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DEVELOPMENT AND CLIMATE CHANGE

Costs of Adapting to Climate Change for **Human Health** in Developing Countries

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Costs of Adapting to Climate Change for **Human Health** in Developing Countries

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* *Note:* This is one of several papers commissioned by the World Bank as part of the Economics of Adaptation to Climate Change study. The results reported in the paper are preliminary and subject to revision. They have benefited from helpful comments from Armin Fidler, Gordon Hughes, Sergio Margulis, Urvashi Narain, Tamer Rabie, and participants at two workshops in Washington on the EACC study. The analysis, results, and views expressed in the paper are those of the author alone and do not represent the position of the World Bank or any of its member countries. Please direct all correspondence on the paper to the author at kpandey@worldbank.org.

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ABSTRACT

This paper is one component of a global study on the Economics of Adaptation to Climate Change (EACC) in developing countries; the focus in this paper is human health. The main human health impacts of climate change are increased incidence of vector-borne disease (malaria), water-borne disease (diarrhea), cardio-respiratory diseases, heat- and cold-related deaths, injuries and deaths from extreme weather events (flooding), and a greater prevalence of malnutrition. Adaptation measures comprise all actions taken to reduce, prevent, or treat these additional cases of disease or death, including actions outside the health sector such as disaster reduction programs, food and water security measures, and the provision of infrastructure services. For tractability and to reduce duplication with other components of the EACC study, the scope of this paper is limited to conventional public health adaptation activities, with a focus on malaria and diarrhea.

Adaptation costs are computed for these two diseases in each country for each of 16 demographic groups. Costs depend on the baseline incidence of disease without climate change, the additional risk that climate change poses, and the unit cost of preventing and treating additional cases of the disease. Earlier estimates of the global cost of adaptation followed a similar approach but held the baseline incidence of disease (the number of people affected) fixed at current levels. This study incorporates a future baseline burden of disease based on World Health Organization projections through 2030 and extensions through 2050 using the same methods. These projections imply significant reductions in both the incidence and the incidence rates of communicable diseases such as malaria and diarrhea. This study also incorporates updates and revisions to the unit cost of prevention and treatment for malaria and diarrhea and updates to the exposure-response functions used to compute the relative risk for malaria.

Average annual adaptation costs in the health sector for diarrhea and malaria prevention and treatment are around $2 billion over the 40-year period 2010–50. These estimates are lower than prior estimates of $4–12 billion in 2030. The estimated adaptation costs in 2010 lie between $3 billion and $5 billion and decline over time in absolute terms to less than half that amount by 2050. Although the declines are consistent across regions, the rate of decline is faster in South Asia and East Asia and Pacific than in other regions. As a result, by 2050 more than 80 percent of the health sector adaptation costs for malaria and diarrheal diseases are incurred by countries in Sub-Saharan Africa.

Estimating the adaptation costs in the health sector is challenging not only because of the large existing uncertainties about how the climate will evolve over the coming century but also because of the complex and often poorly understood chains through which health impacts are mediated. Climate change is difficult to predict with accuracy in any projection model that has to contend with uncertainty about potential collective actions to mitigate greenhouse gases as well as unknown factors in climate science itself. The health outcomes that are linked to climate change also depend on a host of other factors as well, some of which are likely not currently anticipated, such as the emergence of new diseases, and others that are difficult to predict, such as the development of vaccines to address existing and new ailments. Among the sources of uncertainty that are amenable for quantitative analysis, the baseline health status of a country is the single largest determinant of the likely impacts of climate change and the cost of adapting to it.

INTRODUCTION

This paper is one component of a global study on the cost of adapting to climate change in developing countries over the period from 2010 to 2050; the focus of this paper is human health. The potential impacts of climate change on human health have been documented extensively in the literature. Most of the health outcomes related to climate change already occur today as a result of other risk factors. The need to attribute these health outcomes to different risk factors, including climate change, creates uncertainty about the magnitude of the potential impacts. Adaptation to climate change entails the prevention of the adverse health outcomes (mortality and morbidity) that specifically result from climate change. Adaptation actions that affect health outcomes are often either implemented to address multiple goals (access to water supply and sanitation) or taken outside of the health sector (reduce malnourishment through increased agricultural production). As such, estimates of adaptation cost necessarily depend on the sectoral boundaries that are set, which in this study have been defined in relation to other components of the Economics of Adaptation to Climate Change (EACC) study to avoid duplication.

The report on health from Working Group II in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that climate change has begun to negatively affect human health and that projected changes in climate are likely to increase the risks of climate-sensitive health outcomes (Confalonieri et al. 2007). Specifically, climate change is expected to increase malnutrition and consequent health disorders, including child growth and development; increase injuries, illnesses, and deaths due to heat waves, floods, droughts, storms, and fires; increase cases of diarrheal diseases; increase cardiorespiratory diseases where ozone exposure concentrations rise; increase the number of people at risk of dengue fever; increase the geographic range and length of the transmission season of malaria in some regions and decrease the range in others; and bring some benefits to health, including fewer deaths due to exposure to the cold.

There is a great deal of uncertainty about the magnitude of these potential impacts. Since health records, for the most part, do not indicate climate change as the cause for a particular health outcome, most impact estimates are based on models, acting primarily as a multiplier to existing health risk factors. The potential impacts depend on three factors: the exposure to the climatic-risk factor, the exposure-response function, and the baseline frequency of the health outcome (incidence of disease, cause of injury, or premature death). The expected changes in the exposure to climatic factors are combined with the exposure-response function to determine the proportion of a specific health outcome that is attributable to climate. The baseline frequency of the health outcome is used to convert these proportions to absolute impacts. The uncertainty in each of these three factors contributes to the uncertainty in the estimated potential impacts of climate change.

First, there is a great deal of uncertainty about the precise evolution of climate, which depends partly on global efforts to reduce the emission of greenhouse gases (GHGs) and on the way different General Circulation Models (GCMs) translate emission patterns into climate outcomes. Second, the use of exposure-response relationships between climatic factors and health outcomes that are estimated in one location and time period to estimate the health outcomes in a different location or period can be biased and imprecise if the estimated relationships have not been appropriately controlled for differences in non-climate risk factors. Finally, economic development has improved the health conditions across the world and is likely to continue doing so, changing the baseline burden of disease. The extent to which the historical patterns observed in developed countries repeat themselves in developing countries depends on many factors, including the efforts of developing countries to improve health outcomes commensurate with their level of development, the extent to which major global initiatives such as the rollback malaria program succeed, the emergence of new technologies and vaccines, and the emergence of new diseases like HIV, SARS, H5N1, or H1N1.

Estimating the cost of adapting for human health is challenging also because adaptation actions that affect health outcomes are often either implemented to address multiple goals or taken outside of the health sector. Policies and measures to prevent potential health impacts are often implemented to reduce the burden of all preventable diseases and not just those related to climate change. Improvements in water and sanitation services are often undertaken not only to reduce the incidence of all water-borne disease, including diarrhea, but also to meet a broader set of goals such as the Millennium Development Goals. The number of children who are stunted due to malnourishment depends on food production and availability, which can often be increased by expanding irrigation. The need to treat malnourished children (through the promotion of breastfeeding or nutritional programs) and hence the health sector cost of treatment depends on the extent of adaptation that is undertaken in the agriculture sector. Similarly, the effectiveness of early warning and disaster preparedness systems determines the number of injuries and lives lost during extreme weather events such as floods or storm surges; hence it directly affects the demand for health care services and costs.

The scope of this paper is narrowly defined to an estimation of the costs for preventing additional cases of malaria and diarrheal diseases resulting from climate change for two reasons: amenability to quantitatively estimate impacts and adaptation costs at the global level and complementarily with other components of the EACC study. After a rigorous assessment of the evidence, the World Health Organization (WHO) Global Burden of Diseases (GBD) study estimated the global health impacts of climate change from malaria, diarrheal diseases, malnutrition, coastal flooding and inland flooding (McMichael 2004). Other health impacts were not included largely because of the lack of models to quantify these impacts globally. The GBD used two summary measures of population health: disability-adjusted life years lost (DALYs) and mortality. DALYs provide a better measure of population health impacts as they include both the mortality and morbidity impacts. About half of the deaths and disease burden attributed to climate change in the WHO study were due to malnutrition, with the remainder about equally split between malaria and diarrheal diseases.[1]

The complementary EACC study on the cost of agriculture adaptation examines the impacts of climate change on food production and availability and its implications for the number of malnourished children (Nelson et al. 2010). The goal of adaptation in that study is to increase food production to the point where the number of malnourished children declines to the same levels that would have existed without climate change. So in that case, all of the adaptation to reduce malnourishment takes place in the agriculture sector. Similarly, the complementary EACC study on the economics of adaptation to extreme weather estimates the aggregate cost of adaptation related to floods and droughts, a portion of which will likely be incurred in the health sector (Blankespoor et al. 2010).

The secretariat of the U.N. Framework Convention on Climate Change (UNFCCC) estimated the human health costs of adapting to climate change based on the risk assessments in the WHO GBD study (UNFCCC 2007, Ebi 2008, Ebi 2007). While there have been numerous studies on the economic impacts of the health effects of climate change, the Ebi study was the first attempt to measure the global cost of adapting to climate change and was the point of departure for this

1 The study attributed 166,000 additional deaths globally in 2000 to an increase in the average global temperature and associated changes in climate of 0.20 Celsius between 1990 and 2000. Further, climate change alone (holding other risk factors constant) would result in an increase in deaths from malnutrition, malaria, and diarrheal diseases globally of 10, 5, and 3 percent, respectively, by 2030 under the unmitigated emissions scenario (McMichael et al. 2004).

study. It provides estimates of the cost of preventing or treating additional cases of diarrheal disease, malaria, and malnutrition that are attributable to climate change in 2030. The adaptation costs for each cause are estimated in four steps. It starts with estimates of the baseline annual incidence of each disease for 2030, which are assumed to remain unchanged from the incidence of each disease in 2002, the latest year for which estimates were available. It attributes a fraction of the 2030 baseline incidence to climate change using the relative risk of each disease under different climate change scenarios estimated in the WHO GBD Study (McMichael et al. 2004). Next, the total treatment cost for each disease is computed by multiplying the additional cases due to climate change by the average cost of interventions for these diseases available from the Disease Control Priorities in Developing Countries (DCP2) project.[2] The total adaptation costs for malaria and diarrheal diseases in 2030 were estimated at $4–12 billion if emissions reductions result in stabilization at 750 parts per million CO_2 equivalent by 2210.[3]

The remainder of the paper has three sections. The first section describes the methodology and data used to determine adaptation costs, highlighting any differences in methods and updates in data with respect to Ebi (2008). It has four parts: baseline health, relative risk, potential health impacts, and adaptation costs. The analysis does not assess the relative merits of specific interventions or policies to adapt to climate change, and nothing in this paper should be construed as advocating specific adaptation measures. The second section analyzes the sensitivity of the results to various assumptions and the final section of the paper discusses the results and the findings of the study.

METHODOLOGY AND DATA

Adaption costs for malaria and diarrheal disease are determined using the same four steps used in Ebi (2008): establish the baseline incidence of these diseases, determine the relative risk of these diseases from climate change, compute the additional cases of each disease, and estimate the total adaptation cost using the per unit cost of treatment. The adaptation cost estimates differ for a number of reasons, as summarized in Table 1.

First, for consistency with the rest of the EACC study, this study uses a common set of assumptions for climate projections (based on the NCAR and CSIRO GCMs), population, and per capita gross domestic product (GDP) to determine the adaptation costs for 10-year intervals between 2010 and 2050. Second, this study uses updated burden of disease projections for 2010–30 by cause, demographic group, and country that were recently made available by WHO (WHO 2008a, Mathers 2009). These projections are based on updated methods (Mathers and Loncar 2006) and data, which include baseline mortality, incidence, and DALYs at the country level for 16 (age/sex) demographic groups. Third, the study extends the WHO baseline projections to 2050 for diarrheal disease and malaria using the methods outlined in Mathers and Loncar (2006). These projections indicate that the incidence rates and burden of diseases for these two causes will decline in the future and will result in associated declines in the cost of adaptation as well. Third, the exposure response function for malaria is the one used to generate the *World Malaria Report 2008* (WHO 2008b). Finally, the adaptation costs are estimated based on updated exposure-response functions and the unit cost of treatment of these diseases.

BASELINE HEALTH—INCIDENCE AND BURDEN OF DISEASE

The baseline incidence and burden of disease are important determinants of the absolute costs of climate change for human health as they are used to convert relative risks to absolute impacts. For historical periods, the baseline data for specific causes at the global level are determined based on a combination of actual health records, where available, and model-based estimates.[4]

2 See http://www.dcp2.org.

3 The study also estimates the cost of preventing malnutrition under this scenario of $0.1 billion to0.2 billion. In addition, the estimates for preventing or treating additional cases under two other climate scenarios range from $3 billion to $18 billion.

4 WHO published initial estimates of the global incidence and burden of disease for specific causes disaggregated at the regional level as part of the first Global Burden of Disease study for 1990, together with projections for 2000, 2010 and 2030 (Murray and Lopez 1996). WHO has sub-

TABLE 1. COMPARISON OF METHODS AND DATA IN THIS STUDY AND UNFCCC 2007

	UNFCCC 2007, Ebi 2008, Ebi 2007	*This study*
Time frame	2030 only	Every five years between 2010 and 2050
Source of socioeconomic projections data	Per capita GDP based on EMF14 (1995)	Population based on UN projections* GDP based on average of integrated models* (*as in other components of EACC study)
Use of socioeconomic projections	Modify exposure response function for diarrhea	Modify exposure response function for diarrhea Project baseline incidence 2030–50
Baseline incidence	Same as incidence for 2002 (WHO 2004)	2010 and 2030: updated WHO projections of incidence (WHO 2008a, Mathers 2009) 2030–50: projection using WHO projection model (Mathers and Loncar 2006) based on EACC socioeconomic projection data Intermediate years – linearly interpolated
Climate scenario	HadCM2	NCAR and CSIRO A2 scenarios
Exposure response function	Based on WHO GBD (McMichael 2004)	Diarrhea: based on WHO GBD (McMichael 2004) Malaria: based on Craig et al. 1999 (sensitivity WHO GBD: McMichael 2004)
Adaptation options and unit costs	Cost-effective treatment options based on DCP2	Updated cost-effective treatment options based on DCP2

The future baseline for communicable diseases such as malaria and diarrheal diseases can be quite different than the historical baselines, particularly for low-income countries with rapidly rising per capita incomes and human capital levels (Murray and Lopez 1996, Mathers and Loncar 2006).

The adaptation cost estimates in the UNFCCC study were based on the baseline incidence of disease for 2002 at the regional level published by WHO. Since then, WHO has published estimates of mortality and burden of disease for 2004 at the country level for 16 different demographic groups (WHO 2008a). The new estimates indicate a marked increase in the deaths and DALYs for diarrhea, but large declines for malaria (see Table 2). While the incidence of diarrheal disease has risen with increases in population, the burden in terms of deaths and DALYs has increased by nearly 20 percent. In contrast, both the incidence and the burden of malaria have decreased by over 30 percent. These changes reflect both statistical revisions to the data based on improvements in data collection and estimation techniques as well as real changes in health outcomes as countries strive to meet the Millennium Development Goals.

WHO has also updated projections of the future baseline burden of disease for 133 causes through 2030, starting from the 2004 baseline (Mathers and Loncar 2006). These projections are based on new model estimates using 2,605 country-years of health registration data from 106 countries spanning the 1950–2002 period. The models predict mortality rates for a country by cause and demographic group (age, sex) based on changes in per capita incomes and the level of human capital and time as a proxy for the availability of more effective technologies. These projections, like earlier ones (Murray and Lopez 1996), assume that future mortality trends in poor countries will have a relationship to economic and social development similar to those that have occurred in higher-income countries.

The baseline health outcome projections through 2050 used in this study are determined from the WHO projections in two stages: determine the incidence, burden of disease, and mortality rates for each disease for 16 demographic groups and then multiply by the corresponding population projections as used in the EACC study to determine the total incidence or burden of disease. The starting point for this study is the WHO's country-level projections of mortality and DALY rates for each demographic group for the "baseline scenarios" that were available for 2010 through 2030. Since projections of incidence rates were not

sequently published updated estimates for historical periods for 2000, 2002, and 2004 (WHO 2004, WHO 2006). These estimates have undergone several significant revisions based on improved data collection and estimation techniques.

TABLE 2. REVISIONS TO CURRENT BASELINE INCIDENCE AND BURDEN OF DISEASE

	*2002**	*2004**	*Percent change*
Population (million)	6,122	6,437	3
Diarrheal disease			
Incidence (million)	4,513	4,608	2
Deaths (thousand)	1,798	2,162	20
DALYS (thousand)	61,966	71,058	17
Incidence rate (per thousand)	725	718	–1
Mortality rate (per thousand)	0.289	0.336	16
DALYs (per thousand)	10	11	13
Malaria			
Incidence (thousand)	408	241	–41
Deaths (thousand)	1,272	828	–35
DALYS (thousand)	46,486	33,976	–27
Incidence rate (per thousand)	66	37	–43
Mortality rate (per thousand)	0.204	0.129	–37
DALYs (per thousand)	7	5	–29

Notes: * 2002 estimates used in UNFCCC study; 2004 estimates used in this study.

available, they were determined by scaling the demographic-group-specific incidence rates for malaria and diarrhea in each country for 2004 in proportion to the projected changes in the DALY rates between 2004 and 2030 reported in the WHO projections (Mathers 2009).

WHO projections were not available beyond 2030; hence, the incidence and burden of disease for each country were estimated starting from the 2030 projections. Changes in the mortality rates between 2030 and 2050 were estimated based on cause and demographic-group-specific regression results reported in Mathers and Loncar (2006). These results indicate that mortality rates for communicable diseases such as malaria and diarrheal diseases in a country will decline for all age groups (except for those over 70) as per capita incomes and the level of human capital rise in the country. Human capital is more difficult to estimate and project; to be conservative, mortality rates for 2030–50 are estimated based only on the direct effects from changes in per capita income.[5] The predicted changes in the mortality rates were also applied proportionately to the 2030 incidence rates and DALY rates to determine the corresponding rates for the 2030–50 period.

The absolute incidence of disease, the number of deaths, and the DALYs lost for each of 16 demographic groups in a country are determined in the second stage by multiplying the applicable rate with the corresponding population. These estimates provide the counterfactual against which the impacts of climate change are measured in this study (see Tables 3 and 4). They indicate that in 2010 Sub-Saharan Africa accounts for a fifth of the incidence and about half of the DALYs from diarrheal disease and for over 90 percent of the worldwide malaria cases and burden. Projected increases

5 The pessimistic scenario of the WHO projections through 2030 removes improvements in health outcomes attributed to technological improvements for all low-income countries. On the other hand, the baseline scenario removes it for low-income countries in Africa while reducing it to 25 percent of the average for all other low-income countries. Similarly, improvements in health outcomes due to human capital are reduced for all low-income countries to 50 percent in the WHO baseline scenario and to 25 percent in the pessimistic scenario. (See Annex for a list of countries by World Bank region and income group.)

TABLE 3. BASELINE INCIDENCE AND BURDEN OF DISEASE PROJECTIONS, 2010–50

	2004	*2010*	*2020*	*2030*	*2040*	*2050*
Population (million)	6,437	6,871	7,628	8,276	8,799	9,145
Diarrheal disease						
Incidence (million)	4,608	3,409	2,385	1,774	1,469	1,245
Deaths (thousand)	2,162	1,537	1,010	713	726	782
DALYs (thousand)	71,058	50,688	32,127	21,038	18,091	16,012
Incidence rate (per thous.)	718	495	312	214	167	136
Mortality rate (per thous.)	0.336	0.223	0.132	0.086	0.083	0.085
DALYs (per thousand)	11	7.4	4.2	2.5	2.1	1.7
Malaria						
Incidence (million)	240	179	118	78	73	68
Deaths (thousand)	828	771	500	323	286	252
DALYs (thousand)	33,976	29,705	19,151	12,290	10,729	9,317
Incidence rate (per thous.)	37	26	15	9	8	7
Mortality rate (per thous.)	0.129	0.112	0.065	0.039	0.033	0.028
DALYs (per thousand)	5	4.3	2.5	1.5	1.2	1.0

TABLE 4. BASELINE INCIDENCE AND BURDEN OF DISEASE PROJECTIONS, BY REGION, 2010–50

	Diarrheal Disease			*Malaria*		
	2010	*2030*	*2050*	*2010*	*2030*	*2050*
Incidence (million)						
East Asia and Pacific	1,049	633	422	8	3	2
Europe and Central Asia	93	47	30	0	0	0
Latin America and Caribbean	332	173	120	2	1	1
Middle East and North Africa	162	87	64	3	3	2
South Asia	836	344	203	10	4	3
Sub-Saharan Africa	724	337	285	157	68	61
High-income countries	212	153	119	0	0	0
Total	3,409	1,774	1,245	179	78	68
DALYs (thousand)						
East Asia and Pacific	4,825	2,076	1,277	1,206	414	270
Europe and Central Asia	868	300	164	128	121	74
Latin America and Caribbean	1,591	650	455	138	55	40
Middle East and North Africa	1,900	957	762	260	129	99
South Asia	15,663	5,009	2,937	2,337	783	483
Sub-Saharan Africa	25,461	11,779	10,200	25,594	10,764	8,330
High-income countries	379	268	217	42	25	21
Total	50,688	21,038	16,012	29,705	12,290	9,317

in incomes between 2010 and 2050 enable developing countries to invest in improving their population health outcomes. As a result, the incidence, mortality, and burden of disease for malaria and diarrheal disease are expected to decline significantly in all regions, with the largest declines occurring in East Asia and South Asia. By 2050, the disease burdens from these two causes are expected to be primarily located in Sub-Saharan Africa.

RELATIVE RISKS FROM CLIMATE CHANGE

The relative risks of malaria and diarrheal disease from climate change are determined in relation to the historical risks for three time periods centered around the years 2010, 2030, and 2050. They are determined from climate projections from the NCAR CCSM-3 and CSIRO-3 (abbreviated to NCAR and CSIRO) General Circulation Models that are used in all components of the EACC study. The climate projections are converted to relative risks based on exposure response (ER) functions available in the literature. For diarrheal disease, the ER functions are the same as used in the WHO GBD study (McMichael et al. 2004). For malaria, the ER function used in this study is based on a suitability index for malaria developed by Craig et al. (1999), used most recently in the *World Malaria Report 2008* (WHO 2008b). The ER function in the WHO GBD study was based on a suitability index for malaria developed by Tanser et al. (2003), which is analyzed as one of the sensitivity analysis cases.

Climate Scenarios

The Climate Research Unit (CRU) at the University of East Anglia has compiled a series of historic weather data for land areas of the globe at a resolution of 0.5 degree grid squares. The climate data at the grid square level for this period define the baseline risks. Summary statistics have been computed for each grid cell for monthly average, maximum, and minimum temperatures (in degrees Celsius) and precipitation (in millimeters) for the period 1901–2002.

Climate change is characterized in this study based on temperature and precipitation projections from the NCAR and CSIRO models commonly shared with the EACC study and are more fully described in Strzepek and Schlosser (2010). These models were chosen from the larger set of 26 General Circulation Models used for IPCC's Fourth Assessment Report for the purposes of the EACC study. These have relatively similar changes in the global moisture index, but they differ significantly in their patterns of climate change at regional and country level.[6] Monthly temperature and precipitation projections from these models were averaged over the 20-year periods 2000–20, 2020–40, and 2040–60 and compared with the base period 1900–2002. The changes were downscaled to a resolution of 0.5 degree grid squares used in the CRU historical data and added to them to obtain a consistent set of temperature and precipitation estimates for these two models for the three future time periods centered around 2010, 2030, and 2050.

Exposure Response Function for Diarrheal Disease

The ER function for diarrheal diseases used in the WHO GBD study (McMichael et al. 2004) is also used in this study to estimate the relative risk from climate change. The comprehensive review of the literature completed as part of the GBD study indicated that few studies had quantitatively examined the relationship between the incidence of diarrheal disease and climate. The available literature indicated that a 1° Celsius rise in temperature was associated with an increase in the incidence of diarrheal disease of 8 percent in Peru and 3 percent in Fiji (Checkley 2002, Singh 2001). The average of these two, 5 percent, is used in the GBD study and is applied to countries with per capita incomes of less than $6,000. Increases in temperature are assumed not to have any effect on the incidence of diarrheal disease in countries with higher incomes. A more recent study from Bangladesh that found increases in the incidence of non-cholera diarrhea of 5.6 percent for every 1° Celsius rise in temperature provides additional support to the selected ER function (Hashizume 2007). The GBD review did not find clear evidence for estimating the effect of precipitation on the incidence of diarrheal disease.

6 Compare to Hadley.

The relative risks for the incidence of diarrheal disease for 2010, 2030, and 2050 by World Bank region are shown in Table 5 for the NCAR and CSIRO climate change scenarios.[7] The relative risks for intermediate years are linearly interpolated. They reflect the offsetting effects of higher risks with rising temperatures and declining risks with improvements in health services and access to sanitation that often accompany rising per capita incomes.

Climate change is expected to increase the risks of diarrheal disease worldwide by around 3 percent in 2030 and 2 percent in 2050. A large part of this decline is due to improvements in environmental and health services that countries put in place as per capita incomes rise. The lone exception to this declining trend is Sub-Saharan Africa, where the relative risk rises by about 6 percent by 2030 and 8–9 percent by 2050. This represents a more than twofold increase in the climate-related risk between 2010 and 2050. These results are consistent across the two climate projections, since the temperature projections in these two GCMs are similar.

Exposure Response Function for Malaria

The ER function for malaria used in this study is based on a suitability index for malaria transmission developed by Craig et al. (1999) for the MARA/ARMA project. The index has most recently been used in the *World Malaria Report 2008* to estimate the historical incidence of malaria in areas with limited health records (WHO 2008b, Korenromp 2005). The suitability index for an area is constructed from the temperature and precipitation characteristics of that area (see Box 1).

In this study, the suitability index has been applied to each 0.5 degree grid square under the baseline conditions and for the three time periods centered around 2010, 2030, and 2050 based on climate projections from the NCAR and CSIRO GCMs. The population living in transmission-suitable areas is potentially at risk of malaria. Climate change is expected to affect the geographical distribution of malaria to higher latitudes and extend the duration of the transmission season. The relative risk of malaria for each country is computed as the ratio of the population at risk between the future period and the baseline period; as such, it solely focuses on the expansion or contraction in the geographic locations suitable for malaria transmission. This is similar to the way relative risks were determined in the WHO GBD study, which used a different suitability index based on Tanser et al. (2003) for the MARA/ARMA project.[8] (The implications of switching between the two suitability indices are discussed in the sensitivity analysis section of this paper.)

The relative risks for the total burden of disease for malaria resulting from climate change for 2010, 2030, and 2050 are summarized for the NCAR and CSIRO scenarios in Table 6. The relative risks for intermediate years are linearly interpolated. Climate change is expected to increase the risks of malaria in a number of regions. The increases are larger for all regions and over time under the wetter scenario (NCAR). The relative risks for both NCAR and CSIRO scenarios are larger than the relative risks reported in the WHO GBD study (which used projections from the HADCM2 model). Part of this increase reflects differences in the baseline climate used as a counterfactual (average for 1991–2002 for this study versus average for 1961–2000 for the GBD study).[9]

7 The country-level relative risks have been weighted by the baseline incidence in the region to obtain the relative risk of incidence in the region. The incidence rate for diarrheal disease declines faster than the mortality rates as a result, so regional relative risks using the number of deaths or overall burden of disease as weights would result in higher regional relative risk for deaths or burden of disease.

8 Suitability for malaria transmission in any month is determined by four criteria: a) three-month moving average temperature exceeds 19.5o Celsius plus the standard deviation of mean monthly temperatures; b) minimum yearly temperature exceeds 5o Celsius; c) three-month moving average precipitation exceeds 60 millimeters; and d) three-month moving average of precipitation exceeds 80 millimeters for at least one month. An area that meets all four criteria is considered suitable for malaria transmission in that month. In addition, an area whose suitability is interrupted for a month but has met all of the criteria in the preceding and succeeding months is assumed to be suitable for transmission during the interrupted month.

9 Relative risks were also computed for these two climate projections using the exposure response function defined by Tanser et al. (2003) and used in the WHO GBD study. The relative risks for all countries are lower for all regions compared with the relative risks reported in Table 6. For the NCAR scenario, the relative risks worldwide are 1.052, 1.070, and 1.087 for 2010, 2030, and 2050 respectively. The corresponding numbers for the CSIRO scenario are 1.044, 1059, and 1.080.

TABLE 5. RELATIVE RISK: INCIDENCE OF DIARRHEAL DISEASE FROM CLIMATE CHANGE, BY REGION, FOR 2010–50

	NCAR Scenario			*CSIRO Scenario*		
	2010	*2030*	*2050*	*2010*	*2030*	*2050*
East Asia and Pacific	1.048	1.006	1.002	1.030	1.005	1.002
Europe and Central Asia	1.025	1.028	1.000	1.014	1.018	1.000
Latin America and Caribbean	1.005	1.003	1.003	1.003	1.003	1.002
Middle East and North Africa	1.038	1.026	1.012	1.022	1.016	1.009
South Asia	1.046	1.060	1.014	1.035	1.064	1.014
Sub-Saharan Africa	1.041	1.063	1.092	1.027	1.057	1.079
High-income countries	1.000	1.000	1.000	1.00	1.000	1.000
All countries	1.037	1.028	1.024	1.026	1.026	1.020

BOX 1. FUZZY DISTRIBUTION MODEL FOR MALARIA SUITABILITY

No distinct boundaries separate malarious from non-malarious areas. Climatic factors act as spatial gradients shifting the distribution of these areas. The suitability of an area for malaria transmission can be categorized based on the climatic conditions necessary during the transmission life cycle based on fuzzy logic. Transmission is unlikely below 18° Celsius, likely between 22° and 32° Celsius, and unlikely above 40° Celsius. Similarly, transmission is unlikely in areas with less than 0 millimeters of monthly precipitation while it is likely in areas exceeding 80 millimeters. The mean daily minimum winter temperature of less than 4° Celsius makes transmission unlikely, while minimum temperatures exceeding 6° Celsius makes an area suitable for transmission. Each area is assigned a fuzzy value (between 0 and 1) for each month and each criterion. Areas where transmission is likely are assigned a value of 1, while unlikely areas are assigned values of 0. The fuzzy values for intermediate areas are determined using a simple sigmoidal function between the limit points for the criteria. The suitability of an area for transmission in a given month is determined as the minimum fuzzy value across the three criteria. The suitability index for each area is based on the highest fuzzy value spanning any five-month period, constituting a transmission season. Populations living in areas with suitability index larger than 0.5 were considered at risk.

TABLE 6. RELATIVE RISK: BURDEN OF DISEASE (DALYS) OF MALARIA FROM CLIMATE CHANGE, BY REGION, 2010–50

	NCAR Scenario			*CSIRO Scenario*		
	2010	*2030*	*2050*	*2010*	*2030*	*2050*
East Asia and Pacific	1.010	1.010	1.014	1.008	1.009	1.011
Europe and Central Asia	1.000	1.000	1.000	1.000	1.000	1.000
Latin America and Caribbean	1.056	1.056	1.064	1.053	1.050	1.048
Middle East and North Africa	1.000	1.00	1.000	1.000	1.000	1.000
South Asia	1.000	1.050	1.043	1.000	1.000	1.000
Sub-Saharan Africa	1.073	1.096	1.138	1.044	1.072	1.089
High-income countries	1.000	1.001	1.001	1.001	1.001	1.001
All countries	1.064	1.088	1.125	1.038	1.063	1.079

POTENTIAL HEALTH IMPACTS OF CLIMATE CHANGE

Estimates of the additional incidence and DALYs for diarrheal disease and malaria for 2010–50 for the two climate scenarios are summarized in Tables 7 and 8.

The additional incidence and DALYs attributed to climate change for both causes are projected to decline significantly largely reflecting trends in the baseline incidence and DALYs for these causes under both climate scenarios. Sub-Saharan Africa, with the highest baseline burden and the highest relative risks for both causes under both scenarios, accounts for an increasing share of the worldwide burden from these causes.

ADAPTATION COSTS FOR DIARRHEAL DISEASE AND MALARIA

The potential cost of interventions for malaria and diarrheal disease are based on currently deployed cost-effective interventions. The treatment options selected are the same as in Ebi (2008) and were based on the Disease Control Priorities in Developing Countries project (http://www.dcp2.org). For diarrhea, this includes breastfeeding promotion and immunizations against rotavirus, cholera, and measles for children under five, at an average cost per child of $15.03, plus improvements in sanitation at an average cost of $53 per incidence (in 2001 dollars). Both of these costs were converted to 2005 dollars for consistency with the rest of the EACC study and applied to the additional incidence of diarrheal disease.

TABLE 7. DIARRHEAL DISEASE DUE TO CLIMATE CHANGE: ADDITIONAL INCIDENCE AND BURDEN, BY REGION, 2010–50

	NCAR Scenario			*CSIRO Scenario*		
	2010	*2030*	*2050*	*2010*	*2030*	*2050*
Incidence (thousand)						
East Asia and Pacific	47.9	3.7	0.8	30.6	3.0	0.6
Europe and Central Asia	2.2	1.3	0.0	1.3	0.9	0.0
Latin America and Caribbean	1.7	0.6	0.4	1.1	0.6	0.3
Middle East and North Africa	6.0	2.2	0.8	3.5	1.4	0.5
South Asia	36.4	19.5	2.9	28.8	20.7	2.8
Sub-Saharan Africa	28.2	19.8	24.0	18.9	18.4	20.9
High-income countries	0.0	0.0	0.0	0.0	0.0	0.0
Total	122.7	47.2	28.8	84.2	44.9	25.1
DALYs (thousand)						
East Asia and Pacific	203	32	15	133	28	13
Europe and Central Asia	46	19	0	26	13	0
Latin America and Caribbean	16	5	4	10	5	3
Middle East and North Africa	90	52	18	52	34	12
South Asia	732	312	88	554	307	71
Sub-Saharan Africa	1030	714	863	694	670	752
High-income countries	0	0	0	0	0	0
Total	2,117	1,133	987	1,469	1,056	851

TABLE 8. MALARIA DUE TO CLIMATE CHANGE: ADDITIONAL INCIDENCE AND BURDEN, BY REGION, 2010–50

	NCAR Scenario			*CSIRO Scenario*		
	2010	*2030*	*2050*	*2010*	*2030*	*2050*
Incidence (thousand)						
East Asia and Pacific	127	48	52	114	49	42
Europe and Central Asia	0	0	0	0	0	0
Latin America and Caribbean	134	67	64	138	62	54
Middle East and North Africa	0	0	0	0	0	0
South Asia	1	174	116	1	0	0
Sub-Saharan Africa	11,990	6,301	7,905	6,895	5,222	5,800
High-income countries	0	0	0	0	0	0
Total	12,251	6,591	8,136	7,148	5,333	5,897
DALYs (thousand)						
East Asia and Pacific	12	4	4	9	4	3
Europe and Central Asia	0	0	0	0	0	0
Latin America and Caribbean	7	3	2	7	3	2
Middle East and North Africa	0	0	0	0	0	0
South Asia	0	38	20	0	0	0
Sub-Saharan Africa	1,751	949	1,007	1075	721	680
High-income countries	0	0	0	0	0	0
Total	1,771	993	1,033	1,092	728	685

For malaria, the authors of the cost effectiveness analysis recently updated their analysis, which has decreased the unit costs of these interventions.[10] Incremental costs per DALY averted are separately available for WHO's AfrD and AfrE regions for the following treatment options:[11] (a) for AfrD, insecticide-treated bednets (ITN) at $29/DALY; (b) for AfrE, insecticide-treated bednets plus case management with artemisinin-based combination therapy (ACT) at $57/DALY plus indoor residual spraying (IRS) at $60/DALY; and (c) for both regions, ITN plus ACT plus IRS combined with intermittent presumptive treatment in pregnancy (IpTp) at $48/DALY in AfrD and $148/DALY in AfrE. All of these costs were converted to 2005 dollars and applied to the projected additional DALYs for countries in the AfrD and AfrE regions. For all other regions, the average cost per DALY averted in the AfrD and AfrE regions were used.

The average annual adaptation costs in the health sector for preventing and treating diarrheal disease and malaria attributed to climate change in 2010 ranges between $3 billion (CSIRO scenario) and $5 billion (NCAR scenario) (see Table 9). These costs are expected to decline as basic health services improve with development, making residents less susceptible to these diseases. Overall, the average cost of adaptation for diarrheal disease and malaria is around $2 billion a year over the 40-year period 2010–50. Almost all of the costs are related to diarrheal disease, with malaria accounting for

10 Morrel et al. 2005.

11 Countries in WHO AfrD region are Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Saõ Tomé and Príncipe, Senegal, Seychelles, Sierra Leone, and Togo.

Countries in WHO AfrE region are Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, and Zimbabwe.

TABLE 9. AVERAGE ANNUAL ADAPTATION COST TO PREVENT AND TREAT MALARIA AND DIARRHEA, BY YEAR, 2010–50 (BILLION 2005 DOLLARS)

	2010	*2020*	*2030*	*2040*	*2050*
NCAR Scenario					
Diarrheal Disease	4.6	2.4	1.8	1.2	1.1
Malaria	0.2	0.1	0.1	0.1	0.1
Total	4.8	2.5	1.9	1.3	1.2
CSIRO Scenario					
Diarrheal Disease	3.2	2.0	1.7	1.1	0.9
Malaria	0.1	0.1	0.1	0.1	0.1
Total	3.3	2.1	1.8	1.2	1.0

TABLE 10: AVERAGE ANNUAL ADAPTATION COST TO PREVENT AND TREAT MALARIA AND DIARRHEA, BY REGION, 2010–50 (BILLION 2005 DOLLARS)

	2010	*2020*	*2030*	*2040*	*2050*
NCAR Scenario					
East Asia and Pacific	1.8	0.3	0.1	0.1	0.0
Europe and Central Asia	0.1	0.1	0.0	0.0	0.0
Latin America and Caribbean	0.0	0.0	0.0	0.0	0.0
Middle East and North Africa	0.2	0.1	0.1	0.1	0.0
South Asia	1.4	1.0	0.7	0.2	0.1
Sub-Saharan Africa	1.2	1.0	0.8	0.9	1.0
Total	4.8	2.5	1.9	1.3	1.2
CSIRO Scenario					
East Asia and Pacific	1.2	0.2	0.1	0.1	0.2
Europe and Central Asia	0.0	0.0	0.0	0.0	0.0
Latin America and Caribbean	0.0	0.0	0.0	0.0	0.0
Middle East and North Africa	0.1	0.1	0.1	0.0	0.0
South Asia	1.1	0.9	0.8	0.2	0.1
Sub-Saharan Africa	0.8	0.8	0.8	0.8	0.9
Total	3.3	2.1	1.8	1.2	1.0

less than 10 percent. By 2050, most of the additional cases (hence costs) attributed to climate change are expected to occur in Sub-Saharan Africa (see Table 10). These estimates are lower than prior estimates of $4–12 billion in 2030, which was about equally split between diarrheal disease and malaria (Ebi 2008).[12] Reductions in the projected baseline burden of disease is the primary reason for the lower costs estimated in this study. In addition, the costs for malaria are lower due to the 30–40 percent downward revision of the current

12 The costs for diarrheal disease ranged between $2.0 billion and $6.8 billion and for malaria between $1.9 billion and $5.6 billion in 2030 for the $750 scenario. The costs for malnutrition were between $0.1 billion and $0.2 billion.

baseline incidence, mortality, and DALYs between 2002 and 2004 and to revisions in the unit cost treatment.[13]

SENSITIVITY ANALYSIS

There is a great deal of uncertainty around the estimated potential health impacts and the associated costs. The sources of these uncertainties include the baseline health, the climate scenarios, the exposure response functions, and the unit cost of effective intervention methods. A number of analyses were completed to estimate sensitivity of the potential impacts and adaptation costs for diarrheal disease and malaria to the different assumptions, methods, and data (see Table 11). The analyses indicate that the overall trends and regional distributions of the impacts and costs are robust to these changes. Hence, only the aggregate adaptation costs are summarized for each cause over time. The top half of Table 11 provides cost estimates for diarrheal disease followed by malaria in the bottom half. The top row in each block shows the results for the base case, which is reported in detail in the previous section of this paper. Results are reported for the NCAR and CSIRO climate scenarios for 2010, 2030, and 2050. In each case the costs are consistently higher in the wetter NCAR scenario compared with the drier CSIRO scenario.

The first two sensitivity analyses relate to the uncertainty around the cost of treating additional cases of diarrhea or averting additional DALYs from malaria. The cost differences from the base case are large in 2010 for both climate scenarios but rapidly narrow by 2050 as a result of the declining baseline. The effect of the declining baseline is examined in the third sensitivity analysis for each cause. For all years, the baseline incidence of diarrheal disease and the baseline DALYS for malaria are the same as in 2004, which implies a reduction in the baseline per capita incidence and burden when the population is rising. This analysis comes closest to the approach used in Ebi (2008). By far, adaptation costs are highest for this case compared with all other cases.

Two additional cases were run for diarrheal disease, first to estimate costs based on DALYS and second based on an alternate method of extrapolating the incidence of disease based on projections of mortality instead of DALYS. Keusch (2006) provides estimates of the median costs per DALY averted for cost-effective treatments of diarrheal disease of $1,032 for low- and middle-income counties. Separate estimates of costs per DALY averted are also available by World Bank region, ranging from $132/DALY averted in East Asia and the Pacific to $2,564 in the Middle East and North Africa. Applying these regional costs to the additional DALYs from diarrheal disease lowers the costs in the early years compared with the base case, but it makes little difference by 2050. The final sensitivity for diarrheal disease is based on changing the method by which the baseline incidence projections are done from one based on trends in DALY rates to based on trends in mortality rates. Costs are smaller compared with the base case, but not by much.

In the case of malaria, a final sensitivity was run to examine the effect of changing the exposure response function to that used in the GBD study. Impact estimates and adaptation costs are lower with the ER function used in the GBD study by 10–20 percent under the CSIRO scenario and around 40 percent under the wetter NCAR scenario.

Besides the above sensitivity analyses, the estimated costs were also compared with the total cost of eradicating malaria worldwide over the next few decades as estimated by the Roll Back Malaria Partnership (RBMP 2008). Efforts were under way to scale up efforts in all malaria-endemic countries starting in 2009 and 2010 with the intent of eradicating malaria globally over the next few decades. If these goals are indeed met, reduced baseline incidence of malaria would also have the effect of reducing the climate-change-attributed burden of malaria cases. Implementing the RBM program is expected to cost about $5.2 billion annually through 2020, $3.3 billion annually in the 2020s, and $1.5 billion by the 2030s. Assuming that about 5 percent of the current burden of malaria is due to climate change, this implies a share of around $250 million in adaptation cost, which is of the same order of magnitude as the estimated costs for malaria. If the share of the malaria burden attributable to climate

13 Revisions to the unit cost alone have the effect of reducing adaptation costs by seven to eight times.

TABLE 11. SENSITIVITY OF AVERAGE ANNUAL ADAPTATION COST FOR HUMAN HEALTH, SELECTED YEARS (BILLION 2005 DOLLARS)

					NCAR Scenario			CSIRO Scenario		
Cause	*Baseline*	*Health endpoint*	*Exposure response*	*Unit costs*	*2010*	*2030*	*2050*	*2010*	*2030*	*2050*
Diarrheal Disease										
	Mathers with extension	Incidence	GBD	Average	4.6	1.8	1.1	3.2	1.7	0.9
	1. Mathers with extension	Incidence	GBD	**Low**	2.0	0.8	0.5	1.4	0.7	0.4
	2. Mathers with extension	Incidence	GBD	**High**	7.2	2.8	1.7	4.9	2.6	1.5
	3. Constant at 2004 levels	Incidence	GBD	Average	6.3	5.4	3.8	4.3	5.2	3.3
	4. Mathers with extension based on deaths	Incidence	GBD	Average	3.9	1.4	0.9	2.7	1.3	0.8
	5. Mathers with extension	**DALYS**	GBD	**Keuschetal**	2.0	1.2	1.1	1.4	1.1	0.9
Malaria										
	Mathers with extension	DALYs	Craig et al	Average	0.2	0.1	0.1	0.1	0.1	0.1
	1. Mathers with extension	DALYs	Craig et al	**Low**	0.1	0.1	0.1	0.1	0.0	0.0
	2. Mathers with extension	DALYs	Craig et al	**High**	0.2	0.1	0.1	0.2	0.1	0.1
	3. Constant at 2004 levels	DALYs	Craig et al	Average	0.2	0.3	0.4	0.1	0.2	0.3
	4. Mathers with extension	DALYs	**Tanser et al**	Average	0.1	0.1	0.1	0.1	0.1	0.1

Baseline: Mathers with extension (Health Endpoint DALYs) – 2010–30 (WHO projections of DALYs per 1000 people by age, sex within a country); 2030–50 (adjusts 2030 WHO projections of DALYs per 1000 people for changes in income)

Mathers with extension (Health Endpoint Incidence) – 2010–30 (adjusts 2004 incidence rates in proportion to changes in DALYs (or deaths) per 1000 people by age/sex/country); 2030–50 (adjusts 2030 projections of incidence rates for changes in income)

Constant at 2004 levels – Incidence or DALYs held constant at 2004 levels; implies declining baseline rates with rising population

Exposure response function: Diarrhea: all cases are based on the ER function used in WHO GBD; RR determined for grid 0.5 degree

Malaria: suitability index based on Craig et al. (1999) or Tanser et al. (2003). WHO GBD uses Tanser et al. (2003). RR determined at the country level based on population weighted areal extent of suitability.

Heath Endpoint: Choice based on availability of cost data, diarrhea (incidence or DALYs); malaria (DALYs only).

Unit Cost:
Diarrhea Low (breast feeding promotion and immunizations, $15.09 / child) based on Keusch (2006)
High (improved water supply and sanitation, $53 /child) based on Keusch (2006)
Average ($34 /child, average of low and high)
Keusch (2006) based on regional costs per DALY (range $132–2,564 per DALY) http://www.dcp2.org/pubs/DCP/19/Table/19.2

Malaria Low ($29/DALY in AfrD for ITN, $58.50/Daly in AfrE for ITN+ACT+IRS, average of AfrD and AfrE elsewhere)
High ($48/DALY in AfrD, $148/Daly in AfrE, average of AfrD and AfrE elsewhere, for ACT+ITN+IRS+IpTp)
Average (average of low and high) based on Morrel et al. 2005.

change rises to 7 percent by 2030, the adaptation cost for malaria would be around $100 million, consistent with the estimates reported in the study.

DISCUSSION

Estimating the adaptation costs in the health sector is challenging because of the large existing uncertainties about how the climate will evolve over the coming century but also because of the complex and often poorly understood chains through which health impacts are mediated. Climate change is difficult to predict with accuracy in any projection model that has to contend with uncertainty about potential collective actions to mitigate greenhouse gases as well as unknown factors in climate science itself. The health outcomes that are linked to climate change also depend on a host of other factors as well, some of which are likely not currently anticipated, such as the emergence of new diseases, and others that are difficult to predict, such as the development of vaccines to address existing and new ailments.

This paper attempts to examine known factors in the human health–climate change nexus. It builds on prior studies by WHO on the health impacts of climate change and by UNFCCC on the cost to prevent and treat these impacts. The analysis systematically examines the various sources of uncertainty to identify the most important factors affecting the cost of adapting to climate change in developing countries.

Climate change does not create a novel type of environmental exposure. It is expected to alter regional weather patterns, which in turn will result in increased frequency and/or intensity of extreme events as well as increases in average temperature and changes in precipitation levels. Some of these factors affect health directly (such as heatwaves) but often they affect health indirectly through altered transmission pathways for infectious (vector-, rodent-, water-, and food-borne) diseases or decreased productivity of land or ecosystems (resulting in malnutrition or disrupted livelihoods). Climate change will also modulate the exposure-outcome relationship of these complex chains. Modulating influences related to susceptibility and concurring factors will also likely have large effects, depending on local contexts.

The analysis suggests that climate change will account for a small share of the total cases of the weather-sensitive health outcomes in most countries. A disproportionate share of the added burden falls on the poor, particularly in Sub-Saharan Africa, which faces the largest increase in risk and has the least capacity to cope with these risks. More than any other source of uncertainty, the baseline health status of a country is the single largest determinant of the likely impacts of climate change and the cost of adapting to it. Economic development has historically led to significant improvements in the health status of countries. Independently, although not all countries will meet their Millennium Development Goals, most countries are making rapid progress toward meeting them. These goals include reductions in child mortality and the mortality burdens from climate-sensitive diseases such as malaria. The success of such programs will also be an effective mechanism for adapting to the added risks that emanate from climate change.

The analysis explored a number of other sources of uncertainty, including specific climate projections and the cost of alternative interventions. Two specific climate scenarios—globally the driest and the wettest ones—resulted in potential health impacts and cost estimates that were relatively narrow in range, suggesting that uncertainty about the specific differences between climate projections may not be as important. However, this result may just be an artifact of the poor knowledge of exposure-response relationships. Projections from different climate models have generally agreed on warming trends for most places but have significant differences about precipitation, especially at a local scale. The lack of knowledge relating precipitation and health effects means that the effects of this uncertainty in climate projections could not be separately tested. Changes in the cost of intervention vary across locations and may also partially depend on the appropriateness of selected measures in a local context. Often alternative measures are taken together to increase the effectiveness of the different interventions, as is the case for malaria. Variations in unit costs are, however, not sufficient to result in orders of magnitude differences in the global cost of adaptation.

Building adaptive capacity for health will require a cross-disciplinary dialogue between health practitioners, decision makers, the public, and the climate change science community. As a component of the overall need for adaptation to climate change, adaptive strategies in health has to be based on actions that governments, institutions, and the public can take to adjust to impacts, moderate their damage, or cope with their consequences. Most relevant actions for adaptive capacity will be those enabling commonly accepted good public health and development practices, beyond climate change considerations. The creation and maintenance of basic public health infrastructure in terms of training, surveillance, immunization, vector control, and emergency preparedness and response will both provide development benefits and increase resilience to health impacts of climate change. As the situation changes, novel actions and strategies may need to be developed, new technologies invented, and the relationships between natural and man-made systems and human health may need to be better analyzed.

Finally, the cost estimates for the health sector reported in this paper are an underestimate of the total health sector cost determined in the EACC study. To avoid double counting, these estimates are reported in the following complementary papers: the additional cost of climate-proofing hospitals, clinics, and other health sector infrastructure of $200–400 million per year (Hughes et al. 2010); the cost of adapting to extreme weather (floods and droughts) of $6–7 billion per year, some of which occur in the health sector (Blankespoor et al. 2010), and reducing additional cases of malnutrition in agriculture (Nelson et al. 2010). The health sector adaptation cost reported here would be higher if any of the agriculture sector adaptation measures fail, raising levels of malnutrition. Even when these additions are included, the reported costs still underestimate the true cost of adapting to climate change because of the omission of adaptation costs for other health impacts.

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ANNEX — LIST OF COUNTRIES BY WORLD BANK INCOME GROUP AND REGION

Region	*Low Income*	*Lower Middle Income*	*Upper Middle Income*
East Asia Pacific	Cambodia, DPR Korea, Lao PDR, Mongolia, Myanmar, Papua New Guinea, Solomon Islands, Vietnam	China, FS of Micronesia, Fiji, Indonesia, Kiribati, Marshall Islands, Philippines, Samoa, Thailand, Tonga, Tuvalu, Vanuatu	Malaysia, Palau
Europe and Central Asia	Kyrgyzstan, Tajikistan, Uzbekistan	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Georgia, Moldova, TFYR Macedonia, Turkmenistan, Ukraine	Bulgaria, Croatia, Hungary, Kazakhstan, Latvia, Lithuania, Poland, Romania, Russian Federation, Serbia, Slovakia, Turkey
Latin America and Carribean	Haiti, Honduras	Bolivia, Colombia, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Jamaica, Nicaragua, Paraguay, Peru, Suriname	Argentina, Belize, Bolivia, Brazil, Chile, Costa Rica, Dominica, Grenada, Mexico, Panama, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Uruguay, Venezuela
Middle East North Africa	Yemen	Algeria, Djibouti, Egypt, Iran (Islamic Republic of), Iraq, Jordan, Morocco, Syrian Arab Republic, Tunisia	Lebanon, Libyan Arab Jamahiriya, Oman
South Asia	Afghanistan, Bangladesh, India, Nepal, Pakistan	Bhutan, Maldives, Sri Lanka	
Sub Saharan Africa	Benin, Burkina Faso, Burundi, Central African Rep, Chad, Comoros, Côte d'Ivoire, DR Congo, Eritrea, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Nigeria, Rwanda, São Tomé & Príncipe, Senegal, Sierra Leone, Somalia, Sudan, Togo, Uganda, UR Tanzania, Zambia, Zimbabwe	Angola, Cameroon, Cape Verde, Congo, Lesotho, Namibia, Swaziland	Botswana, Equatorial Guinea, Gabon, Mauritius, Seychelles, South Africa

High-income countries: Andorra, Antigua and Barbuda, Australia, Austria, Bahamas, Bahrain, Barbados, Belgium, Brunei Darussalam, Canada, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Kuwait, Luxembourg, Malta, Monaco, Netherlands, New Zealand, Norway, Portugal, Qatar, Republic of Korea, San Marino, Saudi Arabia, Singapore, Slovenia, Spain, Sweden, Switzerland, Trinidad and Tobago, United Arab Emirates, United Kingdom, United States of America.

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