IPCC WGII Fourth Assessment Report – draft for Expert Review

Chapter 8: Human Health

Coordinating Lead Authors
Ulisses Confalonieri (Brazil), Bettina Menne (WHO)

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

Contributing Authors
Taarakegn Abeku (Ethiopia), Mozaharul Alam (Bangladesh), Paul Beggs (Australia), Bernard Clot (Switzerland), Simon Hales (New Zealand), Guy Hutton (UK), Nancy Lewis (USA), Anil Markandya (UK), Glenn McGregor (New Zealand), Kirk Smith (USA), Christina Tirado (WHO), Madeleine Thomson (UK), Tanja Wolf (Germany)

Review Editors
Susana Curto de Casas (Argentina), Anthony McMichael (Australia)

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Executive summary

1 Mortality rates and related health indicators are improving for many countries, but other trends are not favourable and will limit the ability of populations to cope with climate stresses. These include the persisting socio-economic inequalities within and between countries and the heavy burden of HIV/AIDS in some parts of the world. Given present trends, it is unlikely that all health-related Millennium Development targets will be met. For instance, child malnutrition is projected to persist in many developing countries, although the overall burden is expected to decline. (very high confidence)

2 Population growth will have a major influence on the magnitude of climate change impacts and where these occur. Over the next 50 years, approximately 3 billion people will be added to the global population, principally in parts of the world that experience heavy burdens of climate-related disease and injury. (high confidence)

3 Climate-sensitive diseases make up a substantial fraction of the total worldwide burden of disease. For instance, approximately 365 million episodes of malaria occur each year in Africa and 119 million occur in South East Asia, and malnutrition affects 1 in 3 of the global population. A standardized approach to estimating the global burden of disease indicates that climate change is already contributing to mortality and morbidity. Unmitigated climate change is likely to cause greater health effects in the near future. (high confidence)

4 Temperature and precipitation are key determinants of the distribution of many disease-carrying vectors. There is new evidence since the TAR of the role of climate in the dynamics of vector-borne diseases. However, whether an increase in potential for disease transmission leads to more frequent occurrence of disease in human populations depends on a range of non-climatic factors. Research that has appeared since the TAR reinforces the conclusion that projected changes in climate will increase the pressures on many disease control activities. This will apply particularly in parts of the world that are presently on the margins of transmission for malaria and dengue. (medium confidence)

5 Evidence since the TAR supports previous conclusions that climate change could influence the incidence and range of malaria, although the magnitude of the effect is smaller than previously projected. Malaria is being reported at higher altitudes in several continents, but the contributions of rising temperatures and changes in precipitation to changes in distribution of disease are contested.

6 Climatic factors have played a part in the emergence of some infectious diseases, but it is not clear what this means for risks under a future, altered climate. (high confidence)

7 Evidence of the relation between high ambient temperature and mortality has strengthened since the TAR. Estimates of the burden of heat-related mortality attributable to climate change are reduced but not eliminated when allowances are made about acclimatization and adaptation. The increasing number of older adults in developed countries is likely to increase the size of the population at risk from heat. Predictive models do not include changes in the frequency or intensity of severe heat waves, such as occurred in 2003 in Europe. There is also a lack of information on the effects of high ambient temperature on mortality outside developed countries.

8 The 2003 European heat wave that killed 27-40,000 people is notable because it showed that

even developed countries may not be well-prepared to cope with extreme heat. Further, given that a heat wave as severe as this event is most unlikely to have occurred in the absence of anthropogenic climate change, the excess deaths that occurred may be among the first that can be attributed directly to climate change. (medium confidence)

9 There is now evidence that over time populations in developed countries are less affected by cold-related mortality; there is less consistent evidence of growing tolerance to heat.

10 Projected climate changes will probably have some health benefits (mid-range confidence), including reduced cold-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 also over time if temperatures continue to rise.

11 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 there are few studies that have systematically linked climate, environment, and nutritional outcomes at the national or local level. Although predictive models suggest global crop yields will increase with climate change, especially in temperate regions, expert assessments of the prospects for food security are generally pessimistic.

12 New 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.

13 Extreme rainfall events test the integrity of water management systems and increase risk of outbreaks of water-borne disease. The impacts of flooding are particularly severe in areas of environmental degradation, and in communities lacking basic public infrastructure, including sanitation and hygiene.

14 Water scarcity affects health in many ways; however, little has been written about the direct links between climate change, water availability, and health outcomes.

15 Studies since the TAR have provided stronger evidence that climate change is likely to bring deteriorations in outdoor air quality. For instance, concentrations of ground level ozone are projected to increase with rising temperatures, all other considerations unchanged. (medium confidence)

16 The changing seasonal pattern of aero-allergens is now well documented, although the implications for population health require further evaluation. (medium confidence)

17 Populations in geographic regions that are particularly 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 populations in Arctic regions. (very high confidence),

18 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 can be effective.

19 Loss of good health is one of 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. However costing death and disability are contentious and different approaches provide widely varying answers on priorities for expenditure.

20 Decisions for adaptation and mitigation of climate change made in other sectors, such as energy, transportation, water and agriculture can have health impacts, both positive and negative.

21 In general, economic development is associated with improved capacity to adapt to climate changes. But economic growth does not lead necessarily to reduced vulnerability to the health damaging effects of climate change. Critically important are the manner in which growth occurs, the distribution of the benefits of growth, and trends in other factors such as education that have a strong, independent effect on health status.

22 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.

23 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.

24 Future projections of the effects of climate change must take account of the fact that disease control measures that have been successful in developed countries may not translate to other settings.

8.1. Scope and key issues

This chapter describes the observed and projected health impacts of climate change, with an emphasis on current and future populations at risk, and the strategies, policies, and measures to reduce these 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 is still mostly about impacts in developed countries, and there remain important gaps in information for the more vulnerable populations in low and middle income countries. When considering the potential impacts of climate change over the coming century, a range of health futures are considered.

8.1.1. State of health in the world

Physical, social and psychological well-being is essential in sustainable development. Currently, in many respects, human health has improved remarkably over the last fifty years. Average life expectancy at birth has increased world-wide since the 1950s but such improvements in health have not been distributed evenly (WHO, 2003b; WHO, 2004a). In some African countries, trends in life expectancy have been reversed (Lutz *et al.*, 2000; McMichael, 2004). Global child mortality decreased from 147 per 1000 live births in 1970 to about 80 per 1000 live births in

2002 (WHO, 2002). Reductions in child mortality have been particularly compelling in countries of the Eastern Mediterranean and South-East Asia Regions and Latin America, while reductions in African countries have been more modest.

The gross inequalities in health persist both within and between countries (Casas-Zamora and Ibrahim, 2004; McMichael *et al.*, 2004; Marmot, 2005; People's Health Movement *et al.*, 2005). Communicable diseases remain a problem in many developing countries (WHO, 2003a). In Southern Africa, more than 20% of the adult population is infected with HIV/AIDS (de Waal and Whiteside, 2003). Overall, the burden of non-communicable diseases (such as heart disease, stroke, diabetes and cancer) is increasing, accounting for nearly half of the global burden of disease (at all ages), and the burden is growing in low and middle income countries (Mascie-Taylor and Karim, 2003).

The burden of diseases that are climate sensitive is large. Malaria causes around a million child deaths each year (WHO, 2004a). Almost 2 million deaths a year are caused by diarrhoeal diseases and other conditions that are attributable to unsafe water and lack of basic sanitation (Kosek *et al.*, 2003). Worldwide, malnutrition affects one in three people and each of its major forms dwarfs most other diseases globally (WHO, 2000). More than 70% of children with protein-energy malnutrition live in Asia, 26% live in Africa, and 4% in Latin America and the Caribbean (WHO, 2000). A key target of the United Nations Millennium Development Goals is to reduce the prevalence of underweight among children younger than 5 years by half between 1990 and 2015 (UN, 2005). 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.

8.1.2. Findings from the Third Assessment Report

The IPCC Third Assessment Report focussed on a range of diseases and specific health outcomes (McMichael and Githeko, 2001). The main findings of the chapter 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 physical damage, population displacement, and adverse effects on food production, freshwater availability and quality, and would increase the risks of infectious disease epidemics, particularly in developing 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 and might in particular affect populations at the margins of current distribution of diseases;
- Climate change represents an additional pressure on the world's food supply system and is expected to increase yields at higher latitudes and lead to decreases at lower latitudes. This would increase the number of undernourished people in the developing world.
- Deterioration in air quality in many large urban areas, assuming that current emission levels continue. Increases in exposure to ozone and other air pollutants (e.g. particulates) could increase known morbidity and mortality effects.

8.1.3 Key developments since the Third Assessment Report

Since the publication of the TAR, more information is available at national level and at local levels on population vulnerability to climate change. Several countries have undertaken health impact assessments, either as part of a multi-sectoral study, such as the United States, Canada, India, and Portugal (National Assessment Synthesis Team, 2001; Calheiros and Casimiro, 2002; Shukla *et al.*, 2003; Canada, 2004) or a stand alone project, such as the United Kingdom (Department of Health, 2002) and Australia (McMichael *et al.*, 2003a). 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*, 2004). There has been some advancement in the development of climate-health impact models that address the future potential effects of climate change in the later part of the century. Climate change is now an issue of concern for health policy. Some climate-specific adaptation measures have started to be developed and implemented both within the health sector and beyond, 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 factors is based on empirical studies of health effects that can be divided into four main types:

- health impacts of individual extreme events (heat waves, floods, storms, droughts)
- 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.

Major challenges for climate and health impact research are:

- gaps in health and environmental data and information, particularly in low income populations;
- the multiple and multi-causal health outcomes to be considered at population level when dealing with climate change;
- the difficulty of attributing health outcomes to climate or climate change per se
- the difficulty of generalizing health outcomes globally, when many diseases have important local transmission dynamics that cannot be easily represented in simple relationships
- the lack of inclusion of (any) different developmental scenarios in health projections
- the identification of climate-related thresholds for population health.

The assessment of future impacts is to be seen in the context of multiple exposures on certain population groups. These can be addressed through integrated assessments that take into consideration other important determinants of ill health, and health inequalities. Assessments of environmental health exposures require robust evidence of causal effects from a variety of populations and settings to reach the expected high standards of evidence. Certain populations (urban, rural, coastal) are likely to face a range of environmental health problems that may be exacerbated by climate change. Quantitative estimates of future scenario-based health impacts have problems with validity, uncertainty, and contextual reality.

8.2. Current sensitivity to weather and climate

Systematic reviews of high quality empirical studies provide the best evidence for current sensitivity to weather and climate, but such reviews are rare. In order to address uncertainty, we assess the strength of the association between the climate/weather factors and the health outcome(s) for the population(s) concerned.

Published evidence indicates:

- climate change may already be affecting health-relevant insect species, as well as important environmental exposures (e.g. heat waves)
- extreme temperatures cause large increases in deaths in populations that are not adapted
- the important role of climate in the current distribution of malaria, dengue and tick-borne diseases
- health effects of flooding and weather disasters are severe and long lasting.

This section addresses diseases of global relevance [Table 8.1]. More detailed information on the influence of climate on specific infectious diseases can be found in the regional chapters.

[To be prepared figure on current sensitivity to weather and climate]

8.2.1 Heat waves, cold waves and temperature-related mortality

The effects of environmental temperature are considered in the context of episodes of sustained extreme temperatures (by definition, heat waves and cold waves), and also as the underlying relationship between daily temperatures and mortality (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 almost completely on populations in North America (Basu and Samet, 2002), Europe (Koppe *et al.*, 2004; Kovats *et al.*, 2004b) and Japan (Qiu *et al.*, 2002; Ando *et al.*, 2004). In the United States, the population impact of heat waves is greatest in regions where extremely hot weather is infrequent, such as the Midwestern US (including Chicago). In August 2003, a heat wave in Western and Central Europe caused between 27,000 and 40,000 excess 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 cross-cutting case study. The summer of 2003 was probably the hottest in Europe since 1500 (WGI Chapter 3, Box 3.5.5) (Luterbacher *et al.*, 2004). Climatologists now consider it "very likely" that human influence on the global climate has at least doubled the risk of a heat wave such as that experienced in 2003 (Stott *et al.*, 2004). Therefore, the excess deaths that occurred may be among the first that can be attributed directly to climate change.

Published studies have quantified the impacts of selected heat waves using routine death registration data in Europe and North America. Such estimates of excess mortality were associated with different attributes of hot weather including magnitude, duration, and the timing of heat wave in the summer season. The episode studies show that effects are overwhelmingly concentrated in the older age groups and in deaths from respiratory and cardiovascular disease. 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 population affected (Hajat *et al.*, 2005; Kysely, 2005; Hemon and Jougla, 2004).

Heat waves are frequent occurrences in South Asia, and are associated with high mortality in rural populations, the elderly and outdoor workers (Sinha Ray, 1999; Chaudhury, 2000). 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). The EMDAT disaster events database reports more than 5,500 heat wave deaths in South Asia between 1975 and 2001 (CRED, 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 very few hours and over long periods. Accidental cold exposure occurs mainly outdoors, in socially deprived people, workers, alcoholics, the homeless and the elderly in temperate cold climates (Ranhoff, 2000). Cold waves were also reported to be a problem in some warmer climates, such as in subtropical South East Asia (CRED, 2004). Climate change is very likely to decrease the frequency of extreme cold weather, and therefore some coldwave-related deaths might be avoided.

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.*, 2004a). Further information on the effect modifiers (non-climate determinants) for heat-related mortality has shown the importance of individual, social and environmental factors (Basu and Samet, 2003; Koppe *et al.*, 2004). City-level factors, such as climate and the proportion of elderly people are important in determining the underlying temperature-mortality relationship in a population (Curriero *et al.*, 2002). The important determinants of cold related mortality between populations are not clear, and differences between countries are not fully explained by climate or relative income (Healy, 2003).

High temperatures contribute to overall mortality (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].

Research so far has not been able to quantify the separate or interactive effects of high temperature and high pollutant exposures. The same weather conditions that cause heat waves, also cause high pollution exposures. Ozone concentrations were very high during the 2003 European heat wave, but estimates of the mortality attributable to ozone during this event varied widely between populations (Hemon and Jougla, 2004; Stedman, 2004).

Populations are acclimatized to their average climate conditions and important social changes occur that affect population disease profiles and social factors. Therefore, it is not appropriate to assume that the temperature-mortality relationship in a given population does not 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.*, 2003a; Davis *et al.*, 2003b). 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 winter mortality in industrialized populations has reduced since the 1950s (Kunst *et al.*, 1991; Lerchl, 1998).

8.2.2 Wind storms and floods

In the last two decades, some major storm and flood disasters have occurred. In 2003, 150,000 people were affected by floods in China; 30,000 died from storms followed by floods and landslides in Venezuela in 1999; the hurricane Mitch killed 10,000 people in Central America and floods in Mozambique have killed 813 persons in 2000/2001(CRED 2005;World Disasters Report, 2002). Knowledge about the full health and social burden of extreme weather events is still incomplete. Flood events have local and sometimes regional effects: directly through deaths, injuries, communicable diseases and mental health (Ahern et al, 2005; Greenough *et al.*, 2001); indirectly through economic disruption, infrastructure damage and population displacement. Population displacement following disasters leads to increases in communicable diseases resulting from crowding, lack of clean water and shelter and poor nutritional status.

Estimates of floods and tropical cyclone impacts indicate that the burden in terms of deaths and populations affected remains considerable in South Asia and Latin America, despite reductions in vulnerability (CRED, 2004; Schultz *et al.*, 2005). Deaths recorded in disaster databases are from drowning and severe injuries. Indirect deaths from unsafe or unhealthy conditions following the extreme event are also a health consequence of disasters (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 and particularly in Bangladesh (Nicholls, 2003).

There has been increased evidence of the importance of the impacts of disasters on mental health (Mollica *et al.*, 2004; Ahern *et al.*, 2005). The prolonged impairment from common mental disorders (anxiety and depression) may be considerable. Studies in both high income and low 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; Maltais *et al.*, 2005). A systematic review of post-traumatic stress disorder in developed countries found a small but significant effect from this more severe mental illness following disasters (Galea *et al.*, 2005).

Populations with poor sanitation infrastructure and high burden of infectious disease, often experience increased rates of diarrhoeal diseases after flood events. Increases in cholera have been reported in low and middle income countries (Sur *et al.*, 2000; Gabastou *et al.*, 2002), as well as cryptosporidiosis (Katsumata *et al.*, 1998) and typhoid fever (Vollaard *et al.*, 2004). Systematic reviews of the published evidence indicate that the risk of infectious disease following flooding in developed countries is 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).

Evidence shows that in some cases flooding may lead to mobilization of dangerous chemicals from storage or remobilization of chemicals already in the environment, e.g. pesticides. Hazards may be greater when industrial or agricultural land adjoining residential land is affected. Less evidence exists to support the hypothesis that flooding that causes chemical contamination has a clear causal effect on the pattern of morbidity and mortality following these 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 further evidence that the impacts of flooding are not evenly distributed, either in relation to income, age, or gender (Box 8.1). Poorer communities are more likely to live in flood prone areas. A study in the US found that low-income schools had twice the risk of being flooded compared to the reference group (Guidry and Margolis, 2005).

Vulnerability to weather disasters depends on the level of disaster preparedness, responses and management systems (Olmos, 2001). 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 Aceh Besar found that male survivors outnumbered females by almost 3:1; in North Aceh district females accounted for 77% of the deaths (Oxfam, 2005). The 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, may 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; 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, food security and nutrition

Drought is defined as a period of below average precipitation that adversely affects food production systems and causes water scarcity. The most important impact of drought is malnutrition. There have been observational studies on climate variability and drought events in rural populations in low income countries, particularly studies that focus 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).

During non-famine normal years, confounding variables influence the association between malnutrition and infection (i.e. season, family structure, population movement, and living conditions) (Lindtjorn, 1990). 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). Deficiency in micro-nutrients is also associated with drought.

The increasing incidence of drought represents a very serious threat for the many 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, which has increased the population at risk and changes the course of recovery (de Waal and Whiteside, 2003; Gommes *et al.*, 2004). Studies have also shown that HIV transmission has been facilitated by rural-urban population migration associated with rural drought.

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 appears to be strongly controlled by climatic and environmental factors 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). Limited evidence suggests that the spatial limits of the distribution of this and other diseases 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 (Sultan *et al.*, 2005).

Box 8.2: Cross cutting case-study: health and drought in the Sahel

The achievement of the MDGs is considered the most challenging in sub-Saharan 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 rates of mortality in all age groups. Prolonged and repetitive droughts both directly and indirectly contribute in deteriorating population health by causing malnutrition and disease, and indirectly through reducing the availability of money for education and health care. The northern limit of malaria 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).

8.2.4 Food safety

Several studies have confirmed and quantified the effects of temperature on salmonellosis, a common form of food poisoning, mainly transmitted via poultry and eggs (D'Souza *et al.*, 2004; Kovats *et al.*, 2004a). These studies showed that there is an approximately linear increases in reported cases for each degree increase in weekly temperature in Australia, Western and Central Europe and Canada. Temperature contributed to an estimated 30% of cases of salmonellosis in Europe. The evidence is less convincing for an effect of temperature on transmission of Campylobacter infection, a rising cause of food borne disease in industrialised countries (Tam *et al.*, 2004; Kovats *et al.*, 2005; Louis *et al.*, 2005).

Contact between food and pests, especially flies, rodents and cockroaches, is also temperature-sensitive. Calyptrate fly activity is largely driven by weather rather than by biotic factors (Goulson *et al.*, 2005). In temperate countries, especially in northern Europe and northern US, warmer weather and milder winters are likely to increase the abundance of flies and other pest species during summer months, and the pests will appear earlier in the 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), however, little new evidence has emerged since the TAR about the sensitivity of these diseases climate change.

Food safety is an important public health problem as well as an economic concern (Section 8.5). The potential effects of climate change should be seen in the context of the globalisation of food trade, mass tourism, unplanned urbanization, and migration (Kaferstein and Abdussalam, 1999; Korenberg, 2004).

8.2.5 Air quality and disease

Despite control efforts, air quality remains a problem in many developed countries, and concentrations of air pollutants are increasing in developing countries (National Institute for Public Health (RIVM) and Netherlands Organization for Applied Scientific Research (TNO), 2001). In 2000, 0.8 million deaths and 7.9 million disability adjusted life years (DALYs) were lost from urban air pollution, with the largest burden in developing countries in the Western Pacific region and South East Asia and 1.6 million deaths are due to indoor air pollution caused by burning biomass fuels (WHO, 2002b).

Weather at both the synoptic (large) and meso-scales determine 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. For example, air pollution events 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, thus 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).

Fires cause burning injuries and intoxications. Globally, fire related burns were responsible for 238,000 deaths in 2000 (WHO, 2002a). Big fires are also accompanied by an increased number of patients seeking emergency services, including healthcare providers affected by smoke and ash in hospital ventilation systems (Hoyt and Gerhart, 2004). Toxic gaseous and particle air pollutants are released into the atmosphere, which significantly contribute to acute and chronic illnesses of the respiratory system in particular in children, such as increase of cases of pneumonia, upper respiratory diseases, asthma and chronic obstructive pulmonary diseases (WHO, 2002a).

8.2.5.1. 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, winds, solar radiation, atmospheric moisture, venting, and mixing affects both the production of ozone as well as emissions of ozone precursors (Nilsson *et al.*, 2001a; Nilsson *et al.*, 2001b). 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 *et al.*, 2004a).

Exposure to elevated concentrations of ozone has been shown to be 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). Several studies provided also evidence of short-term associations between ozone and mortality (Bates, 2005; Bell *et al.*, 2005; Ito *et al.*, 2005). Outdoor ozone concentrations, activity patterns, and housing characteristics are the primary determinants of ozone exposure (Suh *et al.*, 2000; Levy *et al.*, 2005).

8.2.5.2 Effects of weather on concentrations of other air pollutants

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 Ayra, 2000). Some air pollutants demonstrate clear 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). Thus, local conditions and emissions are more important than global concentrations of pollutants in determining human exposures. Some locations, 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 the topography restricts the dispersion of pollutants (Rappengluck *et al.*, 2000; Kossmann and Sturman, 2004).

8.2.5.3 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 urban-industrial mechanisms (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 regions far removed. When compared with non-dust weather conditions, dust can carry large concentration of coarse particulate concentrations (PM 2.5 – 10), trace elements that can affect human health, and 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 *et al.*, 2004b).

8.2.6 Aeroallergens

There is now stronger evidence that observed higher temperatures are associated with an earlier onset of spring in the northern Hemisphere, and an earlier onset of the production of pollen species that are important to humans, particularly for some late-winter and spring flowering species (D'Amato, 2001; Huynen and et al, 2003; Ziska *et al.*, 2003) (reviewed in detail in Chapter 1). However, the trend is reversed and the beginning of the pollen season has been delayed at higher latitudes; insufficient chilling and/or thicker snow cover may explain this observation (Emberlin *et al.*, 2002; Inoue *et al.*, 2002; van Vliet *et al.*, 2002). Studies from a variety of regions, including Denmark, Japan, and North America, and of pollen from several plant species, have shown changes in pollen seasonality associated with increases in regional temperatures (Teranishi *et al.*, 2000; Levetin, 2001; Emberlin *et al.*, 2002; Frenguelli, 2002; Rasmussen, 2002; Wan *et al.*, 2002; Wayne *et al.*, 2002). The public health significance of climate effects on allergens remains to be shown.

8.2.7 Water and disease

Water related diseases can be classified by route of transmission, thus distinguishing water borne (ingested) and water washed (lack of hygiene). 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 (chapter 3). There are four main considerations, when assessing current climate and health outcomes (primarily diarrhoeal disease):

- linkages between water availability and the health burden due to diarrhoeal diseases.
- the role of extreme rainfall (intense rainfall or drought) in facilitating water-borne outbreaks of diseases either in the piped water supply, or in surface water.
- effects of temperature and runoff on microbiological contamination of coastal, recreational or surface waters.
- 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 any other parts of the population from problems such as malnutrition, infant mortality, and diseases related to contaminated or insufficient water (Millennium Ecosystem Assessment, 2005). The effect of water scarcity on food availably and malnutrition is discussed above in the section on nutrition, and the effect of rainfall on outbreaks of mosquito-borne and rodent borne disease is discussed below.

Several studies have investigated an association between drinking water turbidity and health (Schwartz and Levin, 1999; Aramini *et al.*, 2000; Schwartz *et al.*, 2000; Lim *et al.*, 2002) and there is some indication that 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 loads in watercourses and in drinking water reservoirs (Kistemann *et al.*, 2002). Open finished water reservoirs are at risk for post-treatment faecal contamination by animals. A study carried out in the US found an association between extreme rainfall events and monthly reports of outbreak of waterborne 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).

Mortality due to diarrhoea among children 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 late 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 in low and middle income populations. Temperature was found to be strongly associated with increased episodes of diarrhoeal disease in adults and children in Peru (Checkley et al., 2000;Speelman et al., 2000)(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.*, 2003a; Vasilev, 2003).

The bimodal seasonal pattern of cholera in Bangladesh follows sea surface temperatures in the Bay of Bengal and seasonal plankton abundance (a suggested 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), but this effect of El Niño is mainly confined to the coastal regions. 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.

It has been suggested that higher temperature enhance the concentration of enteric pathogens in coastal or recreational waters and that this poses a risk to human health (Lipp *et al.*, 2001a; Lipp *et al.*, 2001b; Chigbu *et al.*, 2004). Pathogens are also diluted in coastal waters and some pathogens survival depends upon certain environmental conditions. Further research is need to investigate the role of temperature for this mechanism.

8.2.8 Occupational health

Changes in the world's climate have implications for occupational health and safety. Heat stress is an occupational issue. The influence of elevated temperatures on health of workers who work indoors is most pronounced for those who work in metallurgical plants of steel mills and mines (Afanas'eva *et al.*, 1997; Afanas'eva and Suvorov, 2002). Several studies have confirmed the adverse effects of elevated indoor temperatures for workers who work under serious physical stress (Golovkova *et al.*, 2003). However, it is not clear how changes in outdoor temperatures would affect indoor temperatures (and personal exposures) in these settings. Many physiological studies have shown that elevated temperatures reduce productivity in workers. Higher temperatures reduce productivity in shift workers in Viet Nam and Bangladesh (Ahasan *et al.*, 2002).

Outdoor labourers are at risk from heat stroke, and the risk of exposures to hot weather may increase with climate change. The occupations most at risk of heat stroke (mortality and morbidity), based on US data, are construction and agriculture/forestry/fishing (Adelakun *et al.*, 1999). Research in Uzbekistan, Turkmenistan, and Tajikistan has shown a range of health problems associated with working outdoors in high temperatures (Unusov, 1970; Bagirov, 1973; Sultanov, 1973; Momadov *et al.*, 1991; Retnev and Rykova, 1996). Daily wage earners, such as rickshaw pullers, are reported to be at risk of heat-related mortality in South Asia (Kovats and Koppe, 2005).

8.2.9 Vector- and rodent-borne diseases

Vector borne diseases (VBD) are infections transmitted by the bite of infected arthropod species, such as mosquitoes, ticks, 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 (Kovats et al., 2001). Climate effects on vector-borne disease take into account the disease transmission system as a whole and combine climate data with concurrent measurements of the vectorial capacity and infection rate of vectors, abundance and infection rate of reservoir hosts (if any), and 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 cause changes in health, and also avoid the 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, and so the public health relevance needs to be cautiously inferred.

The observed effects of climate change on vectors and human vector borne diseases are also discussed in chapter 1 (section 1.3.7.5.) There is evidence that climate change has already affected the distribution of some vector species, particularly at high latitudes. 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 which may be undergoing analogous evolutionary changes.

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 shifts or altitudinal shifts in tick distribution have been observed in Sweden (Lindgren and Talleklint, 2000; Lindgren and Gustafson, 2001), Denmark (Skarphedinsson *et al.*, 2005), and Canada (Barker and Lindsay, 2000), and altitudinal shifts have been observed in the Czech Republic (Daniel *et al.*, 2004). Climate change is unlikely to explain recent increases in human diseases incidence in Europe or US, as other explanations cannot be ruled out (e.g. human impacts on the landscape, increasing both the habitat and wildlife hosts of ticks) (Randolph, 2001). There is no clear evidence that malaria has not 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). The attribution of changes in human diseases must first take into account the considerable changes in reporting and surveillance (Kovats *et al.*, 2001).

There is also published evidence for the early effects of climate change on vector-borne animal diseases. Climate change is the likely cause of the northern expansion in Europe of mosquito vector of African Horse sickness and blue-tongue virus (Mellor and Hamblin, 2004; Purse *et al.*, 2005). In many of these new locations the mosquito vector is present and active throughout the entire year. Outbreaks of blue-tongue virus in Europe have increased and occurred further north than previously reported (Purse *et al.*, 2005). 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, 2005).

Empirical evidence for the effect of climate on infectious disease comes from studies of inter-annual climate variability (e.g. ENSO) and case studies of outbreaks (e.g. West Nile). The need to control diseases, as well as the consideration 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). The development of new ground and satellite-based indicators of land cover, and other environmental variables have allowed these data to be matched against increasingly accurate climate measurements. The choice of scale for mapping studies is important. At the continental scale, climate may be a good predictor of disease distribution, but at the "local" scale, other environmental factors, such as the availability of breeding sites and surface waters are likely to be more important.

The evidence reviewed here is limited to some diseases which are globally important. More detailed discussion of local and regional specific diseases are addressed in the regional chapters.

8.2.9.1 Dengue

Several studies have found an association between epidemic dengue and inter-annual climate variability (ENSO) in populations in Southeast Asia and the Pacific (Hales *et al.*, 1999; Corwin *et al.*, 2001; Gagnon *et al.*, 2001; Cazelles *et al.*, 2005). However, linkages between climate, weather and dengue are poorly understood as the disease is transmitted by container-breeding mosquitoes in urban areas. 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 as water storage increases thereby providing more breeding sites (Pontes *et al.*, 2000; Depradine and Lovell, 2004; Guang *et al.*, 2005).

Climate-based (temperature, rainfall, cloud cover) maps of a dengue vector *Stegomyia aegypti* density suggest a potential for latitudinal expansion of the vector (Hopp and Foley, 2001). 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 other vector *Ae albopictus,* also indicates potential for northern expansion in North America, and a reduction of its distribution in arid areas with climate change (Alto and Juliano, 2001). A global statistical model of dengue, driven by annual average vapour pressure, also indicates the potential for expansion of the disease (Hales *et al.*, 2002).

8.2.9.2 Malaria

The spatial distribution, intensity of transmission and seasonality of malaria is strongly determined by climate in sub-Saharan Africa where socio-economic development has had only limited impact on curtailing disease distribution (Craig *et al.*, 1999; Hay *et al.*, 2000).

The effect of climate on epidemics of malaria is most important at fringe areas where temperature and rainfall are limiting factors for transmission. Rainfall is a limiting factor for mosquito populations and there is some published evidence of reductions in transmission associated with decadal decreases in rainfall (see Box 8.2 on Sahel). Inter-annual variability in malaria disease is also climate related in specific eco-epidemiological zones (Julvez *et al.*, 1992; Ndiaye *et al.*, 2001; Singh and Sharma, 2002; Bouma, 2003; Thomson *et al.*, 2005b). 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.*, 2003). These studies suggest that malaria outcomes 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 the highlands remains controversial. From analyses of time series in some sites in East Africa, reports have indicated that malaria incidence increased in the apparent absence of co-varying trends of climatic variables (Hay *et al.*, 2002a; Hay *et al.*, 2002b). It has been reported that meteorological variables did not show any trends although malaria admissions increased over a 30 year period in a highland area in Kenya (Shanks *et al.*, 2002). Increase in resistance of the malaria parasite to drugs and decrease in vector control activities have been proposed to be more likely driving forces behind the malaria resurgence. However, other researchers have questioned the validity of such a conclusion indicating that it might have resulted from inappropriate use of climate data sets (Patz et al., 2002).

Dismissing temperature as a driving force in the highlands has been also challenged for being premature due to inappropriate use of variables and methods. Analysis of a de-trended time-series of malaria in Madagascar has indicated that minimum temperature at the start of the transmission season which corresponds with the months when the human-vector contact is greatest accounts for most of the variability between years (Bouma, 2003).An analysis of the historical records of malaria epidemics in highland areas of Kenya and found an association between rainfall and unusually high maximum temperatures and the number of impatient malaria cases 3-4 months later (Githeko and Ndegwa, 2001). Abnormal increase in minimum temperature has been reported to have caused major epidemics in the Ethiopian highlands in the late 1980s and early 1990s (Abeku *et al.*, 2003). A study carried out using data from seven highland sites in East Africa has reported that climate variability played an important role in initiating malaria epidemics in the East African highlands rather than long-term changes in mean temperature (Zhou *et al.*, 2004; Zhou *et al.*, 2005) although the method used to test this hypothesis has been challenged (Hay *et al.*, 2005b).

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

8.2.9.4. 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; Kuper et al, 2000; Vanasco *et al.*, 2002; Ahern *et al.*, 2005). Risk factors for leptospirosis include flooding of open sewers and street during the rainy season for peri-urban populations in low income countries (Sarkar *et al.*, 2002). Increases in fever like illness (probably Leptospirosis) have also been reported following tropical storms in the Caribbean (Trevejo *et al.*, 1998; Sanders *et al.*, 1999).

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 as the true reservoir has not been identified.

8.2.10 Emerging infectious diseases

Emerging infectious diseases are diseases that have recently increased in incidence or geographic range, recently moved into new host population, recently been discovered or are caused by newly evolved pathogens (Daszak *et al.*, 2001). Increases in the latitudinal or altitudinal extension of diseases due to climate change are considered emerging diseases.

Examples of emerging diseases that have been affected by weather and climate variability:

- Nipah virus infection in Malaysia and neighbouring countries. 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 were reservoirs for the virus. The bats were driven to farms to find food (fruits), consequently shedding viruses and causing an epidemic (Chua *et al.*, 1999; Chua *et al.*, 2000).
- 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).

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 emissions scenarios (IPCC, 2000), GEO3 and the World Water Report (Ebi and Gamble, 2005).

Scenario approaches published so far look to the future in the context of emerging infectious diseases, medical technology, population ageing, increasing health and social inequalities and sustained health (Olshansky and Ault, 1986; Olshansky *et al.*, 1998; Martens and Hilderink, 2001; Martens and Huynen, 2003).

An age of emerging infectious diseases could result 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). Recent history has shown us malaria parasites becoming increasing drug resistant, HIV/AIDS lowering life expectancy in several African countries, the mosquito-borne disease West Nile virus crossing the Atlantic, and avian influenza spreading worldwide instantaneously. An age of medical technology could result from increased economic growth and improvements in technology, which may to some extent off-set changes in the physical and social environment, at the risk of widening current health inequalities (Martens and Hilderink, 2001). 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. Such scenarios describe increasing life expectancy, reduced disability, and changing patterns of demand on social services.

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. The scenarios suggest 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.

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.

The total number of people at risk, the age structure of the population, and the density of settlement are all important variables in any projections of effects of climate change. 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 richer countries. On the global level, this leads us to expect that 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.*, 2001). 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). High population growth rates in Africa will affect global trends in major climate sensitive diseases. Currently, 70% of episodes of clinical *Plasmodium falciparum* 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. 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. For instance, 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 (Lieshout *et al.*, 2004; Nicholls, 2004b).

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), while economic inequalities between regions, countries and within countries are growing world-wide (Blakely *et al.*, 2004; Marmot, 2005).

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 (Szreter, 1997). Economic growth is double-sided. Growth entails social change, and while this change may be wealth-creating, it may also cause significant environmental disruption. Rapid urbanization (leading to plummeting population health) in the 19th century, and extensive land clearances (causing widespread ecological damage) in the 20th century, are two examples of the mixed blessings that have accompanied economic development in the past.

Health services provide a buffer against the hazards of climate variability and climate change. For instance, access to cheap, effective anti-malarials and bed nets will be an important influence on future trends in this disease. Emergency medical services have a role (though 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 of future cities, and their design (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, where rising temperatures and higher CO_2 levels will, at least initially, stimulate production of major crops.

8.4 Key future impacts and vulnerabilities

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. Published evidence since the TAR, indicates that the projected increases in high temperatures and changes in rainfall patterns, are likely to have a range of health impacts. Increases in heat waves are likely to lead to increases in heat-related deaths. Climate change is likely to cause increases in ground level ozone concentrations that could increase respiratory morbidity and mortality. Increases in mean temperature facilitating the spread of malaria and dengue fever along the current edges of their geographic distributions, and increases in the length of the transmission season for malaria, with less certainty about the effects from changes in precipitation patterns. Similarly, increases in temperature are likely to be associated with increases in diarrhoeal diseases. Most predictive modelling suggests modest changes in the burden of climate-sensitive diseases over the next few decades, with larger increases beginning mid-century as temperature changes become more significant.

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 also over time if temperatures continue to rise.

Because there are multiple and interacting pathways by which climate change could affect population health, a more integrated assessment was undertaken for health impacts in particularly vulnerable populations living in coastal zones and some urban and rural areas in developing countries. Unless targets and goals designed to reduce underlying vulnerability are met, these regions could experience increasing burdens of climate-sensitive diseases over at least the next few decades. No projections are available on how climate change could affect population health in geographic areas believed to be at particularly risk in the next few decades, such as those living in mountainous regions. Published studies have not projected the potential health impacts from abrupt climate shifts, such as a shutdown of the thermohaline circulation.

[To be prepared figure or table on future vulnerability to climate change under different health and development futures]

8.4.1 Predictive modelling of global and regional estimates of the burden of disease

Predictive models of the health impacts of climate change use different approaches to classify the risk of climate-sensitive diseases. For malaria and dengue, results from predictive 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. 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, vector and disease control activities have virtually eliminated autochthonous cases. Predictive models for other health outcomes often estimate populations at risk or person months at risk using population weighted approaches.

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 underlying 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 disease burdens from relatively easy-to-control diseases (Pitcher *et al.*, in press).

8.4.1.1 Global burden of disease

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 5500,000 DALYs (Ezzati *et al.*, 2002; Campbell-Lendrum *et al.*, 2003; McMichael *et al.*, 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 dengue and *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). 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). Absolute disease burdens are dependent on assumptions of population growth and future baseline disease incidence.

8.4.1.2 Malaria, dengue, and other vector-borne diseases

Evidence since the TAR supports previous conclusions that climate change could influence the incidence and range of malaria, although the magnitude of the effect may be smaller than that previously projected. This partly reflects advances in categorising risk. Table 8.2 summarises studies that projected the impacts of climate change on the rate and range of infectious diseases. Several modelling studies used the SRES climate scenarios, a few applied population scenarios, and none incorporated economic scenarios. Models that rely on universal biological relationships between temperature, vector, and parasite, but with incomplete parameterizations, often over-emphasize relative changes in risk, with the absolute risk remaining small (Martens, 1999; van Lieshout *et al.*, 2004). 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).

Predictive models suggest that climate change in Africa may be associated with both expansions and contractions of the geographic area suitable for transmission of stable *Plasmodium falciparum* malaria (Hartman *et al.*, 2002; Tanser *et al.*, 2003; Thomas *et al.*, 2004; van Lieshout *et al.*, 2004). Using a spatio-temporal validated model of *Plasmodium falciparum* malaria transmission and SRES climate scenarios, east African highlands areas are projected to be at risk of climate change-related increases (Tanser *et al.*, 2003). From an estimated annual average current exposure of 3.1 billion person-months (445 million people exposed), a 5.7% potential increase (mainly altitudinal) in malaria distribution is projected by 2100, with little increase in the latitudinal extent of the disease. The projected extended transmission season 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 has 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.*, 2002) 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 could remain very low, although increased risk could occur in some parts of southeast Europe (Kuhn *et al.*, 2002). In areas outside sub-Saharan Africa, the models indicate that some central Asian areas may be at risk of climate-related increases in malaria suitability, with areas in central America and around the Amazon likely to have reductions in transmission due to decreases in rainfall (van Lieshout *et al.*, 2004). An assessment in India, indicated that, assuming current levels of control, only northern states (Jammu and Kashmir) may be at risk of increases in malaria transmission due to climate warming (Shukla *et al.*, 2003; Mitra *et al.*, 2004; van Lieshout *et al.*, 2004).

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 (Hales *et al*. 2002; de Wet *et al*. 2001; McMichael *et al*. 2003). An empirical global model indicates that vapour pressure is a key determinant of the distribution of dengue, and increases in global temperatures could lead to latitudinal expansion of its distribution (Hales *et al.*, 2002). Future population at risk, taking into account both climate change and population projections, is projected to be 3.5 billion people by 2085. This analysis is based on one model; additional models are needed before confidence can be placed on how climate change could affect the incidence and range of dengue.

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 been strengthened since the TAR, with increasing emphasis on the health impacts of heat waves. Table 8.3 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 deaths due to climate change are projected to be greater than increases in heat-related deaths for temperate-zone populations (Europe, Asian part of Russia, Canada, United States, Australia.). However, projections of cold-related deaths will be over-estimated unless they take into account the effect of influenza and season (Armstrong *et al.*, 2004b).

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 predictive models. On the other hand, the increasing numbers of older adults in developed countries is likely to increase the size of the population at risk, because decreased ability to thermo-regulate is a normal part of the aging process. Overall, the health burden could be relatively small for moderate heat waves because deaths occur primarily in susceptible persons. Predictive models do not include changes the frequency or intensity of extreme events such as occurred in 2003 in Europe, when temperatures were very high for an extended period.

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 (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). 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). The fraction of future ozone concentrations attributable to climate change is the portion that is the consequence of climate change on local temperature and UV. Assuming no change in the levels of ozone precursor emissions, the extent to which changing baseline levels of ozone are projected to have an impact on the frequency of “ozone episodes” will depend on the future 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 8.4 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 2050s under the A2 emissions scenario (Knowlton *et al.*, 2004). The quantification of future pollution health impacts relied on robust projections of city-level pollutant concentrations. Summer ozone-related mortality is projected to increase by 4% in the New York area by the 2050s based on climate 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 done for cities in low or middle-income countries, despite the heavier pollution burdens in these populations.

There are few predictive models of the impacts of climate change on other pollutants and these tend to emphasize the role of local abatement strategies in determining the future levels of pollutants and tend to project the probability of exceedance instead of absolute concentrations (Jensen *et al.*, 2001; Guttikunda *et al.*, 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 northeastern 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 projected changes in meteorological conditions (Department of Health, 2002). Because transboundary transport of pollutants play a significant role in determining local to regional air quality, 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 Urban populations

Urban populations are growing faster in developing than developed countries, with cities and urban areas gaining an estimated 60 million people per year, or over one million per week (UN, 1999). By 2007, the projected global urban population of 3.2 billion people will be larger than the entire global population in 1967. About five billion people are expected to live in cities by 2030, about 60 per cent of the global population of 8.1 billion people.

Rapid and unplanned urbanization is 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, 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, the noise, crowding, isolation, and other possible features of urbanization may increase the prevalence of psychological diseases, such as depression, anxiety, chronic stress, schizophrenia, and suicide (WHO, 2001). Problems associated with urbanization are expected to increase for at least the next few decades, with greater diseases burdens in developing countries.

Urbanization and climate change may work synergistically to increase disease burdens. For example, 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 climate warming (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 to climate change will require a range of diverse and complex adaptation strategies that are likely to include physical modification to the built environment, improved housing standards, and changes in decision-making practices (Kovats and Koppe, 2005).

Climate change may affect the rate of urbanization. In some regions, urban-rural migration may increase because of increased drought conditions due to climate and other environmental changes, which could delay achievement of poverty reduction targets and fuel discontent and civil unrest.

8.4.3 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 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 products (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 area, but attribution of the amount of current and future health burdens to climate change is problematic because the determinants of malnutrition are complex. Few studies have been published since the TAR on food security and the risk of hunger. One study estimated that the percentage of population found to be at risk of hunger rises from a current estimate of 34% to an after climate change level of 64% to 72% by 2050s, although this could be substantially reduced by effective implementation of range of adaptive strategies (Butt *et al.*, 2005). Climate change models predict that those likely to be most adversely affected are the regions already most vulnerable to food insecurity, notably Africa, which stands to lose substantial agricultural land.

In the absence of climate change, expert assessments of future food security are generally pessimistic over the medium term. 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 Millenium Project, 2005). In some regions, available food supplies are projected not to keep pace with population growth, increasing the absolute number of malnourished persons. Using the International Food Policy Research Institute's International Model for Policy Analysis of Agricultural Commodities and Trade, it was projected that global cereal production could increase by 56% between 1997 and 2050, and livestock production by 90%. Income growth and rapid urbanization are major forces driving increased demand for meats, fruits, and vegetables. However, child malnutrition is projected to persist in many developing countries, although the overall burden is expected to decline.

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 there are few studies that have systematically linked climate, environment, and nutritional outcomes at the national or local level. Although predictive models suggest global crop yields will increase with climate change, especially in temperate regions, expert assessments of the prospects for food security remain pessimistic.

8.4.4 Populations in coastal and low-lying areas

One quarter of the world's population resides within 100 km distance and 100m elevation of the coastline, with increases including extensive urbanisation likely over the coming decades (Small and Nicholls, 2003). Climate change could affect coastal areas through sea level rise; increasing ocean temperatures; changing the hydrological cycle; and changing 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 fever, diarrhoeal diseases, heat stress, skin diseases, acute respiratory infections, and asthma (WHO, 2004b). A predictive 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 predictive model analyzed 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, 2004a). 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 decrease 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, Southern Mediterranean, Africa Indian Ocean Coast, South Asia, and Africa Atlantic Coast.

Densely populated regions in low lying areas are vulnerable to climate change. In Bangladesh, under assumptions of a 2C temperature increase, a 30 cm increase in sea level rise, a 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% 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 also indicate that densely populated urban areas are at risk from sea level rise (Chapter 6). In the United States, areas of New Orleans and vicinity are presently 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, these areas could be 2.5 to 4.0 m or more below mean sea level by 2100. A storm surge from a Category 3 hurricane (estimated at 3 to 4 meters without waves) could be 6 to 7 meters above some of the heavily populated areas by 2100, which exceeds the design capacity of existing flood protection levees, potentially putting a very large population at risk.

8.4.5 Mountains

Mountain areas comprise nearly 20 per cent of the Earth's surface, and are inhabited by approximately one tenth of the global human population. Global climate change poses a number of potential risks to mountain habitats, although impacts were not predicted with confidence. It is expected that over time, climate change will affect mountain ecosystems with glaciers and rivers, which are highly sensitive to temperature changes. Such changes around glaciers may have direct impacts with floods, droughts and erratic rainfall thousands of kilometers away. Temperature rise in mountains (especially those higher than 2,500 meters above sea level) may lead to the impairment of oxygen transport in the blood and to possible hypoxic effects in persons with circulatory problems (Kayumov & Makhmadaliev, 2002)

8.5. Costs

Where the impacts of climate change have been formally costed, health costs represent a large proportion of these costs. Even so, in these studies, the health costs are underestimated.

Climate change affects a multitude of health outcomes, but estimates do not cover all these types of costs. The earliest studies have originated from the economics literature – studies either aggregating the 'damage' costs of climate change (Tol 1995, Tol 1996, Fankhauser et al. 1997, Fankhauser and Tol 1997, Tol 2002a, Tol 2002b), or cost-benefit studies of policies to avert climate change (Cline 1991, Nordhaus 1991, Nordhaus and Boyer 2000, Cline 2004). However, given the multi-sectoral nature of these studies (attempting to capture all the major impacts of climate change), the attention to health impacts is limited to predicted deaths from one or two major causes. These include usually heat and cold-related mortality and mortality from malaria. The global economic value of loss of life due to climate change varies between around US$6 billion and US$88 billion, in 1990 US$ (Tol 1995, Tol 1996, Fankhauser et al. 1997, Fankhauser and Tol 1997, Tol 2002a, Tol 2002b). The costs of flooding are limited to market costs and mortality and morbidity cost are not included. Air pollution effects are not included despite good health impact models being available. The impacts on malnutrition are not included although they are potentially large.

Since much of the loss of life takes place in the poorer countries, it makes a great deal of difference as to which estimates are used for the value of a statistical life (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)

Some assessment of first order damage costs for health impacts at the national level are available. The cost of the health impacts of climate change in Fiji were estimated to be USD 5-19 million by the year 2050 from loss of public safety, increased vector- and waterborne diseases, and increased malnutrition from food shortages during extreme events, although this estimate did not include direct damage from cyclones (IGCI, 2000). The impacts of climate change in malaria were estimated to be R1 billion per year in South Africa by 2010 (Turpie *et al.*, 2002). An assessment in the US included also second order impacts of mortality on labour productivity and the US economy (Jorgenson *et al.*, 2004).

8.6 Adaptation: practices, options and constraints

Regional and national agencies and organizations, communities, and individuals will need to adapt to climate change-related health impacts. The degree of response will depend on factors such as who is expected to take action, the current burden of climate-sensitive diseases, the effectiveness of current interventions to protect the population from weather- and climate-related hazards, 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 (Burton *et al.*, 2005; Yohe and Ebi, 2005). Active management of the risks and benefits of climate change needs to be incorporated into the design, implementation, and evaluation of disease control strategies and policies across the institutions and agencies responsible for maintaining and improving population health. Specific adaptation options 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 or feasible; illustrative examples are provided.

There are important prerequisites for adaptation that are currently not met in many parts of the world. In developing countries, a prerequisite for adaptation is the universal access to primary health care. 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.

There are three approaches to the identification of adaptation options. The first evaluates public health interventions in the context of current climate variability. Although considerable public health efforts are directed at the control of vector-borne diseases such as malaria and dengue, the current burden of these diseases makes it clear that more effective interventions are needed. The second approach is the identification of additional adaptation options to cope with future climate change, while maintaining or improving current public health standards. For example, current food safety programs may need to be enhanced to encourage proper food handling in a warmer world. Most adaptations are likely to be incremental changes in current disease management programs to address shifts in the rate and range of diseases.

The third approach is the identification of adaptation options for situations where thresholds could be crossed either because a disease was close to its boundary conditions or because there was a sudden and/or large change in prevailing weather conditions. For example, although climate change likely played a small role in past reductions in malaria incidence in temperate developed countries, this does not provide reassurance that climate will not play a larger role in the determining the future range and intensity of malaria transmission. It will be more challenging to identify pro-active adaptation options for abrupt climate changes.

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 of current programs, are needed to account for and anticipate the effects of climate change. Surveillance programs In particular, surveillance systems 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.

International responses can be developed jointly by two or more countries when adverse health outcomes and their drivers cross borders. For example, Guidelines on Sustainable Flood Prevention were developed by Parties to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes, 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 projections. Early warning systems can be very effective in preventing deaths, diseases, and injuries (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, and a disease prediction model that is accurate, specific, and timely (Woodruff, 2005). An early warning of a potential outbreak will be inadequate if not accompanied by an effective response capability, including a specific intervention plan.

An example of an effective early warning system is the one developed by the Pacific ENSO Application Center (PEAC) in preparation for the 1997/8 El Nino. In June 1997, PEAC alerted governments that a strong El Niño was developing, that changes in rainfall and storm patterns could be expected, that severe droughts could occur as early as December, and that some islands were at unusually high risk of typhoons and hurricanes (Hamnett *et al.*, 1999). In fact, the region did experience extreme drought, as well as several severe storms. 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 some of the resulting disease burdens. For example, despite the water shortage in Phonpei, fewer children were admitted to hospital with severe diarrhoeal disease than normal; this was attributed to frequent public health messages about water safety. On the other hand, micronutrient deficiencies were found in pregnant women in Fiji, especially in regions where the drought was extreme.

8.6.1.3 Community level responses

Communities recognizing the need to enhance local capacity to respond and adapt to the health impacts of climate change 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. One example is a series of workshops organized by the national Inuit organization in Canada, Inuit Tapiriit Kantami, to document climate-related changes and impacts, and to identify and develop potential adaptation measures for local response (Furgal *et al.*, 2002; Nickels *et al.*, 2003). The strong desire among Inuit community residents to be engaged in the process increases the likely success of adaptation measures developed. Community-level adaptation measures suggested include 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 the farming community in Mwea Division, Kenya (Mutero *et al.*, 2004). The approach facilitated identification of opportunities for zooprophylaxis 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

Adaptation occurs at the personal level, as individuals make psychological and/or behavioural changes based on changing weather conditions. Individuals adapt to high ambient temperature by adjusting clothing and activity levels, and by modifying environments 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 care systems

A crosscutting issue is the adaptations that will be needed within health care systems. For example, programs that train health care professionals will require modification to include consideration of early identification of the spread of climate-sensitive diseases.However, in developing countries a prerequisite for this is the provision of universal access to primary health care.

Box 8.3: Contribution to European heat-wave case study: European Health system response to the 2003 heat wave

The public health crises generated by the 2003 heat-wave in France has 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 national and local action plans, that included heat health warning systems, health and environmental surveillance, and meteorological forecasting (Michelon *et al.*, 2005).Other European health Ministries carried out assessments on the health effects of the heat wave (see 8.2.1.1.), some countries developed national heat prevention plans and implemented 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).

8.6.2 Integration of responses across scales

The range of adaptation responses to specific health risks will often cut across 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 increased fluid intake. Heat health warning systems (including intervention plans) 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. Energy efficiency programs can be further developed to reduce the urban heat island.

Interventions designed to increase the adaptive capacity of a community or region also can facilitate achievement of 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 air toxics that may be released from coal-fired power plants and greenhouse gas emissions.

8.6.3 Limits to adaptation

A range of barriers exists to the development and implementation of effective and efficient strategies, policies, and measures to reduce current and future vulnerability to climate change-related health impacts. Fundamental barriers exist in developing countries where adaptation will depend on improvements in not only the public health infrastructure, but also in the medical, water, agriculture, transport, and housing sectors. Over the medium term, the poor are likely to remain poor and vulnerable, with few options for adapting to climate change. Public awareness is needed to mobilize resources.

Barriers exist when either proposed measures are not technically feasible or their effectiveness has not been demonstrated. For example, possible adaptation measures frequently mentioned include vaccinations for a range of climate-sensitive diseases such as malaria and dengue. Although desirable, debate exists on when these vaccines will be feasible. Moreover, feasibility does not ensure effectiveness. For example, the control of vector breeding may be technically feasible but not possible in situations where sites are too numerous and expertise limited, or a vaccine may be feasible but not practical in the face of constraints such special storage and transport requirements or frequent revaccination.

Local constraints include environmental acceptability, economic viability, human skills and institutional capacity, and social and legal acceptability (Burton *et al.*, 2005). Adaptation measures may have environmental consequences that are unacceptable. For example, draining of wetlands can have adverse ecological consequences. Resources, including financial, human skills, and institutional capacity, need to be available to implement the 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. 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.

Resources used for adaptation to climate change will be shared across a range of public health problems, along with other problems of concern to society, leading to 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.*, 2003b). Lack of economic development and other factors can contribute to increasing vulnerability in addition to climate-related stresses. Many of the policies and measures that can be used to reduce future vulnerability to climate change are of value in adapting to current climate, and can be used to achieve other environmental and social objectives. Therefore, policies and measures for adaptation to climate change are best developed in the context of development and environment policies.

8.6.4 Health implications of adaptation strategies, policies and measures

Adaptation strategies, policies, and measures can have short- and long-term consequences, and the potential health risks should be evaluated before implementation. For example, a program was developed in the Tigray region of northern Ethiopia to increase resilience to famine by minimising dependence on rainfed agriculture and by improving food production by constructing microdams and introducing irrigation systems (Ghebreyesus *et al.*, 1999). A longitudinal study determined that the rate of childhood malaria in villages near microdams was increased by 7.3-fold over the rate in control villages. Increased malaria also was found at higher altitudes. Air conditioning of private and public spaces is a primary measure used in the United States to reduce heat-related morbidity and mortality (Davis *et al.*, 2003a). Depending on the energy source used to generate electricity, increased use of air conditioning in Europe could increase greenhouse gas emissions. It also could increase the urban heat island effect and reduce acclimatization (Kovats and Koppe, 2005).

Measures to combat the scarcity of water, such as the re-use of wastewater and irrigation, have implications for human health [Chapter 3]. Water quality guidelines for wastewater irrigation are strict in order to prevent health risks from pathogenic organisms and guarantee crop quality (Steenvoorden and Endreny, 2004). However, in rural and peri-urban areas of most developing 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 Sustainable development

Climate change may affect the achievement of the MDGs (Bank et al., 2003; Davidson *et al.*, 2003; Brew and Washington, 2004), undermine the three pillars of sustainable development (Health Canada, 2003), and put at risk our on earth life sustaining systems (McMichael, 2003) 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; Brundtland, 2002a; von Schirnding, 2002). Some of these health outcomes have shown to be sensitive to climate and a small burden of those diseases has already been attributed to climate change (Campbell-Lendrum et al, 2003). 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 highly 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 shown to be affected and might be even more affected in the future. Together with access to health services, these are present important determinants of population health (Woodward et al., 2000; Health Canada, 2003).

A situation of increased vulnerability to the health impacts of climate change in developing countries is acknowledged (TAR) and examples of mortality and morbidity illustrates the situation (see 8.2.2). How many of the effects described in previous sessions can be reduced? 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 achieve this end, health in sub-Saharan Africa must be treated as a high priority investment in the international development portfolio (Brundtland, 2002b). Funding health programmes is a necessary step towards reducing vulnerability but will not be enough on its own (Brewer and Heymann, 2004; Regidor, 2004a; Regidor, 2004b; De Vogli *et al.*, 2005; Macintyre *et al.*, 2005). Progress depends also on strengthening public institutions; building health systems that work well and 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). Many of these prerequisites are currently not met in many parts of the world and are not expected to be achieved rapidly. A limitation to the involvement of governments in the implementation of strategies for adaptation in developing countries are the several other current basic immediate social and health care needs which press governments to take action. In this context impacts projected by scenarios for decades ahead may not be considered a priority. Within developing countries some social groups deserve especial attention in regard to adaptation and reduction of vulnerability: slum dwellers; subsistence farmers in drylands; ethnically differentiated communites separated from mainstream society; natural resource-dependent communities and those settled in flood-prone or landslide-prone areas. Effective participation of most of these communities in adaptation should involve the mobilization of human and social capital in the form of traditional knowledge of the environment and community organizations and their networks (Adger, 2003). This is particularly the case for traditional resource-dependent communities that already require dense social capital to manage weather-dependent resources effectively and to cope with risks (Berkes, 2000)

Increases in climate variability might affect progress towards the achievement of relevant targets (Thomson *et al.*, 2005a). However, the effects will be very much depending on the rapidity of the change, the scale of change and the intensity. For example an event like the tsunami in 2004, occurring rapidly (few hours) over a large geographic area, has killed millions of persons, impaired thousands of persons with permanent disability, left thousands of orphans and caused several disease outbreaks. An increase of frequency of certain events, e.g. flood, could also reduce the resilience of communities, affect vulnerable regions and localities, and overwhelm the coping capacities of most societies.

8.7.1 Health and climate protection: clean energy

Climate policies that reduce fossil fuel combustion, particularly in the transport (road traffic) sector, will directly benefit health from immediate improvements in urban air quality. Reductions in air pollutant concentrations can be linked to quantifiable benefits for reductions in particulates (Barker *et al.*, 2001; Cifuentes *et al.*, 2001; Li, 2002; West *et al.*, 2004), and tropospheric ozone (via changes in methane emissions) (Fiore *et al.*, 2002; West and Fiore, 2005). 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 developing countries, biomass fuels are used for cooking in households and in small-scale commercial/industrial establishments at low combustion efficiency. A significant, but unknown, portion is harvested non-renewably, thus contributing net CO_2 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 are large in comparison with urban air quality 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 pneumonia (Smith *et al.*, 2004). About half the world's population relies on biomass fuel for a substantial part of annual cooking needs. Thus, 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

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.

Climate-sensitive diseases arise at the conjunction of exposures, human health responses, and facilitating contextual factors, where each has to be favourable for disease occurrence. Uncertainties arise in each area. Uncertainties related to exposure derive from climate models and predictions, and the reader is referred to Working Group I for a discussion of these uncertainties.

As discussed in this chapter, there is a growing body of knowledge on the impacts of climatic factors on the dynamics of infectious diseases, and the direct effects of high temperatures on mortality. Considerable uncertainties remain that can be addressed through further empirical research, but this requires that better models, and better and more health data, particularly from developing countries.

Catastrophic and abrupt climate changes (such as the collapse of the WAIS and 5 m sea level rise) would have significant and considerable impacts on human health. There are few scientific studies exploring potential health impacts in relation to extreme climate scenarios.

Table 8.1: *Principal diseases with relevance for vulnerability to climate change: current disease burden in terms of deaths and DALYs (in brackets) per (thousands) by region and globally, in the year 2000*

GBD cause	***Global total***	***Males***	***Female***	*Africa*	*Americas*	*Europe*	*Asia*
Diarrhoeal diseases	1969	1018	951	690	64	22	1192
	(61671)	(31233)	(30438)	(21103)	(2449)	(887)	(37232)
Malaria	1120	530	590	957	1	0	162
	(42085)	(19921)	(22164)	(35738)	(107)	(20)	(6219)
Dengue	21	10	11	0	3	0	18
	(648)	(281)	(366)	(6)	(85)	(0)	(557)
Protein–energy malnutrition	263	132	131	101	44	5	114
	(16823)	(8569)	(8254)	(5505)	(1067)	(201)	(10050)

* Aggregated WHO regions. Source: (WHO, 2002b)

Table 8.2: *Scenario-based estimates of the impacts of climate change on infectious diseases*

Health effect	**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 emissions 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 90m (A1FI) to 200m (B2b)	(van Lieshout *et al.*, 2004)
Malaria, Africa	Person-months at risk	MARA/ARMA model of stable falciparum transmission	HadCM3, driven by 3 SRES emissions scenarios	No population scenarios (current population)	Increases in person-months, especially in highland areas	(Tanser *et al.*, 2003)
Malaria, Africa	Map of climate suitability	MARA/ARMA model of stable* falciparum transmission [minimum 4 months suitable per year]	HadCM2 medium high, ensemble mean Temperature, rainfall, 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 stable falciparum transmission	16 climate projections to 2100 from COSMIC, climate	None	Highlands become more suitable for transmission, while the lowlands and areas with low precipitation show	(Hartman *et al.*, 2002)

			sensitivities of 4.5° C and 1.4° C, and equivalent CO_2 [350 and 750 ppmv]		varying degrees of change, depending on climate sensitivity and emission stabilization scenarios, and GCM.	
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 main vector (An atroparvus) and other vectors	(Kuhn, 2003)
Malaria and dengue, 5 regions in Portugal	Favourable periods for transmission (% days per year)	Threshold approach based on published literature	PROMES RCM, 2 x CO_2 No time slice	None. Some assumptions about vector distribution and/or introduction.	General increase in % days per year within favourable transmission season	(Calheiros and Casimiro, 2002)
Malaria, Australia	CLIMEX ecoclimatic index	Climate matching model, for main vector An. Farauti s.l.	High, medium and low emissions CSIROMk2, ECHAM4	Assumes adaptive capacity	"Malaria receptive zone" expands southwards to include some regional towns by 2050s. But absolute risk of reintroduction remains very low.	(McMichael *et al.*, 2003a)
Malaria, India, all states	Climate suitability- by months per year	Threshold approach based on published literature	HadRM2	None.	By 2080s, show increases in season suitable transmission in 2 states: Jammu and Kashmir, and Rajasthan.	(Shukla *et al.*, 2003; Mitra *et al.*, 2004)
Dengue, global	Population at risk	Statistical model	IS92a emissions Vapour pressure GCMs (ECHAM4, HadCM2, CCSR/NIES, CGCMA2, CGCMA1)	Population growth – scenario not specified	By 2085: with both population growth and climate change, global population at risk 5-6 billion; with climate change only, global population at risk 3.5 billion.	(Hales et al., 2002)
Dengue, New Zealand	Vector map "hot spots"	Threshold based model (rainfall and temperature).	CLIMPACTS [not specified]	None	Current climate unsuitable for established of endemic dengue. Warming may make transmission more likely.	(deWet et al., 2001)
Dengue, Australia	Vector map "A aegypti"	Statistical model (from global analysis – Hales et al. 2002]	High, medium and low emissions CSIROMk2, ECHAM4	None	Potential transmission area expands southwards to include some regional towns by 2050s. Large population at risk (0.8-1.6 million)	(McMichael et al., 2003)
Diarrhoeal disease, global, 13 world	Diarrhoea incidence [mortality]	Statistical model, derived form cross-sectional study. Inputs:	SRES A1, A2, B1, B2	SRES population growth.	Broadly, increases in incidence as temperature increase.	(Hijioka et al., 2002)

regions		annual average temperature and water supply coverage.				
Diarrhoeal disease, Aboriginal community, central Australia	Hospital admissions in children under 10. Alice Springs.	Statistical model [not specified]	CSIROMk2, ECHAM4 Emissions [low, medium, high]	None. Current admissions.	By 2020, 3-5% increase in admissions, by 2050s, 5-18% increase in admissions compared to baseline.	(McMichael et al., 2003)
Food poisoning, England and Wales	Reports of food poisoning (non specific)	Statistical model, based on observed relationship with temperature	UKCIP98 scenarios	None	Increase of 4000-10,000 cases per year by 2050.	Bentham in (Department of Health, 2002)

* stable transmission defined as high transmission with little fluctuation between

Table 8.3: *Scenario-based 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
UK	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 would result in an estimated 2800 heat deaths per year in the UK in the 2050s (250% increase). Greater reductions in cold-related mortality.	(Keatinge *et al.*, 2002)
Lisbon, Portugal	Heat-related death	Empirical-statistical model, derived from observed summer mortality.	2xCO_2 emissions RCMs: PROMES and HadRM2	SRES population scenarios. Assumes some acclimatization.	Increases in heat related mortality, by 2020s, to range 5.8-15.1 deaths per 100,000, from baseline 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 monthly mortality.	High, medium and low emissions. CSIROMk2, ECHAM4	Population growth, and population ageing. No acclimatization.	Increases in heat-related mortality in over 65s, increases large in temperature cities. Fewer reductions in cold related mortality.	(McMichael *et al.*, 2003a)

Table 8.4: *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-attributable deaths by county	CRF [concentration response function] from published epidemiologic	GISS GCM – linked to RCM - - A2 emissions. Downscaling (MM5)	A2 population projection, with 2000 age structure (no aging) [Emissions of	By 2050s: -A2 climate only: 4.5% increases in ozone deaths. Ozone elevated in all counties. -A2 climate and	(Knowlton *et al.*, 2004)

		literature. Gridded ozone concentrations from CMAQ (Community Multiscale Air Quality model)		precursors-assumptions not clear]	precursors: 4.4% increases in 03-deaths. [Ozone not elevated in all areas due to NO_x interactions]	
England and Wales	Exceedence 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)

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