IPCC WGII Fourth Assessment Report – Draft for Government and Expert Review

Chapter 8: Human Health

Coordinating Lead Authors
Ulisses Confalonieri (Brazil) and Bettina Menne (WHO, Regional Office for Europe)

Lead Authors
Rais Akhtar (India), Kristie L Ebi (United States), Maria Hauengue (Mozambique), R Sari Kovats (United Kingdom), Boris Revich (Russia) and Alistair Woodward (New Zealand)

Contributing Authors
Tarakegn A. Abeku (Ethiopia), Mozaharul Alam (Bangladesh), Paul Beggs (Australia), Bernard Clot (Switzerland), Chris Furgal (Canada), Simon Hales (New Zealand), Guy Hutton (United Kingdom), Tord Kjellstrom (Australia), Nancy Lewis (United States), Anil Markandya (United Kingdom), Glenn McGregor (New Zealand), Kirk Smith (United States), Christina Tirado (Spain), Madeleine Thomson (United Kingdom), Tanja Wolf (Germany)

Review Editors
Susanna Curto (Argentina), Anthony McMichael (Australia)

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Executive Summary

1 Life expectancy and other health indicators are improving in many, but not all, countries. There continues to be marked inequalities in health status within and between countries. Progress is particularly slow in areas where economic development has stalled and there is a heavy burden of diseases such as HIV/AIDS, malaria, and tuberculosis. Given present trends, it is unlikely that the health-related Millennium Development targets will be met in 2015 in all countries (very high confidence). As a consequence, many populations will continue to struggle with stresses of all kinds, including those related to climate. [8.1.1; 8.7].

2 Health outcomes (including injury) that are sensitive to climatic conditions make up a substantial fraction of the total worldwide burden of disease. For instance, almost 1 person in 5 in low-income countries is under-nourished and approximately 365 million episodes of malaria occur annually in Africa. [8.1.1.].

3 Populations that are most vulnerable to the health impacts of climate change include slum dwellers and homeless people in large urban areas, those living in water-stressed regions, settlements in coastal and low-lying areas, and resource-dependent populations (very high confidence)[8.4.2; 8.6.1.3; 8.7].

4 A standardized approach to estimating the global burden of disease indicates that climate change is contributing to mortality and morbidity (low to medium confidence). Climate change will increase the health burdens to 2030; these impacts will be reduced in the medium-term if carbon emissions are stabilized at 550 ppm (very high confidence) [8.4.1.1].

5 Due to the very large number of people that will be affected, under nutrition linked to drought and flooding will be one of the most important consequences of climate change (medium confidence). Although current models suggest global crop yields will increase with climate change, at least till the end of the 21st century, expert assessments of the prospects for food security for populations most dependent on natural resources are generally pessimistic (medium confidence). [8.1.1; 8.2.3; 8.4.2].

6 Climate change is affecting health-relevant insect species (vectors) (medium-low confidence). [8.2.9] whether an increase in potential for disease transmission leads to more frequent occurrence of disease depends on many factors other than climate. Nevertheless, projected changes in climate will increase the pressures on disease control activities in many parts of the world (medium-high confidence) [8.4.1].

7 Research published since the TAR supports previous assessments that climate change will alter the incidence and range of malaria (medium confidence), although the magnitude of the effect is smaller than previously estimated. [8.4.1.2].

8 35000 deaths are directly attributable to the 2003 European heat wave. This event and Hurricane Katrina in 2005 showed that developed countries may not be well prepared for extreme weather events. Further, given that a heat wave as severe as that in Europe in 2003 is very unlikely to have occurred in the absence of anthropogenic climate change, the casualties may include the first deaths that can be attributed to climate change. (low to medium confidence). [8.2.1; 8.2.2;].

9 We know much more about the relation between high ambient temperature and health than at the time of the TAR, but there is still little information on the effects of high ambient temperature on mortality outside developed countries. Population aging will expand greatly the population at

highest risk from heat. Acclimatization and adaptation will reduce the impacts of more frequent heat extremes, but will not eliminate them. (high confidence) [8.2.1; 8.4.1].

10 Climate change will have some health benefits (high confidence), including reduced cold-related mortality and restricted distribution of vector-borne diseases where rainfall is the limiting factor. The balance of positive and negative health effects will vary from one location to another, and will alter over time if temperatures continue to rise. [8.2.1; 8.4.1].

11 Studies from a wider range of countries provide evidence that increases in daily temperature will increase the number of cases of some common forms of food poisoning in temperate regions (medium confidence), and rising sea surface temperatures will increase rates of fish poisoning (ciguatera) in tropical coastal regions (medium confidence).[8.1.3; 8.2.3; 8.2.4].

12 The impacts of flooding are particularly severe in areas of environmental degradation, and in communities lacking basic public infrastructure, including sanitation and hygiene (very high confidence). [8.2.2] Increases in frequency and intensity of flood events will test the integrity of water management systems and increase water-borne disease (medium-low confidence). [8.2.7].

13 Studies published since the TAR provide stronger evidence that climate change will affect air quality, particularly by increasing concentrations of ground-level ozone (high confidence) and other pollutants (medium confidence). [8.2.5; 8.4.1].

14 Loss of good health is one of the biggest cost items in economic calculations of the impacts of climate change; and therefore the ways in which these costs are calculated has a major influence on cost-benefit comparisons. Climate change is likely to reduce economic productivity via exposure of workers to heat stress (medium confidence).[8.6].

15 In general, economic development is associated with improved capacity to adapt to climate change. But on its own, economic development will not insulate the world’s population from the effect of climate change. On current trends, many people will not benefit from improved material prosperity in time to avoid the impacts of climate change. Critically important will be the manner in which economic growth occurs, the distribution of the benefits of growth, and trends in other factors such as education, health care and public health infrastructure that have a strong, independent effect on health status (very high confidence). [8.3.2].

16 Some climate-specific adaptation measures have been developed and implemented both within the health sector and beyond, mostly in relation to preparedness for extreme events and infectious diseases. There has been progress in the design and implementation of climate-health warning systems, established to reduce effects of weather extremes as well as for the seasonal predictions of infectious diseases. Limited evidence suggests that such systems are effective (medium confidence).[8.6.1; 8.6.2].

17 There are important prerequisites for adaptation that are currently not met in many parts of the world. For instance, access to primary health care and basic education are essential elements of strategies to cope with climate change, but are not available to millions of people. Public awareness, good use of local resources, effective governance arrangements and community participation are all required to mobilize and prepare for climate change. These present particular challenges in resource-poor communities.

8.1 Introduction

This chapter describes the observed and projected health impacts of climate change, current and future populations at risk, and the strategies, policies, and measures that have been and can be taken to reduce impacts. The chapter reviews the knowledge that has emerged since the Third Assessment Report (TAR) (McMichael and Githeko 2001), including empirical research on the early effects of climate change. Published research continues to focus on impacts in high-income countries, and there remain important gaps in information for the more vulnerable populations in low- and middle-income countries.

8.1.1 State of health in the world

Health includes physical, social, and psychological well-being. Population health is a primary goal of sustainable development. Moreover, ill health increases vulnerability and reduces adaptive capacity. Populations with high rates of disease and injury struggle with stresses of all kinds, including those related to climate.

In many respects, measures of health have improved remarkably over the last fifty years. For instance, average life expectancy at birth has increased world-wide since the 1950s (WHO 2003a, 2004a). Globally, child mortality decreased from 147 to 80 deaths per 1000 live births from 1970 to 2002 (WHO 2002a). However improvements have not been apparent everywhere, and substantial inequalities in health persist within and between countries (Casas-Zamora and Ibrahim 2004; McMichael *et al.* 2004; Marmot 2005; People’s Health Movement *et al.* 2005). For instance, in parts of Africa, life expectancy has fallen in the last 20 years, largely as a consequence of HIV/AIDS (Lutz *et al.* 2000; McMichael 2004). For other reasons, male mortality increased by 40% in Russia in the early 1990s (Marmot 2005). Reductions in child mortality have been largest in countries of the Eastern Mediterranean and South-East Asia Regions and Latin America, while reductions in African countries have been more modest.

Immunization programmes and other measures have controlled many human infections that were once common, but communicable diseases are still a serious threat to public health in many parts of the world (WHO 2003b). In Southern Africa, for example, more than 20% of the adult population is infected with HIV/AIDS (de Waal and Whiteside 2003). Worldwide, the number of cases of non-communicable diseases (such as heart disease, stroke, diabetes, and cancer) is increasing more rapidly than the growth in population. Non-communicable diseases account for nearly half of the global burden of disease (at all ages) and the burden is growing fastest in low- and middle-income countries (Mascie-Taylor and Karim 2003).

Several causes of ill health are potentially sensitive to climate change. In developing countries, about 17% of the population is undernourished (Food and Agricultural Organization 2006). Progress in overcoming hunger is very uneven; based on current trends, only Latin America and the Caribbean are on target to achieve the Millennium Development Goal of halving the number of people who are hungry. In North Africa and the Near East, the prevalence of hunger is increasing (Food and Agricultural Organisation 2005). Almost 2 million deaths a year, mostly in young children, are caused by diarrhoeal diseases and other conditions that are attributable to unsafe water and lack of basic sanitation (Kosek *et al.* 2003). Malaria, another common disease whose range may be affected by climate, causes around a million child deaths annually (WHO 2004a). In 16 countries (14 of which are in Africa), current levels of under-five mortality are higher than those observed in 1990 (Anand and Barnighausen 2004). The Millennium Development Goal of reducing under-five mortality rates by two-thirds by 2015 is unlikely to be reached in all countries, especially in Sub-

Saharan Africa.

8.1.2 Findings from the Third Assessment Report

The main findings of the IPCC Third Assessment Report (McMichael and Githeko 2001) were:

- An increase in the frequency or intensity of heat waves will increase the risk of mortality and morbidity, principally in older age groups and the urban poor;
- Any regional increases in climate extremes (storms, floods, cyclones, etc.) associated with climate change would cause deaths and injuries, population displacement, and adverse effects on food production, freshwater availability and quality, and would increase the risks of infectious disease, particularly in low-income countries;
- In some settings, the impacts of climate change may cause social disruption, economic decline, and displacement of populations. The health impacts associated with such social-economic dislocation and population displacement are substantial;
- Changes in climate, including changes in climate variability, would affect many vector-borne infections, through ecosystem and other changes. Populations at the margins of current distribution of diseases might be particularly affected;
- Climate change represents an additional pressure on the world's food supply system and is expected to increase yields at higher latitudes and decreases in yields at lower latitudes. This would increase the number of undernourished people in the low-income world, unless there was a major re-distribution of food around the world.
- Assuming that current emission levels continue, air quality in many large urban areas will deteriorate. Increases in exposure to ozone and other air pollutants (e.g. particulates) could increase morbidity and mortality.

8.1.3 Key developments since the Third Assessment Report

Since the publication of the TAR, more information is available at national and local levels on population vulnerability to climate change. Several countries have undertaken health impact assessments, either as part of a multi-sectoral study or a stand-alone project (see Table 8.1). Importantly, there have been more studies that investigate the effect of climate in the context of other social and environmental determinants of disease risk (Izmerov *et al.* 2005). There has been some advancement in the development of climate-health impact models that project the effects of climate change in the later part of the century. Climate change is now an issue of concern for health policy in many countries, which is illustrated by the growing number of health impact assessments. Some climate-specific adaptation measures have been developed and implemented within and beyond the health sector, mostly in relation to preparedness for extreme events and infectious diseases.

8.1.4 Methods used and research gaps

The evidence for current sensitivity of population health to weather and climate is based on five main types of empirical studies:

- health impacts of individual extreme events (e.g. heat waves, floods, storms, droughts, extreme cold);
- spatial studies, where climate is an explanatory variable in the distribution of the disease or the disease vector;

- temporal studies, assessing the health effects of inter-annual climate variability, of short term (daily, weekly) changes in temperature or rainfall, and of longer term (decadal) changes in the context of detecting early effects of climate change;
- experimental laboratory and field studies of vector, pathogen, or plant (allergenic) biology; and;
- studies that examine the effects of adaptation strategies on sensitivity to climate variability.

Major challenges for climate and health impact research include:

- gaps in health and environmental data and information, particularly in low-income populations;
- the multiple, interacting, and multi-causal health outcomes to be considered;
- the difficulty of attributing health outcomes to climate or climate change per se;
- the difficulty of generalizing health outcomes from one setting to another, when many diseases (such as malaria) have important local transmission dynamics that cannot be easily represented in simple relationships;
- limited inclusion of different developmental scenarios in health projections;
- identification of climate-related thresholds for population health; and
- limited understanding of the extent, rate, limiting forces, and major drivers of adaptation of human populations to a changing climate.

The assessment of future impacts must include consideration of multiple simultaneous exposures. An example is the combination of high temperatures and high levels of air pollutants that commonly occurs in urban heat waves. Multiple exposures require integrated assessments that pay attention to the range of determinants of ill health and health inequalities (variations in health status between and within populations). Assessments of health impacts require robust evidence of causal effects from a variety of populations and settings to reach the expected high standards of evidence.

Table 8.1: *National Health Impact Assessments of Climate Change published since the TAR*

Country	Key vulnerabilities due to climate change	Adaptation recommendations
Australia (McMichael *et al.* 2003b)	Increase in heat wave-related deaths (table 8.5); drowning from floods; diarrhoeal disease in Central Australian indigenous community; change in potential transmission zone of dengue fever and malaria (table 8.4); likely increase in environmental refugees from Pacific islands due to sea-level rise.	Not considered.
Bolivia (Programa Nacional de Cambios Climaticos Componente Salud *et al.* 2000)	Intensification of malaria and leishmaniasis transmission. Indigenous populations may be most affected by increases in infectious diseases.	Not considered.
Bhutan (Bhutan NAPA in process of being finalized)	Loss of life from frequent flash floods, GLOFs, and landslides; hunger and malnutrition; spread of vector-borne diseases into higher elevations; loss of water resources and risk of water borne diseases.	Malaria control program; strengthening of hygiene; awareness rising.
Canada (Riedel 2004)	Increase in heat wave related deaths; increase in air pollution related diseases; spread of vector- and rodent-borne diseases; increased problems with contamination of both domestic and imported shellfish; increase in allergic disorders; increased levels of anxiety and depression; impacts on particular populations in Northern Canada.	Monitoring for emerging diseases; emergency management plans; early warning systems; land use regulations; upgrading water and wastewater treatment facilities; measures for reducing the health island effect.
Finland (Carter *et al.* 2005)	Small increase of heat related mortality; changes in phenological phases and increased risk for allergic disorders.	Awareness building and training of medical doctors.

Germany (Zebisch *et al.* 2005)	Observed excess deaths from heat waves; changing ranges in TBE; impacts on health care.	Increase information to the population; early warning; emergency planning and cooling of buildings; insurance and reserve funds.
India (Ministry of Environment and Forest and Government of India 2004)	Increase in communicable diseases, malaria is prevalent and will move to higher latitudes and altitudes in India (plus 10% area with breeding conditions by 2080)	Surveillance systems, vector control measures, public education.
New Zealand (Woodward *et al.* 2001)	Increases in enteric infections (food poisoning); changes in some allergic conditions; injuries from more intense floods and storms; small increase in heat-related deaths.	Systems to ensure food quality,, information to population and health care providers, flood protection, vector control.
Netherlands (Bresser 2006)	Increase in heat-related mortality; increase of air pollutants; risk of more Lyme disease cases, food poisoning and allergic disorders.	Not considered.
Panama (Autoridad Nacional del Ambiente 2000)	Increase of vector borne and other infectious diseases, increase of health problems from high ozone concentration in urban areas, increase in malnutrition	Not considered.
Portugal (Casimiro and Calheiros 2002; Calheiros and Casimiro 2006)	Increase in heat-related deaths and malaria (table 8.4, 8.5), food and water borne diseases;, West Nile fever and Mediterranean spotted fever; a reduction in leishmaniasis risk in some areas.	Address thermal comfort; education and information as well as early warning for heat periods; early detection of infectious diseases
Spain (Moreno 2005)	Increase in heat-related mortality; air pollutants; potential change of ranges of vector and rodent borne diseases.	Awareness raising; early warning systems for heat waves; surveillance and monitoring; review of health policies
Switzerland (Thommen Dombois and Braun-Fahrlaender 2004)	Increase of heat-related mortality; changes in zoonoses; increase in cases of tick borne encephalitis.	Heat information, early warning; GHG emission reduction strategies to reduce secondary air pollutants; set up a working group on climate and health
United Kingdom (Department of Health and Expert Group on Climate Change and Health in the UK 2001)	Health impacts of increased flood events; increased risk of heat wave related mortality (table 8.5).	Awareness-raising.

8.2. Current sensitivity to weather and climate

Systematic reviews of empirical studies provide the best evidence for current sensitivity to weather and climate, but such reviews are rare. In this section, we assess the associations between weather/climate factors and health outcome(s) for the population(s) concerned.

Figure 8.1 presents a graphical presentation on current observed pathways on impacts of weather and climate variability on human health.

Published evidence indicates that:

- climate change may already be affecting health-relevant insect species (vectors), as well as important environmental exposures (e.g. heat waves);
- climate plays an important role in the spatial or temporal distribution of malaria, dengue, tick-borne diseases, cholera, and some other diarrhoeal diseases;
- extreme temperatures cause large increases in deaths;
- the health effects of flooding and weather disasters are severe and long lasting.

This chapter addresses mainly diseases and risk factors of global relevance, as shown in table 8.2.

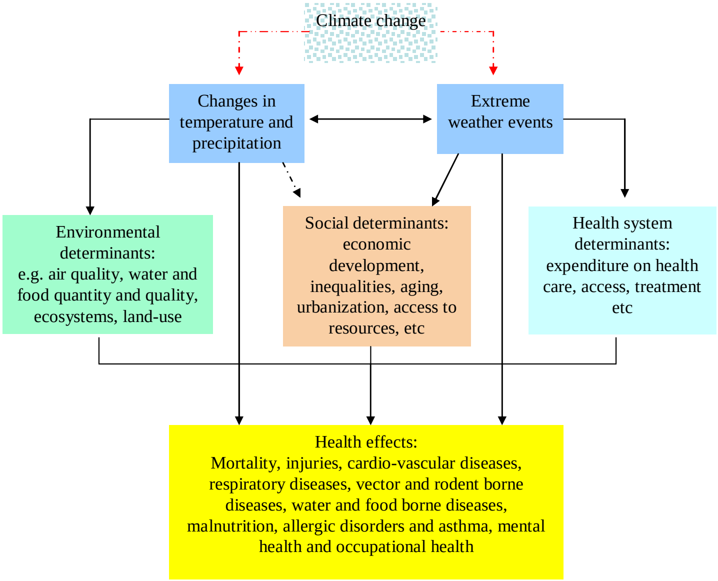

Figure 8.1*: Pathways on how weather and climate variability affect health*

Table 8.2: *Current disease burden in terms of deaths by region and globally, in year 2000.*

	Global total	Males	Female	Africa	Americas	Europe	Asia
Cause of death (deaths (1000s))							
Diarrhoeal diseases	1969	1018	951	690	64	22	1192
Malaria	1120	530	590	957	1	0	162
Dengue	21	10	11	0	3	0	18
Protein–energy malnutrition	3748	1900	1848	1767	50	18	1913

* Aggregated WHO regions. Source: (WHO 2002a; McMichael *et al.* 2003a; Ezzati *et al.* 2004)

More information is available also in other chapters of the 4th assessment report, as outlined in table 8.3.

Table 8.3: *Health outcomes and diseases assessed in AR4*

Health outcomes	**Chapters in the 4AR that address specific health outcomes or specific diseases**
Heat and heat waves attributable mortality and morbidity	1.3.7; 8.2.1; 8.4.1;10.2.4; 10.4.5; 11.4.10; 12.4.11; 14.3.5; 14.5.5
Cold and cold waves attributable mortality and morbidity	8.2.1; 8.4.1.; 15.4.6
Flood attributable mortality and morbidity	8.2.2;10.2.4; 12.4.11
Windstorms attributable mortality and morbidity	1.3.7; 8.2.2
Drought attributable mortality and morbidity	8.2.3; 8.4.2
Fires attributable mortality and morbidity	8.2.5; 13.4.5
Malnutrition	8.2.3; 15.4.6

Food poisoning and safety	1.3.7; 6.4.2.5; 8.2.4;12.4.11; 15.4.6
Air quality and respiratory disorders	8.2.5; 8.4.1;14.5.5.
Allergic disorders and asthma	1.3.7; 8.2.6; 12.4.11; 14.5.5
Diarrhoeal diseases	1.3.7; 8.2.7; 10.2.4; 12.4.11; 14.3.5
Occupational health	8.2.8
UV radiation attributable morbidity	8.2.10; 15.4.6

Specific diseases	
African trypanosomiasis [sleeping sickness]	9.4.3
Campylobacteriosis	1.3.7; 8.2.4
Cholera	1.3.7
Cryptosporidiosis	1.3.7; 15.4.6
Dengue	1.3.7; 8.2.9; 8.4.1;10.2.4; 10.4.5; 11.4.10; 12.4.11; 13.4.5; 16.4.5
Fasioliasis	9.4.3
Filariasis	10.4.5
Giardiasis	10.4.5; 15.4.6
Leishmaniasis	8.2.9; 12.4.11;13.4.5
Leptospirosis	8.2.9
Lyme disease	1.3.7; 8.2.9; 12.4.11; 14.3.5
Malaria	1.3.7; 8.2.9; 8.4.1; 9.4.3; 10.2.4;10.4.5; 11.4.10; 12.4.11; 13.4.5; 16.4.5
Nipah virus infection	8.2.9
Rift Valley fever	9.4.3; 14.3.5
Ross River virus disease	11.4.10
Salmonellosis	1.3.7; 8.2.4;11.4.10; 14.3.5
Schistosomiasis	8.2.9; 10.4.5
St Louis encephalitis	14.3.5
Tick borne encephalitis	1.3.7; 8.2.9; 10.4.5; 12.4.11; 15.4.6.2
West Nile virus infection	14.3.5; 15.4.6.2

8.2.1 Heat waves, cold waves and temperature-related mortality

The effects of environmental temperature have been studied in the context of single episodes of sustained extreme temperatures (by definition, heat waves and cold waves) and as population responses to a range of ambient temperatures (time series studies).

8.2.1.1 Heat waves

Heat wave events are associated with marked short-term increases in mortality. Although there has been more research on heat waves and health since the TAR, it is mostly in populations in North America (Basu and Samet 2002), Europe (Koppe *et al.* 2004; Kovats, R.S. *et al.* 2004), and East Asia (Bai *et al.* 1995; Qiu *et al.* 2002; Ando *et al.* 2004; Choi *et al.* 2005; Kabuto *et al.* 2005). In August 2003, a heat wave in Western and Central Europe caused around 35,000 deaths (Hemon and Jougla 2004; Martinez-Navarro *et al.* 2004; Michelozzi *et al.* 2004; Vandentorren *et al.* 2004; Conti *et al.* 2005; Grize *et al.* 2005; Johnson *et al.* 2005). This event is discussed in detail in the Europe regional chapter and as a crosscutting case study (chapter 4, 7, 12, and 20). The summer of 2003 was the hottest in Europe since 1500 (WGI Chapter 3, Box 3.5.5) (Luterbacher *et al.* 2004). Some climatologists now consider it “very likely” that human influence on the global climate at least doubled the risk of a heat wave such as that experienced in 2003 (Stott *et al.* 2004). Therefore, the deaths that occurred may be among the first that can be directly attributed to anthropogenic climate change.

Published studies quantified the impacts of selected heat waves using routine death registration data in Europe and North America. Estimates of excess mortality were associated with different attributes of hot weather including magnitude, duration, and the timing of the heat wave in the summer season. The episode studies show that effects are overwhelmingly concentrated in the older age groups and in deaths from heat stroke, respiratory and cardiovascular disease. Deaths in younger adults are associated with high risk groups, including the homeless and those with alcohol dependence, mental illness, or severe physical disability (INVS 2004; CDC 2005c). An unknown proportion of deaths are due to short-term mortality displacement. Evidence so far indicates that this proportion is dependent on the severity of the heat waves and the health status of the population affected (Hemon and Jougla 2004; Hajat *et al.* 2005; Kysely 2005).

Heat waves are frequent occurrences in South Asia and are associated with high mortality in rural populations, the elderly, and outdoor workers (Sinha Ray *et al.* 1999; Chaudhury 2000) (see 8.2.8). Eighteen heat wave events were reported in India between 1980 and 1998, with an event in 1988 affecting 10 States and causing 1300 deaths (De and Mukhopadhyay 1998; De *et al.* 2004; Mohanty *et al.* 2005). Heat waves in India in 1998 and 2003 caused an estimated 2,000 excess deaths in Orissa and 4,600 excess deaths, respectively (Mohanty and Panda 2003). The EMDAT disaster events database reports more than 5,500 heat wave deaths in South Asia between 1975 and 2001(Guha-Sapir *et al.* 2004). These mortality figures are likely to refer to reported deaths from heat stroke and are therefore an underestimate of the total impact of these events.

8.2.1.2 Cold waves

Cold waves continue to be a problem in northern latitudes where very low temperatures can be reached in a very few hours and extent over long periods. Accidental cold exposure occurs mainly outdoors, among socially deprived people, workers, alcoholics, the homeless, and the elderly in temperate cold climates (Ranhoff 2000). Mortality during cold waves reported from the high latitude countries is associated with electricity or heating system failures. Cold waves are also reported to be a problem in some warmer climates, such as in subtropical South East Asia (Guha-Sapir *et al.* 2004). Climate change is likely to decrease the frequency of extreme cold weather, and therefore reduce related mortality. Living in cold environments in the Polar regions is associated with a range of chronic conditions in the non-indigenous population (Sorogin 1993) as well as the acute risk from frostbite and hypothermia (Hassi *et al.* 2005).

8.2.1.3 Temperature related mortality – estimates of heat and cold effects

Methods for the quantification of heat and cold effects have seen a rapid development (Braga *et al.* 2002; Curriero *et al.* 2002; Armstrong *et al.* 2004). Further information on the effect modifiers (non-climate determinants) for heat-related mortality has shown the importance of medical, social, and environmental factors (Basu and Samet 2002; Koppe *et al.* 2004). City-level factors, such as climate, topography, heat island magnitude, income, and the proportion of elderly people are important in determining the underlying temperature-mortality relationship in a population (Curriero *et al.* 2002). The determinants of cold related mortality vary between populations, and relate to adaptations in housing, clothing, and other behaviours. Differences between countries are not fully explained by climate or relative income (Healy 2003)

High temperatures contribute to about 1-4% of annual mortality in older age groups in Europe (Pattenden *et al.* 2003), although large uncertainty remains on quantifying this burden in terms of life years lost. Models based on temperature-mortality relationships have been used to estimate future impacts of climate change on temperature-attributable mortality [section 8.4.1.3].

Populations are acclimatized to their current climate. The sensitivity of a population to temperature extremes will therefore change over decadal time scales (Honda *et al.* 1998). There is some indication that populations in the US have become less sensitive to high temperatures from 1964-1988 (as measured imprecisely by population- and period-specific thresholds in the mortality response) (Davis *et al.* 2002; Davis *et al.* 2003b; Davis *et al.* 2003a). Heat-related mortality has declined since 1970s in South Carolina, US, and South Finland, but this trend was less clear for the South of England (Donaldson *et al.* 2003). Evidence is robust that cold-related mortality in industrialized populations has reduced since the 1950s (Kunst *et al.* 1991; Lerchl 1998; Carson *et al.* 2006). The reduction in sensitivity to cold is likely to be due to improved home heating, better general health, and improved prevention and treatment of winter infections.

8.2.2 Wind storms and floods

Knowledge about the full health and social burden of extreme weather events is incomplete. The major impacts on health from windstorms are from the flooding caused by storm surges or heavy rainfall (Venezuela in 1999). High winds also cause deaths and injuries. Flood events have local and sometimes regional effects from deaths, injuries, communicable diseases, toxic contamination, and mental health (Greenough *et al.* 2001; Ahern *et al.* 2005) and through economic disruption, infrastructure damage, and population displacement (Few and Matthies 2006). Population displacement following disasters leads to increases in communicable diseases resulting from crowding, lack of clean water and shelter, and poor nutritional status (Menne 2000). In the last two decades, major storm and flood disasters have occurred. In 2003, 150,000 people were affected by floods in China; in 1999, 30,000 died from storms followed by floods and landslides in Venezuela; in 2000/1, 813 died in floods in Mozambique (IFRC 2002; Guha-Sapir *et al.* 2004), and in 2005, more than 1,300 deaths were attributed to hurricane Katrina (Manuel 2006). Although there is increasing evidence that improved structural and non-structural measures have decreased the mortality from floods and storm surges (EEA 2005), the impact of weather disasters in terms of social and health effects is still considerable.

In terms of deaths and populations affected, floods and tropical cyclone have the greatest impact in South Asia and Latin America (Guha-Sapir *et al.* 2004; Schultz *et al.* 2005). Deaths recorded in disaster databases are from drowning and severe injuries. Deaths from unsafe or unhealthy conditions following the extreme event are also a health consequence, but such information is rarely included in disaster statistics (Combs *et al.* 1998; Jonkman and Kelman 2005). Drowning by storm surge is the major killer in coastal storms (where there are large numbers of deaths). An assessment of surges in past 100 years finds that major events are confined to a limited number of regions, with many events occurring in the Bay of Bengal, particularly Bangladesh (Nicholls 2003).

Populations with poor sanitation infrastructure and high burdens of infectious disease often experience increased rates of diarrhoeal diseases after flood events. Standing water can be a breeding ground for bacteria and mosquitoes. Increases in cholera (Sur *et al.* 2000; Gabastou *et al.* 2002), cryptosporidiosis (Katsumata *et al.* 1998) and typhoid fever (Vollaard *et al.* 2004) have been reported in low- and middle-income countries. Extreme floods or high winds damage sewage treatment works. Approximately 200 sewage plants were damaged by Hurricanes Katrina and Rita in the US in 2005, leading to sewage directly contaminating flood waters and elevated levels of faecal bacteria (E. coli) and Vibrios (CDC 2005a, 2005b; Manuel 2006). Reviews of the published evidence indicate that the risk of infectious disease following flooding in high-income countries is generally low, although increases in respiratory and diarrhoeal diseases have been reported after floods (Miettinen *et al.* 2001; Reacher *et al.* 2004; Wade *et al.* 2004). Flood-related increases in diarrhoeal disease have also been reported in India (Mondal *et al.* 2001) and Brazil (Heller *et al.* 2003). The floods in Mozambique in

2001 were estimated to have caused over 8,000 additional cases and 447 deaths of diarrhoeal disease in the following months (Cairncross and Alvarinho 2006).

Flooding may lead to contamination of waters with dangerous chemicals from storage or from chemicals already in the environment (e.g. pesticides). Chemical contamination following Hurricane Katrina in the US included oil spills from refineries and storage tanks, pesticides, metals, and hazardous wastes (Manuel 2006). Concentrations of most contaminants were within acceptable levels, except for lead and volatile organocarbons (VOCs) in some areas (Pardue *et al.* 2005). There are health risks associated with long-term contamination of soil and sediment (Manuel 2006). There is little published evidence demonstrating a causal effects of chemical contamination on the pattern of morbidity and mortality following flooding events (Euripidou and Murray 2004; Ahern *et al.* 2005). Increases in population density and accelerating industrial development in areas subject to natural disasters increase the probability of future disasters and the potential for mass human exposure to hazardous materials released during disasters (Young *et al.* 2004).

There is increased evidence of the importance of mental disorders as an impact of disasters (Mollica *et al.* 2004; Ahern *et al.* 2005). Prolonged impairment from common mental disorders (anxiety and depression) may be considerable. Studies in both low- and high-income countries indicate that the mental health aspect of flood related impacts is under investigated (Ko *et al.* 1999; Ohl and Tapsell 2000; Bokszczanin 2002; Tapsell *et al.* 2002; Assanarigkornchai *et al.* 2004; Norris *et al.* 2004; North *et al.* 2004; Ahern *et al.* 2005; Kohn *et al.* 2005; Maltais *et al.* 2005). A systematic review of post-traumatic stress disorder in developed countries found a small but significant effect from this illness following disasters (Galea *et al.* 2005). There is also evidence of medium- to long-term impacts on behavioural disorders in young children (Durkin *et al.* 1993; Becht *et al.* 1998; Bokszczanin 2000; Bokszczanin 2002).

Vulnerability to weather disasters depends on the attributes of the person at risk (where they live, age, income, education, disability) and on broader social and environmental factors (level of disaster preparedness, health sector responses, environmental degradation) (Blaikie *et al.* 1994; Menne 2000; Olmos 2001; Adger *et al.* 2005; Few and Matthies 2006). The impacts of flooding are not evenly distributed with respect to income, age, disability, or gender (Box 8.1). Poorer communities, particularly slum dwellers, are more likely to live in flood prone areas. In the US, lower income groups were most affected by Hurricane Katrina, and low-income schools had twice the risk of being flooded compared to the reference group (Guidry and Margolis 2005).

High-density populations in low-lying coastal regions experience a high burden from weather disasters, such as settlements along the North Sea coast in northwest Europe, the Seychelles, parts of Micronesia, the Gulf Coast of the United States and Mexico, the Nile Delta, the Gulf of Guinea, and the Bay of Bengal (Chapter 6). Environmentally degraded areas are particularly vulnerable to tropical cyclones and coastal flooding under current climate conditions.

Box 8.1: Gender and natural disasters

As shown by the 2004 Asian tsunami, disasters affect women and men differently. Surveys in Banda Aceh found that male survivors outnumbered females by almost 3:1; in the North Aceh district, females accounted for 77% of the deaths (Oxfam 2005). Gender-related differences apply to all phases of a disaster: from exposure to risk and risk perception; preparedness behaviour, warning communication and response; physical, psychological, social, and economic impacts; emergency response; and ultimately to recovery and reconstruction (Fothergill 1998). Gender interacts with race, ethnicity, class, and access to resources in the experience of disaster. Women bear a disproportionate share of the burden of poverty. Women are the providers of care (which may put them at greater risk during and following a disaster) and more often than men have limited mobility, restricted access to resources, and may be subject to social isolation (Briceño 2002). Natural disasters have been shown to increase domestic violence and post-traumatic stress disorders in women (Anderson and Manuel 1994; Garrison *et al.* 1995; Wilson *et al.* 1998) (Anderson and Manuel 1994; Garrison *et al.* 1995; Wilson *et al.* 1998; Ariyabandu and Wickramasinghe 2003; Galea *et al.* 2005). However, viewing women as “vulnerable victims” contributes to their exclusion from decision-making. Women make an important contribution to disaster reduction, often informally through participating in disaster management and acting as agents of social change. Their resilience and their networks are critical in household and community recovery (Enarson and Morrow 1998; Ariyabandu and Wickramasinghe 2003).

8.2.3 Drought, nutrition, and food security

Drought is defined as a period of below average precipitation that causes water scarcity and adversely affects food production systems. The effects of drought on health include malnutrition (protein-energy malnutrition and/or micronutrient deficiencies), infectious diseases, and respiratory diseases (Menne and Bertollini 2000). There have been observational studies on climate variability and drought events in rural populations in low-income countries, particularly focusing on adaptation and livelihoods [see chapter 5] (Orindi and Murray 2005). Few studies, however, have linked climate, environment, and nutritional outcomes at the national or local level (Mahapatra *et al.* 2000; Allen 2002). Water scarcity and the risk of water-washed diseases are addressed in section 8.2.7.

Malnutrition increases the risk of dying from an infectious disease. A study in Bangladesh found that drought and lack of food was associated with increased risk of diarrhoea mortality (Aziz *et al.* 1990). Micronutrient deficiencies are also associated with drought. During non-famine normal years, factors such as season, family structure, population movement, and living conditions influence the association between malnutrition and infection in resource-dependent populations (Lindtjorn 1990).

Droughts are associated with increased risk of suicide in farmers in Australia (Nicholls *et al.* 2005), and India. Drought and the consequent loss of livelihoods is also a major trigger for population movements, particularly rural to urban migration. Migration, whether temporary or permanent, has many social effects with a range of health consequences. Recently, rural to urban migration has been implicated as driver of HIV transmission (White 2003; Coffee *et al.* 2005).

Box 8.2: Cross cutting case studies: health and droughts in Africa

Achievement of the Millennium Development Goals (MDGs) is considered the most challenging in Africa where a complex mix of social, environmental, and economic factors impinge on development. The persistent high prevalence of infectious diseases, malnutrition, and micronutrient deficiencies continue to cause high mortality rates in all age groups. The potential for increasing droughts represent a very serious threat for some African countries (Conway *et al.* 2005). The current food crisis in Southern Africa is distinct because HIV/AIDS has created a new class of vulnerable households that increases the population at risk and changes the course of recovery (de Waal and Whiteside 2003; Gommes *et al.* 2004). Prolonged and repetitive droughts contribute to deteriorating population health by causing malnutrition and disease, and through reducing the availability of money for education and health care. (see also 8.4.2.2).

Box 8.3: Drought in the Amazon

In the dry season of 2005, an intense drought affected the western and central part of the Amazon region, especially Bolivia, Peru, and Brazil. In Brazil alone, 300,000 people were affected. The most important health impacts were water-borne infections (due to pathogen concentration) and respiratory problems due to heavy smoke from forest fires. Most affected were rural dwellers and riverine traditional subsistence farmers with limited spare resources to mobilize in an emergency. The local and national governments in Brazil mobilized resources worth US$ 100,000 to provide safe drinking water, food supplies, medicines, and transportation to thousands of people isolated in their communities due to rivers drying up. The lessons learned include that although it was not the most severe drought in the region, the large scale impacts were due to the demographic increase of an inherently vulnerable population and traditional resource-dependent communities are not prepared to cope with extremes (World Bank 2005).

8.2.3.1 Drought and infectious disease

Countries within the Meningitis Belt in semi-arid sub-Saharan Africa experience the highest endemicity and epidemic frequency of meningococcal meningitis in Africa, although other areas in the Rift Valley, the Great Lakes, and southern Africa are also affected. The spatial distribution, intensity, and seasonality of meningococcal (epidemic) meningitis appear to be strongly controlled by climatic and environmental factors, particularly drought, although the causal mechanism is not clearly understood (Molesworth *et al.* 2001; Molesworth *et al.* 2002a; Molesworth *et al.* 2002b; Molesworth *et al.* 2003). Climate plays an important part in the inter-annual variability in transmission, including the timing of the seasonal onset of the disease (Molesworth *et al.* 2001; Sultan *et al.* 2005). Limited evidence suggests that the geographical distribution of meningitis may have changed in West Africa in recent years and this may be attributable to environmental change driven by both changes in land use and regional climate change (Molesworth *et al.* 2003).

Some mosquito-borne diseases that have reservoir hosts show strong drought/non-drought temporal relationships. During drought periods, the activity of mosquitoes is reduced and the population of non-immune reservoir hosts builds up. When the drought breaks, there is a much larger proportion of susceptible hosts to become infected, thus increasing infectivity (Bouma and Dye 1997; Woodruff *et al.* 2002). Drought also may decrease the incidence of diseases such as malaria, because the mosquito vector requires sufficient humidity and standing water for breeding sites (see box 8.2). The northern limit of falciparum malaria in Africa, is in the Sahel (Senegal, Mali, Niger, Chad, Sudan, and Ethiopia) where rainfall is an important limiting factor in disease transmission (Ndiaye *et al.* 2001). There is some evidence that malaria has decreased in association with long-term decreases in annual rainfall in Senegal and Niger (Mouchet *et al.* 1996; Julvez *et al.* 1997). Drought is also associated with dust storms and respiratory health effects (see section 8.2.5.3).

8.2.4 Food safety

Several studies have confirmed and quantified the effects of temperature on common forms of food poisoning, such as salmonellosis (D'Souza *et al.* 2004; Kovats, R. S. *et al.* 2004; Fleury *et al.* 2006). These studies showed that there is an approximately linear increase in reported cases for each degree increase in weekly temperature. Temperature is much less important for transmission of *Campylobacter* (Kovats *et al.* 2005; Louis *et al.* 2005; Tam *et al.* 2006).

Contact between food and pest species, especially flies, rodents, and cockroaches, is also temperature-sensitive. Fly activity is largely driven by temperature rather than by biotic factors (Goulson *et al.* 2005). In temperate countries, warmer weather and milder winters are likely to increase the abundance of flies and other pest species during summer months, with the pests appearing earlier in spring.

Warmer seas may contribute to increased cases of human shellfish and reef-fish poisoning (ciguatera) or poleward expansions of the disease distributions (Lehane and Lewis 2000; Hall *et al.* 2002; Hunter 2003; Korenberg 2004). Little new evidence has emerged since the TAR about the sensitivity of these diseases to climate change.

8.2.5 Water and disease

Water-related diseases can be classified by route of transmission, thus distinguishing water-borne (ingested) and water-washed (lack of hygiene) diseases. Climate variability can affect both water availability and water quality. Access to improved water remains an extremely important global health issue. Changes in rainfall and surface water availability are major concerns of the impact of global climate change (see chapter 3). There are four main considerations when evaluating current climate and health outcomes (primarily diarrhoeal disease):

- Linkages between water availability, household access to improved water, and the health burden due to diarrhoeal diseases;
- The role of extreme rainfall (intense rainfall or drought) in facilitating water-borne outbreaks of diseases through either the piped water supplies or surface water;
- Effects of temperature and runoff on microbiological contamination of coastal, recreational, or surface waters; and
- Direct effects of temperature on diarrhoeal disease.

More than two billion people live in the dry regions of the world and they suffer more than others from problems such as malnutrition, infant mortality, and diseases related to contaminated or insufficient water (WHO 2005). A small and unquantified proportion of this burden can be attributed to climate variability or climate extremes. The effect of water scarcity on food availability and malnutrition is discussed above in section 8.2.3, and the effect of rainfall on outbreaks of mosquito-borne and rodent-borne disease is discussed in section 8.2.9.

Several studies investigating an association between drinking water turbidity and health (Schwartz and Levin 1999; Aramini *et al.* 2000; Schwartz *et al.* 2000; Lim *et al.* 2002) found an indication that it is a determinant of gastro-intestinal illness in the general population, at least in North America and Europe. Extreme rainfall and runoff events may increase the total microbial load in watercourses and drinking water reservoirs (Kistemann *et al.* 2002). Open finished water reservoirs are at risk for post-treatment faecal contamination by animals. A study in the US found an association between extreme rainfall events and monthly reports of outbreaks of water-borne disease (Curriero *et al.* 2001). The seasonal contamination of surface water in early spring in North America and Europe may explain some of the seasonality in sporadic cases of water-borne disease such cryptosporidiosis and campylobacteriosis (Clark *et al.* 2003; Lake *et al.* 2005). Climate change is associated with more extreme rainfall events in temperate regions.

Childhood mortality due to diarrhoea in low-income countries, especially in sub-Saharan Africa, remains high despite improvements in care and the use of oral rehydration therapy (Kosek *et al.* 2003). Children may survive the acute illness but later die due to persistent diarrhoea or malnutrition. Children in poor rural and urban slum areas are at high risk of diarrhoeal disease mortality and morbidity. Several studies have shown that transmission of enteric pathogens is higher during the rainy season (Nchito *et al.* 1998; Kang *et al.* 2001). Drainage and storm water management is important in low-income urban communities, as blocked drains cause increased disease transmission (Parkinson 2003).

There is stronger evidence that temperature variability affects diarrhoeal disease morbidity in all populations. Temperature was found to be strongly associated with increased episodes of diarrhoeal disease in adults and children in Peru (Checkley *et al.* 2000; Speelmon *et al.* 2000; Checkley *et al.* 2004; Lama *et al.* 2004). Associations between monthly temperature and diarrhoeal episodes have also been reported in the Pacific Islands, Australia, and Israel (Singh *et al.* 2001; McMichael *et al.* 2003b; Vasilev 2003).

The bimodal seasonal pattern of cholera in Bangladesh follows sea surface temperatures in the Bay of Bengal and seasonal plankton abundance (an environmental reservoir of the cholera pathogen, *Vibrio cholerae*) (Colwell 1996; Bouma and Pascual 2001). Inter-annual variability of cholera incidence in Dhaka, Bangladesh was associated with climate factors (Rodo *et al.* 2002). Winter peaks in disease were dominant further inland in Bangladesh that were not associated with sea water temperatures (Bouma and Pascual 2001). Although there is some evidence of the importance of sea surface temperature in cholera transmission (Pascual *et al.* 2000; Lipp *et al.* 2002; Rodo *et al.* 2002; Koelle *et al.* 2005), this measure may be a proxy for other climate effects in the region. The possible mechanisms by which increased sea surface temperatures may affect disease transmission from year-to-year remain poorly understood.

Persistence in the environment is critical for movement between hosts. Enteric bacteria may grow in the environment but often the non-host conditions results in decay of the pathogen. *Salmonella* are particularly capable of withstanding a range of environmental conditions (Winfield and Groisman 2003). Other enteric pathogens are often stressed at higher temperatures. *Campylobacter* persist longer at cooler temperatures and are more often detected in environmental waters in winter months (Bolton *et al.* 1987; Jones 2001). Enteric viral diseases remain infective longer in the environment as temperatures decline (Lipp *et al.* 2001; Wetz *et al.* 2004).

8.2.6 Air quality and disease

Weather at both the synoptic and meso-scale determines the development, transport, dispersion, and deposition of air pollutants, with the passage of fronts, cyclonic, and anticyclonic systems and their associated air masses of particular importance. Air pollution episodes are often associated with a stationary or slowly migrating anticyclonic or high-pressure system that reduces pollution dispersion and diffusion (Schichtel and Husar 2001; Rao *et al.* 2003). Airflow along the flanks of anticyclonic systems lying to the east or west of a location can transport ozone precursors, creating the conditions for an ozone event (Lennartson and Schwartz 1999; Scott and Diab 2000; Yarnal *et al.* 2001; Tanner and Law 2002). Certain weather patterns enhance the development of the urban heat island, the intensity of which may be important for secondary reactions within the urban atmosphere, leading to elevated levels of some pollutants (Morris and Simmonds 2000; Junk *et al.* 2003; Jonsson *et al.* 2004).

In some regions, changes in the mean and variability of temperature and precipitation are projected to increase the frequency and severity of fire events (see Chapter 5). Forest- and bushfires cause burns, inhalation and other injuries. Large fires are also accompanied by an increased number of patients seeking emergency services, including healthcare providers, affected by smoke and ash (Hoyt and Gerhart 2004). Toxic gaseous and particulate air pollutants are released into the atmosphere, which significantly contribute to acute and chronic illnesses of the respiratory system, particularly in children, including pneumonia, upper respiratory diseases, asthma, and chronic obstructive pulmonary diseases (WHO 2002b). For example, the 1997 Indonesia fires increased cardiorespiratory hospitalizations and negatively affected activities of daily living (Frankenberg *et al.* 2005; Mott *et al.* 2005). In some regions, forest fires can spread to peat bogs, further decreasing air quality.

8.2.6.1 Ground-level ozone

Ground-level ozone, the primary constituent of urban smog, is a secondary pollutant formed through photochemical reactions involving nitrogen oxides and volatile organic compounds in the presence of bright sunshine with high temperatures. Temperature, wind, solar radiation, atmospheric moisture, venting, and mixing affects both emissions of ozone precursors and production of ozone(Nilsson *et al.* 2001a; Nilsson *et al.* 2001b; Mott *et al.* 2005). Because ozone formation depends on sunlight, concentrations typically are highest during the summer months, although not all cities have shown seasonality in ozone concentrations (Bates 2005). Concentrations of ground-level ozone have been increasing in some regions, particularly in Asia (Wu and Chan 2001; Chen, K. *et al.* 2004).

Exposure to elevated concentrations of ozone are associated with increased hospital admissions for pneumonia, chronic obstructive pulmonary disease, asthma, allergic rhinitis, and other respiratory diseases, and with premature mortality (Mudway and Kelly 2000; Gryparis *et al.* 2004; Bell *et al.* 2005; Ito *et al.* 2005; Levy *et al.* 2005). Outdoor ozone concentrations, activity patterns, and housing characteristics, such as extent of insulation, are the primary determinants of ozone exposure (Suh *et al.* 2000; Levy *et al.* 2005). Although a considerable amount is known about the health effects of ozone in Europe and Northern America, few studies have been conducted in other regions.

8.2.6.2 Effects of weather on concentrations of other air pollutants

Concentrations of air pollutants, such as fine particulate matter (PM), may change in response to climate change because a portion of their formation depends, in part, on temperature and humidity. Air pollution concentrations are the result of interaction among variations in the physical and dynamic properties of the atmosphere on time scales from hours to days, atmospheric circulation features, wind, topography, and energy use (McGregor 1999; Hartley and Robinson 2000; Pal Arya 2000). Some air pollutants demonstrate weather-related seasonal cycles (Alvarez *et al.* 2000; Kassomenos *et al.* 2001; Hazenkamp-von Arx *et al.* 2003; Nagendra and Khare 2003; Eiguren-Fernandez *et al.* 2004). Local conditions and emissions can be more important than global concentrations of pollutants in determining human exposures. Some locations, such as Mexico City and Los Angeles, because of their general climate and topographical setting, are predisposed to poor air quality because the climate is conducive to chemical reactions leading to the transformation of emissions and because the topography restricts the dispersion of pollutants (Rappengluck *et al.* 2000; Kossmann and Sturman 2004).

PM is well known to affect morbidity and mortality (e.g., (Ibald-Mulli *et al.* 2002; Pope *et al.* 2002; Kappos *et al.* 2004), so an increase in PM concentrations would have significant negative health impacts.

8.2.6.3 Long-range transport of air pollutants

Change in wind patterns and increased desertification may lead to increased long-range transport of air pollutants. Under certain atmospheric circulation configurations, transport of pollutants, including aerosols, carbon monoxide, ozone, desert dust, mould spores, and pesticide, may occur over large distances and over timescales of typically four to six days, which can lead to adverse health impacts (Gangoiti *et al.* 2001; Stohl *et al.* 2001; Buchanan *et al.* 2002; Chan *et al.* 2002; Martin *et al.* 2002; Ryall *et al.* 2002; Ansmann *et al.* 2003; He *et al.* 2003; Helmis *et al.* 2003; Moore *et al.* 2003; Shinn *et al.* 2003; Unsworth *et al.* 2003; Kato *et al.* 2004; Liang *et al.* 2004; Tu *et al.* 2004). Sources of such pollutants include biomass burning, as well as industrial and mobile sources (Murano *et al.* 2000; Koe *et al.* 2001; Jaffe *et al.* 2003; Moore *et al.* 2003; Jaffe *et al.* 2004).

Windblown dust originating in desert regions of Africa, Mongolia, Central Asia, and China can affect air quality and population health in remote areas. When compared with non-dust weather conditions, dust can carry large concentration of coarse particulate concentrations ($PM_{2.5}$ – PM_{10}), trace elements that can affect human health, fungal spores and bacteria (Claiborn *et al.* 2000; Fan *et al.* 2002; Shinn *et al.* 2003; Cook *et al.* 2005; Xie *et al.* 2005). Few studies have examined the health impacts of windblown dust and dust storms. Evidence suggests that mortality, particularly from cardiovascular and respiratory diseases, is increased in the days following a dust storm (Kwon *et al.* 2002; Chen, Y. S. *et al.* 2004).

8.2.7 Aeroallergens and disease

Several studies report evidence for climate change effects not only on the timing and duration of pollen season, but also on pollen amounts. An earlier onset (see section 1.3.5.2) followed by a prolonged exposure to (sometimes) increasing concentrations of airborne allergenic pollens (see 1.3.7.5), implies a longer and possibly heavier period of symptom occurrence (D'Amato *et al.* 2002; Weber 2002; Huynen and Menne 2003; Beggs 2004; Beggs and Bambrick 2005). Few studies show the same evolution for allergenic mould spores or bacteria (Corden *et al.* 2003; Harrison *et al.* 2005). Changes in the spatial distribution of natural vegetation (see 1.3.5.4), such as the introduction of new aeroallergens into an area, increases sensitization (Voltolini *et al.* 2000; Asero 2002). The introduction of new invasive plant species with high allergenic pollen, in particular ragweed (*Ambrosia artemisiifolia*), present important risks to human health; ragweed is spreading in several parts of the world (Rybnicek and Jaeger 2001; Huynen and Menne 2003; Taramarcaz *et al.* 2005; Cecchi *et al.* 2006). Rising CO_2 concentrations and temperatures increase ragweed pollen production and prolong ragweed pollen season (Wan *et al.* 2002; Wayne *et al.* 2002; Ziska *et al.* 2003; Rogers *et al.* 2006).

8.2.8 Vector-borne, rodent-borne and other infectious diseases

Vector-borne diseases (VBD) are infections transmitted by the bite of infected arthropod species, such as mosquitoes, ticks, triatomine bugs and flies. VBDs are among the most important health outcomes to be associated with climatic changes due to their widespread occurrence and sensitivity to climatic factors. Climate change can affect vector-borne disease in several ways (Sutherst 2004). An example is given in figure 8.2, which shows the pathways by which climate factors influence human exposure and mosquito population in the case of malaria.

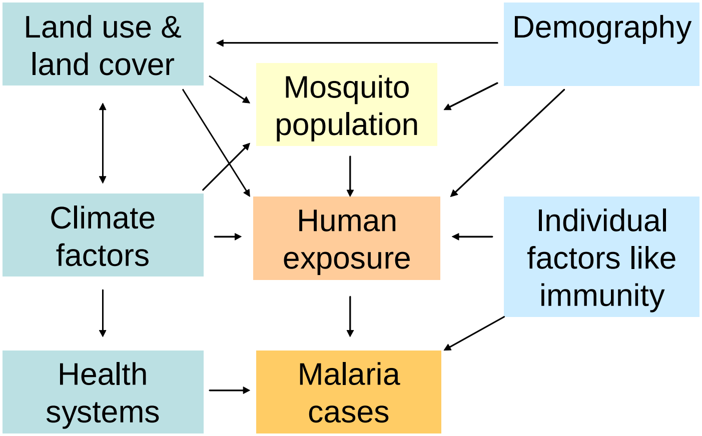

Figure 8.2: *Simplified diagram of factors influencing malaria cases*

Analyzing the effects of climate on vector-borne disease takes into account the disease transmission dynamics as a whole and combines climate data with measurements of the vectoral capacity and infection rate of vectors, abundance and infection rate of reservoir hosts (if any), the infection rate, and eventual health impacts on humans. Separate analyses of climate effects on vectors have been undertaken. Vector studies can detect responses in vector populations before they transmit diseases, and also avoid some important confounding factors, such as changes in treatment regimes, reporting biases, and changes in public awareness of the disease. However, changes in vectors (and even transmission dynamics) can occur without changes in human disease burdens, so the public health relevance needs to be cautiously inferred. The observed effects of climate change on vectors and VBD are also discussed in other chapters (see Table 8.3).

There is some evidence of observed shifts in the distribution of tick vectors of disease and some (non-malarial) mosquito vectors in Europe and North America. Northern or altitudinal shifts in tick distribution have been observed in Sweden (Lindgren and Talleklint 2000; Lindgren and Gustafson 2001) and Canada (Barker and Lindsay 2000), and altitudinal shifts have been observed in the Czech Republic (Daniel *et al.* 2004). Geographic changes in tick-borne infections were observed in Denmark (Skarphedinsson *et al.* 2005). Climate change alone is unlikely to explain recent increases in tick-borne diseases incidence in Europe or North America, because there is considerable spatial heterogeneity in the degree of increase of tick-borne encephalitis, for example, within regions of Europe likely to have experienced similar climate change (Patz 2002; Randolph 2004; Sumilo *et al.* 2006). Other explanations cannot be ruled out (e.g. human impacts on the landscape, increasing both the habitat and wildlife hosts of ticks, and changes in human behaviour that may increase human contact with infected ticks (Randolph 2001).

There is no clear evidence that malaria has been affected by climate change, either in highland areas in Africa and South America (Benitez *et al.* 2004) (see chapter 1) or in continental Russian Federation (Semenov *et al.* 2002; Benitez *et al.* 2004). The attribution of changes in human diseases must first take into account the considerable changes in reporting and surveillance, disease control measures, and population movements (Kovats *et al.* 2001).

In north-eastern North America, there is evidence of recent micro-evolutionary (genetic) responses of the mosquito species *Wyeomyia smithii* to increased average land surface temperatures and earlier arrival of spring in the past two decades (Bradshaw and Holzapfel 2001). Although not a vector of human disease, the species is closely related to important arbovirus vector species that may be undergoing similar evolutionary changes.

Leishmaniasis (which also affects humans) has been reported in dogs (reservoir hosts) in more northern areas in Europe, although the role of previous underreporting cannot be excluded (Lindgren and Naucke 2006). Changes in vector distribution have also been reported in southern Europe (Aransay *et al.* 2004; Afonso *et al.* 2005), but no study has yet investigated the causes of these changes in parasite distribution and vector activity. The re-emergence of kala-azar (visceral leishmaniasis) in cities of the semi-arid Brazilian north-eastern region in the early 1980s and 1990s was caused by rural-urban migration of subsistence farmers who lost their crops due to prolonged droughts (Franke *et al.* 2002; Confalonieri 2003).

Empirical evidence for the effect of climate on infectious disease comes from studies of inter-annual climate variability (e.g. ENSO (Kovats *et al.* 2003b) and studies of disease outbreaks (e.g. West Nile)). The need to control diseases in the context of climate change has led to the development of a range of new modelling and simulation approaches of both vectors and disease at national and continental scales (Seto *et al.* 2002; Peterson and Shaw 2003; Sutherst 2004). At the continental scale, climate may be a good predictor of disease distribution, but at the local scale, other environmental factors are likely to be more important, such as the availability of breeding sites and surface waters.

8.2.8.1 Dengue

Several studies found an association between epidemic dengue and inter-annual climate variability (ENSO) in populations in Southeast Asia, the Pacific, and northern South America (Hales *et al.* 1999; Corwin *et al.* 2001; Gagnon *et al.* 2001; Cazelles *et al.* 2005). However, linkages between climate, weather and dengue are not fully understood as container-breeding mosquitoes in urban areas transmit the disease. Although there is evidence of heavy rainfall or high temperatures precipitating an increase in cases, studies have shown that drought can also have an important effect on transmission because water storage increases, providing more breeding sites (Pontes *et al.* 2000; Depradine and Lovell 2004; Guang *et al.* 2005).

Climate-based (temperature, rainfall, cloud cover) density maps of the dengue vector *Stegomyia aegypti* suggest a potential for latitudinal expansion of the vector (Hopp and Foley 2003). The model was shown to have good agreement with the distribution of observed human cases in Colombia, Haiti, Honduras, Indonesia, Thailand, and Viet Nam (Hopp and Foley 2003). Mapping of the secondary vector *Stegomyia albopictus*, also indicates the potential for northern expansion in North America and a reduction of its distribution in arid areas due to climate change (Alto and Juliano 2001). A global statistical model of dengue, driven by annual average vapour pressure, also indicates the potential for disease expansion (Hales *et al.* 2002).

8.2.8.2 Malaria

The spatial distribution, intensity of transmission, and seasonality of malaria is influenced by climate in sub-Saharan Africa; socio-economic development has had only limited impact on curtailing disease distribution (Craig *et al.* 1999; Hay *et al.* 2002b).

The effect of climate on epidemics of malaria is most important at fringe areas where temperature and/or rainfall are limiting factors for transmission. Rainfall can be a limiting factor for mosquito populations and there is some evidence of reductions in transmission associated with decadal decreases in rainfall. Inter-annual malaria variability is climate-related in specific eco-epidemiological zones (Julvez *et al.* 1992; Ndiaye *et al.* 2001; Singh and Sharma 2002; Bouma 2003; Thomson *et al.* 2005a). A systematic review of studies of ENSO and malaria concluded that the effect of El Nino on the risk of malaria epidemics was well established in parts of South Asia and

South America (Poveda *et al.* 2001; Kovats *et al.* 2003b). These studies suggest that malaria outbreaks can, in part, be predicted from global climate processes once underlying trends are removed.

The role of long-term climate change on the geographical distribution of malaria and its transmission intensity in highland regions remains controversial. Analyses of time series in some sites in East Africa indicate that malaria incidence increased in the apparent absence of co-varying trends of climatic variables(Hay *et al.* 2002b; Hay *et al.* 2002a). There were no trends in meteorological variables although malaria admissions increased over a 30 year period in a highland area in Kenya (Shanks *et al.* 2002). Proposed driving forces behind the malaria resurgence include drug resistance of the malaria parasite and decrease in vector control activities. However, the validity of this conclusion has been questioned because it might have resulted from inappropriate use of climate data sets (Patz 2002; Pascual *et al.* 2006). Re-analysis of updated temperature data from the same sites used by Hay *et al.* (Hay *et al.* 2002b) has shown evidence for a significant warming trend since the end of the 1970s (Pascual *et al.* 2006). In southern Africa, long-term trends of malaria case totals did not show a significant association with climate although seasonal changes in case numbers were significantly associated with a number of climatic variables (Craig *et al.* 2004). Drug resistance and HIV infection were found to be associated with long-term malaria trends in the same area (Craig *et al.* 2004).

A number of studies indicated associations between inter-annual variability in temperature and malaria transmission in the highlands. Analysis of a de-trended time-series of malaria in Madagascar indicated that minimum temperature at the start of the transmission season, corresponding to the months when the human-vector contact is greatest, accounts for most of the variability between years (Bouma 2003). Analysis of malaria epidemics in highland areas of Kenya found an association between rainfall and unusually high maximum temperatures and the number of hospitalized malaria cases 3-4 months later (Githeko and Ndegwa 2001). Analysis of malaria morbidity data during the late 1980s and early 1990s from 50 sites across Ethiopia has shown that epidemics were significantly more often preceded by several months of abnormally high minimum temperature (Abeku *et al.* 2003). A study carried out using data from seven highland sites in East Africa reported that climate variability played a more important role in initiating malaria epidemics in the East African highlands than long-term changes in mean temperature(Zhou *et al.* 2004, 2005) although the method used to test this hypothesis has been challenged (Hay *et al.* 2005b).

Despite the known causal links between climate and malaria transmission dynamics, there is still much uncertainty about the potential impact of climate change on malaria at local and global scales (see section 8.4.1) because of the paucity of concurrent detailed historical observations of climate and malaria, the complexity of malaria disease dynamics, and the importance of non-climatic factors in determining infection and infection outcome, including socio-economic development, immunity, and drug resistance.

8.2.8.3 Rodent borne infections

There is good evidence that diseases transmitted by rodents sometimes increase during heavy rainfall and flooding because of altered patterns of human-pathogen-rodent contact. There have been recent reports of flood-associated outbreaks of leptospirosis (Weil’s diseases) from a wide range of countries in Central and South America and South Asia (Ko *et al.* 1999; Vanasco *et al.* 2002; Ahern *et al.* 2005). Risk factors for leptospirosis for peri-urban populations in low-income countries include flooding of open sewers and street during the rainy season (Sarkar *et al.* 2002).

Cases of Hantavirus Pulmonary Syndrome (HPS) were first reported in Central America (Panama) in

2000, and a suggested cause was the increase in peri-domestic rodents following increased rainfall and flooding in surrounding areas (Bayard *et al.* 2000) although this requires further investigation.

8.2.8.4 Other infectious diseases

The distribution and emergence of other infectious diseases have been affected by weather and climate variability. ENSO-driven bush fires and drought, as well as land use and land cover changes, caused extensive changes in the habitat of some bat species that are the natural reservoirs for the Nipah virus. The bats were driven to farms to find food (fruits), consequently shedding viruses and causing an epidemic in Malaysia and neighbouring countries (Chua *et al.* 2000).

The distribution of schistosomiasis, a water-related parasitic disease that has aquatic snails as intermediate hosts, may be affected by climatic factors. In one area of Brazil, the length of the dry season and human population density were the most important limiting factors on schistosomiasis distribution and abundance (Bavia *et al.* 1999). Over a larger area, there was an inverse association between prevalence rates and the length of the dry period (Bavia *et al.* 2001).

8.2.9 Occupational health

Changes in climate have implications for occupational health and safety. Heat stress due to high temperature and humidity is an occupational hazard that can lead to acute fatalities, as well as chronic ill-health (Wyndham 1965; Afanas'eva *et al.* 1997; Adelakun *et al.* 1999). Both outdoor and indoor workers are at risk of heat stroke (Leithead and Lind 1964; Samarasinghe 2001; Shanks and Papworth 2001). The occupations most at risk of morbidity and mortality from heat stroke, based on US data, include construction and agriculture/forestry/fishing workers (Adelakun *et al.* 1999; Krake *et al.* 2003). Acclimatization in tropical environments does not eliminate the risk as evidenced by metal workers in Bangladesh (Ahasan *et al.* 1999) and rickshaw pullers in South Asia (OCHA 2003).

“Too hot” working environments are not just a question of comfort, but a concern for health protection and the ability to perform work tasks. For unacclimatised persons, the ability to perform at full capacity is reduced at temperatures above 22.5°C; for acclimatized persons, this reduction starts at 26°C (measured as wet bulb globe temperature, WBGT) (ISO International Standards Organization 1989; McNeill and Parsons 1999; Malchaire *et al.* 2002). If work continues beyond these limits, the worker is at high risk of diminished physical work ability (Kerslake 1972), diminished mental task ability (Ramsey 1995), increased accident risk (Ramsey *et al.* 1983), and eventually heat exhaustion or heat stroke (Hales and Richards 1987). The most common direct effect on humans of increasing annual temperatures is likely to be the “slowing down” of work and other daily activities (Mairiaux and Malchaire 1985; McNeill and Parsons 1999; Malchaire *et al.* 2000). Whether it occurs through “self-pacing” or occupational health management interventions, the end result is lower economic productivity (Mairiaux and Malchaire 1985) (section 8.5).

8.2.10 Ultra-violet radiation and health

Exposure to solar ultra-violet radiation, particularly in the ultra-violet B (UVB) band, may harm the eyes, skin, and immune system. At particular risk are pale-skinned populations living in temperate zones with clean air. Conditions linked to prolonged or intense exposures to UV include basal and squamous cancers of the skin, cortical cataract of the eye, and impairments in some aspects of the immune response to infections. There are also important health benefits of UVB: exposure to radiation of this frequency is required for production of vitamin D in the body and lack of sun exposures may lead to osteoporosis and other disorders caused by vitamin D deficiency.

Climate change may modify the health effects of UV exposure in several ways, both positive and negative. The balance of effects is difficult to predict, but is likely to vary depending on location and present exposures to UV. Greenhouse-induced cooling of the stratosphere is expected to prolong the effect of ozone-depletors and as a result increase levels of UV reaching some parts of the Earth's surface. Higher temperatures at the surface may lead, in some locations, to populations spending more time out of doors. In other situations, higher temperatures may discourage people from being outside and so reduce overall exposures to UV. If immune function is impaired and vaccine efficacy is reduced, the effects of climate-related shifts in the distributions of vectors and infections may be greater than would occur in the absence of high UV levels (Zwander 2002; de Gruijl *et al.* 2003; Holick 2004; Gallagher and Lee 2006; Samanek *et al.* 2006).

8.3 Assumptions about future trends

8.3.1 Health in scenarios

The use of scenarios to explore future effects of climate change on population health is at an early stage of development. Published scenarios so far describe possible future pathways based on observed trends or explicit storylines, and have been developed for a variety of purposes, including the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005), the SRES emissions scenarios (Nakicenovic and Swart 2000), GEO3 (UNEP 2002), and the World Water Report (United Nations World Water Assessment Programme 2003; Ebi and Gamble 2005).

Many possible futures have been described. We provide here some examples, exploring possible changes in the patterns of infectious diseases, medical technology, population ageing, and health and social inequalities (Olshansky *et al.* 1998; IPCC 2000; Martens and Hilderink 2001; Martens and Huynen 2003).

Infectious diseases could become more prominent if public health systems unravel, or if new pathogens arise that are resistant to our current methods of disease control, leading to falling life expectancies and economic productivity (Barrett *et al.* 1998). An age of expanded medical technology could result from increased economic growth and improvements in technology, which may to some extent off-set deteriorations in the physical and social environment, but at the risk of widening current health inequalities (Martens and Hilderink 2001). Alternatively, an age of sustained health could result from a more wide-ranging investment in social and medical services leading to a reduction in the incidence of disease, benefiting most segments of the population.

Common to these scenarios is a view that major risks to health will remain unless the poorest countries share in the growth and development experienced by richer parts of the world. It is envisaged also that greater mobility and more rapid spread of ideas and technology world-wide will bring a mix of positive and negative effects on health, and that a deliberate focus on sustainability will be required to reduce the impacts of human activity on climate, water and food resources (Goklany 2002).

8.3.2 Future vulnerability to climate change

Consideration of possible health futures is relevant to climate change because the health of populations is an important element of adaptive capacity. Where there is a heavy burden of disease and disability, the effects of climate change are likely to be more severe than otherwise. For example, in Africa and Asia the future course of the HIV/AIDS epidemic will be a significant influence on how well populations can cope with challenges such as spread of climate-related infections (vector- or water-borne), food shortages and increased frequency of storms, floods, and droughts (Dixon *et al.* 2002).

The total number of people at risk, the age structure of the population, and the density of settlement are important variables in any projections of the effects of climate change. Many populations will age appreciably in the next 50 years. This is relevant to climate change because the elderly are more vulnerable than younger age groups to injury resulting from weather extremes such as heat waves, storms, and floods. It is assumed (with a high degree of confidence) that over the course of the 21st century the population will grow substantially in many of the poorest countries of the world, while numbers will remain much the same, or decline, in the high-income countries. The world population will increase from its current 6.4 billion to somewhat below 9 billion by the middle of the century (Lutz *et al.* 2000). But regional patterns will vary widely. For example, the population density of Europe is projected to fall from 32 to 27 people per km^2, while that of Africa will rise from 26 to 60 people per km^2 (Cohen 2003). Currently, 70% of all episodes of clinical *Plasmodium falciparum* world-wide occur in Africa, and that fraction will rise substantially in the future (World Bank 2004). Also relevant to considerations of the impacts of climate change is urbanization, because the effects of higher temperatures and altered patterns of rainfall are strongly modified by the local environment. For instance, during hot weather temperatures tend to be higher in built-up areas, due to the urban heat island effect. Almost all the growth in population in the next 50 years is expected to occur in cities (and in particular, cities in poor countries) (Cohen 2003). These trends in population dominate calculations of the possible consequences of climate change. These are two examples: projections of the numbers of people affected by coastal flooding and the spread of malaria are more sensitive to assumptions about future population trajectories than to the choice of climate change models (Nicholls 2004; van Lieshout *et al.* 2004).

For much of the world's population, the ability to lead a healthy life is limited by direct and indirect effects of poverty (World Bank *et al.* 2004). Although the percentage of people living on less than 1 USD per day has reduced in Asia and Latin America since 1990, in the sub-Saharan region, 46% of the population is now living with less than 1 USD per day and little improvement is expected in the short and medium term. Poverty levels in Europe and Central Asia show few signs of improvement (World Bank 2004; World Bank *et al.* 2004). Economic growth in the richest regions has outstripped advances in other parts of the world, meaning that global disparities in income have increased in the last 20 years (UNEP and WCMC 2002).

In the future, vulnerability to climate will depend on not only the extent of socio-economic change, but also how evenly the benefits and costs are distributed, and the manner in which change occurs (McKee and Suhrcke 2005). Economic growth is double-sided. Growth entails social change, and while this change may be wealth creating, it may also, in the short-term at least, cause significant social stress and environmental damage. Rapid urbanization (leading to plummeting population health) in Western Europe the 19th century, and extensive land clearance (causing widespread ecological damage) in South America and South East Asia in the 20th century, are two examples of negative consequences of rapid economic growth (Szreter 2004).

Health services provide a buffer against the hazards of climate variability and climate change. For instance, access to cheap, effective anti-malarials and insecticide-treated bed nets will be an important influence on future trends in this disease. Emergency medical services have a role (although not a predominant one) in limiting excess mortality due to heat waves and other extreme climate events.

There are other determinants of vulnerability that relate to particular threats, or particular settings. Heat waves, for example, are exacerbated by the urban heat island effect, so that impacts of high temperatures will be modified by the size and design of future cities (Meehl and Tebaldi 2004). The consequences of changes in food production due to climate change will depend on access to international markets and the conditions of trade. If these conditions exclude or penalize poor countries, then the risks of disease and ill-health due to malnutrition will be much higher than if a more inclusive economic order is achieved. Parry *et al.* estimate that under all SRES scenarios, the world will have sufficient food to feed everyone up to the end of the 21st century (Fischer *et al.* 2002; Parry *et al.* 2004). But this assumes that people in developing countries, where climate change impacts are predominantly negative, will have access to food produced in developed countries.

8.4 Key future impacts and vulnerabilities

Quantitative and qualitative approaches can be used to project how the incidence and geographic range of health determinants and outcomes might change under different climate and socioeconomic scenarios. The potential impacts of climate change have been quantified for a limited range of health outcomes for which the epidemiologic evidence base is well developed; these are reviewed in the first section.

No projections are available on how climate change could affect population health in geographic areas believed to be at particular risk in the next few decades. Thus, the subsequent section takes a primarily qualitative approach to assessing the potential climate change-related health impacts in particularly vulnerable populations living in some urban and rural areas in low-income countries, coastal and low-lying areas, and mountain regions.

Overall, the projected climate changes will probably have some health benefits, including reduced cold-related mortality, reductions in some pollutant-related mortality, and restricted distribution of diseases where temperatures or rainfall exceed upper thresholds for vectors or parasites. The balance of positive and negative health effects will vary from one location to another, and will alter over time if temperatures continue to rise.

8.4.1 Quantitative estimates of climate change-related health impacts

Quantitative models of climate change-related health impacts use different approaches to classify the risk of climate-sensitive health determinants and outcomes. For malaria and dengue, results from models are commonly presented as maps of potential shifts in distribution. The models are typically based on climatic constraints on the development of the vector and/or parasite, and include limited population projections and non-climate assumptions. However, there are important differences between disease risk and experienced morbidity and mortality. Although large portions of Europe and the United States may be at risk for malaria based on the distribution of competent disease vectors, autochthonous cases have been virtually eliminated, in part due to vector and disease control activities. Models for other health outcomes often estimate populations-at-risk or person-months at risk.

Economic scenarios cannot be directly related to disease burdens because the relationships between GDP and burdens of climate-sensitive diseases are confounded by social, environmental, and climate factors (Arnell *et al.* 2004; van Lieshout *et al.* 2004; Pitcher *et al.* in press). The assumption that increasing per capita income will improve population health ignores that health is determined by more than income, that good population health itself is a critical input into economic growth and long-term economic development, and that persistent challenges to development are a reality in many countries, with continuing high burdens from relatively easy-to-control diseases (Pitcher *et al.* in press).

8.4.1.1 Global burden of disease study

The World Health Organization conducted a regional and global comparative risk assessment to quantify the amount of premature morbidity and mortality due to a range of risk factors, including climate change, and to estimate the benefit of interventions to remove or reduce these risk factors. In the year 2000, climate change is estimated to have caused the loss of over 150,000 lives and 5,500,000 DALYs (Ezzati *et al.* 2002; Campbell-Lendrum *et al.* 2003; McMichael 2004). The assessment also addressed how much of the future burden of climate change could be avoided by stabilizing greenhouse gas emissions (Campbell-Lendrum *et al.* 2003). The health outcomes included were chosen based on known sensitivity to climate variation, predicted future importance, and availability of quantitative global models (or feasibility of constructing them): episodes of diarrhoeal disease, cases of falciparum malaria, fatal unintentional injuries in coastal floods and inland floods/landslides, and non-availability of recommended daily calorie intake (as an indicator for the prevalence of malnutrition). Adjustments for adaptation were included in the estimates.

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 diarrhoeal disease and malnutrition, primarily in low-income populations already experiencing a large burden of disease (Campbell-Lendrum *et al.* 2003; McMichael 2004). Absolute disease burdens depend on assumptions of population growth, future baseline disease incidence, and the extent of adaptation. Warmer winter temperatures are projected to result in a small proportional decrease in cardiovascular and respiratory disease mortality attributable to climate extremes in tropical regions, with a slightly larger benefit in temperate regions. The relative risk for diarrhoea in 2030 in low-income countries is projected to be between 1.0 and 1.1 under unmitigated emissions, compared with baseline climate. Countries with an annual GDP of $6,000 or more are assumed to have no additional risk of diarrhoea. The projected impacts of malnutrition vary from a large increase (relative risk = 1.1 – 1.3) in the WHO region SEAR-D (Bangladesh, Bhutan, Democratic People’s Republic of Korea, India, Maldives, Myanmar, Nepal) to no change or a small decrease (relative risk = 0.99 – 1.0) in WHO region WPR-B (Cambodia, China, Cook Islands, Fiji, Kiribati, Lao People’s Democratic Republic, Malaysia, Marshall Islands, Micronesia, Mongolia, Nauru, Niue, Palau, Papua New Guinea, Philippines, Republic of Korea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Viet Nam). High income countries are assumed to suffer no climate change-related malnutrition impacts. Coastal flooding is projected to result in a large proportional increase under unmitigated emissions; however, this is applied to a very low burden of disease. The relative risk is projected to increase as much in high- as in low-income countries. Large changes are projected in the risk of falciparum malaria in countries at the edge of the current distribution, with relative changes much smaller in areas that are currently highly endemic for malaria.

8.4.1.2 Malaria, dengue, and other vector-borne diseases

Studies published since the TAR support previous projections that climate change could influence the incidence and geographic range of malaria, although the magnitude of the effect may be smaller than that previously projected. This partly reflects advances in categorising risk. Table 8.4 summarises studies that projected the impacts of climate change on the incidence and range of infectious diseases. Models with incomplete parameterization of biological relationships between temperature, vector, and parasite often over-emphasize relative changes in risk, even when the absolute risk is small.

Several modelling studies used the SRES climate scenarios, a few applied population scenarios, and none incorporated economic scenarios. Few studies incorporate adequate assumptions about adaptive capacity. The two main approaches used are inclusion of current "control capacity" in the observed climate-health function (Rogers and Randolph 2000; Hales *et al.* 2002) and categorisation of the model output by adaptive capacity, thereby separating the effects of climate change from the effects of improvements in health status (van Lieshout *et al.* 2004).

Malaria is a complex disease to model, and all published models have limited parameterization of key factors that influence the geographic range and intensity of malaria transmission. Given this limitation, models suggest that, in Africa, climate change may be associated with expansions and contractions of the geographic area suitable for transmission of stable falciparum malaria (Hartman *et al.* 2002; Tanser *et al.* 2003; Thomas *et al.* 2004; van Lieshout *et al.* 2004). Some results suggest that the season of transmission may be extended. If true, this may be as important as geographical expansion for the attributable health burden. Although an increase in months per year of transmission does not directly translate into an increase in the burden of malaria deaths (Reiter *et al.* 2004), it could have important implications for vector control.

Few models have projected the impacts of climate change on malaria outside Africa. Climate change is projected to expand the European range of five species of anopheline vectors (Kuhn *et al.* 2002a) based on relationships derived from historical distributions. However, an assessment of absolute malaria risk in Europe under climate change, based on biological relationships, per capita income, and life expectancy, projected that the risk of malaria in most of Europe would remain very low, although increased risk could occur in some parts of southeast Europe (Kuhn *et al.* 2002a). An assessment in Portugal projected an increase in the number of days per year suitable for malaria transmission based on a temperature threshold model; however, the risk of actual transmission was either low or none using a qualitative risk assessment method (Casimiro and Calheiros 2002). Some central Asian areas may be at risk of climate-related increases in malaria suitability, and areas in central America and around the Amazon are likely to have reductions in transmission due to decreases in rainfall (van Lieshout *et al.* 2004). An assessment in India projected that assuming current levels of control, only northern states (Jammu and Kashmir) may be at risk of increases in malaria transmission due to climate change (Mitra *et al.* 2003; Shukla *et al.* 2003; van Lieshout *et al.* 2004). An assessment in Australia based on climatic suitability for the main anopheline vectors and parasite projected a likely southward expansion of habitat in the north of the country, although the future risk of endemicity would remain low due to the capacity to respond (McMichael *et al.* 2003a).

Dengue is an important climate-sensitive disease that is largely confined to urban areas. Expansions of vector species that can carry dengue are projected in parts of Australia and New Zealand (deWet *et al.* 2001; Hales *et al.* 2002; McMichael *et al.* 2003b). An empirical global model based on vapour pressure projects increases in global temperatures could lead to latitudinal expansion of its distribution (Hales *et al.* 2002). Based only on population projections, the future population at risk is projected to be 3.5 billion people by 2085 (35% of the total population). Using the same population increase, the IS92a scenario, and changes in humidity projected by five general circulation models, the population at risk is projected to increase to 5 to 6 billion people. Additional models are needed to increase confidence in these projections.

The only other vector-borne disease to be mapped and quantified for climate change impacts is tick-borne encephalitis in Europe (Randolph and Rogers 2000). Increased temperatures are projected to reduce the endemic range of this disease in Europe.

8.4.1.3 Heat- and cold-related mortality

Evidence of the relationship between high ambient temperature and mortality has strengthened since the TAR, with increasing emphasis on the health impacts of heat waves. Table 8.5 summarizes studies that projected the impacts of climate change on heat- and cold-related mortality. There is a lack of information on the effects of temperature on mortality outside industrialized countries. Reductions of cold-related deaths due to climate change are projected to be greater than increases in heat-related deaths for all temperate-zone populations (Europe, Asian part of Russia, Canada, United States). However, projections of cold-related deaths, and the potential for decreasing their numbers during warmer winters, will be over-estimated unless they take into account the effect of influenza and season (Armstrong *et al.* 2004). Additional research is needed to understand how the balance of heat- and cold-related deaths might change under different climate and socioeconomic scenarios.

Heat-related morbidity and mortality is projected to increase; however, downscaling temperature projections to urban areas is difficult. Heat exposures vary widely, and current studies do not quantify the years of life lost due to high temperatures. Estimates of the burden of heat-related mortality attributable to climate change are reduced but not eliminated when assumptions about acclimatization and adaptation are included in models. On the other hand, increasing numbers of older adults will increase the size of the population at risk because decreased ability to thermo-regulate is a normal part of the ageing process. Overall, the health burden could be relatively small for moderate heat waves because deaths occur primarily in susceptible persons. Models do not include changes in the frequency or intensity of extreme events such as occurred in 2003 in Europe.

8.4.1.4 Urban air quality

Background levels of ozone have risen since pre-industrial times because of increasing emissions of methane, carbon monoxide, and nitrogen oxides, and this trend is expected to continue over the next 50 years (Fusco and Logan 2003; Prather *et al.* 2003). 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 (Stevenson *et al.* 2000; Derwent *et al.* 2001; Johnson *et al.* 2001; Taha 2001; Hogrefe *et al.* 2004). Future emissions are, of course, uncertain, and depend on assumptions of population growth, economic development, and energy use (Syri *et al.* 2002; Webster *et al.* 2002) . Assuming no change in the levels of ozone precursor emissions, the extent to which climate change affects the frequency of future “ozone episodes” will depend on the occurrence of the requisite meteorological conditions (Jones and Davies 2000; Sousounis *et al.* 2002; Hogrefe *et al.* 2004; Laurila *et al.* 2004; Mickley *et al.* 2004).

Current exposure-mortality relationships can be applied to future ozone levels to estimate future attributable premature mortality. Table 8.6 summarizes studies that projected the health effects of changes in ozone concentrations due to climate change. A US study estimated increases in adverse health impacts by the 2050s under the SRES A2 emissions scenario (Knowlton *et al.* 2004). The quantification of future pollution health impacts relied on robust projections of county-level pollutant concentrations. Summer ozone-related mortality is projected to increase by 4% in the New York area by the 2050s based on climatic changes alone (Knowlton *et al.* 2004). Increases in background ozone levels could affect the ability of regions to achieve air quality targets. No studies have been conducted for cities in low- or middle-income countries, despite the heavier pollution burdens in these populations.

There are few models of the impacts of climate change on other pollutants. These tend to emphasize the role of local abatement strategies in determining the future levels of pollutants and tend to project the probability of exceedence instead of absolute concentrations (Jensen *et al.* 2001; Guttikunda *et al.*

Table 8.4: *The impacts of climate change on infectious diseases and vector species*

Health	Metric	Model	Climate scenario, with time slices	Population projections and non-climate assumptions	Main results	Reference
Malaria, global and regional	Population at risk	Biological model, calibrated from laboratory and field data, for falciparum malaria	HadCM3, driven by 4 SRES scenarios. Monthly temperature and precipitation. 2020s, 2050s, 2080s	SRES population scenarios	For countries that currently have a limited capacity to control the disease, the model estimates additional populations at risk by 2080s in the range of 90 million (A1) to 200 million (B2b)	(van Lieshout *et al.* 2004)
Malaria, Africa	Person-months at risk	MARA/ARMA seasonality model of stable falciparum transmission	HadCM3, driven by 3 SRES emissions scenarios	Estimates based on current population.	Increases in person-months, especially in highland areas	(Tanser *et al.* 2003)
Malaria, Africa	Map of climate suitability	MARA/ARMA model of suitability of stable falciparum transmission [minimum 4 months suitable per year]	HadCM2 medium high ensemble mean. Temperature, rainfall, and absence of frost. 2020s, 2050s, 2080s	Climate factors only	Little increased transmission by 2020s. By 2050s and 2080s, localised increases in highland and upland areas, and decreases around Sahel and semi-arid Southern Africa	(Thomas *et al.* 2004)
Malaria, Zimbabwe, Africa	Climate suitability for transmission	MARA/ARMA model of suitability of stable falciparum transmission	16 climate projections to 2100 from COSMIC, climate sensitivities of 4.5° C and 1.4° C, and equivalent CO2 [350 and 750 ppmv]	None	Highlands become more suitable for transmission, while the lowlands and areas with low precipitation showing varying degrees of change, depending on climate sensitivity, emission scenarios, and GCM.	(Hartman *et al.* 2002)
Malaria, Europe	Map. Probability of presence for 5 vector species and vectorial capacity	Statistical model, multivariate regression based on historical distributions, land cover, and climate determinants	HadCM3 SRES A2 and B2	None. No changes in land cover.	Maps – not quantified. General expansion of main vector (An atroparvus) and other vectors	(Kuhn *et al.* 2002b)
Malaria and dengue, 5 regions in Portugal	Favourable periods for transmission (% days per year)	Threshold approach based on published literature	RCM; PROMES for 2040s and HadRM2 for 2080s 2 x CO2	None. Some assumptions about vector distribution and/or introduction.	General increase in annual percent of days within favourable transmission season	(Casimiro and Calheiros 2002)
Malaria, Australia	CLIMEX ecoclimatic index	Climate matching model for main vector An. Farauti s.l.	CSIROMk2, ECHAM4. High, medium, and low emissions.	Assumes adaptive capacity	"Malaria receptive zone" expands southward to include some regional towns by 2050s. Absolute risk of reintroduction remains very low.	(McMichael *et al.* 2003b)

Table 8.5: *Estimates of the impacts of climate change on heat and cold related mortality*

Area	**Health effect**	**Model**	**Climate scenario; time slices**	**Population projections and non-climate assumptions**	**Main results**	**Reference**
United Kingdom	Heat- and cold-related mortality and hospital admissions.	Empirical-statistical model derived from observed mortality.	UKCIP scenarios. 2020s, 2050s, 2080s	No population growth. No acclimatization assumed.	Medium-high climate change scenario results in an estimated annual 2800 heat deaths in the UK in the 2050s (250% increase). Greater reductions in cold-related mortality.	(Donaldson *et al.* 2001)
Four cities in California, USA [Los Angeles, Sacramento, Fresno, Shasta Dam]	Heat-related death	Empirical-statistical model derived from observed summer mortality.	SRES B1 and A1fi emission scenarios. PCM and HadCM3. 2020-2049 2070-2099	SRES population scenarios. Assumes some adaptation.	Annual number of days classified as heat wave conditions increases under all simulations; for Los Angeles by the end of the century, increases of 4-fold under B1 and 6-8-fold under A1fi are projected. Annual number of heat-related deaths increases from about 165 in the 1990s to 319 to 1,182 under different scenarios.	(Hayhoe 2004)
Lisbon, Portugal	Heat-related death	Empirical-statistical model, derived from observed summer mortality.	RCMs: PROMES and HadRM2. 2xCO_2 emissions	SRES population scenarios. Assumes some acclimatization.	Increases in heat related mortality by 2020s to range of 5.8-15.1 deaths per 100,000, from baseline of 5.4-6 deaths per 100,000	(Dessai 2003)
Six cities in Australia [Adelaide, Brisbane, Hobart, Melbourne, Perth, Sydney] Two cities in New Zealand [Auckland, Christchurch]	Heat- and cold-related mortality in over 65s	Empirical-statistical model, derived from observed daily mortality.	CSIROMk2, ECHAM4. High, medium, and low emissions.	Population growth and population ageing. No acclimatization.	Increases in heat-related mortality in over 65s, increases large in temperate cities. Cold-related mortality already minimal at baseline.	(McMichael *et al.* 2003b)

2003; Hicks 2003; Slanina and Zhang 2004); the results vary by region. The severity and duration of summertime regional air pollution episodes are projected to increase in the north-eastern and midwestern United States for the period 2045-2052 because of climate change-induced decreases in the frequency of surface cyclones (Mickley *et al.* 2004). A UK study found that climate change could lead to a large decrease in days with high particulate concentrations due to projected changes in meteorological conditions (Department of Health and Expert Group on Climate Change and Health in the UK 2001). Because transboundary transport of pollutants plays a significant role in determining local to regional air quality (Bergin *et al.* 2005), changing patterns of atmospheric circulation at the hemispheric to global level are likely to be equally important as regional patterns for future local air quality (Takemura *et al.* 2001; Langmann *et al.* 2003).

8.4.2 Vulnerable populations

Particularly vulnerable populations are those groups of people who are more likely to suffer harm and have less ability to respond to stresses imposed by climate variability and change. For example, all persons living in a flood plain are at risk during a flood, but those with lowered ability to escape floodwaters and their consequences (such as children and the infirm, or those living in substandard housing) are at higher risk.

The following sections highlight populations that are likely to face increased climate change-related health risks because of multiple sources of vulnerability. There is a limited literature base to assess for these population groups; however, current vulnerabilities are high and progress on reducing these has been slow.

8.4.2.1 Urban populations

Urbanization and climate change may work synergistically to increase disease burdens. Urban populations are growing faster in low- than high-income countries, with cities and urban areas gaining an estimated 60 million people per year, or over one million per week. By 2007, the projected global urban population of 3.2 billion people will be larger than the entire global population in 1967. Approximately five billion people are expected to live in cities by 2030, about 60 per cent of the global population of 8.1 billion people (UNFPA 1999).

Urbanization can positively influence population health; for example, by making it easier to provide safe water and sanitation. However, rapid and unplanned urbanization is often associated with adverse health outcomes. Urban slums and squatter settlements are often located in areas subject to landslides, floods, and other natural hazards. Lack of water and sanitation in these settlements are not only problems in themselves, but they also increase the difficulty of controlling disease reservoirs and vectors, facilitating the emergence and re-emergence of waterborne and other diseases (Obiri-Danso *et al.* 2001; Akhtar 2002; Hay *et al.* 2005a). Combined with declining economies, unplanned urbanization may affect the burden and control of malaria, with the relative disease burden increasing among urban dwellers (Keiser *et al.* 2004). Currently, approximately 200 million people in Africa (24.6% of the total population) live in urban settings where they are at risk of malaria. In India, unplanned urbanization has contributed to the spread of malaria (Akhtar *et al.* 2002) and dengue (Shah *et al.* 2004). In addition, noise, crowding, and other possible features of unplanned urbanization may increase the prevalence of mental disorders, such as depression, anxiety, chronic stress, schizophrenia, and suicide (WHO 2001). Problems associated with rapid and unplanned urbanization are expected to increase for at least the next few decades, with greater disease burdens in low-income countries.

Table 8.6: *Scenario-based estimates of the impacts of climate change on ozone-related health effects*

Area	**Health effect**	**Model**	**Climate scenario Time slices**	**Population projections and non-climate assumptions**	**Main results**	**Reference**
New York metropolitan region, US	Ozone-related deaths by county	Concentration response function from published epidemiologic literature. Gridded ozone concentrations from CMAQ (Community Multiscale Air Quality model).	GISS GCM linked to RCM. SRES A2 emissions scenario. Downscaling using MM5. 2050s	A2 population projection, with 2000 age structure (no ageing). Assumes no change from USEPA 1996 national emissions inventory and A2-consistent increases in NOx and VOCs by 2050s.	A2 climate only: 4.5% increase in ozone-related deaths. Ozone elevated in all counties. A2 climate and precursors: 4.4% increase in ozone-related-deaths. [Ozone not elevated in all areas due to NO_x interactions]	(Knowlton *et al.* 2004)
England and Wales	Exceedance days (ozone, particulates, NO_x)	Statistical, based on meteorological factors for high pollutant days (temperature, wind speed)	UKCIP scenarios 2000s, 2050s, 2080s	Assumes no change in emissions	Generally, large decreases in days with high particulates and SO_2, moderate decrease in all other pollutants except ozone, which may increase.	(Anderson 2002)

Few studies have investigated the potential interaction between climate change and urban heat island effects; a study in London indicated that the heat island effect could be exacerbated by increasing temperatures (Wilby 2003). Populations in high density urban areas with poor housing will be at risk of future increases in the frequency and intensity of heat waves. Adaptation will require diverse strategies that are likely to include physical modification to the built environment, improved housing standards, and changes in decision-making practices (Koppe *et al.* 2004).

In some regions, changes in temperature, precipitation, and other environmental changes may increase rural-urban migration because of increased drought conditions, which could delay achievement of poverty reduction targets.

8.4.2.2 Rural populations

Climate change could have a range of adverse affects on some rural populations and areas, including increasing food insecurity through geographical shifts in optimum crop-growing conditions and yield changes in crops, reducing water resources for agriculture and human consumption, flood and storm damage, loss of land through floods and a rise in sea level, and increasing rates of climate-sensitive diseases. Water scarcity itself is associated with multiple adverse health outcomes, including diseases associated with water contaminated with faecal and other hazardous substances (including parasites), vector-borne diseases that arise from water storage systems, and malnutrition. Savannah, which covers approximately 40% of the world land area, is where water scarcity constitutes a serious constraint to sustainable development (Rockstrom 2003).

Malnutrition represents a large burden of ill health, particularly in rural areas. Although the International Food Policy Research Institute's International Model for Policy Analysis of Agricultural Commodities and Trade projects that global cereal production could increase by 56% between 1997 and 2050, and livestock production by 90% (Rosegrant and Cline 2003), expert assessments of future food security are generally pessimistic over the medium term. In some regions, available food supplies are projected not to keep pace with population growth, increasing the absolute number of people malnourished. Income growth and rapid urbanization are major forces driving increased demand for meats, fruits, and vegetables. There are indications that it will take approximately 35 additional years to reach the World Food Summit 2002 target of reducing world hunger by half by 2015 (Rosegrant and Cline 2003; UN Millennium Project 2005). Child malnutrition is projected to persist in many low-income countries, although the overall global burden is expected to decline.

Attribution of current and future climate change-related malnutrition burdens is problematic because the determinants of malnutrition are complex. Due to the very large number of people that may be affected, malnutrition linked to drought and flooding may be one of the most important consequences of climate change, but few studies have systematically linked climate, environment, and nutritional outcomes at the national or local level. One study projected that climate change could increase the percentage of the Malian population at risk of hunger from 34% to 64% to 72% by the 2050s, although this could be substantially reduced by effective implementation of range of adaptive strategies (Butt *et al.* 2005). Climate change models project that those likely to be adversely affected are the regions already most vulnerable to food insecurity, notably Africa, which may lose substantial agricultural land.

8.4.2.3 Populations in coastal and low-lying areas

One quarter of the world's population resides within 100 km distance and 100 m elevation of the coastline, with increases likely over the coming decades (Small and Nicholls 2003). Climate change could affect coastal areas through sea level rise, increases in ocean temperatures, changes in the hydrological cycle, and changes in the frequency of extreme events. These changes could affect human health through coastal flooding and damaged coastal infrastructure; saltwater intrusion into coastal freshwater resources; damage to coastal ecosystems, coral reefs, and coastal fisheries; population displacement; changes in the range and prevalence of climate-sensitive diseases; and others. Although some small island states and other low-lying areas are at particular risk, few studies have been conducted of the health impacts of climate variability and change. Climate-sensitive diseases of concern in small island states include malaria, dengue, diarrhoeal diseases, heat stress, skin diseases, acute respiratory infections, and asthma (WHO 2004b). A model of an increase of the summer temperature maximum in the Netherlands by 4° C in 2100, in combination with water column stratification, projected a doubling of growth rates of several species of potentially harmful phytoplankton, which would increase the frequency and intensity of harmful algal blooms in the North Sea (Peperzak 2005).

A model projected the effects of a range of global mean sea-level rise and socio-economic scenarios on changes in flooding by storm surges through the 21st century (Nicholls 2004). Under the baseline conditions, it was estimated that in 1990 about 200 million people lived beneath the 1 in 1000-year storm surge (e.g., people in the hazard zone), and about 10 million people per year experienced flooding. Across all time slices, population growth increased the number of people living in a hazard zone under the four SRES scenarios (A1FI, A2, B1, and B2). Assuming that defences are upgraded against existing risks as countries become wealthier, but sea-level rise is ignored, the number of people affected by flooding decreases by the 2080s under the A1FI, B1, and B2 scenarios. Under the

A2 scenario, a two-to-three fold increase is projected in the number of people flooded per year in the 2080s compared with 1990. Island regions are especially vulnerable, particularly in the A1FI world, particularly Southeast Asia, South Asia, Africa Indian Ocean Coast, Africa Atlantic Coast, and Southern Mediterranean (Nicholls 2004).

Densely populated regions in low-lying areas are vulnerable to climate change. In Bangladesh, under assumptions of a 2°C temperature increase, a 30 cm increase in sea level rise, an 18% increase in monsoon precipitation, and a 5% increase in monsoon discharge in major rivers, it was projected that 4.8% of people living in unprotected dry land areas could face inundation with a water depth of 30-90 cm (BCAS/RA/Approtech 1994). This could increase to 57% of people under assumptions of a 4°C temperature increase, a 100 cm increase in sea level rise, a 33% increase in monsoon precipitation, and a 10% increase in monsoon discharge in major rivers. Some areas could face higher levels of inundation (90-180 cm).

Studies in industrialized countries indicate that densely populated urban areas are at risk from sea level rise (see Chapter 6). As demonstrated by Hurricane Katrina, areas of New Orleans, US, and vicinity are 1.5-3m below sea level (Burkett 2003). Considering the rate of subsidence and using the TAR mid-range estimate of 480 mm sea-level rise by 2100, it is projected that this region could be 2.5 to 4.0 m or more below mean sea level by 2100, and that a storm surge from a Category 3 hurricane (estimated at 3 to 4 meters without waves) could be 6 to 7 meters above areas that were heavily populated in 2004 (Manuel 2006).

8.4.2.4 Populations in mountain regions

Changes in climate are affecting many mountain glaciers, with rapid glacier retreat documented in the Himalayas, Greenland, the European Alps, Ecuador, Peru, Venezuela, New Guinea, and East Africa (WWF 2005). Changes in the depth of mountain snowpacks and glaciers, and changes in their seasonal melting, can have significant impacts on the communities from mountains to plains that rely on freshwater runoff. For example, in China, 23% of the population lives in the western regions where glacial melt provides the principal dry season water source (Barnett *et al.* 2005). Long-term reduction in annual glacier snowmelt could result in water insecurity in some regions.

Little published information is available on the possible health consequences of global climate change in mountain regions. However, it is likely that vector-borne pathogens could take advantage of new habitats in altitudes that were formerly unsuitable, and that diarrhoeal diseases could become more prevalent with changes in freshwater quality and availability (Ebi *et al.* 2006b). More extreme rainfall events are likely to increase the number of floods and landslides. Glacier lake outburst floods (GLOF) are a risk unique to mountain regions; GLOFs are associated with high morbidity and mortality and are projected to increase as the rate of glacier melting increases.

8.4.2.5. Populations in polar regions

Approximately 90 % of the circumpolar population is comprised of non-indigenous residents living primarily in settlements larger than 5000 people. However, it is the indigenous population, spread throughout numerous small and often isolated communities in the circumpolar Arctic that are considered to be some of the most vulnerable communities to climate change (ACIA, 2005). Their vulnerability is related to their close relationship with the land, coastal geographic location, reliance on the local environment for aspects of their diet and economy, and current dynamic state of social, cultural, economic and political change in many regions (Berner and Furgal 2005).

It is projected that summer warming and a strengthening of the Arctic Oscillation may increase the incidence of non-fatal acute myocardial infarctions in Finnoscandinavian regions (Messner 2005). However a general warming in winter months in Arctic regions will reduce excess winter mortality, primarily through a reduction in cardiovascular and respiratory deaths. A reduction in cold-related injuries will likely be seen, assuming that cold protection, including human behavioural factors, do not change (Nayha 2005). Observations in northern Canadian Aboriginal communities suggest that an increase in the number of land-based accidents and injuries associated with unpredictable environmental conditions such as thinning and earlier break up of sea ice are likely to continue (e.g. (Furgal, C. *et al.* 2002). Diseases transmitted by wildlife and insects diseases are projected to have a longer season in some regions such as the north-western North American Arctic, resulting in an increased occurrence of disease and epidemics in key animal species (e.g. marine mammals, birds, fish and shellfish) that can be transmitted to humans (Bradley *et al.* 2005; Parkinson and Butler 2005). The traditional diet of circumpolar residents will likely be negatively affected by changes in animal migrations and distribution and human access to them resulting from warming impacts on snow and ice timing and distribution, in combination with other trends in Arctic communities. Further, warming may indirectly influence human exposure to environmental contaminants in some of these foods (e.g. marine mammal fats) and are known to adversely affect immune and neuromotor functioning in children (AMAP 2002; Kraemer *et al.* 2005). Projected warming in the North Atlantic is estimated to increase rates of mercury methylation, leading to increased concentrations in marine species by 1.7-4.4%, and, thus, increasing human exposure via consumption of fish and marine mammals species (e.g. Western Greenland and Eastern Canadian Arctic) (Booth and Zeller 2005). The interactions of local climate systems with underlying social, cultural, economic, and political change will have significant implications for Arctic residents (Curtis *et al.* 2005).

8.5. Costs and other socio economic impacts

The evidence for the monetization of the health impacts of climate change is limited. The earliest studies either aggregated the ‘damage’ costs of climate change (Tol 1995; Tol 1996; Fankhauser *et al.* 1997; Fankhauser and Tol 1997; Tol 2002a, 2002b), or estimated the costs and benefits of measures to reduce climate change (Cline and Bodnar 1991; Nordhaus 1991; Nordhaus and Boyer 2000; Cline 2004). The global economic value of loss of life due to climate change varies between around USD6 billion and USD88 billion, in 1990 USD (Tol 1995; Tol 1996; Fankhauser *et al.* 1997; Fankhauser and Tol 1997; Tol 2002a, 2002b). The economic methods for estimating welfare costs (and benefits) have several shortcomings. In relation to health effects, the studies include only a limited number of health outcomes, generally heat-cold-related mortality and malaria. Some assessment of direct costs for health impacts at the national level have been undertaken but the evidence base for estimating the health effects is relatively weak (IGCI 2000; Turpie *et al.* 2002; Woodruff *et al.* 2006). Where they have been estimated, the welfare costs of health impacts contribute substantially to the total costs of climate change (Cline, 1992; Tol 2002a).

A range of methods are used to estimate the direct or damage costs of loss of life or years lived with disability, and how deaths in children or the elderly are valued compared with deaths in adults. With respect to climate change, mortality impacts are projected to be greatest in low-income countries, where economist traditionally value life less (van der Pligt *et al.* 1998; Hammitt and Graham 1999; Viscusi and Aldy 2003). Some estimates suggest that replacing national values with a “global average value” would increase the mortality costs by as much as five times (Fankhauser *et al.* 1997). Estimates of economic impact via changes in productivity will also ignore important health impacts in children and the elderly (Bosello *et al.* 2005).

Climate change is likely to have important direct effects on productivity via exposure of workers to heat stress (see section 8.2.8). A number of recent studies have documented the reduced work capacity in relation to heat. The effect occurs above 35°C even in arid conditions (Mommadov *et al.* 2001). It occurs in indoor office environments (Wyon 2004) and factories (Rodahl 2003). Work performance is reduced by heat before physiological limits are reached (Hancock and Vasmatzidis 1998). The economic cost of existing ergonomically suboptimal working environments in the US has been estimated at many billion dollars (Fisk 2000). An estimate of the impact of climate change on these types of costs has not been made.

8.6 Adaptation: practices, options and constraints

The primary response to projected increases in the burden of climate-sensitive health outcomes and determinants will be to enhance current health risk management activities and planning. All health determinants and outcomes that are projected to increase with climate change are problems today. Thus, public health efforts to control these health outcomes will need to be revised, reoriented, and/or expanded just to maintain current levels of disease control. In some cases, programs will need to be implemented in new regions; in others, climate change may reduce current infectious disease burdens. The degree to which programs and measures will need to be augmented to address the additional pressures due to climate change will depend on factors such as the current burden of climate-sensitive diseases, the effectiveness of current interventions, projections of where, when, and how the burden of disease could change with changes in climate and climate variability, the feasibility of implementing additional cost-effective interventions, other stressors that could increase or decrease resilience to impacts, and the social, economic, and political context within which interventions are implemented (Yohe and Ebi 2005; Ebi *et al.* 2006a).

There are important prerequisites for adaptation that are currently not met in many parts of the world, such as access to primary health care, safe water and sanitation, and improved housing in many low-income countries. Public awareness, effective use of local resources, appropriate governance arrangements, and community participation are necessary to mobilize and prepare for climate change. These present particular challenges in resource-poor communities.

Adaptation responses and limitations are dependent on the health outcome and the characteristics of the population of interest, and will vary over time and across geographic locations. Because the range of possible health impacts of climate change is broad and the local situations diverse, enumerating all possible adaptation options is not practical. Examples are provided in the following sections that illustrate technical, educational-advisory, and cultural and behavioural interventions.

8.6.1 Approaches at different scales

8.6.1.1 Responses by international organizations and agencies

A core function of the World Health Organization, in collaboration with other agencies, is the establishment and maintenance of communicable disease surveillance programs to identify, verify, and respond to public health emergencies of international concern. Modifications of current surveillance programs, including addressing spatial and temporal limitations, are needed to account for and anticipate the effects of climate change. Surveillance will be needed in new locations when climate-sensitive diseases and vectors change their range in response to changing climatic, environmental, and other conditions (Kovats *et al.* 2001; Jaenisch and Patz 2002; Wilkinson 2003). Improvements in international surveillance systems facilitate national and regional preparedness and reduce future vulnerability to epidemic-prone diseases. At present, surveillance systems in many parts of the world are incomplete and slow to respond to the emergence of new hazards to human health. With climate change, the pressures on disease control programmes are likely to increase, as discussed elsewhere in the chapter. Improving the responsiveness and accuracy of disease surveillance will have benefits now and will reduce future vulnerability to the adverse effects of climate change.

Donors, international and national aid agencies, emergency relief agencies, and a range of non-governmental organizations play key roles through direct aid, support of research and development, and other approaches to improving current public health responses to climate-sensitive health determinants and outcomes. These agencies and organizations are working with national Ministries of Health to more effectively incorporate climate change-related risks into the design, implementation, and evaluation of disease control policies and measures.

Two or more countries can develop international responses jointly when adverse health outcomes and their drivers cross borders. For example, Guidelines on Sustainable Flood Prevention were developed because floods have intensified in some regions due to human alteration of the environment (UN 2000). The Guidelines recognize that cooperation is needed both within and between riparian countries to reduce current impacts and increase resilience to a changing climate.

8.6.1.2 National level responses

A number of early warning systems (e.g., for heat waves and malaria outbreaks) have been implemented to alert the population and relevant authorities that a disease outbreak can be expected based on climatic and environmental forecasts (Thomson *et al.* 2005a). Early warning systems can be effective in preventing morbidity and mortality (Ebi *et al.* 2004). The effectiveness of disease prediction depends on an understanding of the mechanisms of disease transmission or occurrence, reliable and up-to-date information on exposures and health outcomes, a disease prediction model that is accurate, specific, and timely, and an effective response capability, including a specific intervention plan (Thomson *et al.* 2005a; Woodruff 2005).

For example, the Pacific ENSO Application Center (PEAC) alerted governments when a strong El Niño was developing in 1997/8 that severe droughts could occur and that some islands were at unusually high risk of typhoons and hurricanes; forecasts that proved to be reasonably accurate (Hamnett *et al.* 1999). Decreases in water availability and agricultural production were the main causes of adverse health outcomes (Hamnett *et al.* 1999). The successes of the interventions launched, such as public education and awareness campaigns designed to reduce the risk of waterborne diarrhoeal diseases and vector-borne diseases, limited El Niño-related disease burdens. For example, despite the water shortage in Phonpei, fewer children were admitted to hospital with severe diarrhoeal disease than normal because of frequent public health messages about water safety. However, the interventions did not eliminate all negative health impacts. For example, micronutrient deficiencies were found in pregnant women in Fiji, especially in regions where the drought was extreme (Hamnett *et al.* 1999).

8.6.1.3 Community-level responses

Communities recognizing the need to enhance local capacity are increasingly using participatory approaches that include governments, researchers, and community residents to build awareness of climate-related impacts and adaptation options, and to take advantage of local knowledge and perspectives (see Box 8.4). Effective community participation involves the mobilization of human and social capital.

Box 8.4. Cross cutting case study: Indigenous populations and adaptation

A series of workshops organized by the national Inuit organization in Canada, Inuit Tapiriit Kantami, documented climate-related changes and impacts, and identified and developed potential adaptation measures for local response (Furgal, C. M. *et al.* 2002; Nickels *et al.* 2003). The strong desire among Inuit community residents to be engaged in the process will facilitate successful adoption of the adaptation measures developed. Adaptation measures suggested by the community included taking bottled water on trips to address decreased availability of good natural sources of drinking water due to temperature-related drying of brooks, and using netting and screens on windows and house entrances to prevent bites from mosquitoes and other insects that have become more prevalent. Another example is a study of the links between malaria and agriculture that included participation and input from a farming community in Mwea Division, Kenya (Mutero *et al.* 2004). The approach facilitated identification of opportunities for long-term malaria control in rice irrigated areas through the integration of agroecosystem practices aimed at sustaining livestock systems within a broader strategy for rural development.

8.6.1.4 Individual-level responses

The effectiveness of warning systems for extreme events depend on individuals taking appropriate actions, such as responding to heat alerts and flood warnings Individuals reduce personal exposures by adjusting clothing and activity levels in response to high ambient temperatures and by modifying built environments, such as use of fans, to reduce the heat load (Davis *et al.* 2004; Kovats and Koppe 2005). Individual behaviours will be influenced by cultural practices that may be partially determined by weather conditions, and these behaviours can affect disease incidence.

8.6.1.5 Adaptation in health systems

Health systems will need to respond to climate change. There are effective interventions to deal with many of the most common causes of ill health, but frequently these interventions do not reach those who could benefit most. One way of promoting adaptation and reducing vulnerability to climate change is to promote the uptake of clinical and public health interventions that have been shown to make a difference in high-need regions of the world, to reduce the burden of climate-sensitive diseases. To achieve this end, health in Africa must be treated as a high priority investment in the international development portfolio (Brundtland 2002). Funding health programmes is a necessary step towards reducing vulnerability but will not be enough on its own (Brewer and Heymann 2004; Regidor 2004b, 2004a; de Vogli *et al.* 2005; Macintyre *et al.* 2005). Progress depends also on strengthening public institutions; building health systems that work well, treat people fairly, and provide universal primary health care; providing adequate education, generating demand for better and more accessible services; and, ensuring there are enough staff to do all the work that is required (Haines and Cassels 2004) and to train health care professionals to facilitate early identification of the spread of climate-sensitive diseases. Many of these prerequisites are currently not met in many parts of the world and are not expected to be achieved rapidly.

Box 8.5: Cross cutting case study: The European Heat Wave 2003: Health System Response

In heat wave in summer 2003 lead to 14,800 excess deaths in France, generated public health crises, and led the French government to take various steps to limit the effects of any future heat waves. A French parliamentary inquiry concluded that the health impact was "unforeseen," that the deaths were only detected belatedly, and the lack of a public health response was due to lack of experts and poor exchange of information between public organizations which were under strength because of the holidays and whose responsibilities were not clearly defined (Lagadec 2004; Senat 2004). Health authorities were overwhelmed by the influx of patients and crematoria/cemeteries were unable to deal with the influx of bodies (Michelon *et al.* 2005). In 2004, the French authorities set up local and national action plans that included heat health warning systems, health and environmental surveillance, and meteorological forecasting (Laaidi 2004; Michelon *et al.* 2005). Other European health ministries carried out assessments on the health effects of the heat wave (see 8.2.1.1. and chapter 12), some countries developed and implemented national heat prevention plans and heat health warning systems, and set up rapid surveillance. In addition, there has been some re-evaluation of care of the elderly and structural improvements to residential institutions (adding a cool room) (Kosatsky 2005).

8.6.2 Integration of responses across scales

Adaptation responses to specific health risks will often cut across individual- to national-level scales. For example, depending upon the policy-making structure, administrative units at the community or national level can facilitate high levels of heat acclimatization in a number of ways (Kovats and Koppe 2005). Programs can be implemented that educate individuals as to appropriate behavioural responses to high temperatures, such as to increase fluid intake. Community-base heat health warning systems can be further developed. Consideration of climate change projections can be required in the design and construction of new buildings and in the planning of new urban areas. National energy efficiency programs can include approaches to reduce the urban heat island.

Interventions designed to increase the adaptive capacity of a community or region also can facilitate achievement of greenhouse gas mitigation targets. For example, measures to reduce the urban heat island effect, such as trees, roof gardens, "smart" growth, and others, increase the resilience of communities to heat waves while advancing mitigation by reducing energy requirements. Increasing the proportion of energy derived from solar, wind, and other renewable resources will simultaneously reduce greenhouse gas emissions and air toxics that may be released from coal-fired power plants.

8.6.3 Limits to adaptation

The degree to which adaptation policies and measures are effective depends on the technical, institutional, economic, political, social, cultural, and religious context in which they are developed and implemented (Ebi *et al.* 2006a). Resources, including financial, human skills, and institutional capacity, need to be available to implement the policies and measure, and there needs to be political will on the part of those who influence the distribution of these resources to spend them on adaptation. Choices on which adaptations to implement where, when, and how will be made based on assessments of the balance between competing priorities. For example, different regions may make different assessments of the public health and environmental welfare of the ecological consequences of draining wetlands to reduce vector-breeding sites. Measures not in accordance with local laws and social customs and conventions are unlikely to succeed. For example, although application of pesticides for vector control may be an effective adaptation measure, even in communities with regulations to assure appropriate use, residents may object to spraying. Increasing awareness of climate change-related health impacts and knowledge diffusion of adaptation options are of fundamental importance to removing barriers to adaptation.

Although specific limitations will vary by health outcome and region, fundamental limitations exist in low-income countries where adaptation will partially depend on development pathways in the public health, water, agriculture, transport, and housing sectors. Poverty is the most serious obstacle to effective adaptation. Over the medium term, the poor are likely to remain poor and vulnerable, with few options for adapting to climate change. Therefore, policies and measures for adaptation are best developed within the context of development and environment policies. Many of the options that can be used to reduce future vulnerability are of value in adapting to current climate, and can be used to achieve other environmental and social objectives. However, because resources used for adaptation will be shared across other problems of concern to society, there is the potential for conflicts among stakeholders with differing priorities. Questions also will arise about equity (i.e. a decision that leads to differential health impacts among different demographic groups), efficiency (i.e. targeting those programs that will yield the greatest improvements in public health), and political feasibility (McMichael *et al.* 2003a). Unless effectively addressed, poverty, economic development, and other factors will continue to contribute to increasing vulnerability.

8.6.4 Health implications of adaptation strategies, policies and measures

Because adaptation strategies, policies, and measures can have short- and long-term negative health consequences, potential risks should be evaluated before implementation. For example, a microdam and irrigation program in Ethiopia developed to increase resilience to famine was found to increase local malaria mortality (Ghebreyesus *et al.* 1999). A longitudinal study determined that the rate of childhood malaria in villages near microdams increased by 7.3-fold over the rate in control villages. Increased ambient temperatures due to climate change could further exacerbate the problem. In another example, air conditioning of private and public spaces is a primary measure used in the US to reduce heat-related morbidity and mortality (Davis *et al.* 2003b). However, depending on the energy source used to generate electricity, increased use of air conditioning can increase greenhouse gas emissions, air pollution, and the urban heat island. It also is not practical in many regions of the world.

Measures to combat the scarcity of water, such as the re-use of wastewater and irrigation, have implications for human health [see Chapter 3]. Water quality guidelines for wastewater irrigation are strict to prevent health risks from pathogenic organisms and to guarantee crop quality (Steenvoorden and Endreny 2004). However, in rural and peri-urban areas of most low-income countries, the use of sewage and wastewater for irrigation is common practice, and a source of faecal-oral disease transmission. Irrigation is currently an important determinant in the spread of infectious diseases such as malaria and schistosomiasis (Sutherst 2004). The use of wastewater for irrigation is likely to increase with climate change. The treatment of wastewater remains unaffordable for low-income populations (Buechler and Scott 2000).

8.7 Conclusions: implications for sustainable development

Published evidence indicates that climate change is affecting health already through changes in the distribution of health-relevant insect species (vectors), changes in exposures (e.g. more heat waves), and influences on health determinants (e.g. water quantity and quality; air quality etc). Projected increases in high temperatures and changes in rainfall patterns are likely to have a range of health impacts, such as increases in heat waves are likely to lead to increases in heat-related deaths. Increases in ground-level ozone concentrations could increase respiratory and cardiovascular morbidity and mortality. Increases in mean temperature could facilitate the spread of malaria and dengue fever along the current edges of their geographic distributions in some regions, and increase the length of the transmission season for malaria. Increases in temperature and changes in rainfall distribution patterns are likely to be associated with increases in diarrhoeal diseases. Climate change might affect regions that are already vulnerable to food insecurity and lead to increases in malnutrition in areas where it presents already a large burden of ill health. The summary of direction, magnitude, and certainty of impacts and needs for adaptation is illustrated in figure 8.3

Health is central to the achievement of the Millennium Development Goals and to sustainable development — both in its own right (child mortality, maternal health; HIV/AIDS, malaria, and other diseases) and as a contributor to extreme poverty and hunger, primary education, and gender equality (Haines and Cassels 2004; Thomson *et al.* 2005b). Increases in climate variability might delay progress towards achieving relevant development targets. However, the effects will depend on the rapidity, scale, and intensity of change. Recent extreme events showed that populations and health systems are unable to cope with rapidly occurring events. An increase in the frequency of certain events, e.g. floods could reduce the resilience of communities, affect vulnerable regions and localities, and overwhelm the coping capacities of most societies.

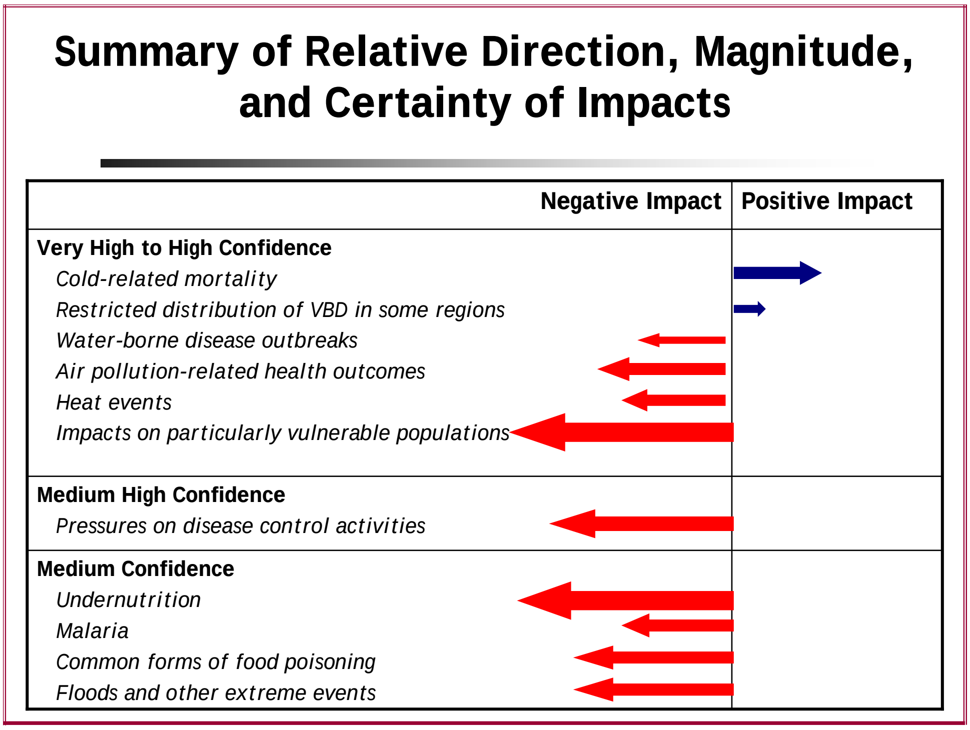

***Fig. 8.3**: Summary of Relative Direction, Magnitude, and Certainty of Impacts*

There are populations that are expected to be more affected by climate change, such as coastal and low-lying areas, urban areas in low- and middle-income countries, mountain populations and rural populations. Other particularly vulnerable groups include natural resource-dependent communities, communities lacking basic public infrastructure, including sanitation and hygiene, and populations with already existing high burdens of disease and high inequalities in health status. Within low- and middle income countries, social groups deserving special attention with regard to adaptation and reduction of vulnerability include slum dwellers; subsistence farmers in drylands and ethnically differentiated communities separated from mainstream society.

There is an urgent need to develop and implement adaptation strategies, policies, and measures, at different levels. A few adaptation initiatives aiming at reducing future health impacts have been initiated. However, there is a need of a stronger, internationally-agreed, adaptation effort. Adaptation will be able to delay some impacts and prevent others in the near term, but will only be effective within a context of development.

On a much longer scale, the complexity of changes will put at risk the continued stability and functioning of the biosphere's natural systems. It is uncertain whether climate change will cause irreversible damage to these life support systems, but the implications for human population are clear. In many countries, water quality, air quality, food safety and security have been affected, with greater impacts projected with continuing climate change.

8.7.1 Health and climate protection: clean energy

Climate policies that reduce fossil fuel combustion, particularly in the transport (road traffic) sector, often also reduce emissions of co-emitted pollutants, which can improve air quality (such as for PM and ozone) and directly benefit health. Such air quality improvements have been linked to quantifiable benefits (Barker *et al.* 2001; Cifuentes *et al.* 2001; Li 2002; West *et al.* 2004); (Air Quality Expert Group 2005 [Final Report due to be published 2006]). In addition, actions to reduce methane emissions will decrease global concentrations of ozone. Much progress has been made since the TAR in the clarification and quantification of these benefits in both health and economic terms (reviewed in detail in WGIII Chapter 11).

In low-income countries, biomass fuels are used in households and small-scale enterprises at low combustion efficiency. A significant, but unknown, portion is harvested non-renewably, thus contributing net carbon emissions. The products of incomplete combustion from small-scale biomass combustion contain a number of health-damaging pollutants, including small particles, CO, polyaromatic hydrocarbons, and a range of toxic volatile organic compounds (Bruce *et al.* 2000). Total human exposures to these pollutants within homes are large in comparison with outdoor air pollution exposures. Current best estimates, based on published epidemiological studies, are that biomass fuels in households are responsible for some 0.7-2.1 million premature deaths each year in developing countries, about two-thirds in children under 5 from acute lower respiratory infections and most of the rest from chronic lung disease in women(Smith *et al.* 2004). About half the world’s population relies on biomass fuel for a substantial part of annual cooking needs. The total contribution to anthropogenic climate forcing is significant, although much less than that from fossil fuels and agricultural practices. Clean development and other mechanisms could routinely calculate the co-benefits of health and climate in making decisions about energy projects, including the development of standard methods to address alternative fuel sources (Smith *et al.* 2000; Smith *et al.* 2005). Projects promoting co-benefits in such poor populations show promise to help achieve cost-effective long-term protection from climate impacts as well as promote immediate sustainable development goals for health (Smith *et al.* 2000).

8.8 Key uncertainties and research priorities

Since the TAR more information is available on population vulnerability to climate change (McMichael *et al.* 2006). This information derives from national climate change impact assessments and from adaptation assessments (Kovats *et al.* 2003a). There is further a growing body of scientific knowledge on the impacts of climatic factors on the dynamics of infectious diseases, and the direct effects of high temperatures and other extreme events (Menne and Ebi 2006). Few studies have been able to address the effects of observed climate warming on human health, due to the lack of appropriate longitudinal health data. This makes the attribution of health effects to observed climate change still very difficult.

This assessment confirms the observation of the TAR, that there is insufficient temporal and spatial environment and health information; in particular, in low income countries where data are limited and other health priorities take precedence for research and policy development.

A key uncertainty in future projections derives from the lack of consideration of different development scenarios including the identification of the extent, rate, limiting forces and major drivers of adaptation of human populations to a changing climate. A key uncertainty about the future health impacts of climate change in the later part of this century is how disease rates will change over time with changes in socioeconomic development, environmental changes, and climate change.

Uncertainties include not just whether the key diseases described in this chapter will be improve, but how fast, where, when, at what cost, and if all population groups will be able to share in these advances. Significant barriers exist to the control of climate-sensitive diseases, such as poor social and economic development, governance and lack of resources. It is apparent that these problems will only be solved over time-frames longer than decades.

Another key uncertainty is exposure to future extreme events and the potential for catastrophic events to which no population can be prepared for. The heat wave in 2003 presented an early example of this. The risk of catastrophic flooding in coastal areas is a major concern for human health and the potential for large scale population displacement. While we know little about the effects in low income countries, there are still unanswered questions about impacts in medium and high income settings. These concern the factors that convey vulnerability, and, more importantly, the changes that need to be made in health care, emergency services, land use and urban design in order to protect populations against heat waves, floods and storms.

Key research activities in the future need to consider multiple simultaneous exposures in particular areas at risk, the impacts of climate change on malnutrition, water and food borne diseases, the economic impacts, and how adaptation could lower health impacts in the future.

There is a need to develop integrated monitoring systems and develop further research capacity. The advances of the last years pointed also to the need to communicate results through various channels in a coordinated fashion.

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