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## Executive Summary

**The health of human populations is sensitive to shifts in weather patterns and other aspects of climate change (*very high confidence*).** These effects occur directly, due to changing incidence in temperature and humidity extremes and occurrence of floods, storms, droughts, and fires. Indirectly, health may be damaged by ecological disruptions brought on by climate change (crop failures, shifting patterns of disease vectors), or social responses to climate change (such as displacement of populations following prolonged drought). Variability is a risk factor in its own right – it is more difficult to protect human health in a highly variable climate than one that is more stable. There is emerging evidence of non-linearities in response (such as mortality due to heat waves) as climates become more extreme. [11.3, 11.5]

**To date, climate change has contributed to global burden of disease (*highly likely*) though the global health effects are relatively small compared with other stressors and not well quantified.** Changes in temperature, rainfall and sea-level have altered distribution of some disease vectors, increased heat wave casualties, and reduced food production for vulnerable populations. [11.4]

**If climate change occurs in the future as projected in scenarios (*to come*), the major effects on health will be:**

- Increased risk of under-nutrition resulting from diminished food production
- Greater incidence of injury and disease due to more intense heat waves, storms, floods and fires
- Some reductions in cold-related injury and disease, but it is not clear how substantial these savings will be, in a more variable climate, and it appears likely that positive outcomes will be exceeded by negative effects of climate change
- Increased pressure on disease control systems due to more favourable conditions in many parts of the world for food- and water-borne diseases, and dengue and other vector-borne infections. [11.5]

**The most important effect of climate change is to multiply current risks to health.** Although new infections and other conditions may emerge under climate change, the largest risks by far apply to health problems that already exist. This means the most vulnerable populations to climate change impacts, world-wide, are those that currently carry the heaviest burden of disease. In these settings, improvements in public health and health care are important elements of adaptation for climate change. [11.6.1]

**There are opportunities to mitigate against climate change, and improve health at the same time. These co-benefit actions include:**

- Reducing local pollution and emissions of climate altering pollutants (CAPs) from energy production through better combustion, energy efficiency, and shifting to renewables
- Reducing rising trends of livestock production, particularly of ruminants, by shifting diets in rich countries to less red meat and dairy products
- Reducing CAP emissions by redesigning communities to rely on more public transport and promote physical activity
- Providing access to reproductive services reducing population growth over time and improving child and maternal health through increased birth spacing. [11.7]

### 11.1. Introduction

This chapter examines what is known about the effects of climate change on human health. We review the diseases and disorders that are sensitive to climate and the factors that cause populations and individuals to be particularly

1 susceptible to ill-health due to variations in climate, and describes steps that may be taken to reduce the impacts of  
2 climate change on human health. The chapter includes also a section on health “co-benefits”. These arise from  
3 interventions to reduce the levels of climate active pollutants that also have positive effects on human health.  
4

5 In the introduction we summarise the major findings on climate change and health from the Fourth Assessment  
6 Report (AR4), and indicate, in broad terms, the most important developments in the field since. We begin with an  
7 outline of measures of human health, the major driving forces that act on health world-wide, recent trends in health  
8 status, and projections for the remainder of this century.  
9

### 10 11 *11.1.1. Background – Present State of Global Health*

#### 12 13 *11.1.1.1. Definitions*

14  
15 There are many definitions of health, but all are concerned in one way or another with the physical, social and  
16 psychological well-being of individuals and groups. Health is both a condition for, and a consequence of,  
17 development, and there is a similar inter-dependence between a country’s social and economic progress and its  
18 ability to protect its population against adverse effects of stressors such as climate change.  
19

20 Which aspects of well-being are emphasized and valued most highly depends on social norms and values. However  
21 there is less diversity in the measures of deviations from (good) health. Premature mortality is the most commonly  
22 reported health statistic, generally in the form of a rate (the frequency of death in a given time period in a defined  
23 age group) or average life expectancy. Commonly mortality rates are adjusted or standardized to a given age-sex  
24 population structure. Life expectancy is calculated from the age-specific death rates for a population, to provide the  
25 average years lived from a given age (e.g. from birth). Measures of non-fatal health outcomes include the occurrence  
26 of disease and the quality of life. The former is commonly expressed as incidence i.e. new cases occurring in a given  
27 population in a given time period (eg annual breast cancer incidence) or prevalence, the number of cases of a given  
28 disease in a population at a specific point in time (eg proportion affected by blindness).  
29

30 Quality of life survey instruments often focus on the level of functional impairment. They may also capture  
31 perceptions of the extent to which a disease reduces the full quality of a healthy life. The most commonly cited of  
32 these metrics is the Disability Adjusted Life Year (DALY), which combines years in full health lost due to  
33 premature death and years lived with less-than-ideal health due to illness or injury (disability). DALYs are widely  
34 used in estimates of population health, not only because this measure combines mortality and morbidity, but also  
35 because it allows aggregation of impacts that share a common underlying cause. Hence the concept of the “burden  
36 of disease” attributable to tobacco use, air pollution and other environmental exposures including climate change.  
37 (World Health Organization, 2008)  
38

#### 39 40 *11.1.1.2. Trends in Health*

41  
42 The Fourth Assessment Report pointed to dramatic improvement in life expectancy in most parts of the world in the  
43 20<sup>th</sup> century, and this trend has continued through the first decade of the 21st century. (Christensen *et al.*, 2009) It is  
44 important to bear in mind that although rapid progress in a few countries (especially China) has swayed global  
45 averages, most countries have experienced substantial reductions in mortality. There have been exceptions, and there  
46 remain sizable and avoidable inequalities within- and between-nations according to education, income and ethnicity.  
47 (Beaglehole and Bonita, 2008) In some countries, official statistics are so patchy in quality and coverage that it is  
48 difficult to draw firm conclusions about health trends. (Byass, 2010) Life expectancy fell in many countries in  
49 Eastern Europe in the 1980s and 1990s, and has been slow to recover. At a regional level, inequalities in mortality  
50 have diminished, and convergence has been particularly marked amongst adults. (Clark, 2011) Amongst children,  
51 mortality rates continue to fall, but the greatest decreases have occurred in urban areas and in wealthy parts of the  
52 world. More than 20 countries, mostly in sub-Saharan Africa, showed no improvement in child mortality between  
53 1990 and 2006. (United Nations, 2010) (see Box 11-1). In eastern and southern Africa, HIV/AIDS contributed to a  
54 substantial rise in mortality in the 1990s with more than 20% of the adult population infected in the worst hit areas.

1 In some countries (eg Malawi, Zambia) this trend has reversed recently; elsewhere (e.g. Zimbabwe) mortality  
2 remains at very high levels.(Reniers *et al.*, 2011)

3  
4 \_\_\_\_\_ START BOX 11-1 HERE \_\_\_\_\_

### 6 **Box 11-1. Climate Change and the Millennium Development Goals**

7  
8 The Millennium Development Goals (MDGs) were established by the world community in 2000, as a way of  
9 focusing attention on some of the most pressing international development goals. Progress toward many of the  
10 goals, which are to be accomplished by 2015--and any subsequent related development efforts--will be affected by  
11 climate change. For example, Goal 4 states that the world community should “reduce by two thirds, between 1990  
12 and 2015, the under-five mortality rate.”<sup>1</sup> Figure 11-1 shows the current trends in reduction in child mortality  
13 worldwide by cause and indicates how far they are expected to fall above the MDG reduction goal by 2015. Each  
14 color represents a different child-mortality “disease wedge” with different risk factors and interventions. It also  
15 indicates overall how much faster they together must decline if the MDG is even to be reached ten years late, i.e., by  
16 2025. There are three ways climate change interacts with these wedges:

- 17 1) Two of the major causes of child mortality, diarrhoeal diseases and malaria, are directly influenced by the  
18 changes in temperature and rainfall to be expected with climate change, probably making their reduction  
19 more difficult as climate change proceeds.
- 20 2) Malnutrition/under-nutrition, which is likely to be exacerbated as climate change progresses, is a major  
21 contributor to all the child-mortality wedges represented here, hampering their reduction as climate change  
22 proceeds
- 23 3) On a more positive note, improving combustion of solid-fuel in poor households will both help reduce one  
24 of the major wedges, ALRI, and mitigate climate change through reduction in CAPs, a co-benefit.

25  
26 [FOOTNOTE 1: <http://www.un.org/millenniumgoals/childhealth.shtml>]

27  
28 [INSERT FIGURE 11-1 HERE

29 Figure 11-1: Projected Child Mortality, 2008-2030, Including Climate-Sensitive Causes. Sources: Mortality  
30 projections by cause from WHO. Population projections from UN DESA. Child mortality rates from IGME.  
31 (Interagency Group for Child Mortality Estimation, 2011; United Nations, Department of Economic and Social  
32 Affairs, Population Division., 2011; World Health Organization, 2008).]

33  
34 \_\_\_\_\_ END BOX 11-1 HERE \_\_\_\_\_

35  
36 Aside from mortality, less is known about trends in other aspects of health. In high-income countries, there are signs  
37 that the reduction in mortality has been accompanied by decline in disability and improvement in physical function.  
38 (Manton, 2008) There are improvements evident also in some of the biggest causes of ill-health in low-income  
39 countries. The incidence of tuberculosis world-wide appears to be falling, albeit unevenly. It is difficult to interpret  
40 malaria statistics – reported declines in total number of cases world-wide must be treated with caution, and progress  
41 appears to be most erratic in countries with highest incidence, but the fall in deaths from malaria is encouraging.  
42 (World Health Organization, 2009b; World Health Organization, 2011b) WHO estimates that the number of new  
43 cases of infection with HIV fell by about 16% between 2000 and 2008. (World Health Organization, 2011b)  
44 However, not all indicators are positive. For instance, child under-nutrition, implicated in about a third of all deaths  
45 under 5 years, has become more common in a number of countries since 2005, and about 180 million children  
46 world-wide are stunted (short for their age) as a consequence. (World Health Organization, 2011b)

47  
48 For specific causes of death, the patterns differ widely by region. The dramatic decline in cardiovascular disease in  
49 high-income countries is not seen in parts of the world that are developing rapidly, such as India and China. In those  
50 countries, the numbers of deaths from heart disease and stroke are increasing for two reasons; ageing populations  
51 and prevalent risk factors such as high blood pressure and cigarette smoking. (Samb *et al.*, 2010) Cancer and mental  
52 disorders such as depression are also reported more commonly than previously in low and middle income countries,  
53 and infectious diseases remain the cause of a substantial amount of early death and morbidity. Maternal mortality  
54 (deaths in pregnancy and childbirth) shows the greatest variation between wealthy and disadvantaged regions

1 globally, no region is tracking sufficiently strongly to reach the Millennium Development Goal for this indicator,  
2 and progress appears to have stalled altogether in some countries. (Hogan *et al.*, 2010; World Health Organization,  
3 2011b).

### 6 *11.1.1.3. Projections for Global Health in the 21<sup>st</sup> Century*

7  
8 Most commentators anticipate mortality rates will continue to fall world-wide, and WHO estimates the total burden  
9 of disease (measured in DALYs per capita) will be cut by as much as 30% in 2030, compared with 2004. (WHO,  
10 2008; World Health Organization, 2008) These projections assume that economic and social development continue  
11 without interruption, particularly among poor populations, and as already noted, the global figures are driven by  
12 trends in a few large countries (China and India in particular). Less optimistic development scenarios would undo  
13 some of the improvements that have occurred, and might lead to a resurgence in HIV/AIDS, a slow down in  
14 improvements in child health indicators, and acceleration in the number of deaths caused by tobacco and road traffic  
15 crashes. (Mathers and Loncar, 2006) In any event, the underlying causes of poor health are expected to change  
16 substantially, with much greater prominence of chronic diseases and injury, largely due to changes in population  
17 structure. On its “baseline development” scenario, WHO projects the top three causes of burden of disease in 2030,  
18 world-wide, to be depression, ischemic heart disease and road traffic accidents. (World Health Organization, 2008)

### 21 *11.1.2. Major Findings of AR4*

22  
23 AR4 concluded that climate change is already adding to the global burden of disease and premature deaths [add in  
24 chapter and section]. Examples cited included impacts on nutrition, changes in disease-carrying vectors, new  
25 patterns of allergic conditions resulting from changed climate and a increase in deaths caused by heat waves.  
26 Looking ahead, the AR4 listed threats to health that may be aggravated by climate change, ranging from  
27 malnutrition to ground-level atmospheric pollution, altered patterns of mosquito-borne diseases, and casualties due  
28 to storms, floods and other extreme climate events. AR4 anticipated some potential positive effects on health (such  
29 as reduced deaths and injuries caused by extreme cold) but concluded that these would be outweighed by the  
30 negative consequences of climate change. Disease and injury due to climate change would not, according to AR4, be  
31 evenly spread, but would be concentrated in groups such as the urban poor, coastal communities, the elderly and  
32 children, and subsistence farmers.

33  
34 The published burden of disease assessment reviewed in AR4 found that nearly 90% of the burden of disease due to  
35 the climate change that had occurred at the start of this century was estimated to fall on young children in  
36 developing countries, mainly because of their vulnerability to malaria, malnutrition, and diarrheal diseases.  
37 (McMichael, 2004) This underlines the point that climate change does not create new diseases or other health risks,  
38 but exacerbates existing ones, particularly in populations already highly vulnerable.

39  
40 Although poverty is a pervasive cause of vulnerability to climate change, AR4 concluded that economic  
41 development alone would be insufficient to ameliorate the risk. The manner of development, the social distribution  
42 of the fruits of economic growth, and investments in critical institutions and services such as education and health  
43 care would be important as well as focused efforts in particular regions, for example where sea-level rise will affect  
44 populations.

### 47 *11.1.3. Developments since AR4*

48  
49 The numbers of papers and reports on climate change and health have grown considerably since the publication of  
50 the AR4. In April 2012, there were approximately 13,500 publications on climate change listed in PubMed, the US  
51 National Library of Medicine database. Almost two thirds of these were published after 2006. In addition, there are  
52 many reviews, reports and international assessments that do not appear in listings such as PubMed but include  
53 important information nevertheless. For instance, the World Development Report 2010 (The World Bank, 2010), the  
54 Climate Vulnerability 2010 report (DARA, 2010), and the 2011 UN Habitat report on cities and climate change

1 (United Nations Human Settlements Programme, 2011). However, many of these publications were reviews and  
2 commentaries, and the number of quantitative studies linking climate change and health is much smaller. One  
3 review of the scientific literature from 2008 to 2011 identified 40 studies, most focused on high-income countries.  
4 (Hosking and Campbell-Lendrum, 2012)  
5

6 In the last 5 years many countries have carried out national assessments of impacts, vulnerability and adaptations to  
7 climate change. In addition to National Adaptation Programs of Action that countries must prepare as one of their  
8 obligations under the UN Framework Convention on Climate Change, international bodies such as the World Health  
9 Organization and the UN Development Program have promoted adaptation planning with a particular emphasis on  
10 health.  
11

12 Since the AR4, there have been developments in the methods applied to investigate climate change and health. They  
13 include more sophisticated modeling of possible future impacts (for example, work linking climate change, food  
14 security, and health outcomes) (Nelson *et al.*, 2010) and improved measures of personal exposures to heat (Maloney  
15 and Forbes, 2011). Other developments include coupling of high-quality, longitudinal mortality data sets with down-  
16 scaled meteorological data, in low-income settings (for instance, through the INDEPTH Network) (see Box 11-2).  
17

18 \_\_\_\_\_ START BOX 11-2 HERE \_\_\_\_\_  
19

### 20 **Box 11-2. Climate Change and Mortality – a Long-Term Observational Study in African and Asian** 21 **Populations** 22

23 Given the dearth of scientific evidence of the relationship between weather/climate and health in low- and middle-  
24 income countries, we report on a collaborative study from sub-Saharan Africa and Asia. The INDEPTH Network  
25 currently has 43 members in 20 countries in Africa, Asia and Oceania. Using standardized health and demographic  
26 surveillance systems members have collected information on births, migration and deaths by cause over an average  
27 of 20 years ([www.indepth-network.org](http://www.indepth-network.org)). Currently, there are about 3.4 million people under surveillance.  
28

29 To study long-term relationships between weather and health, the authors collected information on all deaths  
30 occurring in 11 INDEPTH populations between 1.1.2000 and 31.12.2009 contributing about 10 million person-years  
31 of observation over 10 years. Time dependent methods were used for relating remodeled meteorological data, such  
32 as temperature and rainfall of the day the death occurred of death and several time intervals (from 1 day to 1 month)  
33 before. Analyses related rainfall and high temperature events to mortality, with varying time lags. Studies are being  
34 conducted on both monthly and daily numbers of deaths. Age stratified analysis has shown seasonality in the  
35 number of deaths is different in different age groups. Sex stratified analysis revealed potential differences in  
36 susceptibility to weather related factors according to gender. In the elderly population deaths related to dust storms  
37 and heat have been more pronounced compared with other ages. For example, in Nounain Burkina Faso, the relative  
38 risk of dying for the elderly above 60 years is associated with the temperature on the day preceding the death, as  
39 shown in Figure 11-2, and the effect of daily rainfall on subsequent death from diarrheal diseases in Bangladesh is  
40 shown in Figure 11-3.  
41

42 [INSERT FIGURE 11-2 HERE

43 Figure 11-2: Relationship between the risk of dying and temperature on the preceding day. Y-axis: log(RR), XS-  
44 axis: Temp in °C, lagged by one day.]  
45

46 [INSERT FIGURE 11-3 HERE

47 Figure 11-3: The effect of daily rainfall on daily mortality in diarrheal diseases in AMK HDSS, Bangladesh]  
48

49 By further extending the time frame of observation and applying appropriate modeling techniques, it may be  
50 possible to detect impacts of climate change, as well as the effects over a shorter time frame of varying weather  
51 conditions. (Source: *Global Health Action*, Special Volume, forthcoming).  
52

53 \_\_\_\_\_ END BOX 11-2 HERE \_\_\_\_\_  
54

1 New and emerging topics – It is difficult to identify work that is absolutely novel, but there are a number of areas  
2 that have grown considerably in the last 5 years. Studies of the ways in which responses to climate change may  
3 affect health, so-called “co-benefits”, have multiplied. (Haines and McMichael A., Smith K., Roberts I., Woodcock  
4 J., Markandya A., Armstrong B., Campbell-Lendrum D., Dangour A., Davies M., Bruce N., Tonne C., Barrett  
5 M., Wilkinson P., 2009) Another important, emerging topic is effects of greenhouse emissions other than those  
6 resulting from warming. A prime example is ocean acidification (Doney *et al.*, 2008)– the effects on calcifying  
7 marine species is well documented and the risks for coral reefs are now more closely defined than they were at the  
8 time of the AR4, but the implications for human health specifically have not been explored. There have also been  
9 new publications on the interactions among climate, socioeconomic conditions and health, for example related to  
10 occupational conditions (Kjellstrom *et al.*, 2009b) and malaria (e.g. (Béguin *et al.*, 2011; Gething *et al.*, 2010)) In  
11 general, there is more work underway on the interactions between climate and socioeconomic and other health  
12 determinants. (Gething *et al.*, 2010) There is also growing appreciation of the social upheaval and damage to  
13 population health that may arise from the interaction of large-scale food insecurity, population dislocation, and  
14 conflict. (US EPA, 2007)  
15  
16

## 17 **11.2. Major Climate-Sensitive Health Outcomes**

### 18 **11.2.1. Introduction**

19  
20  
21 In this section we review work done since the last Assessment on the links between climate and significant health  
22 outcomes. We concentrate on research that enlarges our understanding of the ways in which human health can be  
23 affected by variability in the climate, as shown in Figure 11-4. Discussion of the effects of climate change, up until  
24 the present and in the future, is placed later in the chapter (see Sections 11.4 and 11.5).  
25

26 [INSERT FIGURE 11-4 HERE

27 Figure 11-4: Ways in which climate, climate variability, and climate change may influence human health.]  
28

### 29 **11.2.2. Disease and Injury due to Heat and Cold Extremes**

30  
31 A great deal has been written on the links between outdoor temperatures and morbidity and mortality. (Basu and  
32 Samet, 2002; Ye *et al.*, 2012). All-cause mortality is frequently used as the principal outcome of interest, because  
33 individual causes of death (such as heat stroke and hypothermia) do not capture the full impact of temperature  
34 extremes. The temperature at which mortality is lowest on the typically U, V, or J-shaped dose-response curve  
35 between daily mortality and the range of year-round outdoor temperatures (the so-called optimum, or minimum  
36 mortality, temperature) is area dependent; warmer areas have higher optimum temperature and colder areas have  
37 lower optimum temperature. (Curriero *et al.*, 2002) In a Japanese study, the optimum temperature was not related to  
38 long-term average temperature; instead it was highly correlated with the 80 to 85<sup>th</sup> percentile value of daily  
39 maximum temperature. (Honda *et al.*, 2007)  
40

41 It is physiologically plausible that mortality and morbidity of circulatory diseases increase along with an increase in  
42 the ambient temperature; for instance, displacement of blood to skin surface may lead to cardiac pump failure.  
43 Biological mechanisms are less evident for other causes of death that have been related to weather. For instance,  
44 some studies indicate an association of ambient temperature with suicide (Kim *et al.*, 2011; Likhvar *et al.*, 2011;  
45 Page *et al.*, 2007) and accidents (Bai *et al.*, 1995; Honda *et al.*, 1995; Ishigami *et al.*, 2008).  
46

47 Some investigators have reported that mortality increases more during heat waves than would be anticipated on the  
48 basis of physiologic tolerance to temperature alone. (Anderson and Bell, 2011; D'Ippoliti *et al.*, 2010), although the  
49 added effect is relatively small in some series, and apparent only with prolonged heat waves. (Gasparrini and  
50 Armstrong, 2011) Also, in extreme conditions, excess deaths have been noted in younger age groups than are  
51 normally affected by heat. (Rocklov *et al.*, 2011) One explanation may be that duration of extreme heat exposures  
52 compounds the cumulative stress and health risks. Some studies have shown larger effects of heat and heat waves  
53 earlier in the hot season (Anderson and Bell, 2011; Rocklov *et al.*, 2011). This may be testament to the importance of



1 acclimatisation and adaptive measures, or may result from a large group in the population that is genuinely  
2 susceptible to heat early in the season (Rocklov *et al.*, 2009; Rocklov *et al.*, 2011).

3  
4 The extreme heat wave in Europe in 2003 led to numerous epidemiological studies. The initial reports from France  
5 (Fouillet *et al.*, 2008) included age-specific rates, and concluded that a very large proportion of the extra deaths  
6 occurred in elderly people (80% above age 75). It is notable, however, that the extra heat wave-related mortality in  
7 younger ages was also substantial (approximately 3,000 deaths), and among younger people more men than women  
8 died, unlike the older age groups. One explanation may be that men were working outdoors or in other very hot  
9 circumstances. Questions were raised at the time as to why this event had such a devastating effect (Kosatsky,  
10 2005). It is still not clear, but one contributing factor may have been the relatively mild influenza season the year  
11 before. Recent studies have found that when the previous year's winter mortality is low, the effect of summer heat is  
12 increased. This intrinsic relationship between risk factors in winter and summer time may complicate the attribution  
13 of heat and cold effects (e.g. with climate change), given their inter-dependence.

14  
15 Most analyses have focused on mortality and morbidity in relation to heat in high-income countries, but recent  
16 studies have investigated the relation in low- and middle-income countries, suggesting heterogeneity in vulnerability  
17 by age groups and socio-economic factors similar to that seen in higher-income settings. (Bell *et al.*, 2008;  
18 McMichael *et al.*, 2008)

19  
20 Studies of temperature-related morbidity, most commonly based on hospital admission or emergency presentations,  
21 find that cardio-vascular, respiratory and kidney diseases often are more strongly associated with temperature than  
22 other conditions not specifically coded as temperature-related. (Bayentin *et al.*, 2010; Hansen *et al.*, 2008; Knowlton  
23 *et al.*, 2009; Lin and Chan, 2009; Nitschke *et al.*, 2011)

24  
25 Health risks during heat extremes are greater in people carrying out physical activity. The intra-body surplus heat  
26 created by physical activity (only 20% ends up as external “work”; (Parsons, 2003) causes particular vulnerability to  
27 heat effects in these population groups. This has importance for public health promotion of outdoor physical activity  
28 and it is of special relevance to analysis of the impacts of climate change on occupational health (see separate  
29 section below).

30  
31 Cold weather is related to hypothermia, accidents due to slipping on snow or ice, and carbon monoxide poisoning.  
32 (Parsons, 2003) Carbon monoxide poisonings may be considered as indirect effect of cold, due to improper use of  
33 heating devices that involve indoor burning. Another example of the indirect effect of cold would be snow-  
34 shovelers' myocardial infarction in heavy snow areas. (Janardhanan *et al.*, 2010) It is still unclear precisely how  
35 much of the winter excess in mortality is due to seasonal factors, other than temperature variations. In some studies,  
36 it was reported that although deaths were more common in the winter months, within these months there was no  
37 relation between mortality and temperature. (Honda and Ono, 2009), Kinney *et al.* in press.

38  
39 Cold and heat extremes can be prevented by air-conditioning, but this adaptation depends on a secure power supply.  
40 Recent work reports that power outages are themselves associated with excess mortality, and this relation may be  
41 due in part to temperature variations indoors (Anderson and Bell, 2012).

42  
43 The literature on health impacts of temperature extremes reveals heterogeneity in response in various subgroups of  
44 the population, classified by age, sex, underlying disease status, location of residence, and socio-economic factors.  
45 The interplay among these factors is complex, since lower-income groups may, for example, have a higher  
46 prevalence of certain diseases associated with susceptibility, and have less protection from ambient temperatures due  
47 to poorer-quality housing. The comparability of studies is often limited due to differences in measurement  
48 approaches and availability of variables, although certain common variables related to vulnerability—ranging from  
49 access to air conditioning, vegetative cover of an area, age, and community structure- have emerged and are being  
50 explored in efforts to map vulnerability to temperature exposure. (Reid *et al.*, 2009)

### 11.2.3. Injury and Disease Resulting from Storms and Floods

In the IPCC Fourth Assessment Report, floods were reported to be the most frequent natural weather disaster. This is still true; in 2010, the ten most important disasters, judged by the number of people affected, included six floods and these floods accounted for more than 90 percent of the total number of victims, i.e., 175 million people. Most of the losses occurred in mid- to low-income countries such as China, Pakistan (Dar *et al.*, 2011), Thailand, Cambodia, India, and Colombia. However, as exemplified by flooding in Eastern Australia in 2010, developed countries are not immune.

The direct impacts of storms and floods include drowning, injuries, hypothermia and infectious diseases, whereas indirect health effects result from damage to infrastructure, water supplies, displacement and disruption to people's lives (Jonkman and Kelman, 2005); WHO/HPA, 2012). Over the last 10 years, floods in Europe have killed more than 1,000 people and affected over 3.4 million (Jakubicka *et al.*, 2010). Worldwide, it is estimated that two thirds of flood deaths are due to drowning, and 70% of flood-related deaths are male (Jonkman and Kelman, 2005).

The attribution of deaths to flood events has been found to be complex with immediate traumatic deaths being most easily recorded (WHO/HPA, 2012). There is some uncertainty as to whether flood events are associated with a longer-term effect on mortality in the flooded population (e.g. 6-18 months after the flood). A study of the Bristol floods of 1968 reported a 50% increase in mortality rates among those flooded compared to those not flooded during the 12 months following the event (Bennet, 1970). Although others have sought such an effect, the Bristol finding has not been repeated. Understanding the effects of population displacement after a flood is challenging, since it requires the long-term follow up of individual households. A study of mortality patterns in flooded areas in England and Wales from 1994-2005 found a relative reduction in mortality of 10% in years following flooding. It is not clear whether this finding is real or artefactual (for instance, due to missing information on populations from flooded postcodes (Milojevic *et al.*, 2011).

Flood-related injuries have been caused when people are evacuating from flood waters, attempting to save family or valuables, or during the clean-up process (Jakubicka *et al.*, 2010). Following the 2002 floods in Germany, contact with floodwaters was identified as a risk factor for injuries (Schnitzler *et al.*, 2007). Infectious diseases may also be affected. In many countries, heavy rainfall and flooding have led to outbreaks of leptospirosis (caused by contact with bacteria of the genus *Leptospira*, an organism which circulates in a wide variety of animal hosts, including rats). (Lau *et al.*, 2010) Drinking water can become contaminated by bacteria, sewage, agricultural waste or chemicals (CDC, 2011). Floods commonly damage water storage and reticulation systems, and this means that emergency supplies are required. For instance, flooding in Cork, Ireland in 2009 resulted in 18,000 homes being cut off from main water supply; in total, approximately 300,000 litres of bottled water were distributed (Gavin, 2009). The 2006 flooding of an underground aquifer in Hungary, which served 174,000 people, resulted in provision of safe drinking water to consumers (Dura *et al.*, 2010).

Flooding can have profound effects on peoples' mental health and psychosocial resilience that may continue over extended periods of time. However, methodological complexities in analysing and comparing data make it hard to compare and understand these impacts (Murray *et al.*, 2011). A study of the aftermath of the 2007 England and Wales floods found that the prevalence of all mental health symptoms (psychological distress, probable anxiety, probable depression and probable PTSD) was two to five times higher among individuals who reported flood water in the home compared to individuals who did not (Paranjothy *et al.*, 2011). A study of the psychological impacts of flooding found that, among flood-affected adults, 27.9% met criteria for symptoms associated with post-traumatic stress disorder (PTSD), 24.5% for anxiety and 35.1% for depression (Mason *et al.*, 2010). Several factors were associated with greater psychological distress, including: vacating homes following a flood, previous experience of flooding and poor health at time of flood. A longitudinal study (follow up of persons affected by 1998 flood in Oxfordshire) found participants reported continuing psychological effects that they attributed to the experience of being flooded (Tapsell and Tunstall, 2008). The provision of emergency and longer-term mental health care in planning, response and recovery is an important component of flood management (Murray *et al.*, 2011).

#### 11.2.4. Vector-Borne and Other Infectious Diseases

##### 11.2.4.1. Vector-Borne Diseases

Vector-borne diseases (VBDs) are infections transmitted by the bite of infected arthropod species, such as mosquitoes, ticks, triatomine bugs, sandflies and blackflies. VBDs are among the most well-studied of the diseases associated with climate change, due to their widespread occurrence and sensitivity to climatic factors. In general, range shifts of a variety of VBDs and their hosts and vectors in response to rising temperatures have been observed. These range shifts have generally been poleward and upward (toward higher elevations) (Hickling *et al.*, 2006). For example, altitudinal and latitudinal range shifts have occurred for *Ixodes ricinus*, the vector of the agents of Lyme disease and tick-borne encephalitis (TBE) in Europe (Gage *et al.*, 2008), while shifts, contractions and expansions have been reported in sub-Saharan Africa where the tick is a vector for East Coast fever (Olwoch JM, Reyers B, Engelbrecht FA, Erasmus BFN, 2008; Olwoch JM, Reyers B, Jaarsveld ASV, 2009). Northerly range shifts also have been observed for *Ixodes capularis*, a vector of Lyme disease, human granulocytic anaplasmosis, and babesiosis in Canada. In Canada endemic areas for *Borrelia burgdorferi*, the etiological agent of *Lyme borreliosis* (LB) in North America, are increasing (Ogden *et al.*, 2008).

Many studies have reported that the incidence of vector-borne diseases is temperature-related (Bangs *et al.*, 2006; Bi *et al.*, 2007; Halide and Ridd, 2008; Wu *et al.*, 2009) but this is not true in every case. For example, *S. mansoni*, a parasite leading to sparganosis *mansoni*, is not responsive to increased temperatures according to one report (Mangal *et al.*, 2008). Moreover, the distribution of VBDs is influenced by many factors other than climate (examples include land use, population movement, housing quality and urbanization (Vittor *et al.*, 2006)).

##### 11.2.4.1.1. Malaria

Malaria is caused by four distinct species of plasmodium parasite, transmitted between individuals by Anopheline mosquitoes. There were an estimated 247 million malaria cases among 3.3 billion people at risk in 2006, causing nearly a million deaths, mostly of children under 5 years. (WHO, 2008) World-wide, there have been significant advances made in malaria control in the last 20 years (Feachem, 2011), but the disease remains a significant challenge in some locations, particularly in Africa. For example, large outbreaks have occurred in several highland regions in East Africa, and these may be promoted, at least in part, by rising temperatures locally (Chaves and Koenraadt, 2010). Studies of disease trends in Africa, however, emphasize that the relative importance of climate compared to other factors needs further elaboration (Omumbo *et al.*, 2011). The influence of temperature on malaria development appears to be highly non-linear, and is vector-specific (Alonso *et al.*, 2011). Daily temperature fluctuation around low mean temperatures acts to speed up parasite development, whereas daily fluctuation around high mean temperatures tends to slow processes down. Analysis of environmental factors associated with the malaria vectors *Anopheles gambiae* and *Anopheles funestus* in Kenya found that the abundance, distribution and disease transmission are affected in different ways by precipitation and temperature (Kelly-Hope *et al.*, 2009).

##### 11.2.4.1.2. Dengue

Dengue fever is currently a threat in more than 100 countries, and about 70% of the 2.5 billion people presently at risk live in the Asia-Pacific region (see Box 11-3). There is evidence that the disease is associated with climate on spatial (Beebe *et al.*, 2009; Li *et al.*, 2011; Russell *et al.*, 2009), temporal (Descloux *et al.*, 2012; Earnest *et al.*, 2011; Gharbi *et al.*, 2011; Herrera-Martinez and Rodriguez-Morales, 2010; Hii *et al.*, 2009; Hsieh and Chen, 2009; Pham *et al.*, 2011) and spatiotemporal (Chowell *et al.*, 2008; Chowell *et al.*, 2011; Lai, 2011) scales. But the findings are not entirely consistent. Although some report that high rainfall and humidity are strong environmental influences on dengue transmission (Pham *et al.*, 2011; Rohani *et al.*, 2011; Su, 2008), others have found that there were no, or only weak associations between dengue incidence and the two climatic variables. (Chowell *et al.*, 2011; Gharbi *et al.*, 2011; Jury, 2008). In some circumstances, heavy precipitation favours the spread of dengue fever, but drought can also be a cause if household water storage increases the number of suitable mosquito breeding sites (Beebe *et al.*, 2009; Padmanabha *et al.*, 2010). Other factors than climate have a powerful effect on the spread of

1 dengue. In subtropical Taiwan, for example, the degree of urbanization was found to be positively associated with  
2 increasing risk of dengue fever incidence at township level (Wu *et al.*, 2009). Shang *et al.* (Shang *et al.*,  
3 2010) emphasized that the conjunction of imported cases and favorable climate conditions was important in the  
4 initiation of dengue epidemics.

5  
6 \_\_\_\_\_ START BOX 11-3 HERE \_\_\_\_\_

### 7 8 **Box 11-3. Case Study: Dengue Fever**

9  
10 Dengue Fever (DF) and its haemorrhagic manifestations are caused by four antigenically distinct serotypes (1 to 4)  
11 belonging to the Flaviviridae family. Each year within the “dengue belt” (35°N and 35°S latitude) an estimated 50-  
12 100 million cases of Dengue Fever and approximately 500,000 cases of Dengue Haemorrhagic Fever (DHF) and  
13 Dengue Shock Syndrome (DSS) cases are reported (Chadee *et al.*, 2007; Gubler and Kuno, 1997). The risk factors  
14 for DF transmission are summarized in the “epidemiological triad”- the vectors (*Aedes aegypti* and  
15 *Aedes albopictus*), the virus (dengue serotypes 1, 2, 3, and 4) and the susceptible human population (Chadee, 2009).  
16 Prior to 2006, no consistent patterns had been reported on the seasonal distribution of DF and *Ae. aegypti* adult  
17 populations within the Americas (Gubler and Kuno, 1997), but seasonal dengue transmission patterns have recently  
18 been reported in the Caribbean region. However, seasonality in dengue transmission is well known in South East  
19 Asia, with transmission occurring during the wettest months of the year (Chadee *et al.*, 2007; Gubler and Kuno,  
20 1997).

21  
22 Figure 11-5 shows most DF cases (80%) were recorded during the wet season when the *Aedes aegypti* mosquito  
23 population density was four to nine times higher than the dengue transmission threshold (Macdonald, 1956). The  
24 observation of dengue transmission during the wet season was recently used to develop a pre-seasonal treatment  
25 strategy which reduces the mosquito population before the onset of the rains. Studies conducted in Trinidad  
26 demonstrated proof of concept by the application of insecticides (temephos) into water drums, the primary breeding  
27 sites of *Ae. aegypti* in the Caribbean region, prior to the onset of the rainy season. This strategy effectively  
28 controlled the mosquito populations for almost 12 weeks (Figure 11-6) after which the mosquito populations  
29 reverted to levels observed in the untreated control areas.

30  
31 [INSERT FIGURE 11-5 HERE

32 Figure 11-5: Rainfall, temperature, Breteau index, and dengue cases, Trinidad (2002-2004). Source: Chadee *et al.*  
33 (2007).]

34  
35 [INSERT FIGURE 11-6 HERE

36 Figure 11-6: Efficacy of pre-seasonal treatment with temephos on *Aedes aegypti* ovitrap egg counts in Curepe  
37 (treatment) and St. Joseph (control), Trinidad (2003). Source: Chadee (2009).]

38  
39 Studies conducted on global climate models for the Caribbean region reported consistent patterns, with no marked  
40 changes in the “timing of the rainfall seasonality” (J and L, 2010). Therefore with consistency in the timing of the  
41 onset of the rainfall season pre-seasonal treatment strategies can continue to be implemented. However, recent  
42 climate change scenarios for the period 2071-2100 project altered dynamic circulation patterns in both dry and wet  
43 seasons, therefore changing the intensity and frequency of rainfall events (Campbell *et al.*, 2011) In addition, there is  
44 evidence to support greater variability in rainfall patterns during November to January, with the northern Caribbean  
45 region receiving more rainfall than in the southern Caribbean (Campbell *et al.*, 2011). There may be both water  
46 shortages during drought periods and flooding during heavy rainfall episodes thus influencing the breeding habitats  
47 of *Ae. aegypti* and *Ae. albopictus* mosquitoes. In view of these scenarios, vector control strategies will have to be  
48 planned and managed astutely to systematically reduce vector populations.

49  
50 \_\_\_\_\_ END BOX 11-3 HERE \_\_\_\_\_

#### 11.2.4.1.3. Tick-borne diseases

1 Tick-borne diseases are long known and frequently underappreciated threats to public health. Examples are tick-  
2 borne encephalitis (TBE) and *Lyme borreliosis* (LB). TBE is endemic from Alsace-Lorraine in the west to  
3 Vladivostok and north-eastern regions of China in the east, and from Scandinavia to Italy, Greece and Crimea in the  
4 south. Lyme disease is an acute infectious disease caused by the spirochaete bacteria *Borrelia burgdorferi*. There are  
5 foci of Lyme borreliosis in forested areas of Asia, north-western, central and eastern Europe, and the  
6 USA. The main vector is the *Ixodes ricinus* tick in Europe and *I. persulcatus* in Euroasia and Asia. Many studies have  
7 found that climate may have an influence on the distribution of tick-borne diseases (Lukan *et al.*, 2010; Okuthe and  
8 Buyu, 2006; Tokarevich *et al.*, 2011). In southern Sweden, the incidence of LB incidence was positively associated  
9 with mild winters and warm, humid summers (Bennet *et al.*, 2006). The many socioeconomic changes that occurred  
10 at the end of the Soviet era acted synergistically with climate factors to increase TBE incidence in northern Europe  
11 (Sumilo *et al.*, 2007). However, the complex ecology and epidemiology of tick-borne diseases such as Lyme  
12 borreliosis and tick-borne encephalitis make it difficult to attribute changes in disease frequency and distribution to  
13 specific environmental factors such as climate (Gray *et al.*, 2009).  
14  
15  
16  
17

#### 11.2.4.1.4. Other vector-borne diseases

18 Hemorrhagic fever with renal syndrome is a zoonosis caused by the hantavirus, and leads to approximately 150,000  
19 to 200,000 hospitalized cases each year globally. The incidence of this disease has been associated with climatic  
20 factors including local temperature, precipitation, and relative humidity (Fang *et al.*, 2010). Plague, one of the oldest  
21 identifiable diseases, remains endemic in many natural foci around the world. Outbreaks have been linked to  
22 seasonal and inter-annual variability in climate, via the effects of precipitation and temperature on plague hosts and  
23 vectors. (Holt *et al.*, 2009; Nakazawa *et al.*, 2007; Stenseth *et al.*, 2006; Xu *et al.*, 2011).  
24  
25  
26  
27

#### 11.2.4.2. Other Infectious Diseases

28 Significantly higher rates of gram-negative infections among hospitalized patients have been reported during the  
29 summer months, compared with other seasons (Perencevich *et al.*, 2008). In enclosed hospital environments with  
30 inadequate ventilation, hot and humid conditions can enhance transmission of aerosol droplets from other ill patients  
31 and hasten food spoilage. It is well known that the growth of bacterial, viral and fungal pathogens varies with  
32 temperature (Burge, 2006; Danaher *et al.*, 1999; Nelson, 1943), but the role of temperature in the proliferation and  
33 spread of resistant strains such as methicillin-resistant *Staphylococcus aureus* (MRSA), is uncertain.  
34  
35  
36

37 Influenza outbreaks follow a seasonal pattern (Dushoff *et al.*, 2006) (Mahoney 2010) but the underlying mechanism  
38 determining the periodicity is still unknown (Tamerius *et al.*, 2011). The modes of transmission are person to person  
39 contact (including contact with contaminated hosts and surfaces) and through large respiratory droplets.  
40 Overcrowding at indoor sites during the winter (Lofgren *et al.*, 2007) and during heavy rains in tropical regions  
41 (Graham and McCurdy, 2004) provide suitable conditions for airborne spread. In addition, temperature and humidity  
42 may affect host immunity (Tamerius *et al.*, 2011) and antigenic drift and waning immunity may also contribute to  
43 seasonal outbreaks. Temperature and humidity, the El Niño Southern Oscillation (ENSO) (Viboud *et al.*, 2004) and  
44 solar radiation (Sagripanti and Lytle, 2007) have been implicated in influenza transmission in temperate climates but  
45 the role of climate on influenza in the tropics is not well studied. (Soebiyanto *et al.*, 2010). There is some evidence in  
46 the tropics of a high incidence of influenza during the rainy season especially in India, Vietnam and Brazil  
47 (Soebiyanto *et al.*, 2010). but this pattern does not occur in other tropical locations like Singapore, Thailand and  
48 Philippines (Hampson, 1999; Soebiyanto *et al.*, 2010).  
49

50 Illness caused by infection with the rotavirus caused about 450,000 deaths in children under 5 years old in 2008 (Tate  
51 *et al.*, 2012). There are seasonal peaks in the number of cases in temperate and subtropical regions but less distinct  
52 patterns are seen within 10° latitude of the equator (Cook *et al.*, 1990). Variations in the timing of peak outbreaks  
53 between countries or regions (Turcios *et al.*, 2006) (Atchison *et al.* 2010) and variations with time in the same  
54 country (Dey *et al.*, 2010) have been attributed to fluctuations in the number and seasonality of births (Pitzer *et al.*

1 2009, 2011). While vaccination against rotavirus is expected to reduce the total burden of disease, it may also  
2 increase seasonal variation (Pitzer *et al.*, 2011; Tate *et al.*, 2009)

3  
4 Over one-third of the world population is infected with the *Mycobacterium tuberculosis* (TB) bacillus, and 5-10% of  
5 this number may become sick or infectious at some time during their lifetime. It is estimated that 1.7 million people  
6 died from TB in 2009 and many regions report seasonal variations in TB notifications (Luquero *et al.*, 2008;  
7 Nagayama and Ohmori, 2006). TB incidence increased during winter months in China, Mongolia, and South Africa  
8 (Douglas *et al.* 1996, Naranbat *et al.* 2009); in contrast in the UK and Hong Kong outbreaks peaked during the  
9 summer months (Douglas *et al.*, 1996). In the tropics, higher prevalence rates were reported during the wet season in  
10 Cameroon and Thailand (Ane-Anyangwe *et al.*, 2006) (Kongchouv *et al.* 2010). During heavy rains in tropical  
11 regions people congregate indoors and this may provide suitable conditions for airborne spread of TB. There is also  
12 an indirect link between climate and TB, via effects on agriculture, food production and nutritional status (Cegielski  
13 and McMurray, 2004).

#### 14 15 16 **11.2.5. Food and Water-Borne Infections**

17  
18 Human exposure to climate-sensitive pathogens occurs by ingestion of contaminated water or food, incidental  
19 ingestion during swimming or by direct contact with eyes, ears or open wounds. Pathogens in water also can be  
20 concentrated by bivalve shellfish (e.g., oysters) or pathogens in irrigation water can be deposited on produce; both  
21 food sources can then serve as a vehicle for water-associated bacteria and viruses. Pathogens of concern for  
22 waterborne exposure may be either enteric and transmitted by the fecal oral route (enteric viruses, bacteria and  
23 protozoa) or may occur naturally in aquatic systems (bacteria and protozoa), where they may cause a range of  
24 diseases. Climate may act on these pathogens directly by influencing growth, survival, persistence, transmission or  
25 virulence; changing climate or environments may likewise alter or facilitate transmission of the pathogens or affect  
26 the ecology and/or habitat of zoonotic reservoirs.

##### 27 28 29 **11.2.5.1. *Vibrio***

30  
31 *Vibrio* is a genus of native marine bacteria that includes a number of human pathogens, most notably *V. cholerae*  
32 which causes cholera. Although cholera is unique in that it can be transmitted both by drinking water and by  
33 environmental exposure in seawater and seafood, other *Vibrio* species are solely linked to seawater and shellfish.  
34 These primarily include *V. parahaemolyticus* and *V. vulnificus*, with *V. alginolyticus* emerging in importance  
35 (Weis, 2011). Risk of infection is influenced by temperature, precipitation (and accompanying changes in salinity  
36 with freshwater run off, addition of organic carbon or other nutrients or changes in pH), and sea level rise. These  
37 factors, in turn, affect the geographic and temporal range of *Vibrio* risk and illness and likewise affect exposure  
38 routes (direct [e.g., swimming] or via seafood). In countries with endemic cholera, temperature-based models have  
39 been developed that suggest a robust relationship between the disease and temperature (e.g., (Islam, 2009; Paz,  
40 2009; Reyburn *et al.*, 2011)).

41  
42 Martinez-Urtaa *et al.* (Martinez-Urtaza *et al.*, 2010) suggest that climate anomalies have already resulted in  
43 geographic range expansion, particularly among *V. parahaemolyticus*. The influx of *V. parahaemolyticus* into the  
44 north Pacific (Alaska) in 2004 and Chile and Peru in the southern Pacific in 1997 was strongly correlated with  
45 unusually high water temperatures and ocean circulation. Similar expansions were seen in Europe (Martinez-Urtaza  
46 *et al.*, 2010) and there has also been a range expansion among marine zooplankton (Martinez-Urtaza *et al.*, 2010;  
47 Vezzulli *et al.*, 2012) documented rising proportions of *Vibrio*, including *V. cholerae*, among microbial communities  
48 in the North Sea following sea surface temperature elevation and shifts in plankton abundance beginning in 1987. In  
49 addition to geographic range expansion, recent reports show a seasonal expansion of *V. vulnificus* and *V.*  
50 *parahaemolyticus* infections associated with shellfish from US Gulf of Mexico, with an expanding number of cases  
51 in spring and fall months (Martinez-Urtaza *et al.*, 2010).

### 11.2.5.2. Enteric Bacteria and Viruses

There is a general trend for rising rates of gastrointestinal illness (diarrhea) with increasing temperature (Kolstad and Johansson, 2011; Onozuka, 2010) but these estimates often do not take into account specific disease etiology. Salmonella and Campylobacter are among the most common zoonotic food and waterborne bacterial pathogens worldwide and both show distinct seasonality in infection with highest rates at warmer temperatures. The association between climate (especially temperature) and Salmonella may, in part, explain seasonal and latitudinal trends; although some have reported that the link to climatic conditions is stronger for non-outbreak cases than it is for those that occur as part of outbreaks (Lake, 2009).

Among the enteric viruses, there are distinct seasonal patterns in infection and shedding (e.g., feces) that can be related indirectly to temperature. Enterovirus infections in the U.S. peak in summer and fall months (Khetsuriani, 2006). Hand, foot and mouth disease (caused by coxsackievirus A16 and enterovirus 71), shows a linear relationship with temperature in Singapore with a rapid rise in incidence when the temperature exceeds 32°C (Hii *et al.*, 2011). However, it is not clear what the underlying driver is and if temperature is simply reflecting the disease season. Other studies have shown that when released into the environment, enterovirus persistence is negatively correlated with temperature (e.g., (Wetz, 2004)).

Temperature may have a clear mechanistic link with enteric disease risk in Arctic communities, where rising temperatures and loss of permafrost may result in transport of sewage (which is often captured in shallow lagoons) into groundwater or drinking water sources (Martin, D., B. Belanger, P Gosselin, J Brazeau, C. Furgal and S. Dery, 2007). Additionally, thawing may damage drinking water intake systems (for those communities with such infrastructure) (Hess, 2008).

Rainfall has also been associated with enteric infections. Salmonella shows a higher likelihood of uptake by produce crops (lettuce) under both flooding and drought periods (Ge *et al.*, 2012). Studies suggest that drought (Bandyopadhyay *et al.*, 2012) as well as flooding can lead to increased risk of illness. Higher levels of enteric viruses have been noted in drinking water (surface and ground) and recreational water following heavy rainfall events or during the rainy season (e.g., (Futch, 2010; Jofre *et al.*, 2010)). Likewise, cases of hand, foot and mouth disease (echovirus 71 or coxsackievirus A16) in Singapore increase linearly with cumulative rainfall of up to 75 mm per week (Hii *et al.*, 2011).

### 11.2.6. Nutrition

Population nutrition can be considered as a system involving the interaction of three main elements: agricultural production (including post-harvest wastes and storage), governance including prices, and consumption (see Figure 11-7). Many of the factors which constitute these elements are climate-sensitive.

[INSERT FIGURE 11-7 HERE]

Figure 11-7: Nutrition, health, social, environmental interactions: Population and nutrition can be conceptualized as a synthetic state arising from the interaction of social, health and environmental factors, in a complex system. Many relationships are bidirectional. For example, poor population health status can impair social function (e.g. by impaired education). Source (Colin Butler, 2012?).]

Many studies have examined the relations between crop production, climate variability and extreme weather events, and these are described in detail in chapter xx of this report. The effects of higher temperatures and variations in rainfall patterns vary by time, region and crop. To date, the magnitude of changes in land-based agricultural production due to increasing temperatures and changes in rainfall is small compared to increased harvests due to improved farming knowledge and technology (Lobell *et al.*, 2011). The changes are also small in comparison to the amount of food fed to livestock, used for biofuels, consumed beyond baseline needs by over-nourished populations and wasted in other ways (Foley *et al.*, 2011).

1 Social and environmental factors that result in a locally available crop and livestock abundance do not necessarily  
2 mean that the food is consumed locally. Moreover whether food that is ingested provides adequate nutrition is  
3 influenced by other factors, such as the level of physical activity and by conditions that lower appetite (Mangili *et*  
4 *al.*, 2006), nutrient absorption and metabolic rates. People with febrile illnesses, for instance, require more calories  
5 just to maintain body weight(Weisz *et al.*, 2011). Elevations in food price can also lead to a deterioration in ingested  
6 nutritional quality among the poor, as populations “trade off” more expensive micronutrients for less expensive  
7 calories, such as in cooking oil (Hoddinott *et al.*, 2008).

8  
9 Probably of even more importance than fevers and appetite suppressing illnesses are “nutrient bypass” conditions,  
10 such as infections with hookworm and other gastrointestinal helminths. These can prevent ingested nutrients from  
11 being absorbed, and in some cases also cause microscopic bleeding that depletes nutrient stores, such as of iron.  
12 Chronic bacterial intestinal infections can also limit nutrient absorption, even if food is ingested, and can be  
13 complicated by chronic post infective malabsorptive states (Humphrey, 2009).

### 14 15 16 **11.2.7. Occupational Health**

17  
18 Since the AR4 substantial new evidence has accumulated on the effects of heat on working people (Kjellstrom *et al.*,  
19 2009a) and other climate-related health risks for occupational groups (Bennett and McMichael, 2010)

#### 20 21 22 **11.2.7.1. Heat Strain and Heat Stroke**

23  
24 One important feature of human biology is the maintenance of core body temperature ( $T_c$ ) close to 37 °C, the  
25 temperature at which different biochemical and physiological systems function at their optimum. Climate-related  
26 factors that influence heat stress are air temperature, humidity, wind speed, and heat radiation (outdoors usually  
27 from the sun). In addition, body temperature is also affected by the metabolic rate at which a person is working and  
28 the clothing worn (Parsons, 2003).

29  
30 A working person creates internal body heat that needs to be emitted via the skin. In a hot and humid tropical  
31 environment, sweating may be insufficient to prevent body temperature from rising. If the body temperature goes  
32 beyond 38°C, there may be symptoms of sluggishness and lack of concentration. Temperature above 39°C, risks  
33 more serious symptoms of organ damage, eventual unconsciousness (heat stroke), and even death. Pre-existing  
34 disease or malnutrition increases vulnerability. In addition, a hard-working person may sweat more than 5 litres per  
35 work shift, which has to be replaced to avoid dehydration, another serious hazard in hot working environments. A  
36 net water loss of more than 2-3 litres during a day risk damage to kidneys and other organs (Ramsey, J.D.,  
37 Bernard, T.E., 2000).

38  
39 Experimental and field studies have documented the risks of heat strain and heat stroke (Parsons, 2003; Ramsey,  
40 J.D., Bernard, T.E., 2000) and detailed exposure response relationships were described long ago (Wyndham, 1969).  
41 Heat remains an occupational health issue even in a high-income country like the USA (Luginbuhl *et al.*, 2008).  
42 Moreover, for health in hot working conditions work pace should be reduced, which leads to potential conflict  
43 between health protection and economic productivity (Kjellstrom, T., Lemke, B., Hyatt, O., 2011): as workers take  
44 longer rests to prevent heat stroke, hourly productivity goes down.

#### 45 46 47 **11.2.7.2. Heat Exhaustion and Work Capacity Loss**

48  
49 Sensitivity to heat varies considerably (Parsons, 2003), and acclimatization, which takes approximately 1-2 weeks,  
50 reduces the sensitivity, but there is still a limit and international standards of maximum recommended workplace  
51 heat exposure exist for either acclimatized or non-acclimatized people. In hot countries during the hot season, large  
52 proportions of the workforce are affected by the heat exposures, and the economic impacts of reduced work capacity  
53 can be serious (Kjellstrom, T., Lemke, B., Hyatt, O., 2011; Kjellstrom *et al.*, 2009a). When heat exposure is high



1 enough to reduce the effective daily working hours; the productivity of labour is lowered, while the number of  
2 mouths to feed remains the same, potentially placing additional stress on the population. (Lecocq and Shalizi, 2007)

### 5 *11.2.7.3. Other Occupational Health Concerns*

7 Exposure to heat affects psychological performance with a risk of increased mistakes in daily activities and  
8 increased accidental injuries in workplaces (Ramsey *et al.*, 1983; Ramsey, 1995). In areas where vector-borne  
9 diseases, such as malaria and dengue fever, are common, people working in farm fields without effective protection  
10 may experience a higher incidence of these diseases when climatic conditions favour mosquito breeding. (Bennett  
11 and McMichael, 2010) Increasing heat exposure in farm fields during the middle of the day in many places during  
12 the planting and harvesting seasons may also lead to more work during dawn and dusk when some of the vectors are  
13 biting humans more actively.

15 Another risk factor is increased chemical poisoning where solvents are used, because higher temperatures make the  
16 solvents evaporate faster and may lead to higher occupational exposures (Bennett and McMichael, 2010). An  
17 epidemic of chronic kidney disease in Central America has been considered as at least partly linked to daily  
18 dehydration among sugar cane harvesting workers, due to the insufficient drinking water supplied to replace liquid  
19 lost due to sweating (Garcia-Trabanino, 2005). In the Arctic, the part of the world that is now experiencing the  
20 fastest increase of temperatures, traditional hunting and fishing activities are affected by reduction in sea ice and  
21 there is a greater risk of drowning. (Ford *et al.*, 2008)

## 24 *11.2.8. Air Quality*

### 26 *11.2.8.1. Chronic Air Pollution*

28 Tropospheric ozone is formed through photochemical reactions that involve nitrogen oxides (NO<sub>x</sub>), carbon  
29 monoxide (CO), and volatile organic compounds (VOCs) in the presence of sunlight and elevated temperatures (US  
30 EPA, 2007). Therefore, if temperatures rise, many air pollution models (Chang *et al.*, 2010; Ebi and McGregor,  
31 2008; Polvani *et al.*, 2011; Tsai *et al.*, 2008) project increased ozone production especially within and surrounding  
32 urban areas (Hesterberg *et al.*, 2009). Even small increases in atmospheric concentrations of ground-level ozone  
33 may affect health. (Bell *et al.*, 2006; Ebi and McGregor, 2008; Jerrett *et al.*, 2009) For instance, Bell *et al.* (Bell  
34 *et al.*, 2006) found that even levels that meet the US EPA 8-hour regulation (0.08 ppm over 8 hours) were associated  
35 with increased risk of premature mortality. There is a lack of association between ozone and premature mortality  
36 only at very low concentrations (from 0 to ~10 ppb) but the association becomes positive and approximately linear  
37 at higher concentrations (Bell *et al.*, 2006; Ebi and McGregor, 2008; Jerrett *et al.*, 2009). An analysis of 66 United  
38 States cities with 18 years of follow-up (1982-2000), ozone was found to be significantly associated with  
39 cardiopulmonary mortality (Smith *et al.*, 2009). See also section 11.5.5.

### 42 *11.2.8.2. Acute Air Pollution Episodes*

44 Among all air pollutants, literature sources provided most detailed accounts on the relationship between forest fires  
45 and PM<sub>10</sub> levels. For example, during a fire near Denver (USA) in June 2009, 1-hour concentrations of PM<sub>10</sub> and  
46 PM<sub>2.5</sub> reached 370 µg/m<sup>3</sup> and 200 µg/m<sup>3</sup>, and 24-hour average concentrations reached 91 µg/m<sup>3</sup> and 44 µg/m<sup>3</sup>,  
47 compared to the 24-hour WHO air quality guidelines for these pollutants of 50 µg/m<sup>3</sup> and 25 µg/m<sup>3</sup>, respectively  
48 (Vedal and Dutton, 2006). One study of world-wide premature mortality attributable to air pollution from forest fires  
49 estimated there were 339,000 deaths per year (range 260,000 to 600,000). (Johnston *et al.* 2012)

51 Extremely high levels of PM<sub>10</sub> were observed in Moscow due to fires caused by a heat wave in 2010. Daily mean  
52 temperatures in Moscow exceeded the respective long-term averages by 5°C or more for 45 days and 10 new  
53 temperature records were established in July and 9 in August, based on measurements since 1885, and an anti-  
54 cyclone in the Moscow region prevented dispersion of air pollutants. The highest 24-h levels recorded in Moscow

1 during these conditions of high atmospheric pressure and temperature inversion were between 430 and 900  $\mu\text{g}/\text{m}^3$   
2 PM10 most days but occasionally reached 1500  $\mu\text{g}/\text{m}^3$ . The highest 24-h CO concentration was 30  $\text{mg}/\text{m}^3$ , and the  
3 levels of formaldehyde, ethyl benzene, benzene, toluene and styrene were also increased (WHO, 2010a).

#### 6 **11.2.9. Mental Health**

7  
8 There are three main pathways through which climate may affect mental health (Berry *et al.*, 2010). The first is  
9 direct, resulting from traumatic experiences associated with extreme events such as storms, fires and floods.  
10 Manifestations include severe anxiety reactions (such as post-traumatic stress) and longer-term impacts such as  
11 generalised anxiety, depression, aggression and complex psychopathology (Ahern *et al.*, 2005; Norris *et al.*,  
12 2004). For slow-developing events such as prolonged droughts, impacts include chronic psychological distress and  
13 increased incidence of suicide (O'Brien *et al.*, in prep; Alston, 2008). People tend to feel a distressing sense of loss,  
14 known as solastalgia (Albrecht *et al.*, 2007), on witnessing land degrade and they also lose amenity and opportunity.

15  
16 The remaining two pathways are indirect. Firstly, mental health may suffer as a consequence of impacts on physical  
17 health. Heat stress, communicable and vector-borne disease, for example, are potential risk factors for psychiatric  
18 morbidity. Finally community functioning may be disrupted by impacts on agricultural productivity, fishing,  
19 forestry, tourism, mining, subsistence farming and other economic endeavours reliant on the land. Where access to  
20 and productivity of land are compromised, so too are these industries, businesses and households; and when these  
21 fail, livelihoods can fail, families can fail and eventually whole communities can come under pressure. To the extent  
22 that deteriorating community functioning involves loss of social capital (and it tends to), mental health will be at  
23 risk. (Almedom, 2005; Berry *et al.*, 2010; De Silva *et al.*, 2005; Kawachi *et al.*, 2008)( Veenstra, 2005; Yip, 2007).  
24 (Figure 11-8).

25  
26 [INSERT FIGURE 11-8 HERE

27 Figure 11-8: Links between climate change, social capital, and mental health.]

#### 30 **11.2.10. Violence**

31  
32 A study examining the impact of extreme heat on morbidity in Milwaukee, Wisconsin reported a significant and  
33 positive correlation between hot temperatures and accidents and self-harm at a threshold of 27.2°C (Li, T., Horton,  
34 R., Kinney, P., 2011). Another found that assault-related injuries among 15–64 year-olds increased significantly  
35 during heat waves (Nitschke *et al.*, 2007), and yet another suggested a relationship between high temperatures and  
36 increased risk of suicide, with a threshold effect at 18°C (Page *et al.*, 2007). Changes in behavior in times of extreme  
37 heat and cold, however, may reduce the risks of some forms of injury. For example, a significant decrease in  
38 automobile accidents was found during heat waves in the 75+ age group (Nitschke *et al.*, 2007)

39  
40 Soil degradation, freshwater scarcity, population pressures and other forces that are related to climate are all  
41 potential causes of conflict. A study of internal conflict in African countries from 1981–2002 found a positive  
42 correlation between country-level temperature increases and probability of armed conflict and suggested that the  
43 effects of temperature change on agriculture might be a significant factor (Burke *et al.*, 2010). The relationships are  
44 not straightforward, however. A study drawing on data from 1960–99, including more than 160 countries, found that  
45 poverty, low economic growth and high dependence on primary commodity exports were strongly associated with  
46 civil war, while ethnic and religious diversity as well as democracy were not (Collier and Hoeffler, 2004). Another  
47 found that economic and political factors were the strongest predictors of conflict, and environmental and  
48 demographic factors were less prominent (Hauge and Ellingsen, 1998). The resultant ambiguity has recently led to  
49 more highly specified models of the causal patterns between demography, environment and conflict (e.g. (Kahl,  
50 2001)). These take account of variables such as social networks, indigenous knowledge and family cohesion that  
51 reduce vulnerability to climate disasters (Adger *et al.*, 2004) In Sub-Saharan Africa, a study found that climates that  
52 are more suitable for agriculture are associated with a lower risk of conflict (Hendrix and Glaser, 2007). Another  
53 study argues that environmentally induced migration can increase the risk of conflict, particularly in less-developed

1 countries, and the risk is compounded by rapid population growth and limited migration opportunities (Reuveny,  
2 2007).  
3

4 Although the relationship between climate and armed conflict should not be overstated, in view of other social,  
5 cultural, political and economic factors that play a part, there is ample evidence that the depletion and altered  
6 distribution of natural resources may heighten the risk of violent conflict (Brauch, 2002; Tanzler, D., Carius, A.,  
7 2002). Using data from 1950 to 2004 from the tropics, Solomon et al (2010) found that the probability of new civil  
8 conflicts arising doubles during El Niño years relative to La Niña years. A study of a thousand years of violent  
9 conflict in Europe and various reconstructions of temperature and precipitation, found that conflict was exacerbated  
10 during cold periods that were associated with crop failures and food shortages (Tol and Wagner, 2010). Similar  
11 findings have been reported in China (Zhang *et al.*, 2006), and indeed the links between rapid climate change,  
12 starvation and civil disorder and collapse are apparent as far back as the first agricultural settlements roughly 10,000  
13 years before the present. (McMichael, 2012)  
14

#### 15 16 **11.2.11. Aeroallergens and Diseases** 17

18 Warmer conditions generally favour production and release of air-borne allergens (such as plant pollen and  
19 mushroom spores) and, consequently, there may be an effect on asthma and other allergic respiratory diseases,  
20 allergic rhinitis, conjunctivitis and dermatitis. Children are particularly susceptible to problems of this kind (Schmier  
21 and Ebi, 2009). These trends will be strengthened if higher CO<sub>2</sub> levels stimulate plant growth. Visual monitoring and  
22 experiments have shown that increases in air temperature cause earlier flowering of prairie tallgrass (Sherry *et al.*,  
23 2007). Temperature increases stimulate production of allergens not only by plants but also by trees, e.g., birch and  
24 sycamore. Changes in local climate may also bring dust which contains pollen and spores to new regions. For  
25 example, Holland expects to receive new allergens such as pollen of ambrosia and olive trees (de Weger and  
26 Hiemstra, 2009).  
27

28 Time series analysis was used to uncover the relationship between increase in concentrations of grass pollen and  
29 increase in the number of ambulance calls with asthma symptoms, with a time lag of 3-5 days (Heguy *et al.*, 2008).  
30 The relationship between pollen levels and hospital visits with rhinitis symptoms has also been reported (Breton *et al.*,  
31 2006). A cross-sectional study in the three climatic regions of Spain documented a positive correlation between  
32 the rate of child eczema and humidity, and negative correlation between child eczema and air temperature or the  
33 number of sunshine hours (Suarez-Varela *et al.*, 2008).  
34

35 The incidence of bronchial asthma attacks increases during thunderstorms and hurricanes, possibly due to emission  
36 of small-size pollen particles which penetrate into lower airways (D'Amato *et al.*, 2007). Numbers of *Alternaria* and  
37 *Cladosporium* spores in the air also increase during thunderstorms (Pulimood *et al.*, 2007). Such phenomena were  
38 described also during heavy rainfalls in Atlanta, USA (Grundstein *et al.*, 2008), and during severe flooding in New  
39 Orleans in 2005. Physicians in New Orleans hospitals reported an increase in the number of visits of allergic  
40 patients, and even coined a new term "Katrina cough" (Manuel, 2006; Ratard *et al.*, 2006; Solomon *et al.*, 2006;  
41 Wilson, 2006).  
42

43 There are complex interactions between climate variability, air pollution and airborne allergens, and these inter-  
44 dependencies make it difficult to project the health effects of changes in ambient temperatures and rainfall. Some  
45 studies showed that combined effects of air pollutants (PM and NO<sub>2</sub>) and airborne allergens led to an increase in the  
46 number of emergency department visits with bronchial asthma (Erbas *et al.*, 2007). Yet, other authors did not  
47 identify such interactions (Dales *et al.*, 2008; Galán *et al.*, 2003; Villeneuve *et al.*, 2007). Specific types of pollen,  
48 air pollutants, geographic location and local climate may also play a role. (D'Amato and Cecchi, 2008)  
49  
50

#### 51 **11.2.12. Ozone, UV, and Skin Cancer** 52

53 Epidemiological studies have reported relationships between UV levels, maximum summertime day temperatures  
54 and the prevalence of non-melanoma skin cancers. In one study in the United States, the number of cases of

1 squamous cell carcinoma was 5.5% higher for every 1°C increment in average temperatures, and basal cell  
2 carcinoma was 2.9% more common with every 1°C increase. These values correspond to an increase in the effective  
3 UV dose by 2% for each 1°C (van der Leun *et al.*, 2008). Higher temperatures in the northern countries and  
4 countries with temperate climates may result in an increase in the time which people spend outdoors and, thus in  
5 additional UV-induced-adverse effects. Notably, however, skin cancer rates are rising already in many countries, for  
6 other reasons, such as changes in travel and recreation (Diffey, 2004).

### 9 **11.3. Vulnerability to Disease and Injury due to Climate Variability and Climate Change**

10  
11 In the IPCC assessments, vulnerability is said to be “the degree to which geophysical, biological and socio-  
12 economic systems are susceptible to, and unable to cope with, adverse impacts of climate change” (Schneider SH,  
13 Semenov S , Patwardhan A, Burton I, Magadza C, Oppenheimer M, Pitttock B, Rahman A, Smith JB, Suarez A,  
14 Yamin F, 2007). This means vulnerability encompasses both exposure to a hazard, and the response to this exposure.

#### 15 16 17 **11.3.1. Current Sources of Vulnerability**

##### 18 19 *11.3.1.1. Geographic Causes of Vulnerability*

20  
21 Location has an important influence on the potential for losses caused by climate change. (Samson *et al.*, 2011) The  
22 inhabitants of low-lying coral atolls are exquisitely sensitive to flooding, contamination of fresh water reservoirs due  
23 to sea level rise, and salination of soil, all of which may have significant effects on health. (Nunn, 2009) Those  
24 living in inland cities at mid- and low latitudes are more severely affected by heat waves than people living in rural  
25 and coastal settlements. Rural populations that rely on subsistence farming in low rainfall areas are at high risk of  
26 under-nutrition and water-related diseases in future drought, although this vulnerability may be modified strongly by  
27 local factors, such as access to markets and irrigation facilities. (Acosta-Michlik *et al.*, 2008) In high-income  
28 countries, location remains an important measure of susceptibility to the adverse effects of climate change. For  
29 example, living within 100- and 500-year flood zones, or within 5 km of coasts subject to sea level rise have been  
30 proposed, in the United States, as indicators of vulnerability to climate change. (Acosta-Michlik *et al.*, 2008; English  
31 *et al.*, 2009) Regional factors also modulate risk. In the tropics, human populations are often living with  
32 temperatures that are close to tolerable thresholds. In the Arctic, where temperatures are rising more rapidly than any  
33 other region, the changes in sea ice and northern ecosystems may jeopardize food security and increase injury and  
34 drowning (Ford *et al.*, 2008).

##### 35 36 37 *11.3.1.2. Age*

38  
39 Children and the elderly are both at increased risk, though for different reasons. (Perera, 2008). This is evidenced by  
40 the existing health status for important climate-related diseases, particularly malaria, diarrhea, and malnutrition in  
41 children. Thus modest increases in risk for these diseases from climate change lead to relatively large burdens. As a  
42 result, 88% of the total burden of disease from climate change estimated in the 2004 CRA occurred in children  
43 under 5 (McMichael, 2004) . It is also expected that children will be more vulnerable to heat-related illnesses, due to  
44 their small body mass to surface area ratio. Evidence of excess heat-related mortality in this age group is mixed,  
45 however. In California, a study of summer mortality records for 1999-2003 reported a stronger association of heat  
46 and mortality among infants (aged less than 1 year) and those aged 65 years and over than other age groups. (Basu  
47 and Ostro, 2008) Other studies have sought, but not detected, such an association. (Kovats and Hajat, 2008)  
48 Children are more severely affected by many infectious diseases that may be encouraged under climate change.  
49 Malaria is one of the most important – parasite loads are greater and mortality rates higher in childhood (from about  
50 6 months to 3 years) due to less well-developed immune responses to infection with the plasmodium. (Michon *et al.*,  
51 2007; Reyburn *et al.*, 2005; Rowe *et al.*, 2006) Children also dehydrate more rapidly than adults when affected by  
52 diarrhoeal diseases, and case-fatality rates are correspondingly higher. In some circumstances, children may be  
53 protected from climate-related diseases. For instance, maternal antibodies lower the risk of dengue fever in children  
54 in the first year of life. Studies of populations affected by storms, floods and other climate extremes indicate that

1 children may be affected with psychological problems, such as anxiety and behavioural disturbances, although it is  
2 not clear whether these effects are more severe than in other age groups. (Ahern *et al.*, 2005; Durkin *et al.*, 1993;  
3 Price, 1978) Children are generally at greater risk when food supplies are restricted. Although families in many  
4 cultures give priority to feeding children, households with children tend to have lower than average incomes, and  
5 childhood is a particularly sensitive period for health and development. (Cook and Frank, 2008)

6  
7 Older people are at greater risk from storms, floods and other extreme events, in part because they tend to be less  
8 mobile than younger adults and so find it more difficult to avoid hazardous situations and also more likely to live  
9 alone in some cultures. Older people are also more likely to suffer from health conditions that limit the body's  
10 ability to respond to stressful events. Chronic diseases such as diabetes and ischemic heart disease, for example,  
11 magnify the risk of death or severe illness associated with high ambient temperatures. (Basu and Ostro, 2008;  
12 Sokolnicki *et al.*, 2009) People over 65 years are also more strongly affected by air pollution due to ozone and other  
13 photochemical oxidants. (Medina-Ramon and Schwartz, 2008)

#### 14 15 16 *11.3.1.3. Gender<sup>2</sup>*

17  
18 [FOOTNOTE 2: WHO has a review of climate change, gender, and health:  
19 [http://www.who.int/globalchange/publications/reports/gender\\_climate\\_change/en/](http://www.who.int/globalchange/publications/reports/gender_climate_change/en/)]

20  
21 Vulnerability is associated with gender but the relationship is complex (World Health Organization, 2011a) In the  
22 United States, it is reported that men are at greater risk of death following flooding, perhaps because in this setting  
23 men are more commonly exposed to risk (e.g. many of the flood drownings in the US are motor-vehicle related, and  
24 on average, men drive more than women do). (Jonkman and Kelman, 2005) A study of the health effects of flooding  
25 in Hunan province, China, also found an excess of flood deaths among men, often related to rural farming. (Abuaku  
26 *et al.*, 2009) In Canada's Inuit population men are exposed to dangers associated with insecure sea ice, while women  
27 may be more vulnerable to the effects of diminished food supplies. (Pearce *et al.*, 2011), In the Paris 2003 heatwave,  
28 women were more affected than men in every age group except those aged 25-64. In this instance, the male  
29 dominance in the working age group may be related to differential exposures to heat in occupational settings. In  
30 Bangladesh, women are more affected than men by a range of climate hazards, at least in part because a greater  
31 proportion suffers from poverty and poor nutrition, and women are more frequently exposed to water-logged  
32 environments. (Neelormi *et al.*, 2009) There may also be physiological differences in reserve and resilience. After  
33 controlling for differences in age and co-morbidities, it appears that women are more strongly affected than men by  
34 high temperatures (Yu *et al.*, 2010) and ozone air pollution (Medina-Ramon and Schwartz, 2008). There are signs  
35 also that the effect of food insecurity on growth and development in childhood may be more damaging for girls than  
36 boys. (Cook and Frank, 2008)

37  
38 Pregnancy is a period of increased vulnerability to a wide range of environmental hazards, including infectious  
39 diseases (such as malaria and foodborne infections) (Jamieson *et al.*, 2006) and illness and injury resulting from  
40 climate disasters. For example, an increase in spontaneous abortions was recorded in counties in New York State  
41 that had been affected the year before by severe flooding caused by Hurricane Agnes. (Janerich *et al.*, 1981)

#### 42 43 44 *11.3.1.4. Race and Ethnicity*

45  
46 In many countries, race and ethnicity are powerful markers of health status and social disadvantage. Black  
47 Americans have been reported to be more vulnerable to heat-related deaths than other racial groups in the United  
48 States. (Basu and Ostro, 2008) This may be due to a higher prevalence of chronic conditions such as over-weight  
49 and diabetes, (Lutsey *et al.*, 2010) financial circumstances (lower incomes may restrict access to health-protecting  
50 air conditioning), (Ostro *et al.*, 2010) or to community-level characteristics (such as local crime rates or disrupted  
51 social networks). Indigenous peoples who depend heavily on local resources, and live in parts of the world where  
52 climates are changing quickly, are generally at greater risk of economic losses and poor health. Studies of the Inuit  
53 people, for example, show that rapid warming of the Canadian Arctic is jeopardizing hunting activities which many  
54 in these communities rely on for food. (Ford, 2009) In Australia, indigenous peoples experience higher rates of

1 diarrheal diseases and other climate-sensitive conditions than the remainder of the national population and their  
2 general health status is poorer and puts them at additional risk of climate stressors such as heat-waves. (Green *et al.*,  
3 2010)

#### 6 *11.3.1.5. Socioeconomic Status*

7  
8 Socioeconomic status typically reflects, and may be measured by, educational attainment, occupational prestige and  
9 personal income. At a national level, the poorest countries are most susceptible to damage caused by climate change,  
10 including health effects. Likewise, individuals and households most vulnerable to climate hazards are those with  
11 relatively low socioeconomic status. A review of global trends in tropical cyclones found that mortality risk  
12 depended on storm intensity, effective governance, and levels of poverty. (Peduzzi *et al.*, 2012) A study of the  
13 impacts of flooding in Bangladesh found that household risk reduced with increases in both average income and  
14 number of income sources. Poorer households were not only more severely affected by flooding, but they took  
15 preventive action less often, and received assistance after flooding less frequently than did more affluent households.  
16 This was explained partly by financial obstacles to relocation and other coping strategies, but there were differences  
17 also in knowledge of hazards and in beliefs about the preventability of flooding. (Brouwer *et al.*, 2007) Occupation  
18 is also directly related to vulnerability to climate variability and extremes. For instance, outdoor occupations have  
19 been linked with disease and injury caused by flooding in China (Abuaku *et al.*, 2009) and heat-waves in the United  
20 States (Centers for Disease Control and Prevention, 2008). (The effects of heat on working lives are described in  
21 detail elsewhere in this chapter.) But a link with socioeconomic status is not always present. In Brisbane, Australia,  
22 heat-wave mortality was related to age and gender, but not to small area measures of social disadvantage. (Yu *et al.*,  
23 2010) This null finding, contrary to what has been observed elsewhere with individual-level measures of SES,  
24 (Medina-Ramon *et al.*, 2006) may be due to the much greater variability in housing quality in Australia within  
25 neighbourhoods than exists between neighbourhoods, or the relatively flat social gradient in access to protective  
26 factors such as air conditioning and private transport.

#### 29 *11.3.1.6. Neighborhoods*

30  
31 The physical environments around where people live and work can influence the health risks due to climate  
32 variability and climate change. In Cuba, a country with a well-developed public health system, dengue fever has  
33 been a persistent problem in the larger cities, due in part to the lack of a constant supply of drinking water in many  
34 neighbourhoods (leading to people storing water in containers that are suitable breeding sites for the disease vector,  
35 *A. aegypti*). (Bulto *et al.*, 2006) A study of the city of Phoenix, in the US, found the number of heat distress calls  
36 during heat waves was higher in areas affected by the urban heat island effect (which was measured by the  
37 proportion of impervious surfaces and minimum night time temperatures). (Uejio *et al.*, 2011)

38  
39 Climate extremes may promote the transmission of certain infectious diseases and the vulnerability of populations to  
40 these diseases will depend on the baseline levels of pathogen and vector. In the United States, as one example,  
41 arboviral diseases such as dengue and the encephalitides are rarely seen after flooding, compared with the  
42 experience in other parts of the Americas. The explanation lies in the scarcity of dengue and other viruses circulating  
43 in the population, pre-flooding. (Keim, 2008) Schistosomiasis was present in parts of Portugal in the 1950s.  
44 However, disease control efforts have eliminated the microbe from local snail populations so that although there is a  
45 competent vector and climate projections indicate that both parasite survival and vector survival will be favoured by  
46 rising temperatures, the risk of schistosomiasis returning to Portugal is low. (Casimiro *et al.*, 2006) On the other  
47 hand, the high prevalence of HIV infection in many populations in Sub-Saharan Africa multiplies the health risks of  
48 prolonged drought, which may lead to migration, family disruption, deepening poverty, and increased exposure to  
49 unsafe sex.

### 11.3.1.7. Summary

We have divided the causes of vulnerability into sections for convenience. In practice, these factors combine, often in complex and place-specific manner. For example, a study of the spatial distribution of vulnerability to heat in the United States found the strongest contributions were made by neighbourhood green space, personal education and income, the prevalence of diabetes, social isolation and access to air conditioning. (Reid *et al.*, 2009) However there was substantial spatial variation within the US, with greatest vulnerability to heat in the northeast and Pacific coast, and least in the southeast of the country.

There are some factors (such as education, income, health status and responsiveness of government) that might be described as generic causes of vulnerability. Low levels of parental education, for example, are consistently associated with higher child mortality in times of stress, whether it is military conflict, famine, or other natural disasters. (Kiros and Hogan, 2001) But the precise causes of vulnerability, and therefore the most relevant coping capacities, vary greatly from one setting to another. Vulnerability to heat, for example, varies spatially: the factors that are important in rural areas differ from those that put people at risk in cities. (Reid *et al.*, 2009) The lag between high ambient temperatures and increased incidence of salmonella food poisoning varies from one country to another, suggesting that the mechanisms differ (deficiencies in food storage may be the critical link in some places, food handling problems elsewhere). (Kovats *et al.*, 2004)

The 2010 World Development Report concluded that all developing regions are vulnerable to economic and social damage resulting from climate change – but for different reasons. (The World Bank, 2010) The critical factors for Sub-Saharan Africa, for example, are the current climate stresses (in particular, droughts and floods) that are projected to worsen with climate change, sparse infrastructure and high dependence on natural resources. East Asia and the Pacific, on the other hand, are distinguished by the very large number of people living in low-lying areas prone to flooding (this includes roughly half the population of Vietnam).

### 11.3.2. Projections for Vulnerability

Population growth is likely to be one of the strongest influences on vulnerability to the health effects of climate change. Increasing numbers of people, particularly in environments that are already resource-stretched, will magnify harmful impacts. For instance, it is estimated that about 150 million people currently live in cities affected by chronic water shortages (< 100 L per person per day of sustainable freshwater flows). In 50 years, unless there are rapid improvements in urban environments, demographic growth will push the number affected by chronic water shortages to around a billion (and climate change may add another 100 million). (McDonald *et al.*, 2011) Under a “business as usual” scenario, the OECD projects that about 1.4 billion people will be without access to basic sanitation in 2050. (OECD, 2012) The age structure of the population also has implications for vulnerability. The proportion aged over 60 is projected to increase everywhere (rising from about 10% presently to 32% by the end of the century). (Lutz *et al.*, 2008) In some regions, this change will occur much faster (going from 10% to over 40% in China, for example). It is expected that mortality rates will continue to fall, with profound implications. For instance, under relatively conservative assumptions the average years of life remaining globally (a product of average age in the population and prevailing mortality rates) is projected to fall only slightly (43.8 years at present, 41.2 years in 2100). (Lutz *et al.*, 2008) Historically, as populations live longer, age-related disability has reduced, (Vaupel, 2010) but it is uncertain whether older populations in the future will be more robust than at present. A particular concern is the rising prevalence of conditions such as cancer, heart disease and diabetes in many parts of the world.

Future trends in social and economic development are relevant to vulnerability. For instance, it has been observed that the countries with higher Human Development Indices (a composite of life expectancy, education and literacy and GDP per capita) are less affected by floods, droughts and cyclones. (Patt *et al.*, 2010) Therefore policies that improve such measures are likely to reduce future vulnerability. But these relationships are not linear. In the early stages of economic development, historically, health statistics tend to deteriorate as the detrimental effects of rapid social and technological change predominate. (Szreter and Woolcock, 2004) It is important to note also that the relation between national wealth and health is roughly log linear – an extra dollar brings much more health gain in

1 low income countries than in medium and high income settings. This suggests that trends in the distribution of  
2 wealth as be as important as changes in average incomes, with greater equity tending to improve health and reduce  
3 vulnerability. Last, the protective effects of national wealth are most marked for less severe climate extremes. For  
4 instance, Peduzzi (Peduzzi *et al.*, 2012) found “that poverty levels are less significant when facing very intense  
5 tropical cyclones, whereas at the lower intensities only the poorest suffer heavy losses”. Finally, it is not clear that  
6 current patterns of consumption (on which measures of GDP per capita are based) are compatible, long term, either  
7 with environmental protection (Dietz *et al.*, 2012) or low carbon emissions (Steinberger *et al.*, 2012).

8  
9 Other global trends that may impact on future vulnerability include the distribution of wealth and resources  
10 (inequalities within and between countries), urbanization and changes in the nature and location of work. The flow  
11 of people and goods internationally is an important influence on the risk of some climate-sensitive infections, such  
12 as those caused by the dengue and chikungunya viruses. (Randolph and Rogers, 2010) For this reason, future trends  
13 in trade and migration will affect the susceptibility of many populations to diseases associated with climate change.

14  
15 Mal-adaptation may be a source of vulnerability – steps taken to cope with challenges in the present or the near  
16 future may make the situation worse, not better, if more extreme conditions occur. For instance, in Victoria,  
17 Australia, preparation for bushfires was historically based on the message “Prepare, stay and defend, or leave early”.  
18 In February 2009, many householders decided to “stay and defend” but were overwhelmed by unprecedentedly  
19 intense fires that caused 173 deaths. (Parliament of Victoria, 2010)

#### 20 21 22 **11.4. Current Impacts of Climate Change on Health**

23  
24 Although there is strong evidence for the effects of variation in weather and season on a range of health outcomes  
25 (section 11.2), assessment of the health impacts of long-term climate change is much more challenging. Over the  
26 multi-decadal time scales that are necessary to measure climate change, human disease systems are also strongly  
27 affected by a range of other social and environmental factors. This means that robust studies require not only long  
28 time series of data on climate and disease rates, but also on all other established or potential causative factors,  
29 coupled with statistical analysis to apportion changes in health states to the various contributing factors. In addition,  
30 wherever risks are identified, health agencies are mandated to intervene immediately, confounding long-term  
31 analyses. Finally, there is no clear consensus on appropriate methods and standards for studies correlating long-term  
32 time trends in environmental variables and health outcomes. Such studies are therefore relatively rare, and often  
33 inconclusive.

##### 34 35 36 **11.4.1. Effects of Climate Change on Meteorological Hazards to Health**

37  
38 Since AR4, there is stronger evidence both for increases in some meteorological exposures that are hazardous to  
39 human health, and of attribution of these changes to anthropogenic influences. The IPCC Special Report on Extreme  
40 Events SREX [to be updated with data from WG1 of AR5] concludes that it is very likely that there has been an  
41 overall decrease in the number of cold days and nights, and an overall increase in the number of warm days and  
42 nights, at the global scale. The report also identifies statistically significant trends in the number of heavy  
43 precipitation events in some regions, and judges that it is likely that more of these regions have experienced  
44 increases than decreases. It assesses that it is likely that anthropogenic influences have led to increases in extreme  
45 daily minimum and maximum temperatures at the global scale, and that there is medium confidence that  
46 anthropogenic influences have contributed to intensification of extreme precipitation at the global scale.

47  
48 The association between very hot days and increases in mortality in temperate populations is very robust (see studies  
49 reviewed in section 11.2.2 above). It is therefore very likely that the observed increase in very hot days will have  
50 been associated with an increase in the number of heat-related deaths in mid-latitude populations, and similarly a  
51 decline in cold-related deaths. In contrast, due to data scarcity and confounding there is only low confidence in the  
52 evidence that increases in extreme precipitation have increased human exposure to floods to date.



#### 11.4.2. *Effects of Climate Change on Exposures to Health Risks*

Consistent with observed climate change effects on tree and plant species, further studies have confirmed observed changes to seasonality in pollen production in mid to high latitudes. Studies have shown an earlier onset but not an extension of the *Betula* pollen season in Finland (e.g. (Yli-Panula *et al.*, 2009)) and earlier onset of grass pollen season in Spain (García-Mozo *et al.*, 2010). A study of several data series in North America, indicated an extension of the ragweed (*Ambrosia* spp.) pollen season at high latitudes (Ziska *et al.*, 2011). An increase in the length of the season by 13-27 days since 1995 was observed at latitudes above 44N. One published study reported changes in allergic sensitization in humans (Ariano *et al.*, 2010). An increase in the percentages of patients sensitized to five specific pollens over 25 year period in Italy was observed, but the attribution to observed warming remains unclear.

Several studies have reported changes in the latitudinal and altitudinal distribution of ticks in Europe consistent with observed warming trends (see (Confalonieri, U., B. Menne, R. Akhtar, K.L. Ebi, M. Hauengue, R.S. Kovats, B. Revich and A. Woodward, 2007; Gray *et al.*, 2009)), however, there is no evidence so far of any associated changes in the *distribution* of human cases of tick-borne diseases. In North America, there is good evidence of northward expansion of the distribution of the tick vector (*Ixodescapularis*) in the period 1996 to 2004 based on an analysis of active and passive surveillance data (N.H. Ogden *et al.*, 2010).

#### 11.4.3. *Effects of Climate Change on Human Disease*

Climate change effects will be experienced in the context of rapid changes in disease incidence, distribution, and the emergence of new diseases (Jones *et al.*, 2008). Disease systems are strongly affected by local conditions, and few have been investigated intensively to elucidate the role (if any) of decadal temperature changes. Owing to the multiple causes of disease, the contemporaneous increase in temperature (or any other climate variable) preceding a change in incidence or distribution is a necessary but not sufficient criterion for attribution to observed climate change (Omumbo *et al.*, 2011; Pascual *et al.*, 2009; Randolph, 2010). Two disease systems where high quality data are available, and changes in incidence have occurred after observed warming periods are and tick-borne encephalitis cases in central and eastern Europe, and malaria cases in Kericho, Kenya.

Sumilo (Sumilo *et al.*, 2008; Sumilo *et al.*, 2009) conclude that socio-economic factors rather than temperature were the main cause of the upsurge in TBE in the 1980-90s in central and eastern Europe. Spring-time maximum daily temperatures rose in the late 1980s, sufficient to encourage transmission of the TBE virus. But the variations in illness rates across the region suggest the most important influences were greater human-tick contact caused by changes in human behaviour (such as increased foraging), changes in agricultural practices, and increased unemployment. Changes in the observed incidence of TBE in central Sweden remain unexplained (Randolph, 2010).

Further studies have tried to elucidate the role of local warming on malaria transmission in Kericho region of Kenya but these are limited by lack of time series data on non-temperature causes (e.g. drug resistance, vector control measures). Data from local weather stations showed a warming trend (Omumbo *et al.*, 2011). A study using a mosquito-human model showed that predicted malaria cases exhibited a strongly non-linear response to observed warming (Alonso *et al.*, 2011). A detailed review by Chaves and Koenraadt (Chaves and Koenraadt, 2010) concluded that there is robust evidence that decadal temperature changes have played a role in changing malaria incidence but temperature trends should not be considered the main or sole cause of such changes in the east African highland region

At the global level, Gething *et al.* (Gething *et al.*, 2010) compared the distribution of malaria in 1900 with the current distribution of *Plasmodium falciparum* malaria. The study supports previous work that shows that although there has been modest warming over the last century, the current distribution of disease world-wide is much restricted, largely due to control of *P. vivax* malaria in moderate climates with low transmission intensity. This indicates that the protective effects of non-climatic factors, including economic and social development and control interventions were larger than any negative effects of warming on the global malaria distribution during this period.

#### 11.4.4. Estimation of Current Impacts based on Modeling

As reported in AR4, in 2004 the World Health Organization published the first Comparative Risk Assessment (CRA), which used common methods, rule of evidence, and databases for estimating aggregate disease burdens attributable to different risk factors (McMichael, 2004). In addition to other environmental, nutritional, infectious, and behavioral risk factors, these were applied to published and newly developed models for a range of climate-sensitive diseases in order to estimate the effect of global climate change on current disease burdens and likely proportional changes in the future (McMichael, 2004). The approach places climate change within the same criteria for epidemiologic assessment as other health risks and takes into account the size of the burden of climate-sensitive diseases rather than just proportional change, which highlights the importance of small proportional changes in diseases such as diarrhea and malnutrition that cause a large burden (Campbell-Lendrum and Woodruff, 2006).

In 2009, an updated burden of disease assessment of climate change was published by the Global Humanitarian Forum based on the same methods as the WHO CRA, and concluded that about 300,000 premature deaths per year were attributable to climate change at the end of the decade, roughly twice the number reported in the WHO CRA for 2000 (GHF, 2009).

These exercises help clarify important knowledge gaps such as a relatively poor understanding of the role of non-climatic factors (socioeconomic and other) that may modify future climatic influences. We also lack empiric evidence and methods for quantifying more complex climate–health relationships, which consequently are often excluded from consideration. These exercises highlight the need for risk assessment frameworks that not only make the best use of traditional epidemiologic methods but also take into account the specific characteristics of climate change. These include the long-term and uncertain nature of the exposure and the effects on multiple physical and biotic systems that have the potential for diverse and widespread effects, including high-impact events.

### 11.5. Future Risks

This section focuses exclusively on literature that assesses future risks to various time horizons, most typically to 2050. The literature on biological plausibility and empirical evidence of the link between meteorological variables and adverse health outcomes is assessed earlier in the chapter (see Section 4.2).

A few projections of specific health impacts attributable to climate change have been published since AR4, but they do not include all potential impacts, e.g. little has been written on non-communicable diseases, including mental disorders. (Hosking and Campbell-Lendrum, 2012) There is a particular dearth of studies in low and middle-income countries, except in the areas of some infectious diseases. Unfortunately, investigators have used different climate models, time horizons, model assumptions, and scenarios, which makes policy-relevant comparative assessment difficult.

#### 11.5.1. Malnutrition

Lloyd et al. (Lloyd *et al.*, 2011) built a model for estimating future undernourishment (too little food) and child malnutrition, defined as growth retardation (stunting) under two climate change scenarios and a reference scenario without climate change. While the estimates of the proportion of undernourished children were based on food availability projections from Nelson et al. (Nelson *et al.*, 2009), stunting was modeled using “food” and “non-food causes”. The percent increase in severe stunting attributable to climate change in 2050 ranged from 31% in central Sub-Saharan Africa to 61% in South Asia. The comparison was the reference scenario i.e. the world without climate change. In such a world, the trend would be an overall reduction in both undernourished and stunted children.

Nelson et al. (Nelson *et al.*, 2009) compared the number of malnourished children in 2000 with projections to 2050 under three different assumptions: (i) no climate change, (ii) climate change with technological improvement in developing countries only, and (iii) climate change with technological improvements in both developing and developed countries. Table 11-1 provides the data for the NCAR model (the other model used, CSIRO, generates

1 essentially similar projections). Lloyd et al. (Lloyd *et al.*, 2011) estimated that there would be, in addition, a shift to  
2 more severe forms of malnutrition. Unsurprisingly, various degrees of adaptation policies are expected to  
3 moderately reduce the predicted impact of climate change on malnutrition (two last lines in Table 11-1).

4  
5 [INSERT TABLE 11-1 HERE

6 Table 11-1: Number of malnourished children in 2000 and under the NCAR climate model till 2050 using different  
7 assumptions for investment in agricultural productivity: + only in developing countries; ++ both in Dev. and  
8 developed countries. Adapted from (Nelson *et al.*, 2009).]

9  
10 In a subsequent paper, Lloyd et al. (Lloyd, S.J., Kovats, R.S., Chalabi, Z., 2011) went further and estimated the  
11 number of malnutrition-attributable childhood deaths from all causes. The relationship between the severity of  
12 stunting and mortality was drawn from Black et al. (Black *et al.*, 2008). They calculated odds ratios for subsequent  
13 death, given malnutrition, of 1.6 (1.3-2.2) and 4.1 (2.6-6.4) for moderate and severe stunting respectively. For 2030,  
14 their model predicted 108,028 malnutrition-related childhood deaths from climate change (8.0% out of a total of  
15 1,256,440 malnutrition-related deaths). For 2050, they estimated this number to be 96,460 out of 614,361 (15.7%)<sup>3</sup>.  
16 Hence, while the absolute number of children dying from malnutrition would fall by half between 2030 and 2050  
17 due to socioeconomic factors worldwide, the relative proportion attributable to climate change would double.

18  
19 [FOOTNOTE 3: The data were calculated from Table 5, 4a, Lloyd et al. (2011).]

20  
21 In summary, it is anticipated that climate change alone will have a substantial negative impact on childhood  
22 malnutrition and on malnutrition-related child deaths. Optimistic assumptions of economic growth and future  
23 adaptation efforts are likely to counter-act the climate impact on child malnutrition, without eliminating it. Sub-  
24 Saharan Africa and South Asia will be affected most.

### 25 26 27 **11.5.2. Malaria**

28  
29 Since AR4, the World Malaria Map Project has added considerably to our knowledge of the global epidemiology of  
30 malaria (Gething *et al.*, 2011b; Guerra *et al.*, 2008; Hay *et al.*, 2009). Based on comprehensive survey information  
31 (for *Pl. falciparum*, 7,953 surveys were analyzed) and reported cases, it projects major parameters of malaria  
32 epidemiology to a world map based on 2007 data (Hay *et al.*, 2009), after due standardization of, for example, the  
33 definitions of malaria and parasitemia (Smith *et al.*, 2007). Contrary to previous world maps of malaria, the process  
34 of image generation is not based on climate or geographical features. This malaria map was updated for 2010  
35 (Gething *et al.*, 2011a) and it will be revised in the future, as new surveys and data on entomology, malaria  
36 transmission and human infection are generated.

37  
38 Most of the research has focused on the conundrum of “fringe malaria”. The question is, whether malaria will  
39 expand its current geographical limits latitudinally and altitudinally in a warmer world. Gething (Gething *et al.*,  
40 2010) compared the distribution of malaria in 1900 with today’s much smaller expanse of the globe covered by  
41 malaria. He argued that this contraction of the space occupied by malaria had occurred in spite of a warming climate  
42 in the past century and inferred that non-climatic factors, such as economic and social development and control  
43 interventions were overwhelmingly more important for the contraction of the “malaria space” than climate change.  
44 There is wide agreement that the area on the globe, within which malaria has been transmitted, has shrunk by more  
45 than half in the past century. However, the view that therefore climate change does not play a role in malaria has  
46 been challenged. Economic development and effective health systems have made it relatively easy to control  
47 malaria, and it should not be assumed (some say) that these favourable conditions will continue in the future. Further  
48 more, it is much easier to control *P. vivax* malaria and its vectors in moderate climates with low transmission  
49 intensity than *P. falciparum* malaria and its extremely efficient vectors in optimally warm tropical settings.

50  
51 Using the IPCC AR 5 A1B scenario, Béguin et al. (Béguin *et al.*, 2011) projected differences in the population at  
52 risk to 2030 and 2050 using the A1B scenario. Keeping economic growth constant, the model projected 5.2 billion  
53 people at risk in 2050, out of a predicted global population of 8.5 billion. The additional malaria transmission areas  
54 are shown in red in Figure 11-9. On the other hand, keeping climate constant, and assuming the effect of strong and

1 equitable economic growth on malaria, would lead to a projection of 1.74 billion people at risk. Hence the area of  
2 malaria transmission would shrink by the blue shaded zone in the left panel of Figure 11-9. The combined effect of  
3 climate and economic growth would lead to only 1.95 billion people estimated to be at risk of malaria, a substantial  
4 reduction from the present day 3.5 billion estimated at risk by WHO. As we will see in the projections of many  
5 health impacts, the potential impact of climate change can be reduced or even reversed by many health systems,  
6 biological and social factors, the most prominent being sustained, equitable economic and social development (e.g.  
7 Lafferty 2009). It is far from obvious that the latter condition will be achieved in the medium term, particularly in  
8 Sub-Saharan Africa.

9  
10 [INSERT FIGURE 11-9 HERE

11 Figure 11-9: Contraction of the area of malaria transmission through economic development offsets expansion  
12 through higher temperatures. Based on IPCC scenario A1B, projections to 2050. Source: (Béguin *et al.*, 2011).]  
13

14 Another aspect of fringe malaria concerns highland malaria, which has remained a controversial issue since AR4.  
15 There is now widespread agreement that the strength of epidemic malaria and the number of malaria cases have  
16 increased in the past decades in the Kenyan Highlands. What portion of the increase can be ascribed to climate  
17 change, however, continues to be fiercely debated (Alonso *et al.*, 2011; Bouma *et al.*, 2011; Pascual *et al.*, 2006;  
18 Pascual *et al.*, 2008; Pascual *et al.*, 2009; Stern *et al.*, 2011).

19  
20 Given that the overwhelming majority of malaria transmission, new cases and deaths occur within the confines of  
21 the areas in which transmission is possible, it is surprising how little research has been directed to model and predict  
22 transmission changes in the “heartland” of malaria. Rainfall and air humidity are thought to be the major  
23 meteorological drivers of malaria transmission in the core transmission area, as opposed to the “fringes”, where  
24 temperature and its diurnal variations are key. We could identify only two papers which look at rainfall AND  
25 temperature as predictors of malaria transmission in the present transmission area ((Parham and Michael, 2010) for  
26 modeling the Reproductive Number  $R_0$  and (Ye *et al.*, 2009) for seasonal prediction).

27  
28 There has been no prediction of a future sustained introduction of malaria in Northern America or Europe, where it  
29 was once prevalent. Although suitable vectors for *P. vivax* malaria transmission abound in these parts of the world,  
30 the risk of re-introduction is thought to be very low, barring civil strife or a breakdown of health services.

### 31 32 33 **11.5.3. Dengue Fever**

34  
35 The Dengue literature since 2006 abounds in time series analyses looking at time lags of days up to several  
36 months (e.g. (Gharbi *et al.*, 2011)) or for inter-annual anomalies, such as the El Niño/la Niña phenomena (Descloux  
37 *et al.*, 2012). However, we could identify only one single study since 2006 modeling future risk of dengue under  
38 climate change. Åström *et al.* (2012) estimated the changes of the population at risk to the year 2050. The authors  
39 used as the outcome variable the presence or absence of any type of dengue fever in each grid cell of  $0.5^\circ \times 0.5^\circ$   
40 of the globe. The data were based on national routine reporting and scientific surveys as part of the global burden of  
41 disease projections of WHO. The authors used the detailed information on population, GDP growth and greenhouse  
42 gas emissions of the A1B scenario. These data were linked with three different global circulation models run out to  
43 2050. By this time, 4.86 billion people billion were projected to live in areas at risk of dengue, 6.1% or 280 million  
44 more than would have been expected otherwise. If the impact of GDP growth on Dengue is included in the model,  
45 120 million people would no longer be exposed to Dengue in 2050. There is broad agreement between this study  
46 and that by Hales *et al.* (Hales *et al.*, 2002) reported in AR4, as to (i) the influence of climate alone on the  
47 geographic expansion of the area at risk of Dengue and (ii) an opposite trend from economic growth. Both studies  
48 only looked at the margins of the geographic distribution and did not consider changes in intensity of transmission  
49 where Dengue currently is present. As with malaria and health impacts in general economic growth is a strong  
50 confounding factor (Tang *et al.*, 2009), as it is associated with emissions and climate change, and has an  
51 independent effect on health (generally positive).

52  
53 Kearny (Kearny *et al.*, 2009) used biophysical models to predict the geographical extension of vector range in  
54 Australia. He predicted, “Climate change will directly increase habitat suitability throughout much of Australia.”

1 Changes in water storage as a response to a drier climate may be an indirect pathway, through which climate change  
2 affects mosquito breeding. (Beebe *et al.*, 2009)  
3  
4

#### 5 **11.5.4. Schistosomiasis**

6

7 Studies confirming the influence of meteorological and other environmental variables on the snail and the aquatic  
8 stages of the parasite abound (e.g. (Remais *et al.*, 2008)). However, we are only aware of one published study,  
9 which models future changes in the area at risk of schistosomiasis (Zhou *et al.*, 2008). The authors modeled the  
10 transmission index of schistosomiasis due to *S. japonicum* for China based on anticipated changes in the mean  
11 January temperatures for 2030 (not shown in the figure below) and 2050. They concluded that an additional 784  
12 thousand km<sup>2</sup> would become suitable for schistosomiasis transmission in China by 2050 (Figure 11-10).  
13

14 [INSERT FIGURE 11-10 HERE

15 Figure 11-10: Predicted risk map of schistosomiasis(*S. japonicum*) transmission in China in 2050. For comparison  
16 the current risk map in 2000. Green area denotes the range of schistosomiasis in 2000. The blue area shows the  
17 geographic expansion. Adapted from (Zhou *et al.*, 2008).]  
18

19 Mangal *et al.* (Mangal *et al.*, 2008) constructed a mechanistic model of the transmission cycle of another species, *S.*  
20 *mansoni* and reported a peak in the worm burden in humans at an ambient temperature of 30°C, falling sharply as  
21 temperature rises to 35°C. The authors attribute this to the increasing mortality of both the snails and the water-  
22 borne intermediate forms of the parasite, and noted that worm burden is not directly linked to the prevalence of  
23 schistosomiasis.  
24

#### 25 **11.5.5. Air Pollution**

26

27  
28 It is projected that climate change could affect future air quality, including levels of photochemical oxidants and fine  
29 particles (PM<sub>2.5</sub>), and if this occurs there will be consequences for human health. (Bell *et al.*, 2007; Chang *et al.*,  
30 2012; Dong *et al.*, 2011; Lepeule *et al.*, 2012; Meister *et al.*, 2012) High temperatures may magnify the effects of air  
31 pollutants like ozone to increase morbidity and mortality, although findings have been inconsistent (Jackson, J.E.,  
32 Yost, M.G., Karr, C., Fitzpatrick, C., Lamb, B.K., Chung, S.H., Chen, J., Avise, J., Rosenblatt, R.A., Fenske, R.A.,  
33 2010) (Ren *et al.* 2008). Increasing urbanization, the continued use of solid biomass fuels and industrial development  
34 in the absence of emission controls could also lead to increases in ozone chemical precursors (Selin *et al.*, 2009;  
35 Wilkinson *et al.*, 2009) Changes in regional weather patterns could likewise increase exposure to PM<sub>2.5</sub>, although  
36 future projections are very uncertain (Ebi and McGregor, 2008).  
37

38 The number of studies modeling the projected impacts of future climate change on air pollution-related morbidity  
39 and mortality has increased since 2006 (see Table 11-2). Most have focused on exposure to ozone (Bell *et al.*, 2007;  
40 Jackson, J.E., Yost, M.G., Karr, C., Fitzpatrick, C., Lamb, B.K., Chung, S.H., Chen, J., Avise, J., Rosenblatt, R.A.,  
41 Fenske, R.A., 2010; Selin *et al.*, 2009; Tagaris *et al.*, 2009) and there are fewer studies that have examined effects of  
42 particulate matter (Tagaris *et al.*, 2009) or other air pollutants (Cheng *et al.*, 2011). The majority of studies also focus  
43 on future ozone-related mortality in only a few geographical regions, including the U.S. and Canada. Projections are  
44 lacking for other areas of the world, especially developing countries, where air pollutant burdens are increasing.  
45

46 [INSERT TABLE 11-2 HERE

47 Table 11-2: Projected future health impacts of climate change through air pollution.]  
48

49 Ozone-related mortality is expected to increase in the US and Canada (Bell *et al.*, 2007; Cheng *et al.*, 2011; Jackson,  
50 J.E., Yost, M.G., Karr, C., Fitzpatrick, C., Lamb, B.K., Chung, S.H., Chen, J., Avise, J., Rosenblatt, R.A.,  
51 Fenske, R.A., 2010; Tagaris *et al.*, 2009), although the projected effects are not consistent across studies (Selin *et al.*,  
52 2009). Ozone-related cardiopulmonary and respiratory mortality is also projected to increase in the U.S. (Bell *et al.*,  
53 2007; Jackson, J.E., Yost, M.G., Karr, C., Fitzpatrick, C., Lamb, B.K., Chung, S.H., Chen, J., Avise, J., Rosenblatt,  
54 R.A., Fenske, R.A., 2010), Globally, ozone-related mortality is projected to increase by the 2050s. Under a scenario

1 in which present air quality legislation is rolled out everywhere, projected premature ozone-related mortality could  
2 decrease, particularly in Africa, South Asia and East Asia. Under a maximum feasible reduction A2 scenario, it is  
3 projected that 460,000 premature ozone-related deaths could be avoided in 2030, mostly in South Asia, from a  
4 substantial decrease in ozone levels in these areas (West *et al.*, 2007).

5  
6 A study that investigated regional air quality in the United States in 2050, using down-scaled climate models,  
7 concluded there would be about 4000 additional annual premature deaths due to exposures to PM<sub>2.5</sub> (Tagaris *et al.*,  
8 2009). Air pollutant-related mortality increases are also projected for Canada but in this case are largely driven by  
9 the effects of ozone (Cheng *et al.*, 2011). Both ozone and particulate matter-related health impacts vary greatly from  
10 one location to another, within any country (Selin *et al.*, 2009; Tagaris *et al.*, 2009).

11  
12 A study of the interaction between CO<sub>2</sub>, ozone, and PM and compared pre-industrial levels of ozone and PM to  
13 those of the present day. Increasing concentrations of CO<sub>2</sub> were associated with higher concentrations of ozone and  
14 PM on the local level, leading to an estimated 1.1% increase in mortality per degree temperature increase over the  
15 baseline rate (Jacobson, 2008). Approximately 40% of the increase in mortality was attributable to ozone and 60%  
16 to PM, with impacts most apparent in locations with poorer air quality and higher population densities (Jacobson,  
17 2008). The study concluded that restrictions of local and global CO<sub>2</sub> emissions may reduce exposure of local and  
18 regional populations to elevated levels of PM, ozone, and other health-damaging co-pollutants.

#### 19 20 21 **11.5.6. Diarrheal Diseases**

22  
23 Since 2006, there has been only one major study estimating future climate-related diarrhea risk (Kolstad and  
24 Johansson, 2011) (see Table 11-3). For the period to 2030, the authors project an increase of the risk of diarrhea of  
25 8-11%, which is consistent with the estimate of 8-9% of WHO (World Health Organization, 2008). For the periods  
26 2040-69 and 2070-99, Kolstad and Johansson projected risk increases of 15-20% and 22-29% respectively.

27  
28 [INSERT TABLE 11-3 HERE

29 Table 11-3: Projected relative risk of diarrhea relative to the baseline period of 1961-1990, SRES A1B, the  
30 information of 19 climate models was combined. Source: (Kolstad and Johansson, 2011).]

#### 31 32 33 **11.5.7. Heat and Cold**

34  
35 Health effects related to changes in temperature are expected to be both detrimental and beneficial (see summary Table  
36 11-5). Under predicted climate change scenarios, heat waves will likely increase in frequency and intensity and  
37 worsen heat-related exposures, although acclimatization and improvements in energy efficiency may mitigate some  
38 of these effects (Bi and Parton, 2008; Hanna *et al.*; Wilkinson *et al.*, 2007; Wilkinson *et al.*, 2007). In Australia, the  
39 number of “dangerously hot” days, when core body temperatures may increase by  $\geq 2^{\circ}\text{C}$  and outdoor activity is  
40 hazardous, is forecast to rise from the current 4 to 6 days per year to 33-45 days per year by 2070 for non-  
41 acclimatized people. Among acclimatized people, an increase from 1-5 days per year to 5-14 days per year is  
42 expected (Hanna *et al.*). If the proportion of elderly increases, as expected in most countries, this will add to  
43 vulnerability to extreme heat (Luber and Hess, 2007).

44  
45 Cold-related mortality is expected to drop in temperate regions but the increase in heat-related mortality may  
46 outweigh these gains, especially in developing countries with limited adaptive capacities and much larger exposed  
47 populations (Wilkinson *et al.*, 2007). Model predictions in three Quebec cities predict an increase in summer  
48 mortality of 2% and an annual overall mortality rise of 0.5% by 2020. By 2080, summer mortality is predicted to  
49 rise to 10% and annual mortality to 3% compared to current rates, which will outweigh predicted fall and winter  
50 decreases (Doyon *et al.*, 2008). Another study, using years of life lost as the outcome, and located in Brisbane,  
51 Australia, found the gains associated with fewer cold days were outweighed by the effects of more hot days when  
52 warming exceeded 2 degrees. (Huang *et al.*, 2012) The same trend is echoed in a study modeling heat-related  
53 premature mortality in the New York City Metropolitan region. By the 2050’s, an increase in premature mortality  
54 between 47-95% with a mean increase of 70% is expected, compared to the 1990’s (Knowlton *et al.*, 2007).

1 Acclimatization may reduce the expected number of summer heat-related premature mortality regionally by up to  
2 25%. Urban areas are expected to show greater numbers of deaths due to population density but an overall smaller  
3 percentage increase than less-urbanized counties (Knowlton *et al.*, 2007). Socioeconomic status may also play a role  
4 in the uneven distribution of heat-related deaths as households that live in poverty or in older residential  
5 neighborhoods in New York City often do not have air conditioning, which can increase mortality risk. Thus,  
6 despite the uncertainty associated with forecasts regarding climate and future health vulnerability, as well as the  
7 expected reduction in mortality estimates from acclimatization, research still suggests an overall net increase in heat-  
8 related premature mortality (Knowlton *et al.*, 2007).

9  
10 [INSERT TABLE 11-4 HERE

11 Table 11-4: Studies projecting heat mortality due to climate change since 2006: Authors, scenarios and climate  
12 models used, time period for model baseline (turquoise) and date or period of projection. Modified from (Huang *et*  
13 *al.*, 2011).]

14  
15 Goslin *et al.* (Gosling *et al.*, 2009) refined this modeling approach by including not only changes of the annual mean  
16 temperatures but also of its variability, which certainly comes closer to the physiological impact of heat which is  
17 dependent not only on absolute temperature, but also on the acuity and duration of heat-waves.

18  
19 [INSERT TABLE 11-5 HERE

20 Table 11-5: Projected future health impact of climate change through cold and health.]

21  
22 For all the six cities the authors examined—Boston, Budapest, Dallas, Lisbon, London and Sidney—, two conclusions  
23 can be drawn (i) projections of heat mortality is very much influenced by the choice of the scenario, A2 consistently  
24 generating a higher death toll; (ii) Adding variability to level of temperature increases heat-related mortality  
25 substantially: underlying the A2 scenario increases estimates for heat-related mortality attributed to climate change  
26 from the present (1961-90) 35.8/100,000 to 140.5/100,000 in the future (2070-2099).

### 27 28 29 **11.5.8. Work-Related Heat Stress**

30  
31 Climate change is projected to increase the health burden for those working in hot environments (Kjellstrom *et al.*,  
32 2009). Mapping of future heat exposures in Northern Africa, for instance, indicates the very difficult work  
33 conditions that will emerge in the hot afternoons of the hottest months (Kjellstrom and Crowe, 2011). Maps of  
34 occupational heat based on future WBGT increases by 3 degree C (Hyatt *et al.*, 2010) offer a guide to adaptation  
35 measures.

36  
37 Estimates of the effects in the 2050s on work productivity (Kjellstrom *et al.*, 2009a) found that in all of the 21 global  
38 regions there would be an annual loss of fully productive work hours due to heat stress if the workforce distribution  
39 and occupational health programs remained at current levels. The proportion of work days lost due to heat was as  
40 high as 15-18 % in South-East Asia, West and Central Africa and Central America (Kjellstrom *et al.*, 2009a) . If  
41 workforce distributions include fewer people in agriculture and more in services, the estimated work days lost will  
42 be less, in the range 3-4 % in most of these regions (Kjellstrom *et al.*, 2009a) . A more detailed regional analysis of  
43 occupational heat stress health and productivity impacts until 2030 and 2050 was recently completed (Kjellstrom *et*  
44 *al.*, 2012, in press). It is based on global grid cell (0.5 x 0.5 degrees, 90,000 cells) climate analysis and newly  
45 assessed exposure-response relationships for clinical heat stroke effects as well as heat induced work capacity  
46 losses. Even after taking likely changes in workforce distributions into account, the likely additional numbers of  
47 occupational heat stress fatalities may be 12,000 – 30,000 in 2030 and 26,000 – 54,000 in 2050 (Kjellstrom *et al.*,  
48 2012, in press). Non-fatal heat strokes at work may be twice these numbers. People in heavy labor jobs outdoors in  
49 the hot sun are most affected (from 10% work days lost due to heat, increasing to 20% lost in 2050), highlighting the  
50 negative effect on health and well-being equity that these trends in occupational heat stress will have.

51  
52 In summary, recent analysis of future occupational risks due to excessive workplace heat exposure linked to climate  
53 change projects substantial impacts on both occupational heat stroke numbers and work productivity in the hottest  
54 regions of the world.

### 11.5.9. *UV-Induced Skin Cancers*

Other health effects that might be associated with future climate changes are a rise in chronic disease incidence and severity. Sun-induced skin cancers have been predicted to rise from mice experiments when the combined effects of ozone depletion, climate change and a rise in ambient temperature are taken into account (van der Leun *et al.*, 2008). This effect may slow down the progress in reducing carcinogenic UV-B radiation in the wake of the Montreal protocol (West *et al.*, 2007).

### 11.5.10. *Conclusion*

There are few studies modeling the health impacts of climate change, particularly in low and middle income countries, and greater efforts are required to improve the research base for policy makers. Future work should examine closely the roles of economic growth as confounding factor and effect modifier in the climate change and health relation. The relative attribution of the burden of disease to climatic and non-climatic drivers is likely to remain a challenge. A promising complementary approach to tease out the relative importance of climate change to disease burden would be using large population cohorts, particularly in low and middle-income countries.

## 11.6. **Adaptation to Protect Health**

Adaptation is modification of natural or human systems in response to actual or expected climate changes and their effects. It may be deliberate, “planned adaptation”, or result from autonomous feedbacks that involve no explicit, human decision-making.

The importance of adaptation is demonstrated by the recent history of natural disasters, and their impacts on population health. For example, when cyclone Bhola (category 3 in severity) hit East Pakistan (present day Bangladesh) in 1970, more than 500,000 people died. Then in 1991 a cyclone of similar severity caused about 140,000 deaths. In November 2007, cyclone Sidr (category 4) resulted in 5-10,000 deaths, although the population of the country had grown by more than 30 million in the intervening period. (Mallick *et al.*, 2005) Bangladesh achieved this remarkable reduction in disaster mortality through effective collaborations between government, local communities and non-governmental organizations. (Khan, 2008) Alongside improving the general education of the population (which has been greatly assisted by rising literacy rates, especially among women), the country deployed early warning systems and built a network of cyclone shelters. Early warning systems included both high technology information systems and relatively simple measures such as training volunteers who could distribute warning messages by bicycle.

The scientific literature on adaptation to climate change has expanded greatly since AR4, but investment in specific health protection activities is growing less rapidly. A review by the World Health Organization in 2012 estimated that commitments to health adaptation internationally amount to less than 1% of the annual health costs attributable to climate change by 2030. (World Health Organization, 2012) In this section we will concentrate on planned adaptations, including what might be described as “generic” adaptation, and interventions designed specifically to reduce the adverse impacts of climate change.

### 11.6.1. *General Adaptations*

Climate change acts as a multiplier of risk – in most instances, changes in temperature, rainfall and extreme events compound health problems that are already present. Where rates of diarrheal disease among children are already high, for instance, rising temperatures will have much greater effects than in populations where children are seldom affected. One recent review concluded that the baseline health status of a population is probably the single most important predictor of both the future health impacts of climate change, and the costs for that country of adapting.



1 (Pandey, 2010) This means that reducing background rates of disease and injury is an important step to improving  
2 population resilience and minimizing poor health outcomes resulting from climate change.  
3

4 Improvements in basic public health functions such as disease surveillance, monitoring of risky exposures, and  
5 coordination between health and other sectors also constitute adaptation. (Woodward *et al.*, 2011) A United States  
6 review picked out ten “essential public health services” of this kind that underpin coping with the risks associated  
7 with climate change (Frumkin H., Hess J., Luber G., Malilay J., McGeehin M., 2008) For example, food safety in a  
8 time of rising temperatures and extremes in rainfall depends on well-functioning links between human health and  
9 veterinary authorities, integrated monitoring of food-borne and animal diseases and improved detection methods to  
10 pick up pathogens and contaminants in food. (Tirado *et al.*, 2010) In Lusaka, Zambia the incidence of cholera rises  
11 sharply following heavy rainfall, but the risk is much less in parts of the city with effective drainage networks.  
12 (Sasaki *et al.*, 2009)  
13

14 Better access to health care is another example of “generic” adaptation. In Benin, one of the measures that is  
15 proposed as part of the response to sea level rise and floods is expanded health insurance arrangements, so that  
16 diseases that may be aggravated by climate change (malaria, enteric infections) can be treated promptly and  
17 effectively. (Dossou and Glehouenou-Dossou, 2007)  
18

19 Other sectors than health care play an important part in protecting against disease and injury resulting from climate  
20 change. EuroHEAT, a European review of public health responses to extreme heat, reported that transport policies,  
21 building design and urban land use are all important elements of national and municipal heat-health action plans.  
22 (World Health Organization, 2009a) In the United States, a study examined well-established interventions to reduce  
23 the urban heat island effect (replacing bitumen and concrete with more heat-reflective surfaces, and introducing  
24 more green spaces to the city) and estimated these would reduce heat-related emergency calls for medical assistance  
25 by almost 50%. (Silva *et al.*, 2010) (Adaptation priorities may depend on the location – a study in London, UK,  
26 found that built form and other dwelling characteristics had a stronger influence on indoor temperatures during heat  
27 waves than the urban health island effect. (Oikonomou and Wilkinson, 2012)) But in general, urban green spaces  
28 lower ambient temperatures, and also improve air quality, provide shade and may be good for mental health. (van  
29 den Berg *et al.*, 2010) A more variable climate is expected to increase the risk of child under-nutrition in some parts  
30 of the world, but a review of food aid programmes indicates that a rapid response, targeted to those in greatest need,  
31 with flexible financing and the capacity to rapidly scale-up depending on need, may reduce damaging health  
32 consequences. (Alderman, 2010)  
33

34 Migration is a common coping strategy in the face of adverse changes in climate, and may itself have significant  
35 effects on health, both positive and negative. Within the Pacific there has been migration from outer islands to urban  
36 centres, in part at least due to environmental pressures, and this has improved economic and educational  
37 opportunities for some. But there is a cost in infectious diseases and other health problems caused by crowding  
38 associated with a lack of adequate water supplies, waste disposal and housing. (Locke, 2009) Large numbers of  
39 Pacific islanders have also moved to countries around the Pacific rim and comparisons of the health of migrants and  
40 peers in the islands show mixed effects (higher levels of risk factors such as raised blood pressure and cigarette  
41 smoking among migrants, but also lower mortality rates overall and higher life expectancies). Climate-related  
42 migration includes both the movements of population between countries, and within-country shifts, such as flows to  
43 cities from drought and heat affected rural areas. (Acosta-Michlik *et al.*, 2008) Where people choose to live may  
44 reflect a complex balancing of risks and benefits. A study in Indore in India found that low-income households were  
45 willing to live in flood-prone areas because of other advantages provided by these sites, including access to health  
46 care (and low-cost housing). (United Nations Human Settlements Programme, 2011)  
47

48 There are many effects of community organization that are pertinent to climate change adaptation. In the  
49 Philippines, for example, interventions in low-income urban settings include savings schemes, small-scale loans,  
50 hygiene education, local control and maintenance of water supplies, and neighbourhood level solid waste  
51 management strategies. (Dodman *et al.*, 2010) All these have the potential to reduce harmful effects of climate  
52 extremes on health.  
53  
54

## 11.6.2. *Specific Adaptations*

### 11.6.2.1. *Early Warning Systems*

Early warning systems have been developed in many areas as a means of alerting public health authorities to climate-related health risks.

Heat-health warning systems (HHWS) are instruments to prevent negative impacts of the thermal environment on health during heat waves. Weather forecasts are used to predict situations that are associated with an increase in mortality or morbidity. The essential and common components of HHWS are identifying weather situations that adversely affect human health, monitoring weather forecasts and activating mechanisms for issuing warnings. Ebi et al (Ebi *et al.*, 2004) estimate that the Philadelphia Hot Weather Health Watch Warning System saved about 177 deaths in 3 years, at a cost of approximately \$210,000. Few papers have been published since 2006 on the effectiveness of HHWS on mortality or morbidity – the most informative are listed in Table 11-6. Heat warning systems appear to be effective in raising awareness of the risks associated with heat waves, although whether this extends to behavioral changes is less certain. However, when combined with other elements of a health protection plan, as in France after the 2003 heat wave (Fouillet *et al.*, 2008), it is apparent that the impacts of extreme heat can be greatly reduced by deliberate and focused interventions.

[INSERT TABLE 11-6 HERE

Table 11-6: Studies of the effectiveness of heat-health warning systems.]

Early warning systems have also been developed on the basis of predictive models for vector-borne and food-borne infections. In Botswana, forecasts of malaria incidence up to 4 months ahead have been made on the basis of observed rainfall, on the basis of evidence that inter-annual and seasonal variations in climate are associated with outbreaks of malaria in this part of Africa. The outputs from the model include probability distributions of disease risk and measures of the uncertainty associated with the forecasts. (Thomson *et al.*, 2006) The incidence of several bacterial enteric infections is known to vary with ambient temperature, (Fleury *et al.*, 2006) and this information has been used to develop health alerts based on projected temperatures. A study of campylobacteriosis in the United States developed models of monthly disease risk that showed a very good fit in validation data sets ( $R^2$  up to 80%). (Weisent *et al.*, 2010)

### 11.6.2.2. *Vulnerability Mapping*

Remote sensing applications are now sufficiently fine-grained to allow mapping of local factors associated with vulnerability to climate, and guide the allocation of interventions to reduce exposures and/or impacts. For instance, these technologies can be used to map surface temperatures and urban heat island effects at the neighbourhood scale, indicating where city greening and other urban cooling measures should be concentrated, and alerting public health authorities to populations that may be at greatest risk of heatwaves. (Luber and McGeehin, 2008) Mapping at a coarser level, for instance regionally, may also be useful to guide adaptation. In Portugal, modelling of Lyme disease, spread by ticks that are sensitive to ambient temperatures and soil moisture, indicates that future conditions will be less favourable for disease transmission in the south, but more favourable in the centre and northern parts of the country. (Casimiro *et al.*, 2006) Ideally, mapping exercises of this kind might also take account of climate sensitivity and adaptation capacity, in addition to climate exposures, to capture a complete picture of vulnerability. An example of this approach is an assessment of climate change and risk of poverty in Africa. (Thornton *et al.*, 2008)

### 11.6.2.3. *Public Education*

Much of the adaptation to climate change to protect health happens at the neighbourhood and community levels. Information, education and engagement of populations is essential to mobilizing community resources and responding appropriately to natural disasters. For example, the 1997-98 El Nino event resulted in severe drought

1 across much of the Pacific. In some islands, this caused serious health problems (diarrhoeal diseases, malnutrition).  
2 However it was noted in Pohnpei in the Federated States of Micronesia that admissions of children to hospital for  
3 diarrhoeal disease did not rise. It is thought this may be due in part to an effective public education campaign to alert  
4 families to the risks of water-borne diseases. (Ebi *et al.*, 2006) In the summer of 2006, France was affected by the  
5 most severe high temperatures that had occurred since the serious heat-wave of 2003. About 2000 excess deaths  
6 were recorded in the 2006 heat-wave, but this was about 4000 less than was anticipated, on the basis of the  
7 experience in 2003. A national assessment attributed the lower than expected death toll to greater public awareness  
8 of the health risks due to heat, as well improved health care facilities and the introduction, in 2004, of a heat health  
9 watch warning system. (Fouillet *et al.*, 2008),

#### 11.6.2.4. Health Care

14 Health care interventions aimed at primary prevention may reduce harm caused by climate and other environmental  
15 stressors. As one example, following the introduction of vaccination programmes in the US, seasonal outbreaks of  
16 illness caused by rotavirus, a common climate-sensitive pathogen, have been delayed and diminished in magnitude.  
17 (Tate *et al.*, 2009) Post-disaster initiatives are important also. Studies of the severe European heat-waves of the early  
18 2000s showed that there were serious deficiencies in many countries in care of those affected by extreme  
19 temperatures. The EuroHEAT assessment has since recommended a number of practical steps that health services  
20 can take to reduce morbidity and deaths caused by heat. Examples include staff planning over the summer period,  
21 cooling of health care facilities, training of staff in recognition and treatment of heat strain, and monitoring of those  
22 in the highest risk population groups. (World Health Organization, 2009a) In a similar vein, there have been many  
23 studies carried out on the effects of Hurricane Katrina in the US, and what improvements need to be made in order  
24 to deal more effectively with large-scale floods and storms in the future. Diabetes care, for example, was  
25 compromised following Katrina by a lack of blood glucose testing kits, insulin and other diabetes medications, and  
26 calls have been made for these, and similar essential medical supplies for care of individuals with chronic  
27 conditions, to be better stockpiled and more rapidly and appropriately distributed post-disaster. (Cefalu *et al.*, 2006)  
28 The costs of these, and other health adaptation strategies, are not well described. Ebi (Ebi, 2008) estimated that the  
29 costs in 2030 of treating additional cases of diarrheal diseases, stunting and wasting, and malaria, if emissions were  
30 stabilized at 750 ppm CO<sub>2</sub>-equivalent, would be between \$4 and \$12 billion.

### 11.7. Health Co-Benefits

35 Essentially every human activity affects (and is affected by) climate and health in some way, but not all are strongly  
36 linked to either and even fewer to both. Some measures to mitigate the atmospheric concentration of warming CAPs  
37 (climate active pollutants), however, also hold the potential to significantly benefit human health ((Apsimon *et al.*,  
38 2009; Haines *et al.*, 2007; Shindell *et al.*, 2012; Smith and Balakrishnan, 2009; UNEP, 2011)). The health co-  
39 benefits associated with climate change mitigation strategies fall into five categories (Smith *et al.*, 2009; Smith and  
40 Balakrishnan, 2009): (1) Reduction of health-damaging co-pollutants; (2) Increases in active transport from  
41 modifications to the built environment; (3) Increases in urban green-space; (4) Decreases in ruminant meat  
42 consumption; (5) Increased access to reproductive services. In addition, there are also side effects of mitigation  
43 measures including geoengineering that are potentially deleterious for human health, which are addressed in WGIII,  
44 chapter x and y.

46 In Table 11-7, we summarize publications in all five categories, and below provide some additional detail for three  
47 categories.

49 [INSERT TABLE 11-7 HERE

50 Table 11-7: Summary of recent research on co-benefits of climate change mitigation.]

### 11.7.1. Reduction of Co-Pollutants

Most of the publications related to CAPs and health-damaging pollutants relate to fuel combustion and fall into two major categories: 1) improvement in energy efficiency will reduce emissions of CO<sub>2</sub> and health-damaging pollutants if the energy is derived from combustion of fossil fuels or non-renewable biomass fuels, either directly or through the electric power system; in addition, 2) increases of combustion efficiency (decreasing emission of incomplete combustion products) will have both climate and health benefits, even if there is no change in energy efficiency and/or fuel itself is renewable, i.e. carbon neutral. This is because a number of the products of incomplete combustion are climate active and nearly all are damaging to health (Smith and Balakrishnan, 2009).

Studies of the health co-benefits of reduction in air pollutants include sources that produce outdoor air pollution (Bell *et al.*, 2008) and household sources (Po *et al.*, 2011) where much of the pollution exposure occurs indoors. In recent years, however, it has become clear that in many parts of the world, household fuel (poorly combusted biomass and coal) is responsible for a substantial percent of primary outdoor fine particle pollution as well, perhaps a third to a half in China and India, for example (Chafe *et al.* submitted) indicating that reductions in emissions from household sources could yield co-benefits through the outdoor pollution pathway as well.

#### 11.7.1.1. Outdoor Sources

Outdoors, health-damaging pollutants can be separated into two categories -- primary and secondary. Primary co-pollutants, such as particulate matter (PM) and carbon monoxide (CO) are those released at the point of combustion, while secondary co-pollutants, such as tropospheric ozone and sulphate particles, are formed downwind from the combustion source via atmospheric chemical interactions (Jerrett *et al.*, 2009). As noted in Section 11.2, outdoors, the production and distribution of some secondary co-pollutants is exacerbated by temperature-associated attributes of climate change itself, thus posing a positive feedback effect.

The burden of disease from outdoor exposures in a country may often be greater in populations with low socioeconomic status, both because of living in areas with higher exposures and because these populations often have greater pre-existing ill-health and are often subjected to multiple additional negative environmental and social exposures (Morello-Frosch *et al.*, 2011).

#### 11.7.1.2. Household Sources

Globally, the largest exposures from the pollutants from poor fuel combustion occur in the poorest populations. This is because household use of biomass for cooking is distributed nearly inversely with income. Essentially, no poor family can afford gas or electricity for cooking and very few families who can afford to do so, do not. Thus, the approximate 41% of all world households using solid fuels for cooking are all among the poor in developing countries (Adair, submitted).

#### 11.7.1.3. Primary Co-Pollutants

Outdoor exposure to PM, especially to particles with diameters less than 2.5 µm (PM<sub>2.5</sub>), contributes significantly to ill-health including cardio- and cerebrovascular disease, chronic and acute respiratory illnesses, lung cancer, and possibly other diseases. The WHO Comparative Risk Assessment for outdoor air pollution found xx [to be updated with new results in 2012]. Importantly, reductions in ambient PM concentrations have also been shown to decrease morbidity and premature mortality (Boldo *et al.*, 2010).

Because of higher exposures, an additional set of diseases has been associated with combustion products in households burning biomass and/or coal for cooking and heating. Thus, in addition to the diseases noted above, cataracts, low birth weight, and stillbirth have been associated strongly with exposures to incomplete combustion products, such as PM and CO. CO has impacts on unborn children in utero through exposures to their pregnant

1 mothers (WHO, 2010b). There is also growing evidence of exacerbation of tuberculosis (Pokhrel *et al.*, 2010) in  
2 adults and cognitive effects in children (Dix-Cooper *et al.*, 2012). The WHO Comparative Risk Assessment found  
3 xxx [to be updated with new results in 2012]. Importantly, there are also studies showing health benefits of  
4 household interventions, including child pneumonia (Smith *et al.*, 2011), blood pressure (Baumgartner *et al.*, 2011;  
5 McCracken *et al.*, 2007), lung cancer (Lan *et al.*, 2002), and chronic obstructive pulmonary disease (Chapman *et al.*,  
6 2005).

7  
8 Black carbon (BC), a primary product of incomplete combustion, is both a strong CAP and health-damaging (IPCC,  
9 2007; Ramanathan and Carmichael, 2008). A systematic review, meta-analysis, and the largest cohort study to date  
10 of the health effects of BC found that there were probably stronger effects on mortality from exposure to EC than for  
11 undifferentiated fine particles (PM<sub>2.5</sub>) (Smith *et al.*, 2009). The conclusion is that BC abatement represents an  
12 opportunity to achieve both climate mitigation and health benefits, a conclusion shared by other recent reviews as  
13 well (UNEP, 2011).

#### 14 15 16 *11.7.1.4. Secondary Co-Pollutants*

17  
18 Small increases in tropospheric ozone can cause ill-health (see 11.2.8). In addition to being a strong CAP, methane  
19 (CH<sub>4</sub>) is also a significant precursor to regional anthropogenic tropospheric ozone production, which itself is a CAP.  
20 Thus, reductions in CH<sub>4</sub> could lead to reductions in ambient tropospheric ozone concentrations, which in turn could  
21 result in reductions in population morbidity and premature mortality and climate forcing (Figure 11-11).

22  
23 [INSERT FIGURE 11-11 HERE

24 Figure 11-11: Avoided global premature mortalities from a 65 mt-yr<sup>-1</sup> CH<sub>4</sub> emission reduction, beginning in 2010.  
25 Cited from (West *et al.*, 2006).]

26  
27 One study found that a reduction of global anthropogenic CH<sub>4</sub> emissions by 20% beginning in 2010 could decrease  
28 the average daily maximum 8-h surface ozone by 1 ppb by volume, globally (West *et al.*, 2006). When they applied  
29 epidemiologic ozone mortality relationships, a reduction of 1 ppb ozone was estimated to prevent 30,000 premature  
30 all-cause mortalities globally in 2030, and 370,000 between 2010 and 2030. When they considered only  
31 cardiovascular and respiratory mortalities, 17,000 deaths globally were found to be avoidable in 2030 (West *et al.*,  
32 2006). CH<sub>4</sub> emissions are generally accepted as the primary source of tropospheric ozone concentrations above other  
33 ozone precursors (West *et al.*, 2007) and thus, the indirect health co-benefits of CH<sub>4</sub> reductions are  
34 epidemiologically significant.

35  
36 In an analysis of ozone trends from 1998-2008 in the United States, Lefohn *et al.* (Lefohn *et al.*, 2010) found that 1-  
37 hour and 8-hour ambient ozone averages have either decreased or failed to increase due to successful regulations of  
38 ozone precursors, predominantly NO<sub>x</sub> and CH<sub>4</sub> (Lefohn *et al.*, 2010). This analysis agrees with the US EPA (US  
39 EPA, 2009) conclusions that in the US, for the period 1980-2008, emissions of nitrogen oxides and volatile organic  
40 compounds fell by 40% and 47%, respectively (Lefohn *et al.*, 2010; US EPA, 2009). These results point to the  
41 effectiveness of reducing ambient ozone concentrations through regulatory tools that reduce the emissions of ozone  
42 precursors, some of which, like CH<sub>4</sub>, are GHGs.

#### 43 44 45 *11.7.1.5. Case Studies of Co-Benefits of Air Pollution Reductions*

46  
47 A recent UNEP- and WMO-led study of black carbon and tropospheric ozone found that, if all of 400 proposed BC  
48 and CH<sub>4</sub> mitigation measures were implemented on a global scale, the estimated benefits to health would come  
49 predominately from reducing PM<sub>2.5</sub> (0.7 – 4.6 million avoided premature deaths; 5.3 – 37.4 million avoided years  
50 of life lost) compared to tropospheric ozone (0.04 – 0.52 million avoided premature deaths; 0.35 – 4.7 million  
51 avoided years of life lost) based on 2030 population figures (UNEP, 2011). An estimated 98% of the estimated  
52 avoided deaths would come from reducing PM<sub>2.5</sub>, with 80% of the estimated health benefits occurring in Asia  
53 (Anenberg *et al.*, 2012).

1 A study of the benefits of a hypothetical 10-year program to introduce advanced combustion cookstoves in India  
2 found that in addition to reducing premature mortality by about 2 million and DALYs by 55 million over that  
3 period, there would be reduction of 0.5-1.0 billion tons CO<sub>2</sub>-eq (Wilkinson *et al.*, 2009).  
4

5 In their estimation of effects of hypothetical physical and behavior modifications in UK housing, Wilkinson and  
6 colleagues (Wilkinson *et al.*, 2009) found that the magnitude and direction of implications for health depended  
7 heavily on the details of the intervention. However, the interventions were found to be generally positive for health.  
8 In a strategy of housing modification that included combined fabric, ventilation, and fuel switching, along with  
9 behavioral changes, it was estimated that 850 fewer DALYs, and a savings of 0.6 megatonnes of CO<sub>2</sub> per million  
10 population in one year could be achieved. These calculations were made by comparing the health of the 2010  
11 population with and without the specified physical and behavioral modifications (Wilkinson *et al.*, 2009).  
12

13 Markandya *et al.*, (Markandya *et al.*, 2009) assessed the changes in emissions of PM<sub>2.5</sub> and subsequent effects on  
14 population health that could result from climate change mitigation measures aimed to reduce GHG emissions by  
15 50% by 2050 (compared with 1990 emissions) from the electricity generation sector in the EU, China, and India  
16 (Markandya *et al.*, 2009). In all three regions, changes in modes of production of electricity to reduce CO<sub>2</sub> emissions  
17 were found to reduce PM<sub>2.5</sub> and associated mortality. The greatest effect was found in India and the smallest in the  
18 EU. The analysis also found that health benefits greatly offset the cost of GHG emission reductions, especially in the  
19 Indian context where emissions are high but costs of implementing the measures are low (Markandya *et al.*, 2009).  
20

#### 21 22 **11.7.2. Ruminant Meat Consumption** 23

24 Livestock production systems are responsible for approximately one-fifth of all human-caused CAP emissions  
25 (Eshel and Martin, 2006; FAO, 2006; McMichael *et al.*, 2007) with four-fifths of those emissions being generated  
26 by the agricultural sector (Friel *et al.*, 2009). These CAP emissions are predominantly in the form of CH<sub>4</sub> emissions  
27 from the animals or indirectly through growing the animal feed and processing/shipping the livestock products. Red  
28 meat consumption from ruminants (cows, sheep, goats) in turn is associated with higher rates of cancers (including  
29 bowel cancer) and cardiovascular disease (Pan *et al.*, 2012; Sinha *et al.*, 2009). It is also associated with obesity and  
30 other cancers (WHO/FAO, 2003; AO 2003). On the other hand, lack of protein and the micronutrients in meat (e.g.,  
31 iron) are still problems in many poor countries (UN, 2008).  
32

33 McMichael *et al.* (McMichael *et al.*, 2007) found that policies to reach a per capita convergence on 90 grams of  
34 meat with not more than 50 grams of red meat per day from ruminants (i.e., cattle, sheep, goats, and other digastric  
35 grazers) could achieve major health benefits globally, in both developed and developing countries, while  
36 significantly reducing CAP emissions. As of 2007, the global average for meat consumption was 100 g per person  
37 per day, with about a ten-fold variation between developed (200-250 g/day) and developing (25-50 g/day) countries  
38 (McMichael *et al.*, 2007). The proposed shift would be approximately halve global red meat consumption and  
39 distribute it more evenly. Among more developed countries where red meat consumption is especially high,  
40 reductions to 90 g/day might reduce the risk of heart disease, stroke, colorectal cancer, breast cancer and  
41 overweight/obesity (McMichael *et al.*, 2007). In addition, in poor populations, an increase in meat protein  
42 consumption would have health benefits.  
43

44 Friel *et al.* (Friel *et al.*, 2009) analyzed the red meat consumption target recommended by the UK Committee on  
45 Climate Change to reduce UK GHG emissions by 80% by 2050 compared to 1990, which would require a 50%  
46 reduction by 2030. One component of this climate change mitigation portfolio was a 30% reduction in livestock  
47 production through a decrease in meat consumption. Assuming these reductions, the UK and in Sao Paulo, Brazil  
48 were compared using data to model the potential benefits of reduced consumption of livestock products on the  
49 burden of ischaemic heart disease. The burden of IHD would be expected to decrease by approximately 15% in the  
50 UK (equivalent to 2,850 DALYs per million population over one year) and 16% in Sao Paulo city (equivalent to  
51 2,180 DALYs per million population over one year) (Friel *et al.*, 2009).  
52  
53  
54

### 11.7.3. Access to Reproductive Services

Population growth is another factor involved in the consumption of resources and emissions of CAPs. Although population growth rates and total population size do not alone determine emissions (WG1), population size is an important factor. One study showed that CO<sub>2</sub> emissions could be lower by 30% by 2100 if access to contraception were provided to those women expressing a need for it (O'Neill *et al.*, 2010). Slowing population growth through lowering fertility, as might be achieved by increasing access to family planning has been associated with improved maternal and child health in two main ways: increased birth spacing and reducing births by very young and old mothers.

#### 11.7.3.1. Birth and Pregnancy Intervals

Current evidence supports, with moderate confidence, that short birth intervals (defined as birth intervals between <19 and <25 months and inter-pregnancy intervals <6 months) are associated with increased risks of uterine rupture in women attempting a vaginal birth after previous cesarean delivery and uteroplacental bleeding disorders (placental abruption and placenta previa (Bujold *et al.*, 2002; Conde-Agudelo *et al.*, 2007; Huang *et al.*, 2002; Shipp *et al.*, 2001)). Bujold and colleagues (Bujold *et al.*, 2002) reported, in a high quality observational cohort study, a possible dose-response relationship between increased risks of uterine rupture in women with short intervals between births (4.8% for intervals <13 months; 2.7% for intervals 13-24 months; and 0.9% for intervals >24 months) (Bujold *et al.*, 2002).

Several studies indicate correlations between short birth intervals and elevated risk of low-birth-weight ((Adams *et al.*, 1997; Basso *et al.*, 1998; Kallan, 1997; Khoshnood *et al.*, 1998; Rawlings *et al.*, 1995). Zhu *et al.* (Zhu, 2005) found, in a review of three studies performed in the United States that a J-shaped relationship existed between inter-pregnancy spacing in that the lowest risk of adverse birth outcomes (i.e., low birth weight, existed between 18-23 months and risk increased as it departed, in either direction (Zhu, 2005). This J-shaped relationship is reported in other studies as well (Rouso *et al.*, 2002).

Although an ecological analysis, a review across 17 countries shows a strikingly coherent picture of the relationship between birth spacing (as preceding birth intervals), malnutrition, and reductions in child, infant and neonatal mortality (Figure 11-12) with risk of child malnutrition and mortality both increasing with shorter birth intervals (Rutstein, 2005). One study estimated, for example, that shifting birth spacing from current patterns in the world to a minimum of 24 months would reduce by 20% (~2 million) the current excess child mortality in the world (Gribble *et al.*, 2009; Rutstein, 2005).

[INSERT FIGURE 11-12 HERE

Figure 11-12: Reduction in child mortality due to increasing spacing of birth based on studies in 17 countries. Cited from (Rutstein, 2005).]

On the other hand, long inter-pregnancy intervals (between 48 and 60+ months) are independently associated with an increased risk of preeclampsia. In the largest systematic review to date on birth spacing and maternal morbidity and mortality (Conde-Agudelo *et al.*, 2007), the majority of studies reported a likely dose-response relationship with odds ratios increasing with increasing inter-pregnancy or birth interval (Basso *et al.*, 2001; Conde-Agudelo and Belizan, 2000; Mostello *et al.*, 2002).

#### 11.7.3.2. Maternal Age at Birth

Risk of death during delivery is highest in very young and very old mothers, which are also the age groups most wishing to control their fertility (Engelman, 2010). Women who begin child bearing under the age of 20 years are at an increased risk of developing pregnancy complications such as cephalopelvic disproportion, obstructed labor, preterm delivery, toxemia, bleeding, and death (Tsui *et al.*, 2007) Additionally, children born to women under the age of 20 are at an increased with of fetal growth retardation and low birth weight, which can both lead to long term

1 physical and mental developmental problems. (Tsui *et al.*, 2007) Childbearing at later ages (>35 years) is associated  
2 with increased risks for the child of miscarriage, perinatal mortality, preterm birth, low birth weight, congenital and  
3 chromosomal abnormalities, and increased risks for the mother of placental previa, gestational diabetes, cesarean  
4 delivery and maternal death (Cleary-Goldman *et al.*, 2005; Ujah *et al.*, 2005)

5  
6 Thus, providing access to family planning saves women's lives by reducing the total number of births and, in  
7 particular, through the reduction of births in high-risk groups (Prata, 2009). Studies have found that when women  
8 have access to family planning, it is the highest risk age groups (youngest and oldest women) who reduce their  
9 fertility most, in other words, family planning has a differential impact on maternal mortality reduction through  
10 reducing births in the highest risk groups (Diamond-Smith and Potts, 2011).

## 11.8. Conclusions

14 [here just repeating executive summary]

### 16 **The health of human populations is sensitive to shifts in weather patterns and other aspects of climate change (very high confidence).**

18 These effects occur directly, due to changing incidence in temperature and humidity extremes and occurrence of  
19 floods, storms, droughts, and fires. Indirectly, health may be damaged by ecological disruptions brought on by  
20 climate change (crop failures, shifting patterns of disease vectors), or social responses to climate change (such as  
21 displacement of populations following prolonged drought). Variability is a risk factor in its own right – it is more  
22 difficult to protect human health in a highly variable climate than one that is more stable. There is emerging  
23 evidence of non-linearities in response (such as mortality due to heat waves) as climates become more extreme.

### 25 **To date, climate change has contributed to global burden of disease (highly likely) though the global health effects are relatively small compared with other stressors and not well quantified.**

27 Changes in temperature, rainfall and sea-level have altered distribution of some disease vectors, increased heat wave  
28 casualties, and reduced food production for vulnerable populations.

### 30 **If climate change occurs in the future as projected in scenarios xxx, the major effects on health will be:**

- 31 - increased risk of under-nutrition resulting from diminished food production
- 32 - greater incidence of injury and disease due to more intense heat waves, storms, floods and fires
- 33 - some reductions in cold-related injury and disease, but it is not clear how substantial these savings will be,  
34 in a more variable climate, and it appears likely that positive outcomes will be exceeded by negative effects  
35 of climate change
- 36 - increased pressure on disease control systems due to more favourable conditions in many parts of the world  
37 for food- and water-borne diseases, and dengue and other vector-borne infections

### 39 **The most important effect of climate change is to multiply current risks to health.**

40 Although new infections and other conditions may emerge under climate change, the largest risks by far apply to  
41 health problems that already exist. This means the most vulnerable populations to climate change impacts, world-  
42 wide, are those that currently carry the heaviest burden of disease. In these settings, improvements in public health  
43 and health care are important elements of adaptation for climate change.

### 45 **There are opportunities to mitigate against climate change, and improve health at the same time. These co-benefit actions include:**

- 47 - Reducing local pollution and emissions of climate altering pollutants (CAPs) from energy production  
48 through better combustion, energy efficiency, and shifting to renewables
- 49 - Reducing rising trends of livestock production, particularly of ruminants, by shifting diets in rich countries  
50 to less red meat and dairy products.
- 51 - Reducing CAP emissions by redesigning communities to rely on more public transport and promote  
52 physical activity
- 53 - Providing access to reproductive services reducing population growth over time and improving child and  
54 maternal health through increased birth spacing.



## 11.9. Key Uncertainties and Research Recommendations

[to be developed]

### Frequently Asked Questions

#### **FAQ 11.1: How is climate change thought to affect human health?**

There are three major routes by which changes in climate change are thought to affect health 1) by direct impacts, such as heat stress and floods; 2) by indirect impacts mediated through the natural environment, such as shifts in patterns of disease-carrying mosquitoes and waterborne diseases; and 3) impacts mediated through societal systems, such as malnutrition from altered agricultural production and stress from population displacement due to sea-level rise.

#### **FAQ 11.2: Are there also benefits for health?**

Yes, some populations in temperate areas may be at less risk from extreme cold and some populations may benefit from greater agricultural productivity, but the overall impact for nearly all populations and for the world as a whole is expected to be much more negative than beneficial.

#### **FAQ 11.3: Who is most affected?**

As climate change mainly acts to exacerbate existing disease patterns and does not create significant new ones, those populations already under stress from disease are likely to be most affected. Thus, most assessments indicate that it is poor and disenfranchised groups everywhere that will bear the most risk and, globally, the greatest burden will fall on poor countries, particularly on poor children, who are most affected today by such climate-related diseases as malaria, malnutrition, and diarrhea.

#### **FAQ 11.4: What is the most important adaptation strategy to reduce the health impacts?**

Accelerating current public health and medical interventions directed toward reducing existing disease in the world, particularly for climate-related diseases in poor countries, is the single most important step that can be taken to reduce the health impacts of climate change.

#### **FAQ 11.5: What are health “co-benefits” of climate mitigation measures?**

A number of mitigation measures to reduce emissions of climate-altering pollutants (CAPs) seem to have important direct health benefits in addition to reducing the risk of climate change, a relationship called “co-benefits.” For example, increasing energy efficiency reduces health-damaging air pollution from fuel combustion; reducing red meat consumption reduces both CAPs and the risk of chronic disease such as cancer; and providing access to reproductive health services slows population and energy demand growth and reduces risks of child and maternal mortality.

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Table 11-1: Number of malnourished children in 2000 and under the NCAR climate model till 2050 using different assumptions for investment in agricultural productivity: + only in developing countries; ++ both in Dev. and developed countries. Adapted from (Nelson *et al.*, 2009).

Scenario	South Asia	East Asia/Pacific	Eu + Centr. Asia	LA & Carrib.	Middle East/N.Africa	Sub2-Sah. Africa	Devel. Countr.
2000	75.6	23.8	4.1	7.7	3,5	32.7	147.9
2050							
No climate change	52.3	10.1	2.7	5.0	1.1	41.7	113.3
NCAR	59.1	14.5	3.7	6.4	2.1	52.2	138.5
NCAR + adaptation	54.2	10.1	3.0	4.9	1.4	44.1	118.9
NCAR ++adaptat'n	53.7	10.5	3.0	4.8	1.3	43.5	117.2

Table 11-2: Projected future health impacts of climate change through air pollution.

United States	Ozone-related morbidity and mortality	Multipollutant, multiscale air quality from Community Multiscale Air Quality (CMAQ) Modeling System	GISS-GCM driven by A1B SRES emissions scenario for the period 1950-2055 and downscaled to a 36-km resolution using Mesoscale Meteorological model version 5 (MM5)	Global temperature increase of 1.59°C in 2050, compared to 1990s	Population held constant at 2000 levels	Climate change-driven air quality-related health effects will adversely affect greater than 2/3 of the continental U.S	Potential Impact of Climate Change on Air Pollution-Related Human Health Effects (Tagaris et al. 2009)
	PM <sub>2.5</sub> -related morbidity and mortality	Meteorological data from Goddard Institute for Space Studies (GISS) Global Climate Model (GCM)			Mortality rates held constant at 2000 levels	Approximately 4000 additional annual premature deaths due to climate change impacts on PM <sub>2.5</sub> compared to 300 due to climate change-induced ozone changes	
		Penn State/NCAR Meso scale Model (MM5 model) used to downscale GISS-GCM outputs to a regional scale			Disease incidence rates held constant at 2000 levels	PM <sub>2.5</sub> and ozone-related health impacts vary spatially	
		Health effect analysis conducted using U.S. EPA's Environmental Benefits Mapping and Analysis Program (BenMAP)				Increased premature mortality due to elevated ozone concentrations will be offset by lower mortality from reductions in PM <sub>2.5</sub> in 11 states	
South-central Canada (Montreal, Ottawa, Toronto, Windsor)	air pollution mortality	GCM	GCM downscaled using regression-based statistical method for the periods 2040-2059 and 2070-2089	Air temperature from SRES A2 and B2 scenarios	Population and age structure not directly taken into account	Air pollution-related mortality could increase about 20–30% by the 2050s and 30–45% by the 2080s, projected with climate change	Differential and combined impacts of extreme temperatures and air pollution on human mortality in south-central Canada. Part II: future estimates (Cheng et al. 2008)
						Increase in air pollution-related mortality would be largely driven by increases in ozone effects	
Africa, Middle East, South Asia, Southeast Asia, East Asia, Japan and Australia, Former Soviet Union, Europe, North America, Latin America	Premature ozone-related mortality	GCM	GCM and LMDz-INCA models driven by SRES A2 emissions scenario for 2030	Baseline simulation from 2000	World population of 9.17 billion by 2030	Under current legislation (CLE) scenario, estimated reduction in premature ozone-related human mortalities by 190,000 globally in 2030, mostly in Africa	Human mortality effects of future concentrations of tropospheric ozone (West et al. 2007)
		Laboratoire de Météorologie Dynamique (LMDz)-Interaction Chimie - Aérosols (INCA) chemistry-climate model			Spatial distribution by region based on 2003 population from Landscan database	Under maximum feasible reduction (MFR) scenario, estimated reduction in premature ozone-related human mortalities by 460,000 in 2030, with the greatest reductions in South Asia	
					Constant baseline mortality rates through 2030		

Table 11-3: Projected relative risk of diarrhea relative to the baseline period of 1961-1990, SRES A1B, the information of 19 climate models was combined. Source: (Kolstad and Johansson, 2011).

Region	Time period		
	2010–2039	2040–2069	2070–2099
A–South America	1.09 (0.04)	1.17 (0.07)	1.25 (0.11)
B–North Africa	1.10 (0.04)	1.19 (0.08)	1.27 (0.11)
C–Middle East	1.11 (0.05)	1.20 (0.08)	1.29 (0.12)
D–Equatorial Africa	1.08 (0.04)	1.15 (0.06)	1.23 (0.10)
E–Southern Africa	1.09 (0.04)	1.18 (0.07)	1.26 (0.11)
F–Southeast Asia	1.08 (0.03)	1.15 (0.06)	1.22 (0.09)

For each time period and each region, data is listed as the mean of the RR projection matrix.

Table 11-4: Studies projecting heat mortality due to climate change since 2006: Authors, scenarios and climate models used, time period for model baseline (turquoise) and date or period of projection. Modified from (Huang *et al.*, 2011).

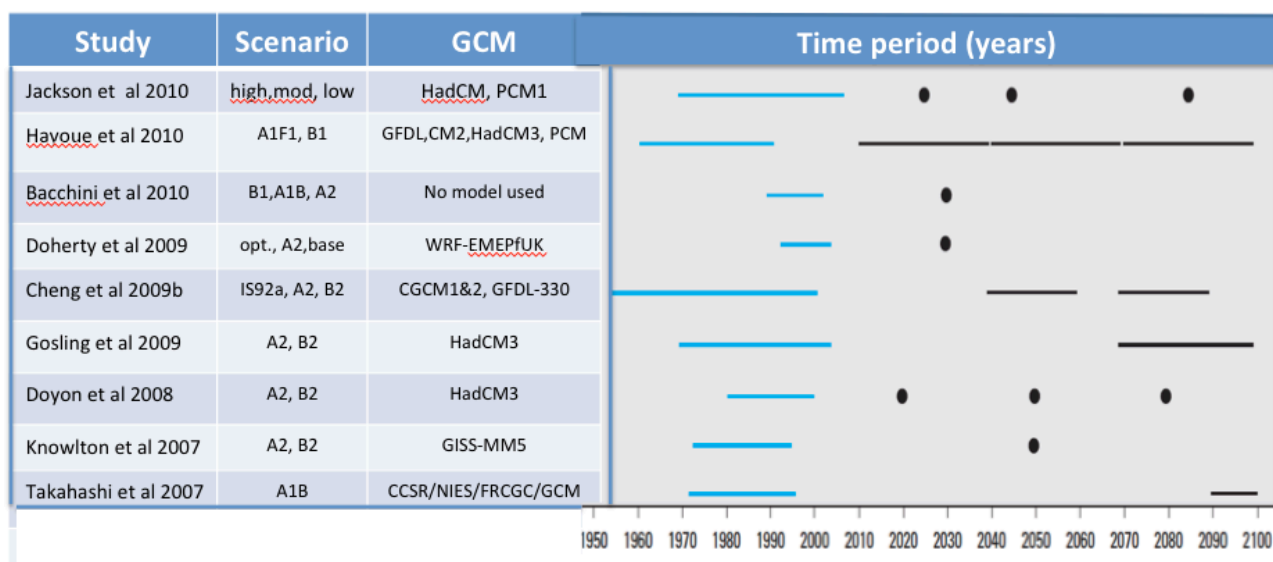




Table 11-5: Projected future health impact of climate change through cold and health.

Area	Health effect	Model	Climate scenario, time slices	Population projections and other assumptions	Reference
South-central Canada (Montreal, Ottawa, Toronto, Windsor)	Mortality	3 Canadian GCMs, 2 US GCMs downscaled	2040-2059 2070-2089	Based on population growth between 1954-200?	Differential and combined impacts of extreme temperatures and air pollution on human mortality in south-central Canada. Part II: Future estimates Cheng et al. 2008
Greater Seattle area in US	Mortality	PCMI-B1	2025	2005-2030 population projections from Washington Office of Financial Management	Public health impacts of climate change in Washington State: projected mortality risks due to heat events and air pollution (Jackson, J.E., Yost, M.G., Karr, C., Fitzpatrick, C., Lamb, B.K., Chung, S.H., Chen, J., Avise, J., Rosenblatt, R.A., Fenske, R.A., 2010)
Chicago, Illinois	Mortality	HADCM-A1B Composite models	2045 2085 A1B, B1	Projections extended beyond 2030 Population from 2025 a constant in calculation of future excess deaths during extreme heat events	Toward a Quantitative Estimate of Future Heat Wave Mortality under Global Climate Change (Peng <i>et al.</i> , 2011)
		cccma.cgcm3.1 cnrm.cm3 csiro.mk3 gfa1.cm2.0 miroc3.2medres mpi.echam5 mri.cgcm2.3.2a	2081-2100 A1, A2, B1		
Chicago	Mortality	GFDL CM2.1 HadCM3 PCM	2000-2099 A1F1, B1		Climate change, heat waves, and mortality projections for Chicago (Hayhoe <i>et al.</i> , 2010)
Montreal, Quebec City, Saguenay, Canada	Mortality	GCM	2010-2039 2040-2069 2070-2099 A2, B2		The potential impact of climate change on annual and seasonal mortality for three cities in Quebec, Canada (Doyon <i>et al.</i> , 2008)
Gulf contries (Yemen, Oman, UAE, Qatar, Bahrain)	All-cause mortality	HadCM3	2020-2050	Population estimates from Population Action International for 2025 and 2050.	Human health risk assessment due to global warming-A case study of the Gulf countries
		CGCM2	2070-2099	Population estimates for 2100 were extrapolated	(Husain and Chaudhary, 2008)
		NCAR-PCM	A2, B2		

California	Mortality		2025		Quantifying the health impacts of future changes in California
			2050		(Ostro <i>et al.</i> , 2011)
			A2, B1		
New York City	Mortality	GISS-MM5	2050	Population totals for each of 31 counties in NYC metropolitan region were from the US Census 2000 survey & were held constant throughout modeling period.	Projecting Heat-Related Mortality Impacts Under a Changing Climate in the New York City Region
			A2, B2		(Knowlton <i>et al.</i> , 2007)
Boston, Budapest, Dallas, Lisbon, London, Sydney	Mortality	HadCM3			Climate change and heat-related mortality in six cities Part 2: climate model evaluation and projected impacts from changes in the mean and variability of temperature with climate change
					(Gosling <i>et al.</i> , 2009)
40 cities in US	Mortality	coupled atmospheric-oceanic GCM	2020-2029		
			2045-2055		
			2090-2099		
3 cities in Alabama, US	mortality	CRCM	2041-2050		Estimating the health impact of climate change with calibrated model output
		CHCM3	A2		(Zhou, J., Chang, H.H., Fuentes, M., 2012)
15 Canadian cities	mortality	GLM	2040	1981-2000 population baseline	Climate change and future temperature-related mortality in 15 Canadian cities
		CRCM4	2060		(Martin <i>et al.</i> , 2011)
			2080		
			A2		

Table 11-6: Studies of the effectiveness of heat-health warning systems.

Effectiveness parameter	Location	Study design	Key findings on effectiveness	Commentary
Mortality	France	Regression analysis	<p>Excess mortality during the 2006 heat wave in France was markedly less than expected (2,065 excess deaths versus 6,452 predicted). Reduction in mortality most pronounced in women and the elderly (Fouillet et al., 2008).</p> <p>The mortality reduction may be partly attributable to the differences in the intensity and geographical scope of the heat wave. Some decrease may be attributed to increased public awareness of the risk of heat, and the measures put in place after the 2004 heat wave (Fouillet et al., 2008; IPCC SREX., 2012 Ch9 9.2.1.5).</p>	<p>HHWS vary from those based solely on issuing of heat alerts through to comprehensive systems and responses (IPCC SREX., 2012 Ch9 9.2.1.5.1).</p> <p>The main features typical of a HHWS are timely accurate warnings, tailored communications, notification of adaptation actions to the most vulnerable populations and heat avoidance advice to general populations (Lowe et al., 2011).</p>
	Philadelphia, US	Regression and economic analysis	Implementation of the Philadelphia HHWS is likely to have reduced daily mortality by 2.6 lives during heat events and could save 117 lives over 3 years (Ebi et al., 2004; IPCC SREX, 2012 Ch9 9.2.1.5.1). Net economic savings estimated at over US\$450m.	<p>The number of studies looking at effectiveness is limited.</p> <p>There are methodological challenges in assessing the effectiveness of HHWS interventions.</p>
	Czech Republic	Regression analysis	<p>Decrease in mortality in the 2003 European heat waves compared to heat waves in earlier years (Kysely and Kriz., 2008).</p> <p>Mortality decrease attributed in part to that the 2003 heat wave was less severe in central Europe compared to western Europe and night-time temperatures were not particularly elevated.</p> <p>Part of mortality decrease may be due to greater public awareness of heat-related risk, regular biometeorological forecasts and warnings, enhanced media coverage; as well as improvements in socioeconomic factors, general health, medical-technological changes and more widespread use of air conditioning. Stronger family and neighborhood ties in rural areas were also considered as possible protective factors.</p>	<p>Most HHWS and associated response plans have been implemented relatively recently.</p> <p>Other challenges include heat waves being relatively rare events; meteorological variation between events; differential distribution of vulnerability; level of heat acclimatization; and that several public health interventions are often implemented simultaneously. Therefore attribution to one factor over another is difficult. (IPCC SREX., 2012; Bassil and Cole., 2010; WHO Regional Office for Europe., 2009).</p>
Public awareness of an extreme heat episode and subsequent changes in behavior	Phoenix, Arizona, U.S	Cross-sectional survey	<p>Survey of general public on risk perception and warning response to heat episodes (Kalkstein and Sheridan., 2007).</p> <p>Majority of population were aware when a heat advisory warning had been issued. However, only about half the population actually changed behavior in response to a heat event. Variation in awareness across different demographic groups (greater awareness in women and those aged &gt;65 years).</p>	<p>HHWS may be able to reduce mortality. However, the extent of mortality reduction attributable to HHWS interventions versus other factors such as meteorological factors or changes in population vulnerability is unclear (IPCC SREX., 2012; Bassil and Cole., 2010).</p> <p>Further testing, development and evaluation are required to assess the most effective HHWS approaches. Particular areas include efficacy of existing plans; timely and accurate forecasts and warnings; vulnerable groups; improving uptake of adaptation advice; and how to best communicate across diverse groups (SREX, 2012 Ch9 9.2.1.6; Bassil and Cole., 2010; Lowe et al., 2011)</p>
	France	Cross-sectional survey	<p>Survey of general public in 2005-2006 to assess awareness and practices during heat alerts (INPES., 2006 - Cited and discussed in Bassil and Cole., 2010)</p> <p>Recall of media heat alerts was high (74%). High proportion (73%) of respondents reported increased efforts to support vulnerable friends and family. However, only 63% of the elderly reported being helped and only 14% asked for help when they felt discomfort. In 2006, 63% of respondents took protective measures against the</p>	

Effectiveness parameter	Location	Study design	Key findings on effectiveness	Commentary
			heat compared to 48% in 2005.	
	3 US cities and Toronto, Canada	Cross-sectional survey	<p>Survey of people aged &gt;65 years to assess knowledge of heat warnings (Sheridan., 2007).</p> <p>Knowledge of the heat warning system was high (90%) and likely due to extensive media coverage (particularly television). However, the details of the heat mitigation plans were less well understood and few people changed practices in response to the warnings. Many did not believe the messages were applicable to them or that they were vulnerable. Some confusion between heat precautions and ozone precautions.</p>	
	UK	Cross-sectional survey	<p>Study evaluated the component of the Heatwave Plan for England that focused on elderly people living in the community (Abrahamson et al., 2008). Survey assessed knowledge and perceptions of heat-related health risks, and protective behaviors.</p> <p>May be more effective to provide behavior modification advice to the whole population rather than targeting elderly people who may not perceive the advice is relevant to them. Few respondents considered themselves old or at risk from the effects of heat, despite many having a chronic illness. Most respondents had taken appropriate steps to reduce the effects of heat.</p> <p>Some respondents expressed practical concerns regarding the role and appropriateness of primary care for advice and support. No consensus on the effectiveness on the Heatwave Plan's media approach. Respondents suggested plausible and innovative ways to disseminate advice, as well as suggestions to harness existing community networks and resources to provide assistance.</p>	
Montreal, Canada	Cross-sectional survey	<p>People aged 41-88 years with chronic cardiac and/or lung conditions were interviewed regarding heat awareness and response during a hot summer in 2005 (Kosatsky et al., 2009).</p> <p>Most recalled heat advisory warnings in the media, with television being the predominant source. Of those who recalled advisories, 85% named at least one recommended protective measure; and most judged the recommendations useful.</p> <p>High awareness about effects of heat on health, including that people with heart or lung disease are at greater risk. However, most were unaware that heat waves have a greater effect on health when they occur at the beginning of summer. Some confusion between extreme heat and smog.</p> <p>All respondents reported that they "always" or "often" employed at least one measure to protect themselves from extreme heat.</p>		

Table 11-7: Summary of recent research on co-benefits of climate change mitigation.

Co-benefit category	Benefits for health	Benefits for climate	Publications since 2006
Reduction of co-pollutants from outdoor and household sources	Can reduce cardio- and cerebrovascular disease, chronic and acute respiratory illnesses, lung cancer, premature mortality, incidences of low birthweight and stillbirths, and possibly tuberculosis; less money spent on energy costs; promotes healthy homes	Reduce CAP emissions associated with household fuel use	(McCracken <i>et al.</i> , 2007)
			(Markandya <i>et al.</i> , 2009)
			(Smith and Balakrishnan, 2009)
			(Smith <i>et al.</i> , 2009)
			(Wilkinson <i>et al.</i> , 2009)
			(Boldo <i>et al.</i> , 2010)
			(Pokhrel <i>et al.</i> , 2010)
			(Baumgartner <i>et al.</i> , 2011)
			(Smith <i>et al.</i> , 2011)
			(UNEP, 2011)
Increases in active transport from modifications to the built environment, including smart growth	Increased physical activity; reduced obesity; reduced chronic disease; improved mental health; reduced exposure to air pollution; increased local access to essential services, including food stores; enhanced safety	Reduce CAP emissions associated with vehicle transport; possible mitigation of emissions through sequestration	(Anenberg <i>et al.</i> , 2012)
			(Dix-Cooper <i>et al.</i> , 2012)
			(Woodcock <i>et al.</i> , 2009)
			(Grabow <i>et al.</i> , 2011)
			(Reed and Ainsworth, 2007)
			(Kaczynski and Henderson, 2008)
			(Casagrande <i>et al.</i> , 2009)
			(Rundle <i>et al.</i> , 2009)
			(Durand <i>et al.</i> , 2011)
			(McCormack and Shiell, 2011)
Increases in urban green space	Reduced temperatures and heat island effects; reduced noise; enhanced safety; psychological benefits; better self-perceived health status	Reduce air pollution; more carbon sequestration (through forests and soil)	(Babey <i>et al.</i> , 2007)
			(Mitchell and Popham, 2007)
			(Babey <i>et al.</i> , 2008)
			(Maas <i>et al.</i> , 2009)
			(van den Berg <i>et al.</i> , 2010)
			(van Dillen <i>et al.</i> , 2011)
Less ruminant (red) meat consumption	May reduce (ischaemic) heart disease, stroke, colorectal cancer, breast cancer and prevalence of overweight/obese individuals	Less CH <sub>4</sub> emissions; lower energy intensity per calorie (?)	(McMichael <i>et al.</i> , 2007)
			(Friel <i>et al.</i> , 2009)
			(Sinha <i>et al.</i> , 2009)
			(Jakszyn <i>et al.</i> , 2011)
			(Pan <i>et al.</i> , 2012)
Increased access to reproductive health services	Lower child and maternal mortality from increased birth intervals and shifts in maternal age.	Potentially slower growth of energy consumption and related CAP emissions; less impact on land use change, etc.	(Xu <i>et al.</i> , 2012)
			(Smith and Balakrishnan, 2009)
			(Conde-Agudelo <i>et al.</i> , 2007)
			(Engelman, 2010)
			(O'Neill <i>et al.</i> , 2010)
			(Diamond-Smith and Potts, 2011)

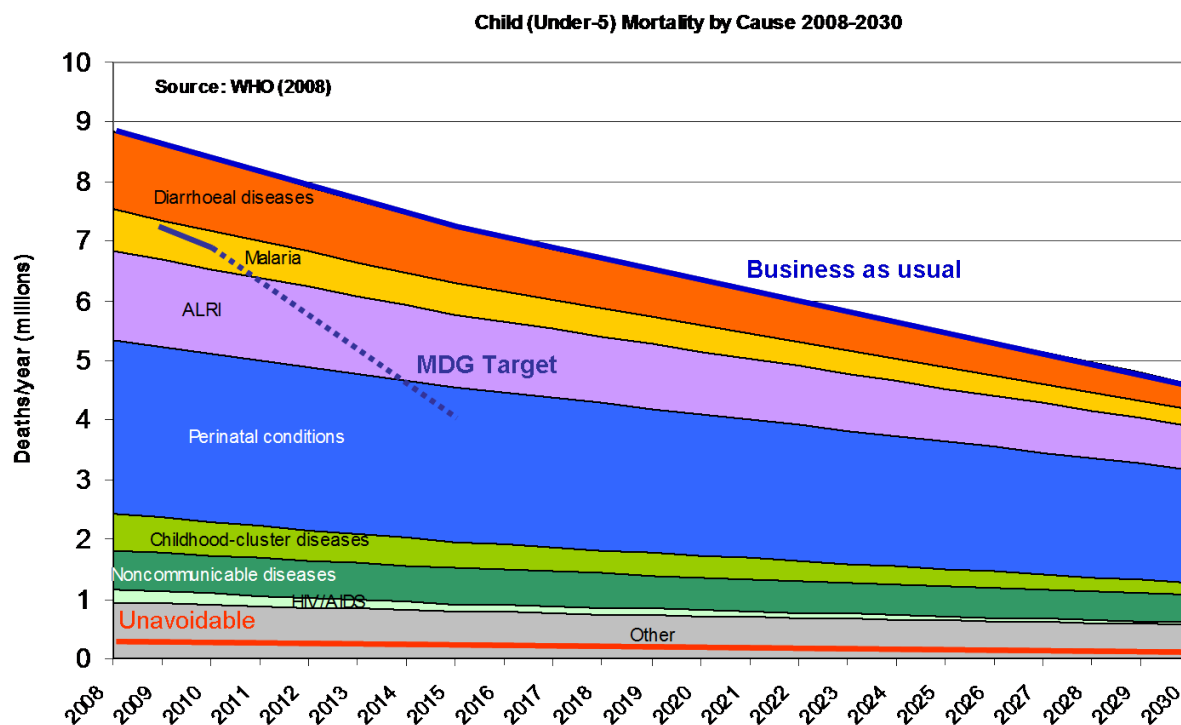


Figure 11-1: Projected Child Mortality, 2008-2030, Including Climate-Sensitive Causes. Sources: Mortality projections by cause from WHO. Population projections from UN DESA. Child mortality rates from IGME. (Interagency Group for Child Mortality Estimation, 2011; United Nations, Department of Economic and Social Affairs, Population Division., 2011; World Health Organization, 2008).

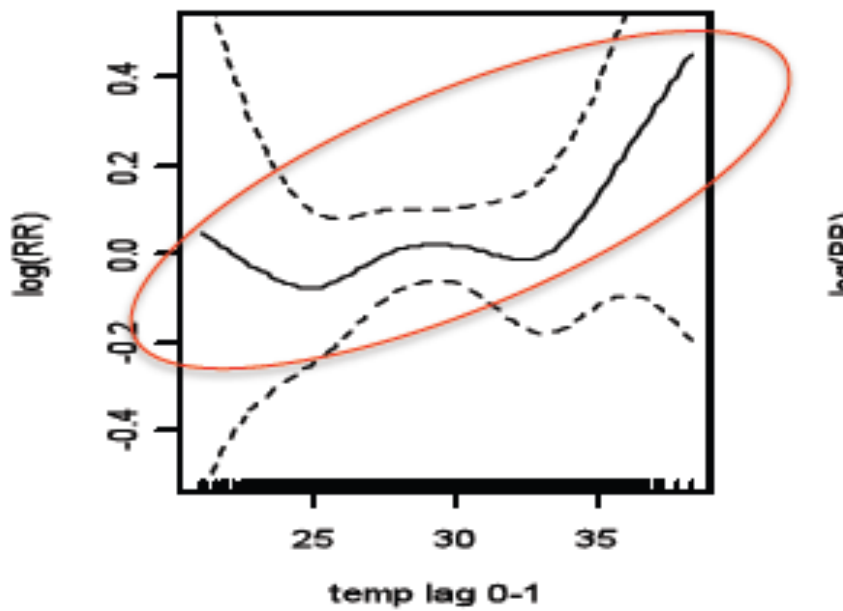


Figure 11-2: Relationship between the risk of dying and temperature on the preceding day. Y-axis: log(RR), X-axis: Temp in °C, lagged by one day.

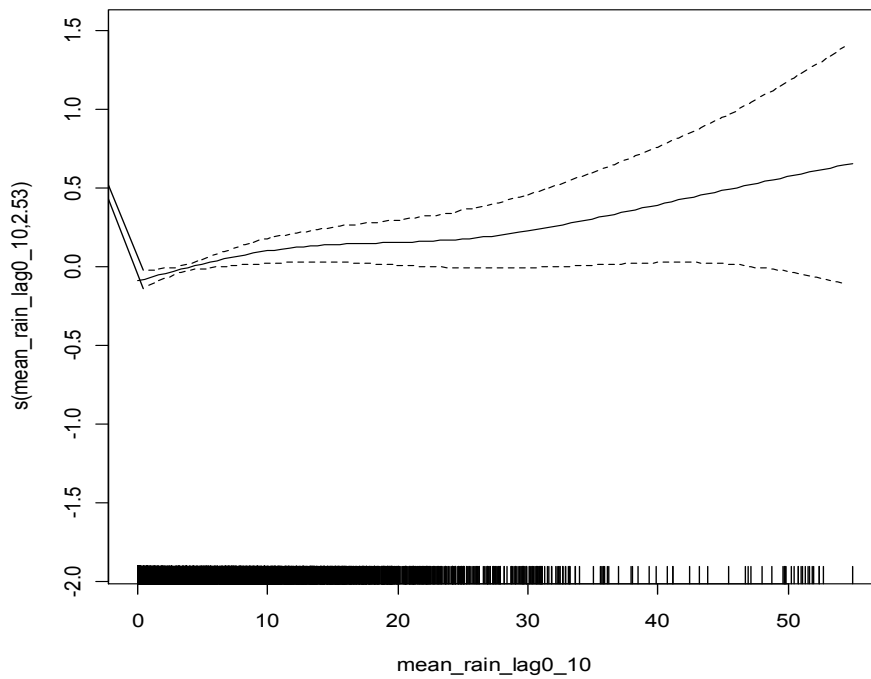
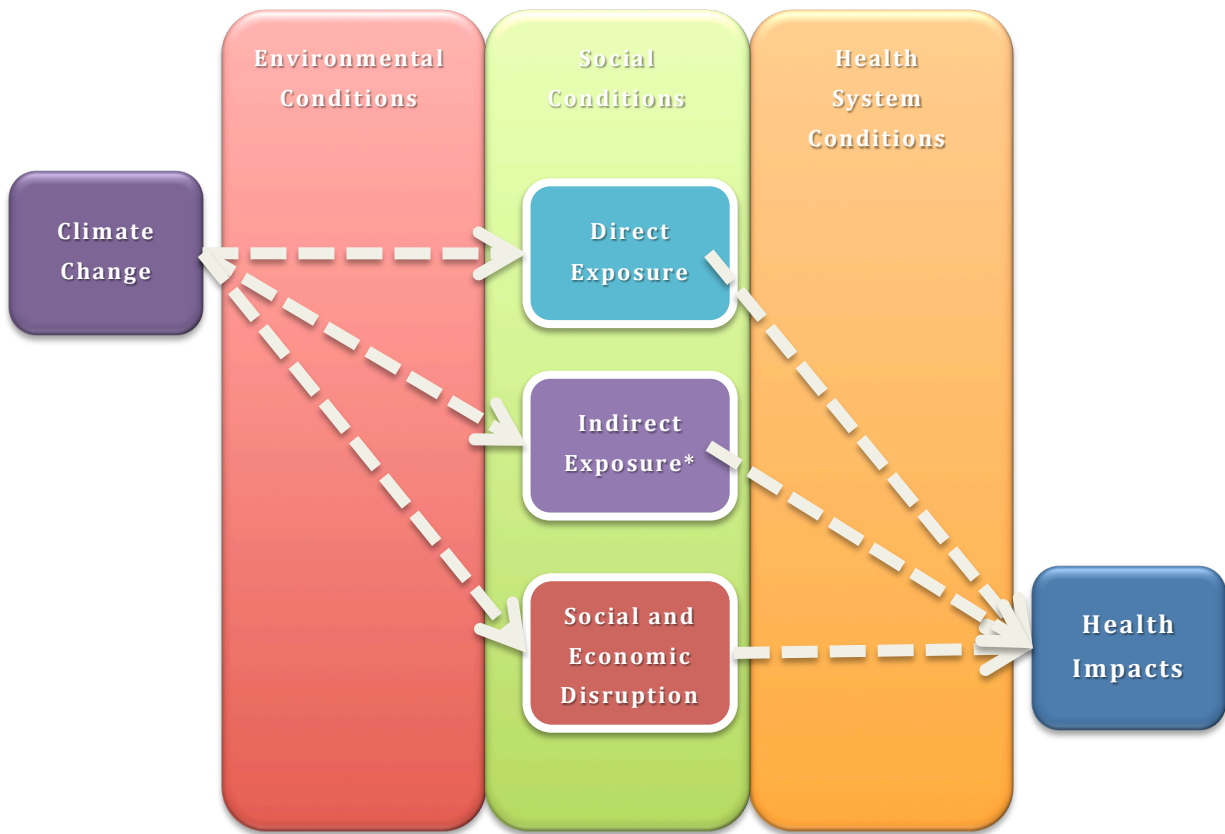


Figure 11-3: The effect of daily rainfall on daily mortality in diarrheal diseases in AMK HDSS, Bangladesh.



\*Changes in water, air, food quality; vector ecology; ecosystems, agriculture, industry, and settlements  
 †Arrow inside 'condition' box indicates modifying influence

Figure 11-4: Ways in which climate, climate variability and climate change may influence human health.  
 Source: E. Garcia (2011).



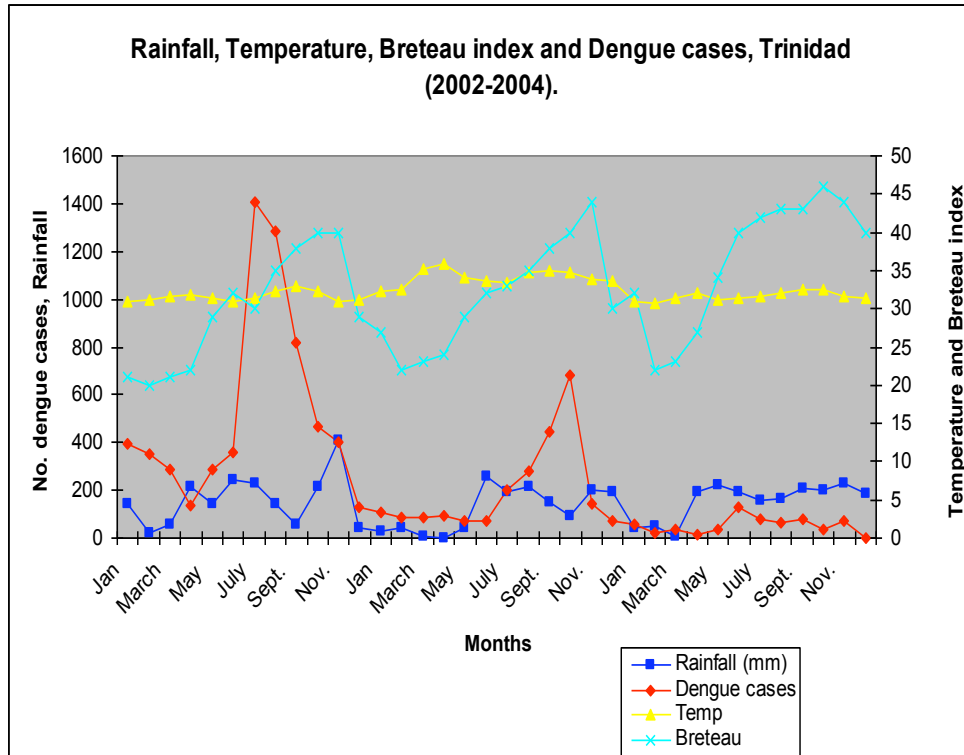


Figure 11-5: Rainfall, temperature, Breteau index, and dengue cases, Trinidad (2002-2004). Source: Chadee *et al.* (2007).

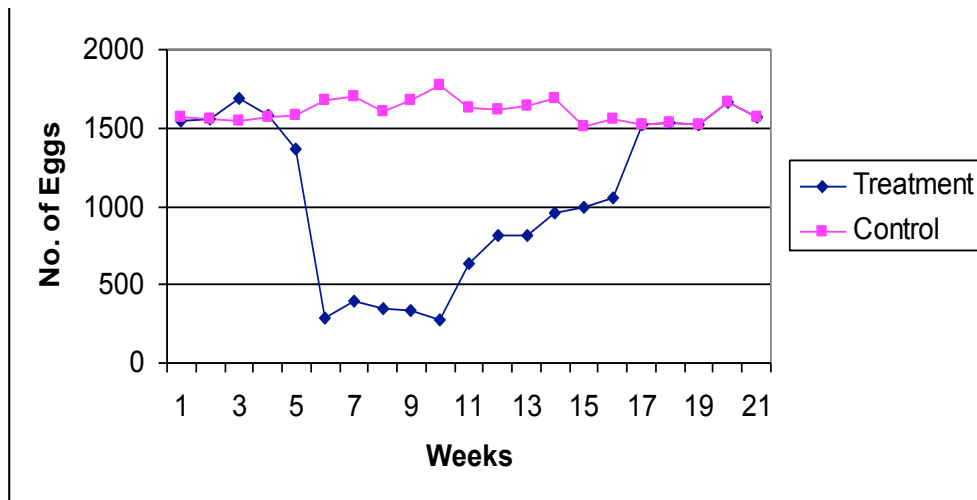


Figure 11-6: Efficacy of pre-seasonal treatment with temephos on *Aedes aegypti* ovitrap egg counts in Curepe (treatment) and St. Joseph (control), Trinidad (2003). Source: Chadee (2009).

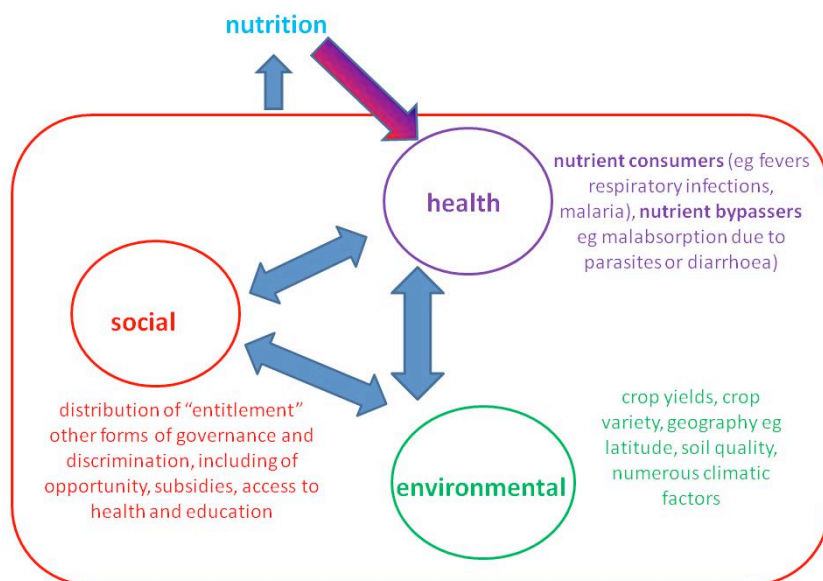


Figure 11-7: Nutrition, social, health, environmental interactions: Population and nutrition can be conceptualized as a synthetic state arising from the interaction of social, health and environmental factors, in a complex system. Many relationships are bidirectional. For example, poor population health status can impair social function (e.g. by impaired education). Source (Colin Butler, 2012?)

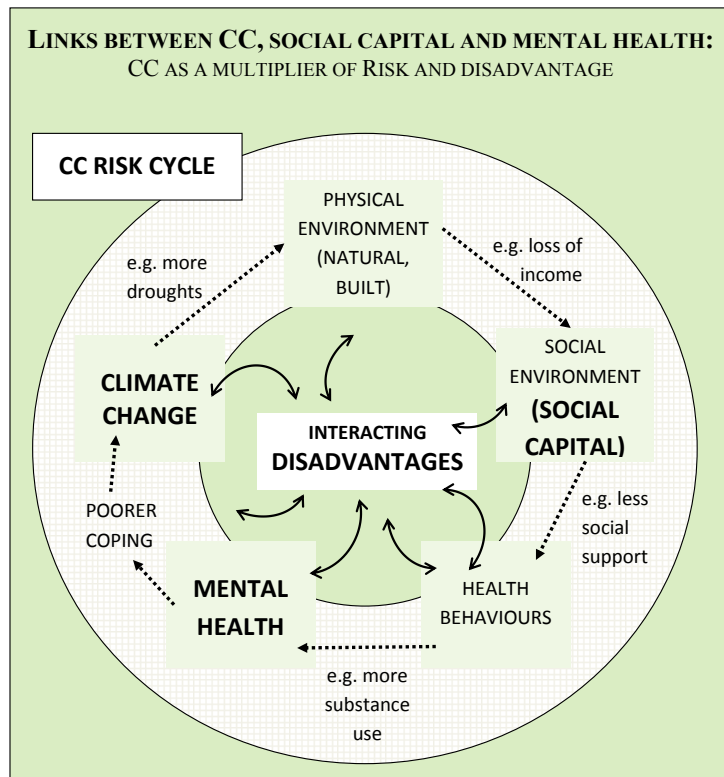


Figure 11-8: Links between CC, social capital, and mental health. Source: (Colin Butler, 2012?).

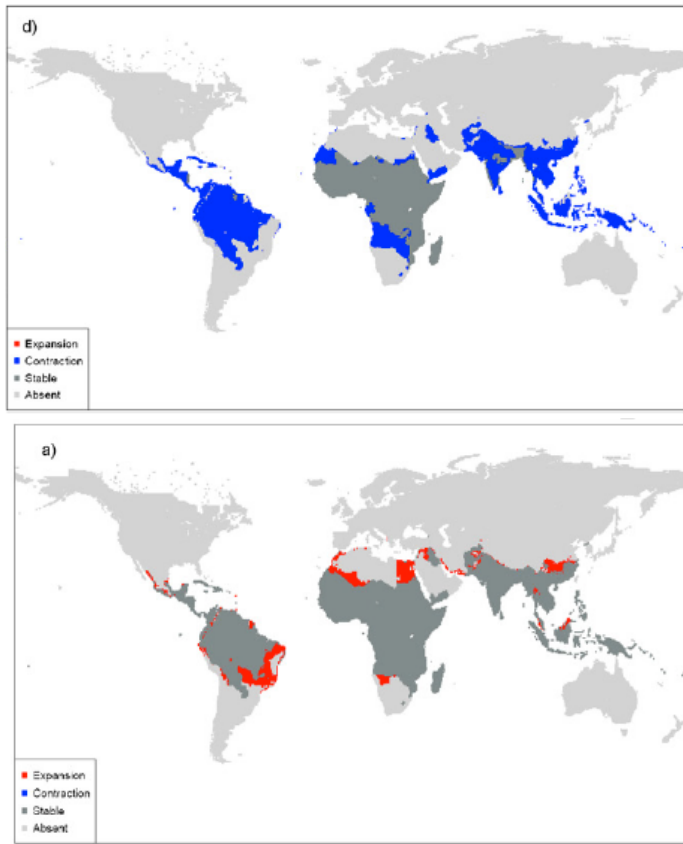


Figure 11-9: Contraction of the area of malaria transmission through economic development offsets expansion through higher temperatures. Based on IPCC scenario A1B, projections to 2050. Source: Béguin *et al.* (2011).

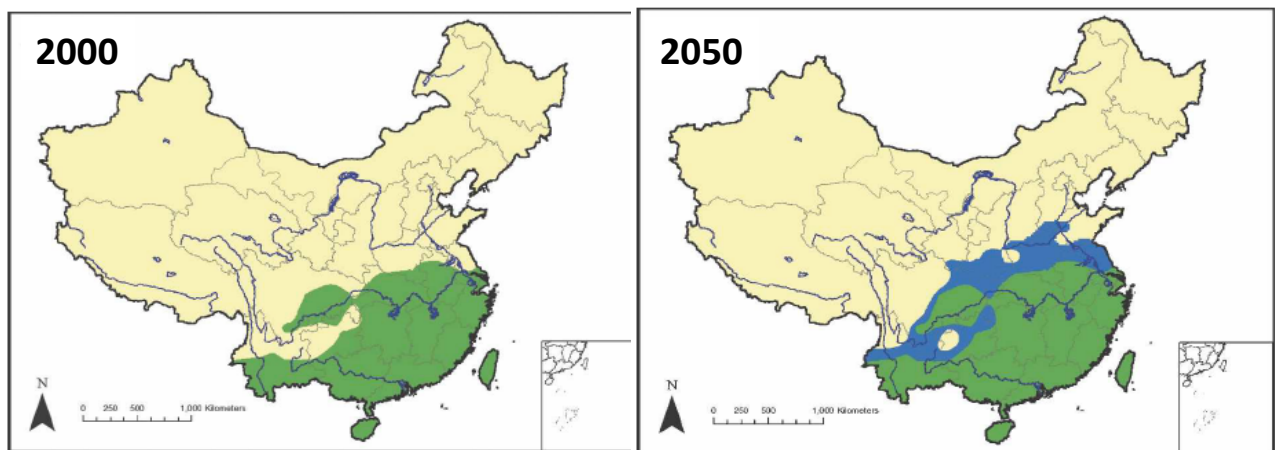


Figure 11-10: Predicted risk map of schistosomiasis (*S. japonicum*) transmission in China in 2050. For comparison the current risk map in 2000. Green area denotes the range of schistosomiasis in 2000. The blue area shows the geographic expansion. Adapted from (Zhou *et al.*, 2008).

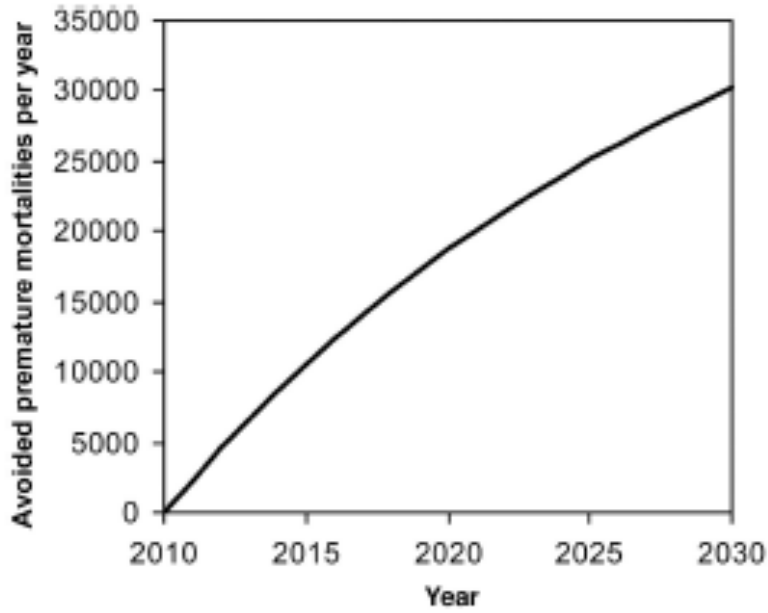


Figure 11-11: Avoided global premature mortalities from a 65 mt-yr<sup>-1</sup> CH<sub>4</sub> emission reduction, beginning in 2010. Cited from (West *et al.*, 2006).

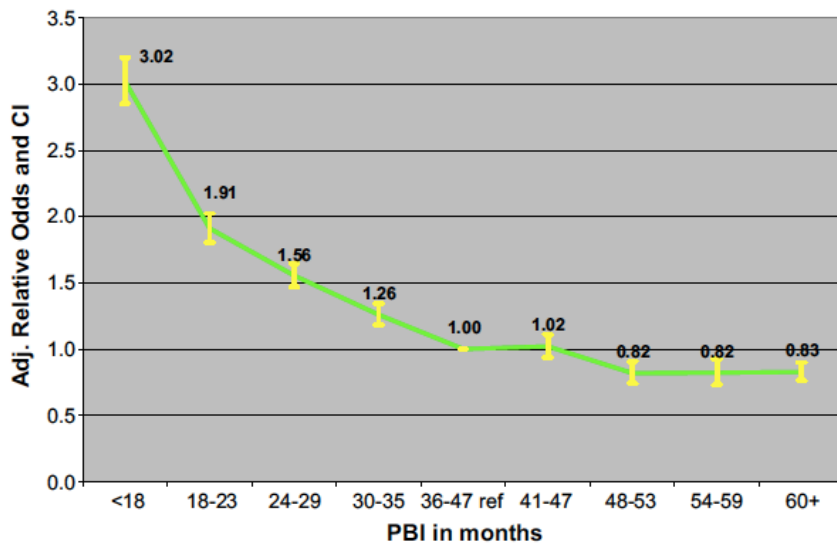


Figure 11-12: Reduction in child mortality due to increasing spacing of birth based on studies in 17 countries. Cited from (Rutstein, 2005).