

Climate-Associated Changes in Health Outcomes

Kristie L. Ebi, Ph.D., MPH
Carnegie Institution for Science

Introduction

Climate change has the potential to affect any health outcome that is seasonal or that is associated with weather and climate. In addition, many key determinants of human health, such as food and freshwater availability, are strongly influenced by weather and climate. Climate-sensitive health outcomes include injuries, illnesses, and deaths associated with extreme weather events, and the effects of changing weather patterns mediated through ecological systems, such as water- and food-borne diseases, vectorborne and zoonotic diseases, respiratory diseases associated with ground-level ozone and aeroallergens, and undernutrition. Climate change also may result in resource depletion and other processes that could lead to large-scale migration, with associated health impacts. While negative health effects are projected for all countries, the largest impacts are expected in lower-income populations, primarily those living in tropical and subtropical countries.

Health Risks of Climate Change

Infectious Diseases

Climate is a primary determinant of whether a particular location has environmental conditions suitable for the transmission of a range of infectious diseases. Increasing temperatures could affect vector and rodent borne diseases, in terms of the density of insects and rodents in a particular area (and therefore the likelihood of infection) and by changing the geographic range of the vector and pathogen. Expansion in range can expose new populations who have little or no immunity to new infections, which could result in large disease outbreaks. Although understanding of the potential impacts of climate change on infectious diseases is still in its relatively early stages, expert assessments have concluded that climate change is expected to be among the most important drivers of infectious disease in the future.ⁱ A UK review considered scenarios for the next 10-25 years of infectious diseases in humans, animals, and plants for the UK and sub-Saharan Africa, and aimed to produce a vision of new systems needed for disease detection, identification and monitoring. The key driver in the UK was expected to be increasing ambient temperature. In Africa, where people, animals and crops live in conditions of much greater moisture stress, rising temperature were still considered to be important but less so than changes to rainfall patterns and the frequency of droughts. Climate-change mediated spread of infectious diseases was expected to cause direct human suffering, especially in Africa, and increasingly challenge current production systems of livestock and crops in the UK and Africa.

Malaria is the most important vectorborne disease in the world; it is also a preventable disease. About 40% of the world's population is at risk of contracting malaria, and roughly 75% of cases occur in Africa, with the remainder occurring in Southeast Asia, the western Pacific, and the Americas.ⁱⁱ In sub-Saharan Africa, malaria remains the most common parasitic disease and is the main cause of morbidity and mortality among

children less than five years of age and among pregnant women.ⁱⁱⁱ The 1990 Global Burden of Disease study estimated that malaria accounted for approximately 10.8% of years of life lost across sub-Saharan Africa.^{iv}

There has been a great deal of interest in modeling how the incidence and geographic range of malaria could change under different climate change projections. Results from several models suggest that climate change could alter the season of transmission and geographic range of malaria in Africa, particularly sub-Saharan Africa.^v The results suggest that climate change will be associated with geographic expansions of the areas suitable for stable *falciparum* malaria in some regions and with contractions in others; the projected areas of expansion are larger than the projected areas of contraction. For instance, Ethiopia, Zimbabwe, and South Africa are projected to show increases of more than 100% in person-months of exposure later in this century, changes that could dramatically increase the burden of those suffering with malaria.^{vi}

Studies have shown that some areas in Asia are projected to be at increased risk of malaria, while reductions have been projected for some areas in Central America and around the Amazon, due to decreases in rainfall.^{vii} An assessment in Australia based on climatic suitability for the main *Anopheles* vectors projected a likely southward expansion of habitat, although the future risk of endemicity would remain low due to the capacity to respond.^{viii}

Climate change could affect the incidence and geographic range of a large number of vectorborne and zoonotic diseases of concern include dengue fever, Lyme disease, plague, Chagas disease, Rift valley fever, and leishmaniasis; expansions and contractions of ranges are possible as ecosystems and transmission pathways change with changing weather patterns.^{ix}

Several food- and waterborne diseases that cause significant numbers of cases of illness are climate sensitive, suggesting that climate change may affect their incidence and distribution. For example, an approximately linear association between temperature and common forms of food-borne diseases such as salmonellosis suggests increasing cases with increasing temperature.^x Limited projections suggest these risks could increase with climate change.^{xi}

Air Pollution

In some regions, climate change may increase concentrations of selected air pollutants, particularly ozone, and could decrease concentration of other pollutants, such as particulate matter (due to increasing heavy precipitation events). There is extensive literature documenting the adverse health impacts of exposure to elevated concentrations of air pollutants. In 2000, there were 800,000 deaths from respiratory problems, lung disease, and cancer that were attributed to urban air pollution, with the largest burden in low-income countries in the Western Pacific and South East Asia.^{xii} In addition, there were 1.6 million deaths attributed to indoor air pollution caused by burning biomass fuels, such as wood and dung.

More is known about the potential impacts of climate change on ground-level ozone than on other air pollutants. Acute exposure to elevated concentrations of ozone is associated

with increased hospital admissions for pneumonia, chronic obstructive pulmonary disease, asthma, allergic rhinitis and other respiratory diseases, and with premature mortality.^{xiii}

Changes in concentrations of ground-level ozone driven by scenarios of future emissions and /or weather patterns have been projected for Europe and North America, with most projections suggesting increasing concentrations.^{xiv xv} Higher ozone concentrations will likely increase a range of health problems and increase premature mortality in susceptible individuals.^{xvi} Despite the heavier pollution burdens, no studies have been conducted for cities in low- or middle-income countries.

Malnutrition

Climate change threatens human health through its effect on under-nutrition and food insecurity. More than 800 million people are undernourished, causing over 15% of the total global disease burden, and over three billion people are micronutrient deficient.^{xvii} The prevalence of undernourishment has fallen over recent decades, with reductions in Asia and Latin America partly offset by increases in Africa and the Middle East. Almost 60% of the world's undernourished people live in South Asia, while the highest incidence of undernourishment is in Sub-Saharan Africa, where more than one-third of the population is underfed.

Recent projections suggest that half of the world's population could face severe food shortages by the end of the century as rising temperatures take their toll on farmers' crops; a greater proportion of this will be in Africa.^{xviii} Harvests of staple food crops such as rice and maize could fall by between 20% and 40% as a result of higher temperatures during the growing season in the tropics and sub-tropics. Although data are limited, malnutrition associated with drought and flooding may be one of the most important consequences of climate change due to the large number of people that may be affected.^{xix}

Extreme Weather Events

The adverse health consequences of flooding and windstorms often are complex and far-reaching, and include the physical health effects experienced during the event or clean-up process, effects brought about by damage to infrastructure related to water supply, sanitation, and drainage, and population displacement.^{xx} Extreme weather events are also associated with mental health effects, such as post-traumatic stress disorder, resulting from the experience of the event or from the recovery process. These psychological effects tend to be much longer lasting and may be worse than the direct physical effects.^{xxi} More than 90% of the disasters that occurred in 2007 were the result of extreme weather- or climate-related events, together accounting for 95% of the reported fatalities and 80% of the total USD82 billion economic losses. The health impacts of extreme events in low- and middle-income countries are substantially larger.

Heat waves affect human health via heat stress, heatstroke, and death,^{xxii} as well as exacerbating underlying conditions that can lead to an increase in mortality from all causes of death.^{xxiii} Older adults, children, city-dwellers, the poor, and people taking certain medications are at the highest risk during a heat wave. The numbers of heat-related deaths are projected to increase with climate change.^{xxiv}

Projections suggest that regions affected by moderate droughts are set to double by the end of the century, with areas affected by extreme droughts increasing from 1% today to 30% in 2100. The most striking impact is expected in parts of southern Europe, North, West and Southern Africa, western Eurasia, and the US. The loss of livelihoods due to drought is a major trigger for population movements that may cause additional adverse health burdens. The effects of drought on health include malnutrition (protein-energy malnutrition and/or micronutrient deficiencies), infectious and diarrheal diseases, and respiratory diseases.^{xxv} Droughts, especially in rural areas, have a tendency to influence migration into cities, increasing urbanization and stressing the socio-economic conditions already affected by high levels of city population growth.

Prolonged droughts fuel fires, releasing respiratory pollutants, while floods can create mosquito breeding sites, foster fungal growth, and flush microbes, nutrients and chemicals into bays and estuaries, causing water-borne disease outbreaks from organisms like *E. coli* and cryptosporidium.^{xxvi}

Global Assessments of the Health Impacts of Climate Change

The most comprehensive evaluation of the health burden due to climate change used a comparative risk assessment approach to estimate total health burdens from climate change in 2000 and 2030, and to project how much of this burden might be avoided by stabilizing greenhouse gas (GHG) emission.^{xxvii} The health outcomes (diarrhoea, malaria, malnutrition, heat-related mortality, and injury from floods and landslides) were chosen based on sensitivity to climate variations, likely future importance, and availability of quantitative global models (or the feasibility of constructing them). The projected relative risks attributable to climate change in 2030 vary by health outcome and region, and are largely negative, with the majority of the projected health burden due to increases in diarrheal disease and malnutrition, primarily in low-income populations already experiencing a large burden of disease. The study is described in more detail in the Annex.

These results are consistent with a review that concluded that health risks are likely to increase with increasing global mean surface temperature, particularly in low latitude countries.^{xxviii} Actual health burdens depend on assumptions of population growth, future baseline disease incidence, and the extent of adaptation.

Research Needs

A recent cross-agency working group in the U.S. summarized the research needs for better understanding of the linkages between climate change and health.^{xxix} Overarching themes include focusing on systems and complexity, enhancing risk communication and public health education, co-benefits of mitigation and adaptation strategies, and urgency and scope

- Improve characterization of exposure- response relationships, particularly at regional and local levels, including identifying thresholds and particularly vulnerable groups. This needs to be done within the context of complex systems.
- Collect data on the early effects of changing weather patterns on climate-sensitive health outcomes.
- Collect and enhance long-term surveillance data on health issues of potential

concern, including vectorborne and zoonotic diseases, air quality, pollen and mold counts, reporting of food- and water-borne diseases, morbidity due to temperature extremes, and mental health impacts from extreme weather events.

- Develop quantitative models of possible health impacts of climate change that can be used to explore the consequences of a range of socioeconomic and climate scenarios.
- Understand local- and regional-scale vulnerability and adaptive capacity to characterize the potential risks and the time horizon over which climate risks might arise.
- Develop downscaled climate projections at the local and regional scale in order to conduct the types of vulnerability and adaptation assessments that will enable adequate response to climate change, and to determine the potential for interactions between climate and other risk factors, including societal, environmental, and economic.
- Improve understanding of designing, implementing, and monitoring effective and efficient adaptation options.
- Understand the co-benefits of mitigation and adaptation strategies.
- Enhance risk communication and public health education.

ANNEX

Estimating Current and Future Population Health Burdens Attributable to Climate Change: the WHO Global Burden of Disease Study

The first global estimate of current and possible future population health burdens attributable to climate change was conducted as part of the World Health Organization's *Global Burden of Disease (2000)* project (McMichael et al. 2004). This study remains the most comprehensive projection of the health impacts of climate change.

The Global Burden of Disease study used published information on climate-health (exposure-effect) relationships to estimate the proportion of the actually observed cases of a specified disease (e.g., malaria or child diarrhea) that could be reasonably attributable to climate change. The steps to estimate the current attributable burden of disease and premature death were:

- (i) Determine or estimate changes in temperature (and other climate variables) over the recent past.
- (ii) Determine (to the extent possible given data limitations), for each disease of interest, the current rates of incidence or premature death, by geographic region.
- (iii) Determine from the published scientific literature, for each disease of interest, the increase in disease risk per unit increase in temperature or other climate variable (i.e. the relative risk).
- (iv) Apply the relative risk to the existing rates of disease or death to estimate the 'population attributable fraction' (assuming all persons are equally exposed to the change in climate).

Estimation of the attributable burden of disease and premature death was limited to malaria, malnutrition, diarrheal disease, and floods, plus, as a minor contribution, the impacts of heatwaves. It is important to note that this study was conservative because it was limited to those health outcomes for which the baseline climate-health relationship had already been reasonably well characterized in the literature. Also, cautious assumptions were made that the health risks would be significantly reduced with economic development.

The same method was used to estimate the future burden of disease and premature death attributable to climate change for the year 2030. This requires, for a specified future time:

- A modeled scenario of global climate change, geospatially differentiated at the appropriate scale.
- Estimations, by region/country, of population size, and age structure.
- Estimations, by region/country, of the future baseline (counter-factual) rates of disease incidence or premature death.
- Assumptions about the applicable relative risk (e.g. does it stay constant, increase, or decrease over time, given that there will be changes in the target population, including changes due to adaptive actions).

2030 was chosen as the time horizon because, among other reasons, beyond a few decades into the future, there is increasing uncertainty about trends in social, economic, and political circumstances, population living conditions, and the background population health profile.

Study Details

The World Health Organization (WHO) Global Burden of Disease study began in 1992 with the objective of quantifying the burden of disease and injury in human populations (Murray and Lopez 1996). The burden of disease refers to the total amount of premature death and morbidity within a population. The goals of the study were to produce the best possible evidence-based description of population health, the causes of lost health, and likely future trends in health in order to inform policy-making. The WHO Global Burden of Disease 2000 project (GBD) updated the earlier study (Murray et al. 2002). It drew on a wide variety of data sources to develop internally consistent estimates of incidence, prevalence, and mortality, and severity and duration, for over 130 major health outcomes, for the year 2000 and beyond.

To the extent possible, the GBD synthesized all relevant epidemiologic evidence on population health within a consistent and comprehensive framework, the comparative risk assessment. Twenty-six risk factors were assessed, including major environmental, occupational, behavioral, and lifestyle risk factors. Climate change was one of the environmental risk factors assessed (McMichael et al. 2004).

The GBD used two summary measures of population health, mortality and the Disability Adjusted Life Years lost (DALYs) (Murray and Lopez 1996). DALYs provide a better measure than mortality of the population health impacts of diarrheal diseases, malnutrition, and malaria. The attributable burden of DALYs for a specific risk factor was determined by estimation of the burden of specific diseases related to the risk factor; estimation of the increase in risk for each disease per unit increase in exposure to the risk factor; and estimation of the current population distribution of exposure, or future distribution as estimated by modeling exposure scenarios.

For climate change, the questions addressed were what would be the total health impact caused by climate change between 2000 and 2030, and how much of this burden could be avoided by stabilizing greenhouse gas emissions (McMichael et al. 2004). The alternative exposure scenarios were:

- Unmitigated emission trends (UE) (i.e. approximately following the IPCC IS92a scenario);
- Emissions reductions resulting in stabilization at 750 ppm CO₂-equivalent by 2210 (s750); and
- Emissions reductions resulting in stabilization at 550 ppm CO₂-equivalent by 2170 (s550).

Climate change projections were generated using the HadCM2 global climate model (Johns et al. 2001). The health outcomes included were chosen based on sensitivity to climate variation, predicted future importance, and availability of quantitative global models (or feasibility of constructing them); these were:

- the direct health impacts of heat and cold,
- episodes of diarrheal disease,
- cases of *Plasmodium falciparum* malaria,
- fatal unintentional injuries in coastal floods and inland floods/landslides, and
- estimated prevalence of malnutrition (indicated by non-availability of recommended daily calorie intake).

Both global and WHO region-specific estimates were generated.

Results From the WHO Global Burden of Disease Project

Table 1 summarizes the health outcomes included, as well as the assumed mechanism by which climate change induces each of the specified health outcomes.

Table 1: Health Outcomes Included in the WHO Global Burden of Disease Project

Class	Mechanism	Outcome
Direct impacts of heat and cold:	Thermal stress due to higher temperatures	Cardiovascular disease deaths
Water-washed, waterborne, and foodborne disease:	Higher temperatures encourage proliferation of bacterial pathogens	Diarrhoea episodes
Vector-borne disease:	Rainfall and temperature affect vector abundance. Temperature affects incubation period of parasite in mosquito	Malaria cases
	Temperature affects incubation period of virus in mosquito	Dengue cases
Natural disasters*:	Increased floods and landslides due to sea level rise and extreme rainfall.	deaths due to unintentional injuries other unintentional injuries (non-fatal)
Risk of malnutrition	Changes in food production and per capita food availability.	non-availability of recommended daily calorie intake

Source: McMichael et al. 2004

For the year 2000, the mortality attributable to climate change was estimated to be 154,000 (0.3%) deaths, and the attributable burden was 5.5 million (0.4%) DALYs, with approximately 50% of the burden due to malnutrition (McMichael et al. 2004). These estimates are for the year 2000, by which time the amount of climate change since the selected baseline year (1990) was small (approximately 0.2°C). Therefore, future disease burdens would be expected to increase with increasing climate change, unless (implausibly) fully effective adaptation measures were implemented.

Approximately 46% of the DALYs attributable to climate change were estimated to have occurred in the WHO South-East Asia Region (which includes South Asia), 23% in countries in the Africa region with high child mortality and very high adult male mortality, and 14% in countries in the Eastern Mediterranean region with high child and adult male mortality.

Table 2 summarizes the estimated numbers of deaths occurring in 2000 as a result of the impacts of climate change on the occurrence of the five specified health outcomes

amenable to quantitative modeling (see Annex 2 for WHO regions). Figure 3 maps these results by WHO region.

Table 2: Estimated mortality (000s) attributable to climate change in the year 2000, by cause and WHO region

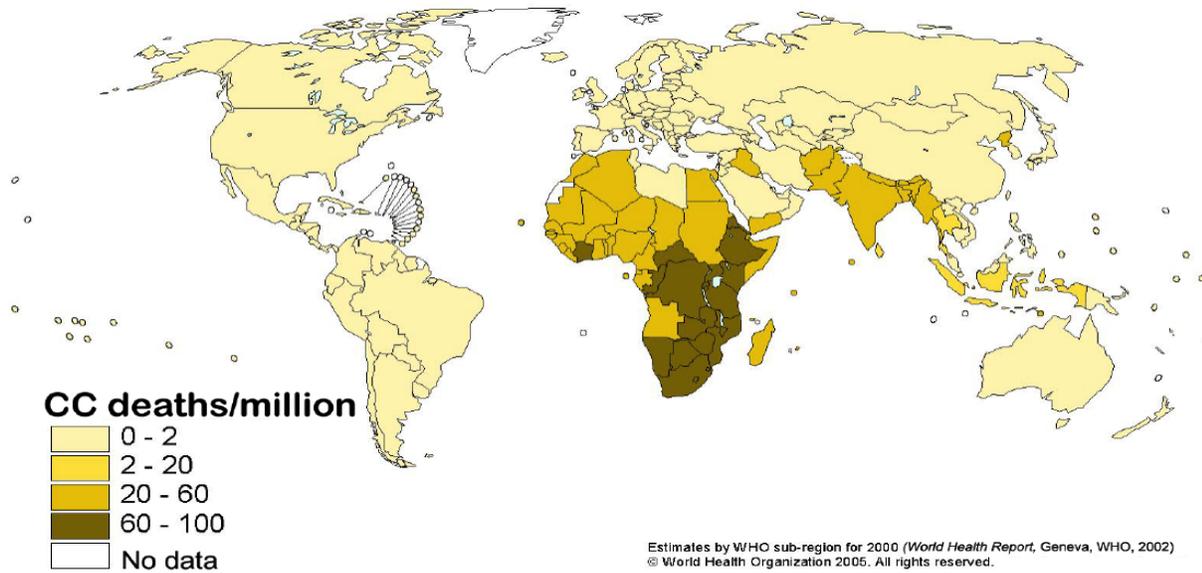
Table 20.16 Estimated mortality (000s) attributable to climate change in the year 2000, by cause and subregion

<i>Subregion</i>	<i>Malnutrition</i>	<i>Diarrhoea</i>	<i>Malaria</i>	<i>Floods</i>	<i>CVD</i>	<i>All causes</i>	<i>Total deaths/million population</i>
AFR-D	8	5	5	0	1	19	66.83
AFR-E	9	8	18	0	1	36	109.40
AMR-A	0	0	0	0	0	0	0.15
AMR-B	0	0	0	1	1	2	3.74
AMR-D	0	1	0	0	0	1	10.28
EMR-B	0	0	0	0	0	1	5.65
EMR-D	9	8	3	1	1	21	61.30
EUR-A	0	0	0	0	0	0	0.07
EUR-B	0	0	0	0	0	0	1.04
EUR-C	0	0	0	0	0	0	0.29
SEAR-B	0	1	0	0	1	2	7.91
SEAR-D	52	22	0	0	7	80	65.79
WPR-A	0	0	0	0	0	0	0.09
WPR-B	0	2	1	0	0	3	2.16
World	77	47	27	2	12	166	27.82

CVD Cardiovascular disease. As described in section 3.6, the estimated cardiovascular deaths represent temperature-related mortality displacement. Therefore no disease burden is estimated for deaths from this cause in Table 20.17.

Figure 3: Burden of Premature Deaths Attributable to Climate Change, for Year 2000

Deaths from climate change



Malaria in 2030

The WHO GBD study used the calculated relative risks to estimate the excess number of incident cases of diarrheal diseases, malnutrition, and malaria in 2030 for the three scenarios (unmitigated emissions (UE) and stabilization scenarios at 550 and 750 ppm CO₂-equivalent).

Diarrheal Diseases

For the estimations for diarrheal diseases, developing countries were defined as those with per capita incomes less than US\$6,000/year in 1990 US dollars. For such countries, the exposure-response relationship used was a 5% increase in diarrheal incidence per °C increase in temperature; this estimate was based on two studies (Checkley et al. 2000; Singh et al. 2001). The study assumed that the climate sensitivity of diarrhea would decrease with increasing GDP; once a country was projected to reach per capita incomes of UD\$6,000/year, then overall diarrhea incidence was assumed to not respond to changes in temperature. The study assumed that diarrheal incidence in richer countries is insensitive to climate change.

The relative risks for each region are a population-weighted average of the countries within the region. The model output was used to generate mid-range estimates; the high relative risks were calculated as a doubling of the mid-range estimate.

Malnutrition

Estimates of national food availability were based on the effects of temperature and precipitation, and the beneficial effects of higher CO₂ levels, projected using the

IBSNAT-ICASA dynamic crop growth models (IBSNAT 1989). Principal characteristics of this model include:

- No major changes in the political or economic context of world food trade or in food production technology;
- Demographic change follows the World Bank mid-range estimate (i.e. 10.7 billion by the 2080s);
- GDP to accumulate as projected by EMF14 (Energy Modeling Forum 1995); and
- A 50% trade liberalization in agriculture is introduced gradually by 2020.

Note that malnutrition has multiple causes. Access to a range of affordable quality foods is required for adequate nutrition. There may be sufficient food production within a country, but families may not have access because the food is not culturally desirable, it is too expensive, or there is inadequate transportation. Subsistence farmers and the urban poor are particularly at risk. Therefore, economic and political factors can be as important as climate in determining food availability. However, this model focused only on the association between climatic factors (including CO₂) and national food availability.

Analyses suggested that the model output was positively related to more direct measures of malnutrition, including incidence of underweight, stunting, and wasting in children <5 years of age. The relative risks of malnutrition were interpreted as being directly proportional to the incidence of underweight. Again, the model output was used to generate mid-range estimates; the high relative risks were calculated as a doubling of the mid-range estimate.

Malaria

Estimates for the projected populations at risk of *Plasmodium falciparum* malaria were based on the MARA/ARMA model (MARA/ARMA 1998). As for other health outcomes, the model output was used to generate mid-range estimates; the high relative risks were calculated as a doubling of the mid-range estimate.

The total estimated excess numbers of cases are shown in Tables 1-3 in Annex 3.

Summary

The projected relative risks attributable to climate change in 2030 vary by health outcome and region, and are largely negative, with the majority of the projected disease burden due to increases in diarrheal disease and malnutrition, primarily in low-income populations already experiencing a large burden of disease (McMichael et al. 2004). Absolute disease burdens depend on assumptions of demographic change, future baseline disease incidence, and the extent of adaptation. Table 3 summarizes the current number of cases of the three health outcomes, the projected number of cases under the unmitigated emissions scenario, and the percentage increase (Ebi 2008).

Table 3: Comparison of current diarrheal disease, malnutrition, and malaria cases with estimated climate change impacts in 2030 assuming the 750 ppm of CO₂ scenario (thousands of cases)

	Diarrheal diseases	Malnutrition	Malaria
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Total	4,513,981	46,352	408,227
Climate change impacts	131,980	4,673	21,787
% increase	3%	10%	5%

Climate change alone, without considering other factors that could increase or decrease incidence, is projected to increase the burden of diarrheal diseases, malnutrition, and malaria by several percentage points worldwide. Although there is high uncertainty in the regional estimates, as would be expected, those regions with high current burdens of these health outcomes are projected to experience the largest increase in 2030. For example, unmitigated emissions are projected to more than double the number of incident cases of diarrheal disease in Africa and parts of Southeast Asia. The largest increase in malnutrition is projected to occur in the parts of Southeast Asia where malnutrition is currently severe. The largest increase in incident cases of malaria is projected to occur in Africa and parts of the Eastern Mediterranean region.

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