CHAPTER 7

How much disease could climate change cause?

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Introduction

Given the clear evidence that many health outcomes are highly sensitive to climate variations, it is inevitable that long-term climate change will have *some* effect on global population health. Climate change is likely to affect not only health but also many aspects of ecological and social systems, and will be slow and difficult (perhaps impossible) to reverse. Many therefore would judge that there is already sufficient motivation to act, both to mitigate the causes of climate change, and to adapt to its effects. However, such actions would require economic and behavioural changes bringing costs or co-benefits to different sectors of society. Decision-makers, from individual citizens to national governments, have numerous competing claims on their attentions and resources. In order to give a rational basis for prioritizing policies, at the least it is necessary to obtain an approximate measurement of the likely magnitude of the health impacts of climate change.

Quantification of health impacts from specific risk factors, performed in a systematic and consistent way using common measures, could provide a powerful mechanism for comparing the impacts of various risk factors and diseases. It would allow us to begin to answer questions such as: on aggregate, are the positive effects of climate change likely to outweigh the negative impacts? How important is climate change compared to other risk factors for global health? How much of the disease burden could be avoided by mitigating climate change? Which specific impacts are likely to be most important and which regions are likely to be most affected?

Caution is required in carrying out and presenting such assessments. Richard Peto, in his foreword to the first global burden of disease study (*1*), echoed the economist John Kenneth Galbraith in suggesting that epidemiologists fall into two classes: those who cannot predict the future, and those who know they cannot predict the future. Given the importance of natural climate variability and the potential for societal and individual factors to mediate the potential effects of climate change, only approximate indications of likely impacts can be expected. However, it is important to make such estimates available to policy-makers, along with a realistic representation of the associated uncertainty; or remain in the current unsatisfactory condition of introducing a potentially important and irreversible health hazard throughout the globe, without any quantitative risk assessment.

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This chapter outlines the estimation of disease burden caused by climate change at global level, performed in the framework of a comprehensive World Health Organization (WHO) project. After the quantification of disease burden for over 100 diseases or disease groups at global level (2), WHO has defined a general methodology to quantify the disease burden caused by 26 risk factors (Comparative Risk Assessment) at selected time points to 2030 (3). Major environmental, occupational, behavioural and lifestyle risk factors are considered including: smoking, alcohol consumption, unsafe sex, diet, air pollution, water and sanitation, and climate change. Despite the scale of the challenge, this has presented a unique opportunity to compare the health consequences of climate change to other important risk factors determining human health, and to estimate future disease burdens.

General methods

Disease burdens and summary measures of population health

The burden of disease refers to the total amount of premature death and morbidity within the population. In order to make comparative measures it is necessary to use summary measures of population health. These, first, take into account the severity/disability and duration of the health deficit, and, second, use standard units of health deficit. The Disability-Adjusted Life Year (DALY), for example, has been used widely (4) and is the sum of:

- years of life lost due to premature death (YLL)
- years of life lived with disability (YLD).

The number of years of life lost (YLL) takes into account the age at death, compared to a maximum life expectancy. Years of life lived with disability (YLD) takes into account disease duration, age of onset, and a disability weight that characterizes the severity of disease.

Estimating burden of disease attributable to a risk factor

Estimation of attributable burdens, using a measure such as DALYs, thus enables Comparative Risk Assessment: i.e. comparison of the disease burdens attributable to diverse risk factors. For each such factor, we need to know the:

1. burden of specific diseases
2. estimated increase in risk of each disease per unit increase in exposure (the "relative risk")
3. current population distribution of exposure, or future distribution as estimated by modelling exposure scenarios.

Since the mid 1990s, WHO has published estimates of the global burden of specific diseases or groups of diseases in the annual World Health Report. The most recent updates of the measurements of these burdens (2) constitute the total disease burden that can be attributed to the various risk factors. For calculating the attributable fraction for diarrhoeal disease, for example, the exposure distribution in the population is combined with the relative risk for each scenario with the following formula (Impact fraction, adapted from Last) (5):

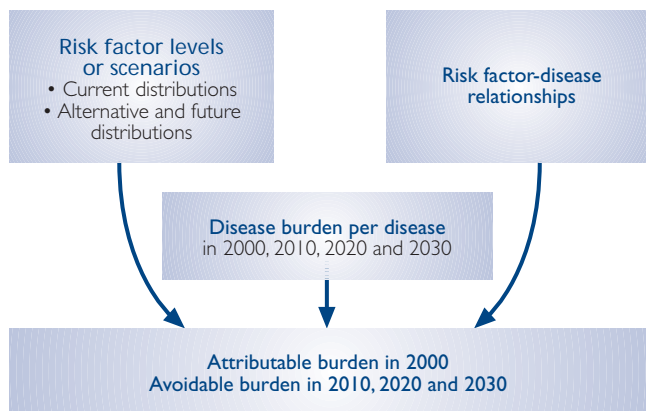$$IF = \frac{\sum P_i RR_i - 1}{\sum P_i RR_i}$$

FIGURE 7.1 Key input data for estimating the global burden of disease caused by climate change.

Each exposure scenario is characterized by a relative risk (RR_i) compared to the individuals that are not exposed to the risk factor, or that correspond to a baseline "theoretical minimum" exposure scenario. The proportion of the population in each exposure scenario is P_i. The key input data for this estimate are summarized in Figure 7.1.

The attributable burden is estimated by multiplying the impact fraction by the disease burden for each considered disease outcome, given in the WHO World Health Report (*2*).
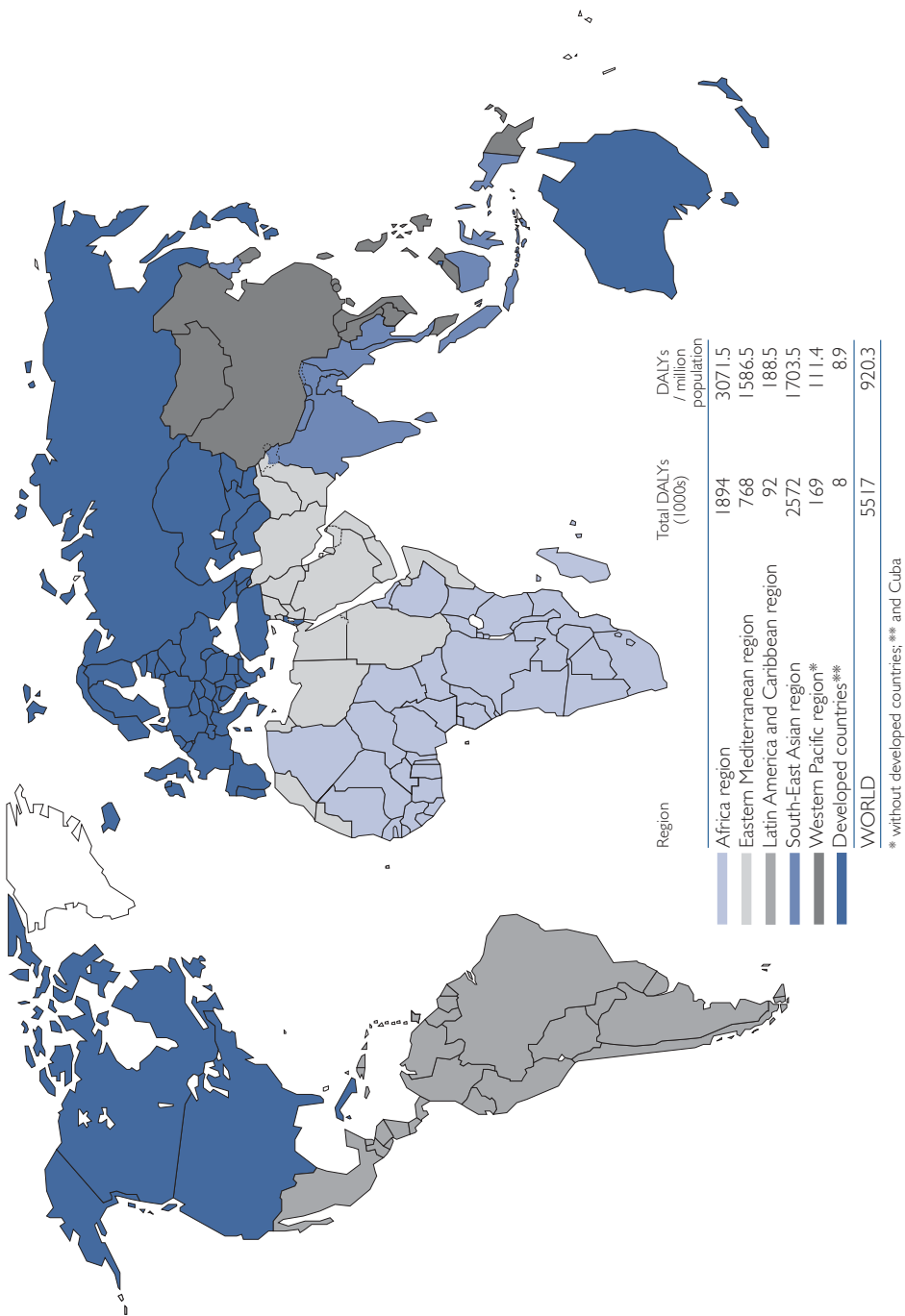
In addition to the attributable burden, the avoidable burden at future time points can be estimated by defining an alternative distribution of the risk factor in the study population and comparing projected relative risks under the alternative scenarios. In this case, the relative risks that are calculated for each scenario are applied to future "climate-change independent" trends produced by WHO, which attempt to take account of the most probable future changes due to climate-independent factors—e.g. improving socioeconomic and control conditions. The analysis therefore attempts to estimate the additional burden that climate change is likely to exert on top of the disease burden that otherwise would have occurred, if climate were to remain constant.

In this comprehensive project assessing the disease burden due to 26 risk factors, disease burden is estimated by sex, seven age groups and fourteen regions of the world. The full details of the analysis are presented in McMichael et al. (*6*). In this chapter, disease burdens are divided only into five geographical regions, plus a separate division for developed countries, which is the combination of the WHO regions: Europe, America A, and Western Pacific A (Figure 7.2). The attributable disease burden for climate change is estimated for 2000. In theory, avoidable burdens can be calculated for the years to 2030, however (at the time of writing) future projections of DALY burdens, in the absence of climate change, are not yet available for these. Instead, we present the climate-related relative risks of each outcome for 2030—i.e. the scenario-specific estimate of the likely proportional change in the burden of each of these diseases, compared to the situation if climate change were not to occur.

Type of evidence available for estimating disease burden due to climate change

The effects of climate change on human health are mediated by a variety of mechanistic pathways and eventual outcomes (chapters 3, 5, 6). There may be

FIGURE 7.2 Estimated impacts of climate change in 2000, by WHO region.

Region	Total DALYs (1000s)	DALYs / million population
Africa region	1894	3071.5
Eastern Mediterranean region	768	1586.5
Latin America and Caribbean region	92	188.5
South-East Asian region	2572	1703.5
Western Pacific region*	169	111.4
Developed countries**	8	8.9
WORLD	5517	920.3

* without developed countries; ** and Cuba

long delays between cause and certain outcomes, and reversibility may be slow and incomplete. Various methods have been developed for quantitative estimation of health impacts of future climate change (7). Ideally, future projections would be based on observations of the effects of the gradual anthropogenic climate change that has occurred so far. However, measurements of climate change and its effects, followed by formulation, testing and modification of hypotheses would take several decades due to the:

- lack of long-term standardized monitoring of climate sensitive diseases;
- methodological difficulties in controlling for effects of non-climatic differences and natural climate variability;
- relatively small (but significant) climatic changes that have occurred so far, that are poor proxies for the larger changes forecast for the coming decades.

While such direct monitoring of climate change effects is desirable, currently it does not provide the information necessary for quantitative estimation. The best estimation of future health effects of climate change therefore comes from predictive modelling based on the most comprehensive current understanding of the effects of climate (not weather) variation on health in the present and recent past, and applying these relationships to projections of future climate change.

Definition of risk factor and exposure scenario

Definition of the risk factor

For the purpose of this assessment, the risk factor climate change is defined as changes in global climate attributable to increasing concentrations of greenhouse gases (GHG).

Definition of exposure levels

As described in chapter 2, climate is a multivariate phenomenon and therefore cannot be measured on a single continuous scale. Also, climate changes will vary significantly with geography and time and cannot be captured fully in global averages of various climate parameters. The exposure scenarios used in this assessment are therefore comprehensive climate scenarios (i.e. predictions of the magnitude and geographical distribution of changes in temperature, precipitation and other climate properties) predicted to result from future patterns of GHG emissions.

Definition of baseline exposure scenario

In order to estimate discrete disease burden attributable to climate change, exposure scenarios need to be compared to a baseline exposure scenario that acts as a reference point. A logical baseline scenario would consist of a climate scenario not yet affected by any change due to GHG emissions. This is difficult to define accurately. The IPCC Third Assessment Report (8) shows clear evidence of changes in global average temperature of land and sea surface since the mid nineteenth century, and of extreme events throughout the last century (chapter 2, Figure 2.5 and Table 2.2), which it concludes mainly are due to human activities. However, given natural climate variability there is no clearly defined consensus on precisely what current climate conditions would have been, either now or in the future, in the absence of GHG emissions.

The baseline scenario therefore has been selected as the last year of the baseline period 1961 to 1990, i.e. 1990. This period is the reference point considered by the World Meteorological Organization and IPCC, and is supported by IPCC conclusions that the majority of climate change since this period has been caused by human activity. The selection of this baseline scenario implies that the generated results of attributable disease burden will be rather conservative, as any human-induced activity before that period is not addressed.

Scenarios considered for 2030

The exposure scenarios under investigation are selected according to the following projected emission levels:

1. unmitigated emission trends (i.e. approximately following the IPCC "IS92a" scenario (9))
2. emissions reduction resulting in stabilization at 750 ppm CO_2 equivalent by 2210 (s750)
3. more rapid emissions reduction, resulting in stabilization at 550 ppm CO_2 equivalent by 2170 (s550).

The predicted temperature changes and rise in sea level associated with these scenarios are outlined in Table 7.1 and Figure 7.3.

Methods for estimating exposure to climate change

Projections of the extent and distribution of climate change were generated by applying the various emission scenarios described above to the HadCM2 global climate model (GCM). This is one of the models approved by the IPCC, verified by back-casting (11), and provides results that lie approximately in the middle of the range of alternative models. The HadCM2 model generated estimates of the principal characteristics of the climate, including temperature, precipitation and absolute humidity for each month, at a resolution of 3.75° longitude and 2.5° latitude. The climate model outputs used here are estimated as averages over thirty-year periods.

Each scenario describes changes in global climate conditions, incorporating geographical variations. All of the population is considered as exposed to the scenario: i.e. Pi (above) is 100% in each case. However, the climate conditions experienced under different scenarios will vary between regions and between climate

TABLE 7.1 Successive measured and modelled global mean temperature and sea level rise associated with the various emissions scenarios. Future estimates are from the HadCM2 global climate model, produced by the UK Hadley Centre.

	1961–90	1990s	2020s	2050s
Temperature (°C change)				
HadCM2 Unmitigated Emissions	0	0.3	1.2	2.1
S750	0	0.3	0.9	1.4
S550	0	0.3	0.8	1.1
Sea level (cm change)				
HadCM2 Unmitigated Emissions	0	N/a	12	25
S750	0	N/a	11	20
S550	0	N/a	10	18

Source: reproduced from reference 10.

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FIGURE 7.3 The global average temperature rise predicted from various emission scenarios: unmitigated emissions scenario (top line), emission scenario which stabilises CO_2 concentrations at 750 ppm by 2210 (middle) and at 550 ppm in 2170 (bottom). *Source: reproduced from reference (10).*
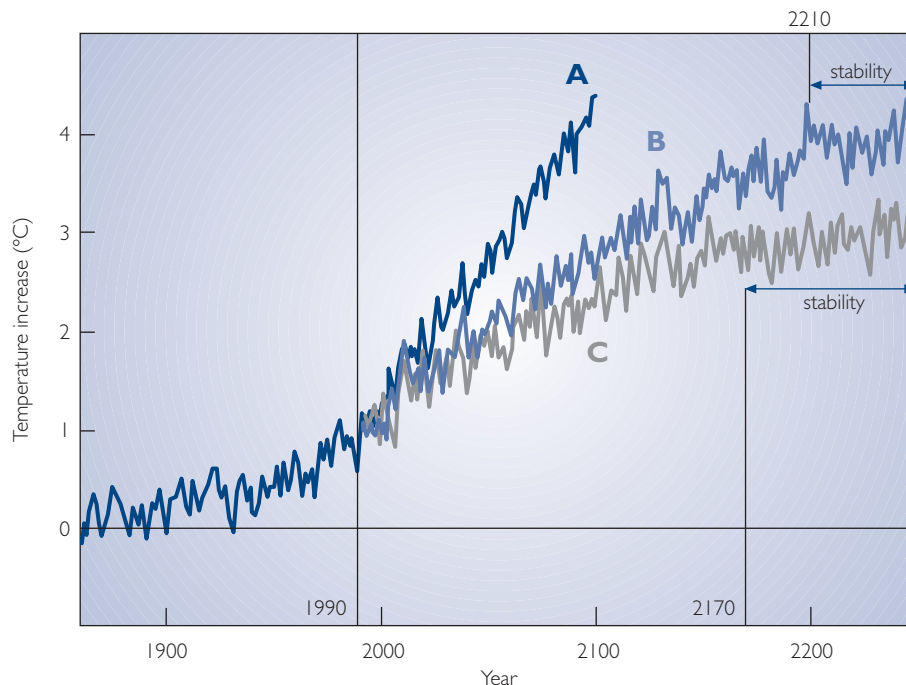
scenarios (e.g. under most future climate scenarios high latitudes will remain generally cooler than the tropics, but will experience greater rates of warming). The risk of suffering health impacts also will be affected by socioeconomic conditions and other factors affecting vulnerability. Such variations are considered in the calculations of relative risks for each disease, rather than in relation to exposure.

Outcomes to be assessed

While a wide variety of disease outcomes is suspected to be associated with climate change, only a few outcomes are addressed in this analysis (Table 7.2). These were selected on the basis of:

- sensitivity to climate variation
- predicted future importance
- availability of quantitative global models (or feasibility of constructing them).

The strength of evidence relating to each of these was reviewed through reference to all papers in the health section of the most recent IPCC report (*12*), from other wide ranging reviews of climate change and health (*13*) and a systematic review of the scientific literature using relevant internet search engines (Medline and Web of Science).

Additional likely effects of climate change that could not be quantified at this point include:

TABLE 7.2 Health outcomes considered in this analysis.

Type of outcome	Outcome	Incidence/Prevalence
Direct impacts of heat and cold	Cardiovascular disease deaths	Incidence
Food and water-borne disease	Diarrhoea episodes	Incidence
Vector-borne disease	Malaria cases; dengue cases	Incidence
Natural disasters[a]	Fatal unintentional injuries	Incidence
Risk of malnutrition	Non-availability of recommended daily calorie intake	Prevalence

[a] Separate estimation of impacts of coastal floods, and inland floods/landslides.

- changes in pollution and aeroallergen levels
- recovery rate of the ozone hole, affecting exposure to UV radiation (*14*)
- changes in distribution and transmission of other infectious diseases (particularly other vector-borne diseases and geohelminths)
- indirect effects on food production acting through plant pests and diseases
- drought
- famine
- population displacement due to natural disasters, crop failure, water shortages
- destruction of health infrastructure in natural disasters
- risk of conflict over natural resources.

Some of these may be included in future assessments as additional quantitative evidence becomes available.

Methods for estimating risk factor-disease relationships

The choice of modelling approach depends also on the availability of high-resolution data on health states and the possibility of estimating results that comply with the framework of the overall Comparative Risk Assessment.

As outlined above, estimates are based on observations of shorter-term climatic effects in the past, i.e. the effect of daily, seasonal or inter-annual variability on specific health outcomes, or on processes that may influence health states, e.g. parasite and vector population dynamics. In undertaking such an approach, it is necessary to appreciate that factors other than climate also are important determinants of disease, and to include in the quantitative estimates the likely effects of modifying factors such as socioeconomic status. Assumptions regarding these effect modifiers need to be clearly stated, together with an indication of the uncertainty range around the quantitative estimates.

There are two principal sets of assumptions relating to the definition of scenarios and health effects. Firstly, the secondary effects of climate change mitigation policies (e.g. the likely health benefits of reduced air pollution) are not considered here. Secondly, it is acknowledged that modifying factors such as physiological adaptation and wealth will influence health impacts due to climate change (*12*). Effects of improving socioeconomic conditions on the baseline (i.e. climate–change independent) rates of the diseases already are included in the WHO future scenarios (e.g. diarrhoea rates are projected to decrease over time as richer populations install improved water and sanitation services). However, changing socioeconomic conditions and physiological and other adaptations also will affect populations' vulnerability to the effects of climate change, and therefore the relative risk under each scenario. For example, improving water and sanitation also will affect the degree to which diarrhoea rates will be affected by temperature changes or more frequent flooding. The following sections describe

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how such affects are accounted for in both the relative risks and the uncertainty estimates for each health impact. No future actions taken specifically to adapt to the effects of a changing climate are considered.

For quantifying health impacts, all independent models linking climate change to quantitative global estimates on health or related impacts (e.g. numbers of people flooded or at risk of hunger) described in the IPCC Third Assessment Report (15) were considered. Where global models do not exist, local or regional projections were extrapolated. Models were further selected on the basis of validation against historical data and plausibility of both biological assumptions and extrapolation to other regions. In order to estimate relative risks for specific years, there is a linear interpolation of the relative risks between the various 30 year periods for which complete climate scenarios exist (e.g. between 2025, as the middle of the period described by the 2011–2040 climate scenario, and 2055, as the middle of the 2041–2070 scenario).

Specific health impacts

Direct physiological effects of heat and cold on cardiovascular mortality

Strength of evidence

The association between daily variation in meteorological conditions and mortality has been described in numerous studies from a wide range of populations in temperate climates (16, 17). These studies show that exposure to temperatures at either side of a "comfort range" is associated with an increased risk of (mainly cardio-pulmonary) mortality. Increases in other disease measures, such as General Practitioner consultations, have been associated with extreme temperatures (18, 19). However, it is not clear how these endpoints relate to quantitative measures of health burden.

Cardiovascular disease (CVD) has the best characterized temperature mortality relationship, followed by respiratory disease and total mortality in temperate countries. These relationships are supported by strong evidence for direct links between high and low temperatures and increased blood pressure, viscosity and heart rate for CVD (20, 21) and broncho-constriction for pulmonary disease (22).

The IPCC Third Assessment Report chapter on human health (11) also concludes that the frequency and intensity of heatwaves increases the number of deaths and serious illness. Yet the same report states that, in temperate countries, climate change would result in a reduction of wintertime deaths that would exceed the increase in summertime heatwave-related deaths.

Given the limited number of studies on which to base global predictions, quantitative estimates are presented only for the best supported of the direct physiological effects of climate change—changes in mortality attributable to extreme temperature for one or several days.

Exposure distribution and exposure-response relationships

The global population was divided into five climate zones according to definitions of the Australian Bureau of Meteorology (23). The polar zone is small and was excluded. Temperature distributions vary greatly within one climate zone. However, due to poor availability of meteorological data at daily time-scales, a single city was chosen to define a representative daily temperature distribution for each region. To give estimates of the mean temperature and variability under

TABLE 7.3 Synthesized relationships between temperature and cardiovascular mortality.

Climate zone	Heat[a]	Cold[a]	T[b]	Model	Source
Hot and dry	1.4	0.6	20	Seasonally adjusted, 1–6 day lags, all cause mortality	ISOTHURM (Delhi)
Warm humid	0.9	1.6	20	Seasonally adjusted, 1–6 day lags, all-cause all-age mortality	ISOTHURM (São Paulo)
Temperate	1.13	0.33	16.5	Seasonally adjusted, 1–2 day lag, cardiovascular disease	Kunst *et al.* 1993
Cold	1.13	0.33	16.5	Seasonally adjusted, 1–2 day lag, cardiovascular disease	Kunst *et al.* 1993

[a] Coefficient of % change in mortality per 1 °C of change in temperature.
[b] Temperature associated with lowest mortality rate.

each climate scenario, these distributions were "shifted" according to the projections of changes in the mean monthly temperature.

An exposure-response relationship was applied in each climate zone. Although many published studies describe the health effects of temperature, few have used daily values, controlled sufficiently for seasonal factors, or given adequate representation to populations in tropical developing countries. For cold and temperate regions, a relationship from a published study was used (*24*); for tropical countries and hot and dry countries a study (ISOTHURM) currently undertaken at the London School of Hygiene and Tropical Medicine (*25*) (Table 7.3).

The proportion of temperature-attributable deaths was calculated using the heat and cold mortality coefficients described in Table 7.3. Climate change attributable deaths were calculated as the change in proportion of temperature-attributable deaths (i.e. heat-attributable deaths plus cold-attributable deaths) for each climate scenario compared to the baseline climate.

The observation that temperatures associated with the lowest mortality vary between climate zones is supported by studies on various United States' cities (e.g. Braga et al. (*26*, *27*)) and suggests that populations adapt at least partially to local conditions over time. However, the likely extent of adaptation has not been quantified for a globally representative range of populations. In our projections for the future, we assume that the temperature associated with lowest mortality rates (T[b] above) increases in line with the projected change in summer temperatures. No adjustment is made to the temperature-mortality slopes, i.e. it is assumed that populations biologically adapt to their new average temperatures, but remain equally vulnerable to departures from these conditions. Because this assumption about adaptation has not been formally tested, we include calculations assuming no adaptation as the other end of our uncertainty range. No adjustment is made for improving socioeconomic status: while rich populations appear to be partially protected by the use of air conditioners (e.g. studies in Chicago, USA (*28*)), research in populations with a wider range of socioeconomic conditions failed to detect a difference in susceptibility (work in São Paulo, Brazil (*29*)).

There also is evidence for a "harvesting effect", i.e. a period of unusually lower mortality following an extreme temperature period. This indicates that in some cases extreme temperatures advance the deaths of vulnerable people by a relatively short period, rather than killing people who would otherwise have lived to average life expectancy. However, this effect has not been quantified for temperature exposures and is not included in the model. As there is large uncer-

TABLE 7.4 Range of estimates of relative risks of cardio-vascular disease mortality attributable to climate change in 2030, under the alternative exposure scenarios.

Region	Relative risks		
	Unmitigated emissions	S570	S550
African region	(1.000–1.011)	(1.000–1.008)	(1.000–1.007)
Eastern Mediterranean region	(1.000–1.007)	(1.000–1.005)	(1.000–1.007)
Latin American and Caribbean region	(1.000–1.007)	(1.000–1.005)	(1.000–1.004)
South-East Asian region	(1.000–1.013)	(1.000–1.009)	(1.000–1.008)
Western Pacific region[a]	(1.000–1.000)	(1.000–1.000)	(1.000–1.000)
Developed countries[b]	(0.999–1.000)	(0.999–1.000)	(0.998–1.000)

[a] without developed countries.
[b] and Cuba.

tainty about the number of years that the casualties would have lived (i.e. the attributable years which are lost by exposure to the risk factor) the relative risk estimates will be used to calculate only attributable deaths, not DALYs.

Table 7.4 shows the range of estimates for the relative risk of cardiovascular mortality under the range of climate scenarios in 2030.

Quantification of temperature's effects on health due to climate change could be improved by the following research:

- additional analyses of the exposure-response relationship in tropical developing countries
- standardization of methods used to build exposure-response relationships
- adaptation
- investigation on additional outcomes, including inability to work in extreme temperatures.

Diarrhoeal disease

Diarrhoeal disease is one of the most important causes of disease burden, particularly in developing countries (2). As outlined in chapter 5, there is strong evidence that diarrhoea (particularly that caused by the bacteria and protozoan pathogens which predominate in developing regions) is highly sensitive to variations in both temperature and precipitation over daily, seasonal, and inter-annual time periods (30–33). It is therefore very likely that long-term climate change will lead to consistent changes in diarrhoea rates.

Despite the described quantitative relationships, this assessment addresses only the effects of increasing temperatures on the incidence of all-cause diarrhoea, as there are additional uncertainties in generating estimates for the effect of precipitation, or for specific pathogens:

- studies have addressed only a small part of the temperature spectrum represented globally—temperature-disease relationships are conditioned by the prevailing types of pathogens and modes of transmission and therefore may vary according to local circumstances;
- type of pathogen, whose occurrence varies with temperature, may affect the severity of disease;
- existing evidence on the link between climate and pathogen-specific diarrhoea cannot be used because important information is unknown, e.g. the partial contribution of each pathogen to all-cause diarrhoea;

- effects of changing rainfall patterns are not addressed because of the difficulties in extrapolating the observed non-linear relationships, and stochastic effects on outbreaks, to other regions.

Exposure distribution and exposure-response relationships

The change in mean annual temperature, per scenario, was estimated for each cell of a 1° latitude by 1° longitude population grid map. This was converted into a population-weighted average change in temperature for each country.

Although the influence of seasonality on diarrhoea is well recognized, only two studies describe a quantitative relationship between climate and overall diarrhoea incidence:

1. Checkley and co-workers (*32*) used time series analyses to correlate temperature, humidity and rainfall to daily hospital admissions in a paediatric diarrhoeal disease clinic in Lima, Peru. Correlations were controlled for seasonal variations and long-term trend. The analysis indicated an 8% (95% CI 7–9%) increase in admissions per 1 °C increase in temperature across the whole year. There was no significant independent association with rainfall or humidity. While the study design gives high confidence in the results, its scope is limited to the more severe (i.e. hospitalizing) diarrhoeal diseases and to children.
2. Singh et al. (*34*) used time series analyses to correlate temperature and rainfall to monthly reported diarrhoea incidence in Fiji. Reported overall incidence increased by 3% (95% CI 1.2–5.0%) per 1 °C temperature increase, and a significant increase in diarrhoea rates if rainfall was either higher or lower than average conditions. The use of monthly averages of climate conditions, and the lack of a clear definition of diarrhoea are likely to introduce a random effect and hence an underestimation of effects.

There appear to be no similar published studies showing clear and consistent evidence for changes in overall diarrhoea incidence with increased temperature in developed countries. The relative importance of pathogens which thrive at lower temperatures appears to be greater in populations of regions with higher standards of living, specifically access to clean water and sanitation (for which there is no clear and consistent evidence for peaks in all-cause diarrhoea in warmer months), compared to less well-off populations (where diarrhoea is usually more common in warmer, wetter months). This is demonstrated best by clear summer peaks of diarrhoea in black, but not white, infants in 1970s Johannesburg (*35*).

Here, countries are defined as "developing" if they have (or are predicted to have, for future assessment years) per capita incomes lower than the richer of the two study countries (Fiji) in 2000—approximately US $6000 per year in 1990. For such countries, a dose-response relationship of 5% increase in diarrhoea incidence per 1 °C temperature increase is applied to both sexes and all age groups. This is consistent with the relationships derived from the two studies described above. The 5% figure is chosen rather than the arithmetic mean of the constants from the two studies (5.5%): firstly to avoid giving a false impression of precision based on only 2 estimates, each with their own confidence intervals, secondly in order to be conservative. A wide uncertainty range (0–10%) is placed on this value in extrapolating these relationships both geographically and into the future. For developed countries, in the absence of further information, a (probably conservative) increase of 0% in diarrhoea incidence per 1 °C temperature increase (uncertainty interval −5 to 5%) is assumed.

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TABLE 7.5 Range of estimates of relative risks of diarrhoea attributable to climate change in 2030, under the alternative exposure scenarios.

Region	Relative risks		
	Unmitigated emissions	**S570**	**S550**
African region	(0.99–1.16)	(0.99–1.13)	(0.99–1.11)
Eastern Mediterranean region	(0.98–1.16)	(0.98–1.11)	(0.98–1.11)
Latin American and Caribbean region	(0.92–1.08)	(0.94–1.06)	(0.95–1.05)
South-East Asian region	(0.99–1.17)	(0.99–1.13)	(0.99–1.12)
Western Pacific region[a]	(0.92–1.09)	(0.95–1.06)	(0.95–1.06)
Developed countries[b]	(0.94–1.06)	(0.94–1.06)	(0.93–1.08)

[a]   without developed countries.
[b]   and Cuba.

Regional relative risks are calculated by multiplying the projected increase in temperature by the relevant exposure-response relationship, using population-weighted averages. For projections of relative risks, developing countries reaching a per capita GDP above US $6000 per year are considered to have the same risk as developed countries, i.e. no effect of temperature on diarrhoea incidence. The resulting estimates of relative risks are given in Table 7.5.

Future research

Investigation of exposure-response relationships from a wider climatic and socioeconomic development could improve the accuracy of estimations. Studies also should explicitly measure economic development and improved levels of sanitation, which are very likely to influence populations' vulnerability to the effects of climate variation on diarrhoeal disease.

Malnutrition

Strength of evidence

Malnutrition is considered as the single most important risk factor to global health, accounting for an estimated 15% of total disease burden in DALYs (*2*). While multiple biological and social factors affect the influence of malnutrition, the fundamental determinant is the availability of staple foods. Climate change may affect this availability through the broadly negative effects of changes in temperature and precipitation and broadly positive effects of higher CO_2 levels on yields of food crops (*36, 37*)). The food trade system may be able to absorb these effects at the global level. However, climate change can be expected to have significant effects on food poverty in conjunction with variation in population pressure and economic capacity to cope (*38*).

Evidence for climate change effects on crop yields is strong. Crop models have been validated in 124 sites in 18 countries over a wide range of environments (*39*)). Major uncertainties relate to the extent this relationship will be maintained over long-term climate change, and in particular how the world food trade system will adapt to changes in production (*40, 41*). The IPCC has concluded with "medium confidence" that climate change would increase the number of hungry and malnourished people in the twenty-first century by 80 to 90 million.

While substantial literature describes effects of climate on individual crops, only one group has used these estimates to predict the numbers of people at risk of hunger (*38*). All results presented are based on work by this group. Although these are the most complete models currently available, they do not take into

account more complex pathways by which climate change may affect health, such as the relative importance of fruit and vegetable availability, animal husbandry, and the effect on micronutrient malnutrition this may induce. The consequences of decreasing water sources and synergistic effects of malnutrition and poverty also cannot be modelled currently. Due to these omissions, the current estimate probably is conservative.

Exposure distribution and exposure-response relationship

Global maps of temperature and rainfall at 0.5° latitude by 0.5° longitude, and estimates of atmospheric CO_2 levels, were generated for each scenario and time point.

The IBSNAT-ICASA dynamic growth models (42) for grain cereals and soybean were used to estimate the effect of projected changes in temperature, rainfall and CO_2 on future crop yields. These crop yield estimates are introduced in the world food trade model "Basic Linked System' (43) to provide national food availability. This system consists of a linked series of 40 national and regional food models for food production, the effects of market forces and Government policies on prices and trade, and trends in agricultural and technological conditions (further details in Fischer (44)). Principal characteristics of the model include the following:

- assumes no major changes in political and economic context of world food trade
- population growth occurs according to the World Bank mid-range estimate (45)—10.7 billion by the 2080s
- GDP increases as projected by the Energy Modelling Forum (46)
- 50% trade liberalization is introduced gradually by 2020.

National food availability is converted into the proportion of the population in each region who do not have sufficient food to maintain a basal metabolic rate of 1.4, the UN Food and Agriculture Organization's definition of under-nourishment (47). The model generates outputs for continents principally made up of vulnerable developing countries (i.e. excluding North America, Europe and China). Although the broad geographical scale of the food model precludes detailed analysis, the model outputs correlate with incidence of stunting and wasting (48) at the continental level. For this analysis, it is therefore assumed that projected changes in food availability will cause proportional changes in malnutrition.

The relative risks of malnutrition are shown in Table 7.6. Uncertainty ranges around these estimates are difficult to quantify, as aside from applying alternative climate scenarios to a series of Hadley centre climate models, no sensitivity analyses have been carried out on other model assumptions. Hence, there are several possible sources of uncertainty, including the variation of critical parameters (particularly rainfall) between different climate models, and the influence of food trade and future socioeconomic conditions affecting the capacity to cope with climate-driven changes in food production. The mid-range estimates therefore are derived from a simple application of the model described above. In the absence of further information at this point, uncertainty intervals are defined as ranging from no risk to doubling of the mid-range risk.

Focus for research

For the purpose of estimating burden of disease, priorities for future research should include:

TABLE 7.6 Range of estimates of relative risks of malnutrition attributable to climate change in 2030, under the alternative exposure scenarios.

Region	Relative risks		
	Unmitigated emissions	S570	S550
African region	(1.00–1.05)	(1.00–1.09)	(1.00–1.00)
Eastern Mediterranean region	(1.00–1.12)	(1.00–1.20)	(1.00–1.06)
Latin American and Caribbean region	(1.00–1.00)	(1.00–1.22)	(1.00–1.10)
South-East Asian region	(1.00–1.27)	(1.00–1.32)	(1.00–1.22)
Western Pacific region[a]	(1.00–1.00)	(1.00–1.05)	(1.00–1.02)
Developed countries[b]	(1.00–1.00)	(1.00–1.00)	(1.00–1.00)

[a] without developed countries.
[b] and Cuba.

- sensitivity of estimates to the outputs of various different climate models
- estimation of uncertainty around exposure-response relationships
- validation of the climate-malnutrition model against past data
- improved resolution of model outputs, e.g. to national level
- correlation of model outputs with health outcomes at higher resolution
- investigation of synergistic effects of water availability and poverty on malnutrition.

Natural disasters caused by extreme weather and sea level rise

Natural disasters caused by extreme weather events are a significant cause of mortality and morbidity worldwide (*49*, *50*). These impacts are influenced by short and long-term averages and variability of weather conditions (*51*, *52*), and are likely to be affected by the observed and predicted trends towards increasingly variable weather (see chapter 2).

Weather events considered for estimating disease burden include the following:

- coastal flooding, driven by sea level rise
- inland flooding and mudslides caused by increased frequency of extreme precipitation.

Due to lack of quantitative information, climate change effects on the following impacts of natural disasters could not be quantified. However, the aggregate effect of such longer-term mechanisms may very well be greater than from the acute effects:

- effects of wind storms
- effects of melting snows and glaciers on floods and landslides
- longer term health impacts resulting from population displacement
- consequences of damage to health systems
- infectious disease outbreaks and mental problems due to emergency situations (such as living in camps).

Exposure distribution and exposure-response relationship

Coastal floods: Published models estimate the change in sea levels for each scenario (*53*, *54*). The number of people affected has been estimated by applying these changes to topography and population distribution maps. The model has

shown good results in comparison with detailed assessments at national level (summarized in Nicholls (*54*)).

Inland floods and mudslides: Despite clear causal links, inland floods and mudslides have not yet been quantitatively related to health impacts (*55*). At local level such natural disasters are determined by the frequency of extreme precipitation over a limited period (hour, day or week) and the average amount of precipitation. Health impacts are modulated by the topographical distribution of population as well as social aspects of vulnerability, including the quality of housing and early warning systems (*56*).

In the absence of detailed information, this analysis makes the *a priori* assumption that flood frequency is proportional to the frequency of monthly rainfall exceeding the highest monthly rainfall that would, under baseline (i.e. 1961–1990) climate conditions, occur in every 10 years (i.e. the upper 99.2% confidence interval of the distribution of monthly rainfall). The change in the frequency of such extreme events under the various climate scenarios was calculated for each cell of the global climate model grid. Using GIS software, this was overlaid on a map of global population distribution at 1° by 1° resolution. This allowed the calculation of the measure of exposure (i.e. the *per capita* change in risk of experiencing such an extreme weather event) within each region.

In contrast to the other health impacts considered in this assessment, health impacts caused by natural disasters do not refer to a specific disease, with an associated burden calculated by WHO. It is therefore not possible directly to apply the impact fraction calculations described above. Instead, it is necessary to estimate the impacts *attributable to these climate events* under baseline climate conditions; relative risk estimates for future scenarios are applied to these numbers. The numbers of such deaths and injuries are based on the EM-DAT database (*57*), which records events resulting in at least one of the following: (1) >10 people killed, (2) >200 injured or (3) a call for international assistance. Although the most rigorously compiled and most comprehensive database available at the global scale, this is probably subject to significant under-reporting, so that estimates are likely to be conservative. EM-DAT quotes numbers of people killed, injured and affected. However for this assessment only the numbers of people killed are used as the EM-DAT group (EM-DAT Director, pers. comm.) considers injury numbers for floods to be unreliable, and currently it is not possible to fully characterize the health impact of being affected by flooding. Annual incidence of death attributable to such disasters under baseline climate conditions was estimated as 20-year averages for each region.

Baseline incidence rates alter over time, according to vulnerability. Some factors decrease vulnerability, such as improving flood defences implemented by populations becoming richer, and some increase vulnerability, such as increasing population density in coastal areas. Adjustments were made to account for these effects. Nicholls' model (*54*) incorporates coastal flooding defences in line with GNP change and population distribution. For inland floods, vulnerability effects are approximated by an analysis for all natural disasters (*58*). These effects are not specific to inland floods but nevertheless were applied as the specific relationship has not been modelled. There is some evidence that young children and women are more vulnerable to acute impacts of natural disasters from earthquakes (*59*) and famines (*60*). This information is considered insufficient to apply to these estimates, equal impacts for all age and sex groups therefore are assumed.

TABLE 7.7 Range of estimates for the relative risks of flood deaths attributable to climate change in 2030.

Region	Inland floods			Coastal floods		
	Unmitigated emissions	S570	S550	Unmitigated emissions	S570	S550
African region	(1.00–2.27)	(1.00–2.65)	(1.00–3.16)	(1.20–1.79)	(1.15–1.59)	(1.13–1.55)
Eastern Mediterranean region	(1.00–6.83)	(1.00–6.69)	(1.00–3.16)	(2.16–5.61)	(1.86–4.46)	(1.80–1.55)
Latin American and Caribbean region	(1.00–4.24)	(1.00–4.43)	(1.00–3.74)	(1.80–4.20)	(1.61–3.43)	(1.57–3.28)
South-East Asian region	(1.00–1.75)	(1.00–2.39)	(1.00–2.49)	(1.06–1.21)	(1.04–1.15)	(1.04–1.15)
Western Pacific region[a]	(1.00–3.13)	(1.00–2.70)	(1.00–2.50)	(1.03–1.10)	(1.02–1.08)	(1.02–1.07)
Developed countries[b]	(1.00–8.79)	(1.00–8.69)	(1.00–7.73)	(1.32–2.27)	(1.34–2.36)	(1.45–2.81)

[a] without developed countries.
[b] and Cuba.

Uncertainty of these estimates of course is related to the frequency of extreme weather events as modelled by the various climate scenarios and models, and to evolving protection over time due to projected increases in GNP. Results for coastal flooding are more reliable; they are driven by changes in sea level rise that are relatively consistent across climate models. The estimates are much more uncertain for inland flooding, as precipitation predictions vary considerably between climate models and scenarios. In addition, while the models do account for changes in protection proportional to GNP, individual responses to risk have not been quantified (*61*). As it can be expected that individual response acts as protection, the results are considered as an upper limit. Mid-estimates are assumed as 50% of the upper limit, the lower estimate assumes that 90% of the projected impacts would be avoided. For inland flooding estimates, the upper and lower estimates are expanded to include a relative risk of 1 (i.e. no change) to 50% greater exposure and no adaptation, to take account of the greater uncertainty inherent in the precipitation estimates.

The ranges of estimates for relative risks of floods in different regions are presented in Table 7.7.

Future research

The link between extreme weather events and the health impacts of the resulting disasters are surprisingly poorly researched. Substantial improvements could be made by improved investigation of:

- current health impacts from natural disasters, particularly in developing countries
- more detailed description of disasters
- analysis of health impacts versus intensity of precipitation at higher temporal and spatial resolution
- formal sensitivity analyses for each model parameter
- longer-term health effects: particularly those resulting from population displacement or drought periods and their effects on food production.

Such research would improve the accuracy of estimates and the inclusion of probably more important health effects.

Falciparum *malaria*

Strength of evidence

Vector-borne diseases are among the most important causes of global ill-health, particularly in tropical regions (*2*). As described in chapter 6, substantial laboratory (*62*, *63*) and field evidence (*64*) indicate that both vectors and the pathogens they transmit are highly sensitive to climate conditions, and therefore likely to be affected by future climate change. There is, however, considerable debate over the degree to which potential climate-driven increases in geographical distributions and rates of disease will be prevented by modifying factors (availability of sufficient rainfall or suitable habitat) and the effects of control programmes, socioeconomic developments and population immunity (*11*, *65–68*).

Although climate change is likely to have some effect on all climate-sensitive diseases, only a few have been investigated at the global scale. This assessment is restricted to *falciparum* malaria, which has been subjected to more detailed study, by more independent research groups, than other diseases.

Exposure distribution and exposure-response relationships

The main parameters affecting vector-borne diseases include temperature, rainfall, and absolute humidity. These were mapped for each considered scenario as described above. Quantified relationships between climate, vector population biology and disease incidence have not been described in generalized models, as they depend upon a variety of modifying factors also described above. In addition, the complexity of immune response of populations to changing exposure to infection is difficult to predict (*69*, *70*). The only global models available to date predict changes in geographical and temporal distributions, and therefore populations at risk, rather than incidence of disease. This analysis assumes that relative changes in disease incidence are proportional to changes in the population at risk.

Of the various models that investigate the relationship between climate and malaria, only two have been validated directly to test how well they explain the current distribution of the disease over wide areas. The MARA climate model (Mapping Malaria Risk in Africa) (*71*, *72*) is based on observed effects of climate variables on vector and parasite population biology and malaria distributions in local field studies. This information is used to define areas that are climatically suitable for *falciparum* malaria transmission, and therefore the population at risk, throughout Africa. Predictive distribution maps generated from the model show a close fit to the observed margins of the distribution in Africa, based on a detailed historical database, independent of the data used to create the original model. The major disadvantages of the model for this exercise are that the validation by visual rather than statistical comparison of the predicted and observed maps, and the distribution limits, are assumed to be constrained only by climate rather than by control or other socioeconomic factors. While the validation indicates that this is a reasonable assumption for Africa, it may be less appropriate for other regions.

The other validated model is that of Rogers and Randolph (*66*) which uses a direct statistical correlation between climate variables and observed disease distributions to give a highly significant and reasonably accurate fit to the current global distribution of all malaria. This model has the significant advantages of not making *a priori* assumptions about climate–disease relationships, and being tested directly against observed data. However, the quality of the available distribution data (relatively coarse maps of the distribution of both *falciparum* and *vivax*

malaria) means that the model can be validated only against a subset of the original data used for model building, rather than a completely independent data set. Neither is it clear what effect the combination of distributions of different parasites, with different climate sensitivities, may have on model sensitivity to future climate changes.

As both models are informative but imperfect descriptions of climate-malaria relationships, and have not been directly compared with one another, the results of both are considered in this assessment. Relative risks presented here are the ratios of the population at risk in each region, relative to the population at risk under the 1961–1990 climate, according to the MARA model. "Population at risk" is considered as the population living in areas climatically suitable for more than one month of malaria transmission per year. In order to estimate disease burdens, these relative risks are multiplied with the baseline incidences of malaria for each region. This method is conservative, as it accounts only for malaria in the additional population at risk and not for increasing incidence within already endemic populations. An additional conservative assumption built into the model is that climate change will not cause expansion of the disease into developed regions, even if they become climatically suitable. We are therefore estimating climate-driven changes in the population at risk within those regions where current and predicted future socioeconomic conditions are suitable for malaria transmission.

Possible sources of uncertainty may include:

- results based on different climate projections, as for the other factors
- the degree to which the model validated for Africa applies to other regions
- the relationship between the increase of the population at risk and the incidence of disease for each region
- the influence of control mechanisms.

These uncertainties are likely to be considerable, but have not been formally quantified. As the other model validated for field data (66) predicts practically no increase in the population at risk even under relatively severe climate change, the lower uncertainty estimate assumes no effect. The upper range is estimated as a doubling of the mid-range estimate.

TABLE 7.8 Range of estimates for the relative risks of malaria attributable to climate change in 2030, under the alternative exposure scenarios.

Region	Relative risks		
	Unmitigated emissions	S570	S550
African region	(1.00–1.17)	(1.00–1.11)	(1.00–1.09)
Eastern Mediterranean region	(1.00–1.43)	(1.00–1.27)	(1.00–1.09)
Latin American and Caribbean region	(1.00–1.28)	(1.00–1.18)	(1.00–1.15)
South-East Asian region	(1.00–1.02)	(1.00–1.01)	(1.00–1.01)
Western Pacific region[a]	(1.00–1.83)	(1.00–1.53)	(1.00–1.43)
Developed countries[b]	(1.00–1.27)	(1.00–1.33)	(1.00–1.52)

[a] without developed countries.
[b] and Cuba.

Future research

Additional information on the following would contribute to improvements in quantitative predictions of vector-borne disease frequency caused by climate change:

- models relating climate parameters to disease incidence rather than areas and populations at risk
- relationships between climate and other vector-borne diseases
- effects of population vulnerability
- model validation with past and current data on climate parameters and disease frequency
- effects of climate variability rather than change in average values alone.

Aggregated estimates for 2000

Projections of DALYs for specific diseases are required in order to convert relative risks into estimates of burden of disease. While DALY projections for the period to 2030 will shortly be released by WHO, currently they are available for 2000 alone. The application of the relative-risk models described above may give a better estimate of the current health impacts of climate change than directly measuring long-term changes in health states and correlating them against long-term changes in climate (see chapter 10). Although it is perhaps counter-intuitive and somewhat unsatisfactory to use models rather than direct observation to estimate current disease, it is a necessary consequence of both the poor surveillance data that is available for monitoring long-term trends, and the difficulties of separating out the contributions of climatic and non-climatic factors.

Relative risks for 2000 have been estimated as described above, and applied to the disease burden estimates for that year, with the exception of the effects of extreme temperatures on cardiovascular disease, for the reasons described above (Table 7.9). While the resulting estimates are clearly of limited value in informing policies related to future GHG emissions, they do address two purposes. Firstly, illustrating the approximate magnitude of the burden of disease that already may be caused by climate change, if current understanding of climate-health relationships is correct. Secondly, serving to highlight both the specific diseases (particularly malnutrition, diarrhoea and malaria) and the geographical regions (particularly those made up of developing countries) that are likely to make the greatest contribution to the future burden of climate-change associated disease.

TABLE 7.9 Estimates for the impact of climate change in 2000 in thousands of DALYs, given by applying the relative risk estimates for 2000 to the DALY burdens for specific diseases quoted in the World Health Report (2002) (2).

	Malnutrition	Diarrhoea	Malaria	Floods	Total	Total DALYs/ million population
African region	616	414	860	4	**1894**	**3071.5**
Eastern Mediterranean region	313	291	112	52	**768**	**1586.5**
Latin American and Caribbean region	0	17	3	72	**92**	**188.5**
South-East Asian region	1918	640	0	14	**2572**	**1703.5**
Western Pacific region[a]	0	89	43	37	**169**	**111.4**
Developed countries[b]	0	0	0	8	**8**	**8.9**
World	2847	1460	1018	192	**5517**	**920.3**

[a] without developed countries.
[b] and Cuba.

Conclusions

Attempts to predict the future health impacts of any risk factor are necessarily uncertain. They rely on a reasonable projection of future exposures to the risk factor, unbiased measurement of the relationship between the exposure and health impacts, and the assumption that this relationship will either hold constant, or change in a predictable manner.

Climate change differs from other health risk factors in that considerable effort has been devoted to generating and evaluating formal models to forecast future climate in response to likely trajectories of atmospheric gaseous compositional change. Arguably we therefore have better information on future climate than for most health exposures. Substantial knowledge also has been accumulated on the relationship between climate variations (either over short time periods or geographically) and a series of important health impacts. Although this information is far from complete, it provides a basis for a first approximation of the likely scale of climate change effects on a range of impacts.

The health impacts of climate change were estimated for the disease outcomes that (1) are of global importance, (2) the IPCC concludes are most likely to be affected by climate change, and (3) for which sufficient information for global modelling was available.

Climate change is expected to affect the distribution of deaths from the direct physiological effects of exposure to high or low temperatures (i.e. reduced mortality in winter, especially in high latitude countries, but increases in summer mortality, especially in low latitudes). However, the overall global effect on mortality is likely to be more or less neutral. The effect on the total burden of disease has not been estimated, as it is unclear to what extent deaths in heat extremes are simply advancing deaths that would have occurred soon in any case.

It is estimated that in 2030 the risk of diarrhoea will be up to 10% higher in some regions than if no climate change occurred. Uncertainties around these estimates mainly relate to the very few studies that have characterized the exposure-response relationship.

Estimated effects on malnutrition vary markedly across regions. By 2030, the relative risks for unmitigated emissions relative to no climate change vary from a significant increase in the south-east Asia region, to a small decrease in the western Pacific region. There is no consistent pattern of reduction in relative risks with intermediate levels of climate change stabilization. Although these estimates appear somewhat unstable due to the high sensitivity to regional variation in precipitation, they are large and relate to a major disease burden.

Proportional changes in the numbers of people killed in coastal floods are very large, but induce a low disease burden in terms of people immediately killed and injured. Impacts of inland floods are predicted to increase by a similar order of magnitude and generally cause a greater acute disease burden. In contrast to most other impacts, the relative increase in risks tends to be similar in developed and developing regions. However, these apply to baseline rates that are much higher in developing than developed countries. Estimates are subject to uncertainty around the likely effectiveness of adaptation measures, and around the quantitative relationships between changes in precipitation, the frequency of flooding and associated health impacts. The suggestion of a trend towards decreasing incidence with increasing GHG emissions in some regions most probably is due to the uncertainties inherent in predicting precipitation trends.

Relatively large changes in relative risk are estimated for *falciparum* malaria in regions bordering current endemic zones. Relative changes are much smaller in areas that already are highly endemic, mainly because increases in transmission in already endemic zones are not considered in this analysis. Most temperate regions are predicted to remain unsuitable for transmission, either because they remain climatically unsuitable (most of Europe), and/or socioeconomic conditions are likely to remain unsuitable for reinvasion (e.g. the southern United States). The principal uncertainties relate to the reliability of extrapolations made between regions, and the relationship between changes in the population at risk of these diseases and disease incidence.

Application of the models derived above to the disease estimates for the present (i.e. 2000) suggest that, if the understanding of broad relationships between climate and disease is realistic, then climate change already may be having some impacts on health. This shows the advantages of using the DALY system to take into account not only the proportional change in each impact, but also the size of the disease burden. Although proportional changes in impacts such as diarrhoea and malnutrition are quite modest (compared to floods for example) they are likely to be extremely important in public health because they relate to such a large burden of disease. Similarly, such analyses emphasise that the impacts are likely to be much larger in the poorest regions of the world. Unfortunately, the relatively poor health surveillance systems that operate in many of the areas likely to be most affected by climate change, coupled with the difficulties of separating climatic and non-climatic influences, make it extremely difficult to test directly whether the modest expected changes have occurred or been prevented by non-climatic modifying factors. Improvements in models, and particularly in the collection of health surveillance data, will be essential for improving the reliability and usefulness of such assessments.

The total estimated burden for the present is small in comparison to other major risk factors for health measured under the same framework. Tobacco consumption, for example, is estimated to cause over ten times as many DALYs (*3*). It should be emphasised, however, that in contrast to many risk factors for health, exposure to climate change and its associated risks are increasing rather than decreasing over time.

All of the above models are based on the most comprehensive currently available data on the quantitative relationships between climate and disease. However, other factors clearly affect rates of all of these diseases and in many cases interact with climatic effects. As far as possible, the effect of non-climatic factors (both current and future) has been included in these analyses. Understanding of the interactions between climate and non-climatic effects remains far from perfect, and the degree to which population adaptation (physiological, behavioural or societal) may absorb climate-driven changes in risk represents the greatest degree of uncertainty in our projections. Research on these interactions clearly is necessary, and should greatly improve the accuracy of future estimates, as well as indicating how best to adapt to climate change.

In every assessment of disease burden at global level, a model relying on a number of hypotheses needs to be constructed, as only a fraction of the necessary data is ever available. While these results still bear considerable uncertainty, the international climate research community (represented by the UN IPCC) concludes that anthropogenic climate change has occurred already, will continue to occur and will adversely affect human health. This first global assessment, based

on a comparable and internally consistent method, provides the opportunity to explore the diverse and potentially large health impacts anticipated.

This assessment serves not only to generate the best estimates possible given current knowledge, but also to highlight the most important knowledge gaps that should be addressed in order to improve future assessments. A very large part of possible health effects were not included in this assessment, either because of insufficient baseline data on health and climate or because the exposure-response relationships have been inadequately researched for quantifying those impacts. No indirect (air pollution and then disease), synergistic (poverty), or longer-term effects (displacement of populations) have been considered in this analysis. In addition the projections are made only until 2030, which is somewhat unsatisfactory for a health exposure that accumulates gradually and perhaps irreversibly. For these reasons the estimates should be considered not as a full accounting of health impacts but as a guide to the likely magnitude of some health impacts of climate change, in the near future.

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