water quality and on the rehabilitation of piped water supply and sewage systems. The programs are justified on the grounds that the benefits are concentrated primarily among the poor. Hygiene programs have estimated benefits far in excess of costs and should receive the highest priority. The same applies to programs aimed at encouraging the disinfection of drinking water. All interventions to improve WASH also have the benefit of reducing the burden of malnutrition.

Table 15 Prevalence of Underweight in Children Under Age Five in Colombia

	Urban	Rural	Total
Moderate and severe underweight 2009	2.9%	4.7%	3.4%
Severe underweight 2009	0.5%	0.9%	0.6%
Moderate and severe underweight by household wealth index			
Lowest			7.7%
Second			5.0%
Middle			3.4%
Fourth			3.3%
Highest			1.6%
Moderate and severe underweight, 2000	n.a.	n.a.	n.a.
Severe underweight 2,000	n.a.	n.a.	n.a.
Moderate and severe underweight by household wealth index			
Lowest			9.3%
Second			9.0%
Middle			5.6%
Fourth			4.4%
Highest			3.0%

Source: ENDS 2010.

Commonly used indicators of poor nutritional status in children are underweight, stunting and wasting. Underweight is measured as weight-for-age relative to an international reference population.[9] Stunting is measured as height-for-age, and wasting is measured as weight-for-height. Underweight is an indicator of chronic or acute malnutrition or a combination of both. Stunting is an indicator of chronic malnutrition, and wasting an indicator of acute malnutrition. Underweight status among children under age five is most commonly used in assessing the risk of mortality and morbidity from poor nutritional status (Fishman et al. 2004).

A child is defined as moderately underweight or stunted if his or her weight or height is in the range of –2 to –3 standard deviations (SD) below the weight or height of the median child in the international reference population, and severely underweight or stunted if the child's weight or height is –3 SD below the weight or height of the median child in the reference population. The standard deviations are also called z-scores and noted as WAZ (weight-for-age z-score). ENDS 2010 is used here to provide some perspectives on the nutritional status among children under age five in Colombia.

Malnutrition status improved in all income groups, with the greatest improvement achieved in the

[9] The recently published WHO international reference population (representing a diverse group of countries) is increasingly replacing the international reference population defined by the US National Center for Health Statistics (NCHS).

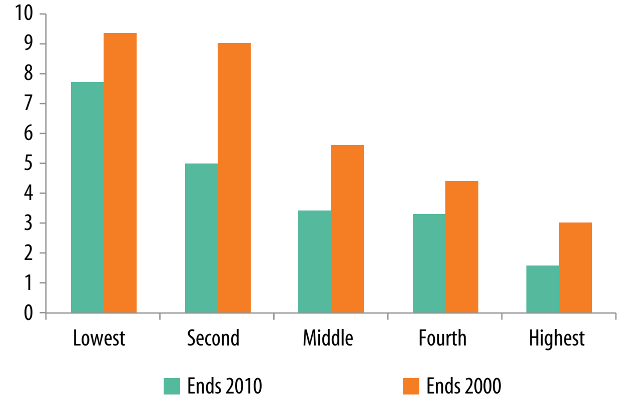
second-lowest income group (about 4% fewer children under age five were malnourished in Colombia by 2009).

Measuring the burden of disease and subsequent economic costs from environmental health risks is important in helping policy makers to better integrate environmental health into economic development, and specifically in their decisions related to resource allocation among various programs and activities to improve child health. Building on previous estimates, and due to the linkages among environmental health, malnutrition and disease, WHO recently revised the burden-of-disease estimates, taking into account malnutrition-mediated health impacts associated with inadequate water and sanitation provisions and improper hygiene practices (Fewtrell, Prüss-Üstün et al. 2007).

The new WHO estimates reveal that the environmental health burden in children under age five is substantially higher when all linkages through malnutrition, especially in those subregions where malnutrition and poor environmental conditions coexist, are incorporated. In a study of the linkage between the global disease burden and the environment (Prüss-Üstün and Corvalán 2006), it was estimated that 50% of malnutrition is attributable to the environment, essentially to water, sanitation and hygiene (pooled expert opinion based on literature review).

Blössner and de Onis (2005) presented a methodology to quantify the burden of disease associated with malnutrition. To quantify the impact of malnutrition, it is necessary to factor in population data of weight-for-age (WA) in children and the disease burden (deaths, incidence and DALYs) of infectious diseases and protein-energy malnutrition (PEM). For Bolivia, such information may be obtained from DHS 2008 and WHO deaths, incidence and DALY tables from Global Burden of Disease (GBD) 2008.

Figure 8 Malnutrition Status (percent) by Income Groups in Colombia



Sources: ENDS 2000, ENDS 2010.

The basic method applied to estimate the consequences of malnutrition in terms of health impact from infectious diseases in children under age five consists of the following steps (Blössner and de Onis 2005; Fishman et al. 2004):

- Estimation of the number of children with a WA below −1 standard deviations (SD) of the mean;
- Estimation of fractions of mortality due to diarrheal disease, malaria, measles, lower respiratory infections, other infectious diseases (besides HIV) and PEM that are attributable to malnutrition, based on relative risks from the literature;
- Calculation of the disease burden attributable to malnutrition by multiplying mortality, incidence and DALY statistics with attributable fractions.

Fishman et al. (2004) present estimates of increased risk of cause-specific mortality and all-cause mortality in children under age five with mild, moderate and severe underweight from a review of available studies. Severely underweight children (WA <−3 SD) are 5 times more likely to die from measles, 8 times more likely to die from acute lower respiratory infections (ALRI), nearly 10 times more likely to die from malaria, and 12 times more likely to die from diarrhea than non-underweight children (WA >–1 SD). Even mild underweight doubles the risk of death from major diseases in early childhood (see Table 16).

Child underweight also increases the risk of illness. Fishman et al. (2004) present estimates of increased risk in children under age five with moderate and severe underweight (WA <–2 SD). The largest increased risk of illness is for pneumonia/ALRI. No increased risk of measles is confirmed (see Table 16 and Table 17).

The WA prevalence rates and the relative risks of cause-specific mortality can be used to estimate the population-attributable fractions (AF) of mortality from underweight in children under age five:

$$AF = \left(\sum_{i-1}^{n} P_i RR_i - 1\right) / \sum_{i-1}^{n} P_i RR_i \qquad (1)$$

where RR_i is the relative risk of mortality for each of the four WA categories (i) in Table 5; and P is the percentage of children in each of the four categories (i).

In addition to these malnutrition-related mortalities, Fishman et al. (2004) include 100% of PEM mortality and a share of mortality from perinatal conditions (low birth weight associated with low maternal pre-pregnancy body mass index [BMI <20 kg/m^2]). About 9% of infants had low birth weight (<2,500 g) in Colombia in 2008.[10]

ENDS 2010 data, needed to estimate the prevalence of child underweight in Colombia using the NCHS reference population, were not available at the time this report was being prepared. Applying the assumption (Blossner, Ortiz 2005) about normal distribution of malnourished children under age five, mild underweight children under age five were estimated for Colombia.

Table 16 Relative Risk of Mortality from Mild, Moderate and Severely Underweight in Children Under Age Five

Weight-for-age (WA)	<–3 SD	–2 to –3 SD	–1 to –2 SD	>–1 SD
Pneumonia/ALRI	8.1	4.0	2.0	1.0
Diarrhea	12.5	5.4	2.3	1.0
Measles	5.2	3.0	1.7	1.0
Malaria	9.5	4.5	2.1	1.0
All-cause	8.7	4.2	2.1	1.0

Source: Fishman et al. (2004).

Table 17 Relative Risk of Illness from Moderate and Severe Underweight in Children under Age Five

Weight-for-age (WA)	<–2 SD	>–2 SD
Pneumonia/ALRI	1.86	1.0
Diarrhea	1.23	1.0
Measles	1.00	1.0
Malaria	1.31	1.0

Source: Fishman et al. (2004).

Table 18 Attributable Fractions of Under-Five Child Mortality and Morbidity from Underweight

	Mortality	Morbidity
Pneumonia/ALRI	5.7%	0.3%
Diarrhea	7.4%	0.9%
Malaria	6.3%	0.3%
Measles	N/A	N/A
Protein-energy malnutrition (PEM)	100%	100%
Other causes	6.0%	N/A

Source: Estimated in this report.

[10] Source: ENDS 2010.

The application of the relative risks of illness and WA malnutrition rates to (1) indicates that about 6% of pneumonia/ALRI mortality and 7% of diarrhea mortality in children under age five in Colombia are from malnutrition (Table 18).

Table 19 presents the deaths among children under age five that could be associated with malnutrition. Since mortality and incidence from diarrheal and lower respiratory diseases in children were already counted as an impact of inadequate WASH and of indoor air pollution, only other diseases were included in the costs of malnutrition. Morbidity was not included because no data were available on the prevalence of other diseases.

4.4 *Cost of inadequate WASH in Colombia*

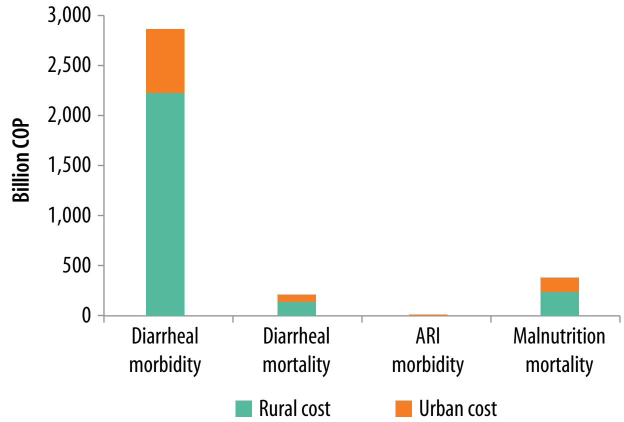
The estimated annual cost of health impacts from urban air pollution is presented in Table 20 and Figure 9.The cost of mortality among children under age five is based on using the human capital (HC) approach (discounted lifetime income of the average person in Colombia). Annual mortality cases associated with inadequate WASH (Table 14 and Table 19) are multiplied by an average value of mortality case using the HC approach.[11] Morbidity is valued using the cost of illness (COI) approach

Table 19 Estimated Deaths among Children under Age Five that could be Associated with Malnutrition in Colombia, 2009

	Number of malnutrition-related deaths
Post-neonatal deaths	59
Measles	3
Protein-energy malnutrition (PEM)	400
Other causes	560
Total	1022

Source: Authors' estimates.

Figure 9 Estimated Annual Cost of Health Impacts Associated with Inadequate WASH



Source: Authors' estimates.

Table 20 Estimated Annual Cost of Health Impacts (Billion Pesos)

Health categories	Urban annual cost (billion pesos)	Rural annual cost (billion pesos)
Mortality:		
Children under age 5: diarrheal mortality	140	70
Children under five: malnutrition-related mortality	232	148
Morbidity:		
Diarrheal illness	2,214	629
ARI illness[a]	10	2
TOTAL COST (mortality and morbidity)	2,596	849

Source: Estimates by the authors.
* Annual cost is rounded to nearest billion.
[a] Malnourishment-related illness.

[11] 351 million COP

(Annex 1). The WTP proxy applied is based on the ratio of cost of illness to willingness to pay reported for Bogotá (PDDB 2010). The cost per case (comprising cost of illness plus the proxy for WTP) is the basis for the estimation of the COI for diarrhea (Annex 1) by multiplying each cost for the cases in Table 14.

Table 21 details the baseline data that were used for the estimation of the cost of illness and the costs of time lost to illness. For purposes of comparability with previous estimates (see Annex 3), this analysis kept most of the assumptions regarding duration of illness, rate and length of hospitalization, average time lost per health end-point, frequency of doctor visits, and discount rate. It also valued time lost to illness at 75% of the average urban wage, and applied this cost both to working and nonworking individuals, based on the assumption of an equivalent opportunity cost for both categories.

Table 21 Baseline Data for Cost Estimation

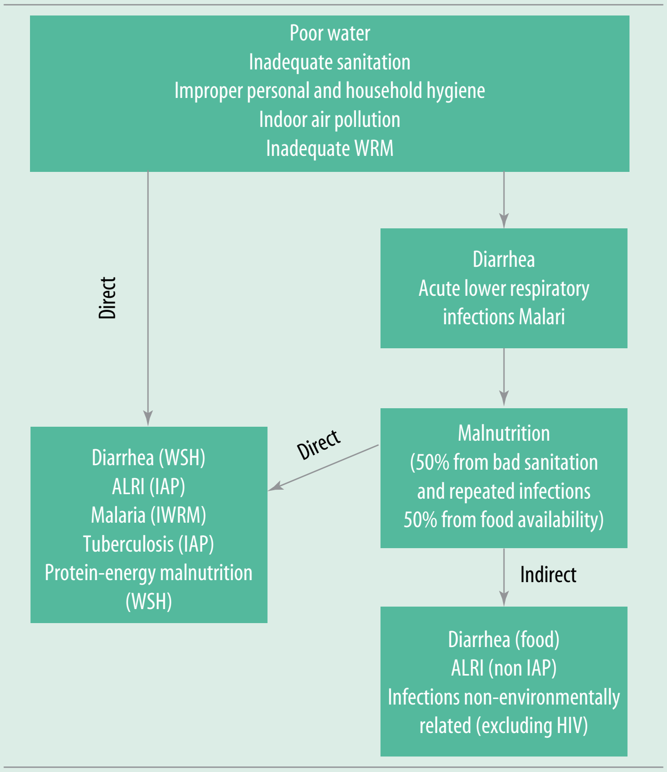
	Baseline	Source:
Percent of diarrheal cases treated at medical facilities (children < age 5) and with medicines	37–46%	ENDS 2010.
Percent of diarrheal cases treated with ORS (children < age 5)	68–77%	ENDS 2010.
Percent of diarrheal cases treated at medical facilities (population > age 5) and with medicines	30–35%	Estimated from a combination of INS data and ENDS 2010.
Average cost of doctor visits (urban and rural): pesos	29,000	Per consultations with pharmacies, medical service providers, and health authorities.
Average cost of medicines for treatment of diarrhea: pesos	3,600–12,600	
Average cost of ORS per diarrheal case in children: pesos	1,200	
Average duration of diarrheal illness in days (children and adults)	3–4	Assumption.
Hours per day of caregiving per case of diarrhea in children	2	Assumption.
Hours per day lost to illness per case of diarrhea in adults	2	Assumption.
Value of time for adults (caregiving and ill adults): pesos/hour	1,500–3,600	Based on urban and rural wages in Colombia.
Hospitalization rate (% of all diarrheal cases): children under age 5	0.75%	Adjusted based on evidence from Egypt (Larsen 2004). No data available for Colombia.
Hospitalization rate (% of all diarrheal cases): children under age 5	0.50%	
Average length of hospitalization (days)	2	Adjusted from Egypt (Larsen 2004).
Time spent on visitation (hours per day)	4	Assumption.
Average cost of hospitalization (pesos per day)	180,000	Per consultations with hospitals.
Percent of diarrheal cases and hospitalizations attributable to water, sanitation and hygiene	88%	Prüss-Ustün et al. 2004.

Source: Authors.

Box 2 The Association between Inadequate Water Supply, Sanitation and Hygiene and Prevalence of Malnutrition

Malnutrition in children under five years of age makes infections worse and often more frequent. Substantial research confirms that early childhood repeated infections, including diarrhea, may account for at least one third of weight gain retardation in children under five years of age, thus contributing as much as half of disease burden from malnutrition. WHO study (Fewtrell et al. 2007) reports that malnourished children have a risk of dying from various diseases that is several times higher than non-malnourished children. Then the disease burden from inadequate water supply, sanitation and hygiene (WASH) as much as doubles compared to only considering the direct effect of inadequate WASH on diarrhea. The methodology proposed by WHO incorporates not only direct health risks from environmental factors (such as diarrheal disease burden from poor water and sanitation), but also seeks to include the indirect risks (concentrating on WASH and its indirect impact on mortality through malnutrition). Thus, while a traditional burden of disease calculation would associate WASH with only diarrheal diseases (see figure below), the inclusion of the indirect path implies the need to include all diseases attributable to malnutrition (as 50% of the consequences of malnutrition are, in turn, attributed to poor WASH).

The Health Effects of Environmental Risks Factors



Source: World Bank (2008) Environmental Health and Child Survival. Epidemiology, Economics. Experiences. Washington DC.; Fewtrell, L., A. Prüss-Üstün, R. Bos, F. Gore and J. Bartram. 2007. Water, Sanitation and Hygiene- Quantifying the health impact at national and local levels in countries with incomplete water supply and sanitation coverage. Environmental Burden of Disease series, No. 15. Geneva, World Health Organization.

5. Indoor Air Pollution from the Use of Solid Fuels—Detailed Technical Findings

5.1 *Indoor smoke and health*

Household air pollution from use of solid fuels for cooking and other purposes is associated with substantial health effects, particularly among young children and adult women, because these groups tend to spend the most time in the household environment. Combustion of solid fuels generates fine particulates (smoke) and other pollutants harmful to human health. Combustion of biomass (straw/shrubs/grass, agricultural crop residues, and animal dung) tends to generate the most smoke, followed by wood and coal/charcoal. Fossil fuels (e.g., liquid petroleum gas [LPG], biogas, kerosene) are the cleanest and generate the least smoke.

About 50% of rural households in Colombia use wood/charcoal and other solid fuels (e.g., agricultural residues, straw), according to ENDS 2010. The rate was about 60% in 2000 (ENDS 2000). Only about 2% of urban households use these fuels (Table 22).

Combustion of solid fuels for cooking is a major source of household air pollution in developing countries. Combustion of these fuels is associated with an increased risk of several health outcomes. The risks are generally reported relative to the risks of health effects from the use of liquid fuels (e.g., LPG). The evidence from studies around the world is summarized in meta-analyses by Desai et al. (2004), Smith et al. (2004), Dherani et al. (2008), Kurmi et al. (2010), and Po et al. (2011) and include elevated risks of acute lower respiratory infections (ALRI) in children under age five, and chronic obstructive pulmonary disease (COPD), chronic bronchitis (CB), lung cancer, and tuberculosis in adult women.[12] Ezzati and Kammen (2001, 2002) also document elevated risks of ALRI in adult women and acute upper respiratory infections (AURI) in children and adult women. Studies of the health effects of outdoor ambient particulate matter (PM) have found that exposure to PM increases the risk of cardiovascular mortality (Pope et al. 2002). A recent study in Guatemala found that cooking with wood on open fires, compared to cooking with wood and using an improved chimney stove, is associated with higher systolic blood pressure among adult women (McCracken et al. 2007). Elevated systolic blood pressure is associated with an increased risk of cardiovascular disease and mortality (Lawes et al. 2004).

Table 22 Household Fuels Used for Cooking in Colombia, 2010 (percent)

	Urban	Rural
Electricity	4.5	2.7
LPG, natural gas	90.9	45
Kerosene	0.2	0.2
Coal, lignite	0.1	0.9
Firewood, straw	1.9	49.3
No cooking in household	2.5	1.7

Source: ENDS 2010.

In light of the evidence from these studies, the relative risks of health effects from the use of wood and other biomass fuels for cooking applied in this study to Colombia are presented in Table 23. These relative risks are applied to children under age five and to adult women in households using these fuels, because these are the household members who are most exposed to air pollution from cooking. Only acute respiratory infections and COPD were considered as health impacts of indoor air pollution in Larsen (2002).

[12] CB is a subset of COPD.

Table 23 Relative Risks of Health Effects from Cooking with Wood and other Biomass Fuels Applied to Colombia

Population group	Health outcome	Relative risk ratios (RR)
Children < age 5	Acute respiratory infection (ALRI)	2.0
Women ≥ age 30	Chronic obstructive pulmonary disease (COPD)	2.8
	Chronic bronchitis (CB)	2.4
	Ischemic heart disease	1.19
	Cerebrovascular disease	1.26
	Hypertensive heart disease	1.51
	Other cardiovascular disease	1.12
	Lung cancer (LC)	1.5

Source: Based on Desai et al. (2004), Smith et al. (2004), Dherani et al. (2008), Kurmi et al. (2010), Po et al. (2011), and estimates of cardiovascular disease risks based on McCracken et al. (2007) and Lawes et al. (2004) as presented in Larson (2012).

To calculate the fraction of health outcomes associated with the use of wood and other biomass for cooking, the following attributable fraction formula is applied:

$$AF = \left(\sum_{i-1}^{n} P_i RR_i - 1\right) / \sum_{i-1}^{n} P_i RR_i \qquad (7.1)$$

Pi=1 and Pi=2 is the share of the population cooking with wood or other biomass and with other types of fuels, respectively; and RR is the relative risk of morbidity and mortality from indoor cooking with wood and biomass. The attributable fractions are then multiplied by the estimated annual baseline mortality in Colombia for each health outcome in order to arrive at annual premature mortality associated with the use of wood and biomass.

5.2 *Baseline mortality and morbidity*

Baseline mortality is estimated from DANE 2010, which presents estimates of cause-specific mortality in Colombia by age group. ARI mortality and morbidity in children under age five is presented in Table 24 below.

Table 24 ARI Illness in Colombia among Children Under Age Five in 2000–2009

<table>
<tr><th></th><th>Urban</th><th>Rural</th><th>Total</th></tr>
<tr><td>ARI mortality, 2000 (%)</td><td colspan="3">7.5%</td></tr>
<tr><td>ARI mortality, 2009 (%)</td><td colspan="3">7–12%</td></tr>
<tr><td>ARI morbidity, 2000 (prevalence last 2 weeks)</td><td></td><td></td><td>12.3%</td></tr>
<tr><td>ARI morbidity, 2009 (prevalence last 2 weeks)</td><td>6.1%</td><td>5.7%</td><td>6.0%</td></tr>
<tr><td colspan="4">By household wealth index</td></tr>
<tr><td>Lowest</td><td></td><td></td><td>6.5%</td></tr>
<tr><td>Second</td><td></td><td></td><td>6.9%</td></tr>
<tr><td>Middle</td><td></td><td></td><td>6.7%</td></tr>
<tr><td>Fourth</td><td></td><td></td><td>4.7%</td></tr>
<tr><td>Highest</td><td></td><td></td><td>3.8%</td></tr>
</table>

Sources: ENDS 2000, ENDS 2010.

ARI prevalence among children under age five decreased by more than 50% in the last 10 years. ARI mortality is at about the same level; the difference may be explained by reporting errors and the uncertainty of WHO estimates of deaths by cause among children under age five.

5.3 *Mortality and morbidity attributable to indoor household solid fuel use*

An estimated 950 to 1,050 children and women died prematurely from the use of wood and other biomass fuels for cooking in Colombia in 2009 (see Table 25). About 200 of these deaths were among children under age five and 800 were among adult women. The deaths represent 11,600 years of life lost (YLL) per year, of which about 60% are among children under age five.[13] Morbidity from the use of wood and other biomass fuels can be estimated in the same manner as for mortality by multiplying the attributable fractions from equation (1) with baseline cases of morbidity. Baseline cases of ARI in Colombia are estimated from ENDS in the same manner as for diarrheal prevalence. The baseline prevalence of COPD is estimated from Caballero et al. (2008) and Shibuya et al. (2001).

Estimated annual cases of ARI and CB from the use of wood and other biomass fuels are about 3 million in 2009, representing a loss of about 6,400 DALYs (see Table 25).[14]

Annual cases of mortality attributed to indoor air pollution are presented in Figure 10.

5.4 *Health cost of indoor household solid-fuel use*

The estimated annual cost of health impacts attributed to indoor air pollution in rural areas is presented in Table 27. The cost of mortality is based on the Value of a Statistical Life (VSL) for adult women and the HC approach for children under age five.

Table 25 Estimated Annual Mortality from Household Use of Wood and Biomass for Cooking in Colombia, 2009

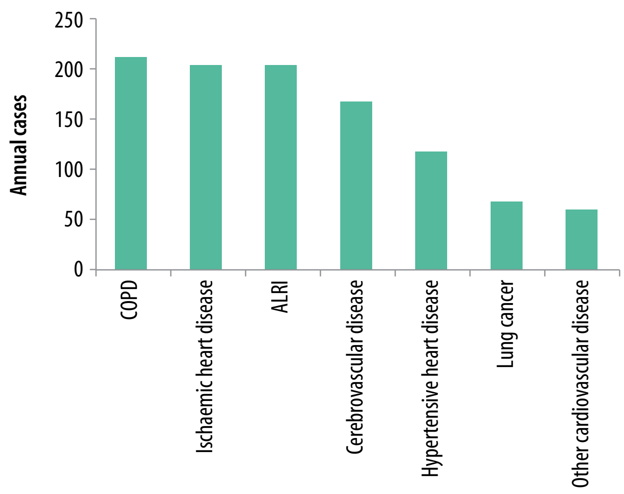
Health outcome	Population group	Annual baseline mortality	Attributable fraction from use of solid fuels	Annual mortality from use of solid fuels	DALYs (YLL) from use of solid fuels
ALRI	children u-5	603	33%	201	6,837
COPD	females 30+	442	47%	209	1,255
Ischemic heart disease	females 30+	2,320	9%	201	1,208
Cerebrovascular disease	females 30+	1,427	12%	164	985
Hypertensive heart disease	females 30+	556	20%	113	678
Other cardiovascular disease	females 30+	950	6%	54	323
Lung cancer	females 30+	310	20%	62	350
Total		6,608	n/a	1,004	11,635

Source: Authors' estimates.

13 Years of life lost (YLL) are estimated according to WHO's calculation of DALYs using age weighting and a three-percent discount rate.
14 Cases of cardiovascular disease and lung cancer are not estimated due to data constraints. DALYs are estimated according to WHO's calculation of DALYs.

The estimated cost per case of premature mortality or specific health end-point is presented in Table 10. Adult mortality is valued with the VSL approach. The VSL used in this assessment is that utilized by the government in Bogotá for the Bogotá Ten-Year Decontamination Plan (*Plan Decenal de Descontaminación de Bogotá,* 2010). In that report, the value of statistical life was derived from: (i) Arigoni et al. (2009) in São Paulo, (ii) Hammit and Ibarran (2002) in Mexico City, and (iii) Bowland and Beghin (2001) in Santiago de Chile. The PDDB does not specify which value is chosen or, in the case of a combination of the values from the three studies, which relative weight of pooling method was used. However, since the value is not far off from the most recent (and perhaps

Figure 10 Annual Cases of Mortality Attributed to Indoor Air Pollution in Colombia



Source: Authors' estimates.

Table 26 Estimated Annual Cases of Morbidity from Household Use of Wood and Biomass for Cooking in Colombia, 2009

Health outcomes	Population group	Annual baseline cases	Attributable fraction from use of solid fuels	Annual cases from use of solid fuels	DALYs from use of solid fuels
ARI	children u-5	1,825,000	33%	608,300	1,004
ARI	females 30+	1,148,000	33%	382,698	2,679
COPD	females 30+	2,500	47%	1,184	2,664
Total		2,975,500	n/a	992,182	6,347

Source: Authors' estimates.

Table 27 Estimated Annual Cost of Health Impacts (Billion Pesos)

Health categories	Total Annual Cost (billion pesos)	Percent of total cost*
Mortality:		
Children under age 5	73	6%
Adult females over age 30	882	78%
Morbidity:		
COI	46	4%
WTP to avoid illness	128	11%
TOTAL COST (mortality and morbidity)	1129	100%

Source: Authors' estimates.
*Annual cost is rounded to nearest billion, and percentages are rounded to nearest percent.

most relevant) reference (Arigoni et al. 2009; see Annex 1), we found it most appropriate to use a locally generated value for VSL. The mortality of children under age five is valued using the human capital approach (discounted lifetime income of the average person in Colombia). Morbidity is estimated using the COI approach (Annex 1). Likewise, the WTP proxy applied is based on the ratio of cost of illness to willingness to pay reported for Bogotá (PDDB 2010). The cost per case (comprising cost of illness plus the proxy for WTP) is the basis for the estimation of the annual costs in Table 27 by multiplying each cost for the cases in Table 26.

Table 29 details the baseline data that were used for the estimation of the cost of illness and the costs of time lost to illness. For purposes of comparability with previous estimates (see Annex 3), we kept most of the assumptions regarding duration of illness, rate and length of hospitalization, average time lost per health end-point, frequency of doctor visits, and discount rate. We also valued time lost to illness at 75% of the average urban wage, and applied this cost both to working and nonworking individuals, based on the assumption of an equivalent opportunity cost for both categories.

The mean estimated annual cost of health impacts from indoor air pollution associated with the use of traditional fuels (mainly fuelwood) in rural areas of Colombia is 1.129 trillion COP (0.22% of GDP in 2009). Child mortality represents 6% of cost; female mortality represents about 78% of cost. Acute respiratory illness (ARI) in children and adult females and COPD morbidity of adult females represent 16% of the cost.

Table 28 Estimated Unit Cost by Health End-Point

Health categories	Total cost per case (000 pesos)	Cost-of-Illness per case (000 pesos)[a]	WTP proxy[b] (000 pesos)
Mortality: women over age 30	1,100,000	N/A	N/A
Mortality: children under age 5	351,000	351,000	N/A
COPD	8,060	2,500	5,560
ARI: children under age 5	300	90	210
ARI: women over age 30	420	130	290

Source: Authors' estimates.
[a] Per treated case.
[b] Per all cases attributed to indoor air pollution.

Table 29 Baseline Data for Cost Estimation in Rural Colombia

	Baseline	Source
Acute Respiratory Illness (ARI):		
Percent of ARI cases treated at medical facilities (children < age 5)	44.5%	ENDS 2010 (rural children).
Percent of ARI cases treated at medical facilities (adults > age 15)	35–40%	Estimated from a combination of INS data and DHS 2000.
Average cost of doctor visits in rural areas (mainly primary healthcare centers): pesos	29,000	Per consultations with pharmacies, medical service providers, and health authorities.
Cost of medicines for treatment of ARI: pesos	4,000–24,000	
Percent of ARI cases treated with medicines	44.5%	ENDS 2010.
Value of time for adults (caregiving and ill adults): pesos/hour	1,500	Based on rural wages in Colombia.
Chronic Obstructive Pulmonary Disease (COPD):		
Average duration of Illness (years)	20	Based on Shibuya et al. (2001).
Percent of COPD patients hospitalized per year	1.5%	From Schulman et al. (2001) and Niederman et al. (1999).
Average length of hospitalization (days)	10	
Average number of doctor visits per COPD patient per year	1	
Percent of COPD patients with an emergency doctor/hospital outpatient visit per year	15%	
Estimated lost workdays (including household workdays) per year per COPD patient	2.6	Estimated based on frequency of doctor visits, emergency visits, and hospitalizations.
Cost of hospitalization (pesos per day)	213,000	Per consultations with medical service providers and health authorities.
Cost of emergency visit (pesos): rural	72,000	
Cost of doctor visit (pesos) (mainly primary health clinic): rural	29,000	
Value of time lost to illness (pesos per day)	12,000	Based on rural wages in Colombia.
Annual real increases in economic cost of health services and value of time	2%	Estimate.
Annual discount rate	3%	Applied by WHO for health effects.

Source: Authors.

6. Conclusions and Policy Recommendations

The 2005 Colombia Country Environmental Analysis, Environmental Priorities and Poverty Reduction, concluded that: "The analysis of the cost of environmental degradation conducted shows that the most costly problems associated with environmental degradation are urban and indoor air pollution; inadequate water supply, sanitation, and hygiene; natural disasters and land degradation." Colombia has made substantial progress in the last years in reducing the population exposure to urban air pollution, inadequate water and sanitation, and indoor air pollution from solid fuel use. However, these forms of environmental degradation continue to have a significant impact on the Colombian society in terms of premature mortality and disease.

The analysis in this report relied on large sets of statistics and data from various ministerial departments, institutions, and institutes in Colombia. It also has drawn heavily from Colombian and international research studies, and benefited from various methodological approaches applied by international organizations such as the World Health Organization. Publicly available, easily traceable information and indicators were used as much as possible, in order to facilitate contrast and upcoming updates. The estimation of the cost of environmental damage included many aspects, both economic and otherwise, although effects considered were only those related to the three mentioned factors (UAP, WASH, IAP). All costs calculated in this report are expressed in monetary terms, and they include the cost to society due to premature mortality, as well as the cost of healthcare provision to individuals suffering from pollution-related illnesses and the value individuals place in avoiding resulting pain and discomfort. Time losses or savings are valued at the opportunity cost of time.

In addition, the results of the health costs analysis are useful to track progress made by policy interventions as well as to further environmental protection and environmental health agendas. Ambitious policy interventions can find adequate justification in the large health and economic cost of environmental degradation in Colombia. The results show that addressing these environmental risks should continue to be a priority in the environmental and public health policy agenda of Colombia. The mean estimated annual cost of health impacts from indoor air pollution associated with the use of traditional fuels (mainly fuelwood) in rural areas of Colombia is 1.129 trillion COP (0.22% of GDP in 2009). Child mortality represents 6% of cost; female mortality represents about 78% of cost. Acute respiratory illness (ARI) in children and adult females and COPD morbidity of adult females represent 16% of the cost.

Both the health impact assessment and the economic valuation can be utilized by policy makers and stakeholders in the process of setting environmental objectives and priorities. The World Bank and other donors could also use the results to establish support priorities. The report may be useful for the Colombian Ministry of Finance and the National Planning Department because preferences and values are expressed in monetary terms, thus the results can provide additional guidance for the allocation of resources across diverse socio-economic development goals.

At the request of the Government of Colombia, the methodology used in this study as well as other approaches to environmental valuation and case studies from the region were presented to a group of technical experts and decision-makers at the "Andean Workshop on the Costs of Environmental Degradation" in November 2012, and intended to transfer the methodology to the local experts and government agencies, to enable them to carry out similar periodic assessments.

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Annex 1. Economic Basis for Choice of VSL and WTP

The evidence base for willingness to pay (WTP) to avert mortality and morbidity risks from air pollution in Colombia is still scarce. However, there are some important studies that derive estimates from other examples in the Latin American context. One such study was conducted as a technical background for the Bogotá Ten-year Decontamination Plan (*Plan Decenal de Descontaminación de Bogotá,* 2010). In this report, the value of statistical life from was derived from: (i) Arigoni et al. (2009) in São Paulo, (ii) Hammit and Ibarran (2002) in Mexico City, and (iii) Bowland and Beghin (2001) in Santiago de Chile. The PDDB does not specify which value is chosen or, in the case of a combination of the values from the three studies, which relative weight of pooling method was used. For the cost of illness, the following assumptions were made by analysts in the PDDB evaluation:

- 90% of all urgent cases that are treated at a healthcare facility are in Acute Respiratory Illness (ARI) rooms.
- Average duration of the hospitalization for respiratory causes is 5 days. Average disability duration for respiratory causes is 10 days. For cardiovascular disease (CVD) causes, the values are 5.5 days and 11 days, respectively (AHA 2008).
- One emergency room (ER) visit entails 1 lost workday and 3 additional days of average disability duration.
- One visit to an ARI room entails 0.5 lost workday and 1.5 total average disability duration.
- Average duration of Intensive Care Unit (ICU) hospitalization is 8 days, with an average total duration of disability of 24 days.
- Symptoms from a respiratory disease entail an average total duration of disability of 3 days.

The resulting unit costs by health end-point from the PDDB are listed below:

The most recent reference used by the PDDB report is a study by Ortiz et al. (2009), which was considered for this analysis and later discarded in the presence of a locally generated VSL. This study aims to estimate the population's willingness to pay (WTP) to reduce risks of death associated with "typical" air pollution policies and consequently the value of a statistical life (VSL) in São

Table A.1 Economic Variables: "Plan Decenal de Descontaminación de Bogotá" (Thousands of Colombian Pesos, 2009)

Item	Cost of medical care	Lost productivity	Cost of illness (COI)	Willingness to pay (WTP)
VSL	N/A	N/A	N/A	1,008,000
Hosp. adm.: respiratory causes	1,290	470	1,760	4,000
Hosp. adm.: CVD causes	1,370	520	1,980	4,600
ER care: respiratory causes	310	130	440	670
Care in ARI rooms	50	60	110	N/A
Care in ICUs	6,600	1,000	7,600	N/A
Respiratory symptoms (< age 5)		95	95	400

Source: Plan Decenal de Descontaminación de Bogotá (2010).

Paulo, Brazil. Uniquely for that country, the study uses a methodology that has previously been tested in several industrialized countries (US, Japan, Canada, South Korea, England, France and Italy) and involves a computer-based contingent valuation survey. This survey instrument was adapted to the Brazilian context and was used to elicit willingness to pay measures of reductions in risk of death in Brazil.

Key features of the survey instrument involve eliciting the health status of the respondents and their families; explaining basic concepts of probability and proposing simple practice questions to familiarize the respondents with the probability concepts introduced; presenting the leading causes of death for a Brazilian individual of the respondent's age and gender, and setting these in the context of common risk-mitigating behaviors; and asking about the individual's willingness to pay for risk reductions of a given magnitude that occur at a specified time.

The mean and median willingness to pay values were estimated using the interval data model that can be generated from the dichotomous choice with a follow-up question format. The responses to willingness to pay and follow-up questions were combined to generate intervals in which the unobservable respondents' willingness to pay is to be found. The Weibull probability distribution was selected for the random variable of willingness to pay. The statistical willingness to pay model using the Weibull distribution is estimated using the maximum likelihood method. The corresponding values of a statistical life were estimated using both median willingness to pay estimates (conservative estimates) and mean willingness to pay values. They were obtained by dividing the willingness to pay figures by the corresponding annual risk reduction being valued. It was assumed that respondents implicitly considered the risk reduction evenly over the ten-year period, which makes it possible to avoid discounting the respondents' annual payments.

The values of a statistical life estimated from 1-in-1,000 risk reductions are much higher than those estimated using the 5-in-1,000 risk reduction. This is purely due to the lack of proportionality between the willingness to pay estimates regarding the differences in the size of risk reductions. It is suggested that the VSL estimates derived from mean and median willingness to pay estimates for a 5-in-1,000-risk reduction are of greater policy relevance since they represent more conservative estimates than those estimated using willingness to pay estimates for 1-in-1,000-risk reduction. Thus, for policy assessments in São Paulo conservative values of a statistical life ranging between 0.77–1.31 million USD (VSL estimate based on median and mean 5-in-1,000 risk reduction correspondingly) are suggested. An upper value of 1.3 million USD was adopted as a higher bound to apply benefit transfer to Colombia.

When compared with European and North American estimates, these values seem to be higher than expected. Given the close link between willingness to pay estimates and the population's income, lower willingness to pay values for developing countries might be expected. A possible reason for the high WTP and VSL estimates found in the current study might have been the "cooperative" behavior observed in many of the respondents. It is possible that those respondents tried to be "cooperative" or helpful by saying "yes" to every question. It was believed that the relatively high figures in this valuation exercise may be partly due to this bias. The value of a statistical life excluding possible "yeah-say" responses using parametric estimation of mean and median annual willingness to pay in 2003 (Weibull distribution, 95% CI) is 0.4 to 0.5 million USD (VSL estimate based on median and mean 5-in-1,000 risk reduction correspondingly) and in 2009 0.45 to 0.56 million USD.[15] A lower value of 0.4 million USD (VSL based on median 5-in-1,000 risk reduction, excluding "yes-"saying respondents) was adopted as a lower bound to apply benefit transfer to Colombia.

Applying a similar analysis, in the *"Plan Decenal de Descontaminación de Bogotá"* (PDDB 2009) a VSL at the level of 0.47 million USD was applied. Thus, the midpoint of all estimates described above is 1.09 billion COP or 0.5 million USD. The latter estimate was applied in the report (Table A.1).

Table A.2 Application of Benefit Transfer Approach to Estimate VSL for the Population Dying from Pollution in Colombia

Value of Statistical Life (VSL)		Median 5-in-1,000 risk reduction, excluding "yes" saying respondents	Mean 5-in-1,000 risk reduction, excluding "yes" saying respondents	Median 5-in-1,000 risk reduction	Mean 5-in-1,000 risk reduction	*Plan de Descontaminación de Bogotá*, 2009	Midpoint estimate
VSL estimates from Brazil (USD million)	Ortiz et al. 2009	0.45	0.56	0.77	1.46		
Colombia GDP (USD billion), 2009	WDI 2012	235	235	235	235		
Colombia GDP (COP billion), 2009	WDI 2012	5.09E+05	5.09E+05	5.09E+05	5.09E+05		
Population (million) in 2009	WDI 2012	45.65	45.65	45.65	45.65		
GDP per capita (USD) in 2009		5,166	5,166	5,166	5,166		
Exchange rate (year average 2003)		2,156	2,156	2,156	2,156.3		
VSL in Colombia million USD		0.28	0.35	0.54	0.91	0.47	0.51
VSL in Colombia billion COP		0.61	0.76	1.16	1.97	1.008*	1.1

**Source*: Plan Decenal de Descontaminación de Bogotá (PDDB 2009).
Note: GDP per capita (current USD): Brazil 8,251, Colombia 5,166 (Source: WDI 2012).

[15] Adjusted using CPI presented by US Department of Labor, Bureau of Labor Statistics (2012).ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt.

Annex 2. Air Quality Monitoring Data and Pollution Concentration Extrapolation in Medium-Large Municipalities in Colombia

A large number of Colombians potentially exposed to air pollution live in cities that lack systematic measurements of air pollutant concentrations. The question for the analyst estimating the health impacts of air pollution is whether to drop those cities from the analysis or to extrapolate measurements from cities that do have monitoring networks. For a fair extrapolation, cities with and without measurements should otherwise be largely comparable. A complete analysis of this comparability is beyond the scope of this report, but some basic variables can shed light on the uncertainties involved. In this and other CEA-related work, the size and proportion of the urban population of municipalities are used as proxies for exposure to significant concentrations of inhalable particles. The minimum cutoff point of 100,000 inhabitants is explicitly set as a proxy for exposure to significant concentrations of particulate matter (PM) in outdoor air. Therefore, it is expected that the municipalities with monitoring networks are by definition larger than those without such networks. Moreover, the force behind the establishment of air-quality monitoring networks (in Colombia and elsewhere) is precisely the presence of air-quality problems, in turn commonly linked to the size of urban settings. Tables A.3 and A.4 below summarize basic size and urban population parameters for cities with and without monitoring networks in Colombia.

With regard to the “urban” character of both groups of cities, the question remains whether the proportion of the urban population within those unmonitored municipalities is comparable to the proportion in cities where air pollution is monitored. According to Table A.4, the average proportion of the urban population seems to be lower in cities without a monitoring network. With regard to the significance of that difference, the dissimilarly sized, small and non-normally distributed samples preclude the use of a t-statistic contrast, an acceptable alternative being a non-parametric test (e.g., a Mann-Whitney U test [16] featured below):

- U1 = 561,0
- U1 = n1n2 + 0.5(n1) (n1 + 1) – R1
- U2 = 267,0
- U2 = n1n2 + 0.5(n2) (n2 + 1) – R2

Level of significance 5%; Ucrit = 287. Null hypothesis (no differences between the mean of the two samples) is rejected at the set level of significance.

Table A.3 Size of Cities With and Without Air Pollution Monitoring Network Coverage in Colombia

Type of municipality	Sum population	Avg. municipality population	Max. municipality population	Avg. urban population
With M.N.	17,943,138	780,136	7,259,597	754,120
Without M.N.	8,617,545	239,376	1,179,098	210,914

Source: Authors' estimates.

[16] Where n1, n2 are the sizes of samples 1 and 2, and R1, R2 are the sums of the ranks for samples 1 and 2.

Graph A.1 below represents the samples' respective point estimates of proportion of urban population.

Therefore, we cannot rule out the possibility that the two groups of cities have a different proportion of urban population. Similarly, other health-relevant baseline variables (e.g., population structure, access to health services) might show systematic differences between the two groups. The uncertainty in such an extrapolation, along with the rapidly shrinking size of the population not covered by monitoring networks, are the reasons why we decided to exclude from the analysis the cities for which there were no measurement data as of 2012.

Table A.4 Proportion of Urban Population (Out of Total Population) in Colombian Cities With Over 100,000 Inhabitants

Parameter	% Urban population cities >100,000 with M.N.	% Urban population cities >100,000 without M.N.*
Average	91.12	82.76
Minimum	68.76	39.31
Maximum	99.78	99.86
SD	7.80	15.48
N (S. size)	23	36

Source: Authors' estimates.
*The city of Uribia was considered an outlier and excluded from the analysis.

Graph A.1 Percentage of Urban Population in Cities > 100K Inhabitants in Colombia

Source: Authors' estimates.

Annex 3. Methodological Differences and Similarities, and Comparative Results with Previous Estimates

One objective of this report is to update results from a previous study (Larsen 2004) on the economic cost of environmental degradation in Colombia. As such, and for purposes of comparability, it draws heavily from that study in terms of structure, references and assumptions. In terms of structure, it is identical: the steps toward this update are sequential, starting with the existing evidence on environmental exposures, re-estimating the mortality and morbidity effects attributable to such exposure, and valuing their socioeconomic impacts. Below are the main points of disagreement and, where relevant, continuity.

Mortality: In previous estimates for the effect of urban air pollution (Larsen 2004), and because of the admitted underestimation that registered deaths supposed with regard to the total amount of deaths in DANE statistics, crude mortality rates were estimated for each city, using a regression equation that included urban population share, population share above age 50, external death rate and child mortality rate. However, reporting and statistical methodologies have improved substantially in the last decade; DANE no longer reports an issue with differences between registered and estimated death rates, so data are drawn directly from its departmental databases without further transformation.

Exposed population: For purposes of comparison with previous results (Larsen 2004), it is important to mention once more that we are not taking into account those mortality and morbidity end-points occurring in cities for which there are no data on urban air-pollutant concentration. In Larsen 2004, the population in that category of cities represented 42% of the exposed population and 35% of the total cases considered. Therefore, caution should be exercised when comparing these percentages with previous reported figures. For instance, we cannot conclude that total premature mortality attributable to urban air pollution in 2009 (a total of 5,027 premature deaths/37,703 lost DALYs) represents an improvement over the previous estimate of 2004 (6,040 deaths/45,300 lost DALYs). In fact, when cities without monitoring networks are included in the analysis, assuming an exposure of the average $PM_{2.5}$ and PM_{10} concentrations of cities with measurement data, there is a net increase in the total reported cases and DALYs (see Table A.5). Most of this increase can be explained through the increase in the urban population and consequently of the population exposed.

Human Capital Approach: We are not reporting a cost based on the Human Capital Approach, since we believe that an indicator based on foregone income due to premature mortality severely underestimates the true cost to society that excess mortality represents in a rapidly improving context such as that of urban Colombia. However, if we apply the Human Capital Approach, then mortality related health cost of urban air pollution is estimated at about 420 billion COP. Then total annual health cost associated with urban air pollution is estimated at about 1.6 billion COP. An annual estimate consistent with the estimation in the Larson, 2002 report where for mortality valuation an average between the value estimated at VSL and the Human Capital Approach value would be at about 3.55 billion COP annually, or 0.72% of GDP.

Willingness to pay proxy: Although we also translate different health effects from environmental risks into DALY metrics for purposes of comparability, we

Table A.5 Comparison between 2004 Results for Health Effects of Urban Air Pollution and Current Analysis Including All Cities with Over 100,000 Inhabitants in Colombia

Health categories	2012 Update Including Cities Without M.N. Total cases	2012 Update Including Cities Without M.N. Total DALYs (000)	2004 results Total cases	2004 results Total DALYs (000)
Premature mortality	7,147	53,601	6,040	45,300
Chronic bronchitis	6,604	14,528	7,410	16,300
Hospital admissions	14,806	237	12,970	210
ER/outpatient hospital visits	290,451	1,307	255,000	1,150
Restricted activity days	51,081,865	15,325	42,000,000	12,640
LRI in children	583,864	3,795	585,000	3,800
Respiratory symptoms	162,573,589	12,193	135,000,000	10,100
Total	N/A	100,986	N/A	89,500

Note: ER: Emergency room; LRI: Lower Respiratory Infections.

are discontinuing in this report the approach based on supplementing cost-of-illness (medical costs and costs of time lost to illness) values with a proxy of willingness to pay (WTP) multiplied by GDP per capita to avoid or reduce the risk of illness. There is sound evidence that individuals place a much higher value on avoiding pain and discomfort associated with illness than that reflected solely in medical costs; this has also been observed specifically in connection with air-pollution risks (Alberini and Krupnick 2000, Arigoni et al. 2009). However, using DALYs and per capita GDP as components for a proxy to lost value is too far-fetched a step. Instead, we apply the WTP proxy used in the Bogotá ten-year air-quality management plan (PDDB 2009), which in turn is based on Inter-American Development Bank (IADB) estimates (Cifuentes et al. 2005) and a local study (Lozano 2004) which used benefit transfer to calculate the WTP value. For morbidity outcomes, the WTP/COI ratio is 2.27, which is a figure remarkably similar to the upper estimate reported by Alberini and Krupnick (2000) between 1.61 and 2.26 times, depending on pollution levels. The latter also note that such ratios are similar to those for the United States, despite the differences between countries, which further reinforces the solidity of such a proxy for WTP value. By using this WTP/COI ratio instead of the DALY-GDP proxy, the cost per case is bound to differ substantially in this study compared to the previous 2004 report. One especially drastic contrast is the cost per case of chronic bronchitis. Although we agree on placing a larger cost in a burdensome illness such as CB, we would rather apply consistent WTP values for all air pollution-related outcomes in the absence of specific information for CB.

Baseline data for cost estimation: We kept most of the assumptions regarding duration of illness, rate and length of hospitalization, average time lost per health end-point, frequency of doctor visits and discount rate. We also valued time lost to illness at 75% of the average urban wage, and applied this cost both to working and nonworking individuals, based on the assumption of an equivalent opportunity cost for both categories.

In the context of updating the results from the Larsen (2004) study, the differences between the estimated costs in 2002 and those in 2010 might seem surprising. It is certainly counterintuitive to obtain unit costs of healthcare services that are lower a decade later, currency value shocks excluded. After the passage of the healthcare reform law (Law 100 of 1993), healthcare financing in Colombia relies in essence on a public insurance scheme funded mainly through social security contributions, taxes and subnational transfers. Virtually everyone in Colombia receives health services in one of three possible ways: (i) *Régimen contributivo*, a mandatory healthcare insurance linked to and paid through deductions from salaries of those who are formally employed. Coverage provided is comprehensive; (ii) *Régimen subsidiado*, a less-comprehensive insurance scheme for those whose payment capacity is lower; and (iii) Those without any payment capacity whose healthcare is provided almost exclusively by the network of public hospitals and healthcare facilities, and paid for by departmental governments. As of 2010, the percentage of the population covered by publicly paid health insurance was around 93% (Ministerio de la protección social—MIPS 2011).

Public and private healthcare providers compete in the provision of services, most of which are funded by public entities that act effectively as insurance providers themselves. Private voluntary insurance represents only about 16% of healthcare payment in Colombia, largely concentrated in higher-income groups (Baron 2007). Unsurprisingly, reliable estimates of private healthcare costs are hard to obtain and difficult to contrast. Private healthcare providers, both independent professionals and entities, represent about 60% of healthcare expenditure, with services largely paid for by these public insurance entities at fixed rates (Gideion et al. 2010). Therefore, the publicly listed prices that public insurers pay providers are considered an adequate reflection of the true cost of illness.

Another approach considered was to use Bogotá costs (PDDB) for whole of urban Colombia. However, true costs (i.e., unsubsidized or without controlled pricing) of healthcare delivery in Bogotá are likely larger than in the rest of the country's urban settings. Real urban wages in Bogotá are on average 29% higher than the mean wage of all urban areas of Colombia combined (DANE-GEIH 2011), which suggests a lower value of time lost to illness at a national level. However, whereas the private medical salaries in Bogotá might reflect a similar difference with the rest of urban areas, other inputs to the cost of medical care would not necessarily follow the same patterns. The average cost of hospitalization resulting from the PDDB estimates would be around 258,000 COP per day. We found that the values used in the PDDB were quite close to the upper bound of the public prices (SOAT 2009) of the most common treatment and healthcare usage scenarios for health outcomes attributable to air pollution. The result of applying Larsen's (2004) assumptions to these values is summarized in Table A.6 below:

Cost of chronic bronchitis (CB): There is still little evidence of healthcare usage and costs of patients regarding the cost of a new case of chronic bronchitis. Moreover, estimates of incidence are rare in general. In Colombia, a recent study

Table A.6 Cost of Selected Health Services and Time Lost to Air Pollution-Related Health Outcomes

	2002 values (Larsen 2004)	Update 2012
Cost of hospitalization (pesos per day)	280,000	259,601
Cost of emergency visit (pesos): urban	90,000	71,635
Cost of doctor visit (pesos): urban	40,000	28,654
Value of time lost to illness (pesos per day)	20,000	31,320

Source: Authors' estimates.

(PREPOCOL 2009) estimates the prevalence of clinical COPD at 3.2% in adults over age 40, but we could not find data either on incidence or regarding usage and cost of healthcare by patients. Therefore, we relied on the same information used before—by Schulman et al. (2001) and Niederman et al. (1999)—from the United States and Europe and applied it to Colombia. The estimate of lost workdays per year is based on the frequency of estimated medical treatment plus seven additional days for each hospitalization and one extra day for each doctor and emergency visit. These days are added to reflect the time needed for recovery from illness. The estimated cost of a new case of CB assumes a 20-year duration of illness over which medical costs and value of time experience an annual real increase of 2%, and costs are discounted at a three-percent rate per year, a value commonly applied by WHO for health effects.

Estimates of cost savings due to changes in pollution levels in Bogotá: The average PM_{10} concentration in Bogotá declined from 66 μg/m^3 in 2002 to 59 in 2010 and then further to an average of 48 in 2012. For decision-making purposes, it is important to assess the health benefits that this decline in pollution levels in Bogotá brought about. To assess the benefits, sensitivity analysis is carried out that shows the changes in mortality and morbidity and the associated costs in Bogotá in two cases: a high concentration scenario with the average levels of PM_{10} measured in Bogotá in 2002, and a low concentration scenario with the levels measured in 2012. It is assumed that the ratio of $PM_{2.5}$ to PM_{10}, with the former being the pollutant due to which the health damages occur—is between 40 and 60%, and the midpoint of 50% is used in this calculation. It is estimated that 200 additional mortality cases would have occurred in Bogotá had the pollution level remained unchanged compared with the 2002 level; and 440 fewer mortality cases would have occurred, *ceteris paribus*, with a concentration level on average equal to 48 μg/m^3 (i.e., the level measured in 2012). Thus, the set of policy measures, including the introduction and enforcement of more stringent fuel quality standards in Bogotá and other measures, and which led to the lower measured levels of PM_{10} in Bogotá, resulted in a reduction of mortality cases in Bogotá by 7% in 2010 relative to what they would have been had air quality not improved. A further improvement in air quality in 2012 resulted in a reduction of mortality cases in Bogotá by 16% compared with the baseline scenario. The percentage savings in costs due to a reduction in mortality and morbidity are approximately the same. If one compared the annual health costs and mortality cases avoided in Scenario 2 compared with Scenario 1, one could interpret the findings as follows: there has been a reduction of annual mortality and morbidity costs (and a reduction of mortality cases) by 23% in Bogotá alone. If the costs of the policy interventions and investments were available, it would be possible to carry out cost-benefit analysis of the interventions carried out throughout that period; and other cities and metropolitan areas can also be included in the scenario analysis with some additional data.

Table A.7 Bogotá: Mortality and Morbidity Costs in the Baseline 2010 Case and in High and Low Pollution Scenarios

	2010 baseline case	Scenario 1: High concentration 1/	Scenario 2: Low concentration 2/
Air pollution, PM_{10} (average annual concentration, μg/m^3)	59	66	48
$PM_{2.5}$ (estimated annual average concentration, μg/m^3)	24–36	27–40	20–29
Estimated mortality range due to UAP in Bogotá (number of cases)	2,580–3,000	2,830–3,150	2,060–2,640
Midpoint estimate of mortality due to UAP in Bogotá (number of cases)	2,790	2,990	2,350
Mortality increase (reduction) over baseline (number of cases)		200	(440)
Cost of mortality and morbidity (billion COP) 3/	3,515	3,767	2,961
Increase (reduction) of morbidity and mortality costs over baseline (billion COP)		252	(554)
Increase (reduction) of morbidity and mortality costs over baseline (%)		7%	–16%

Source: Authors' estimates.
Notes:
1/ Scenario 1 uses the average PM_{10} concentration of 66 μg/m^3 observed in Bogotá in 2002.
2/ Scenario 2 uses the average PM_{10} concentration of 48 μg/m^3 observed in Bogotá in 2012.
3/ Morbidity costs are estimated as 26% of mortality costs, based on the estimates in this study.

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