CHAPTER 5

Impacts on health of climate extremes

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Introduction

Extreme climate events are expected to become more frequent as a result of climate change. Climate extremes can have devastating effects on human societies. History records widespread disasters, famines and disease outbreaks triggered by droughts and floods. These complex, large-scale disruptions exert their worst effects in poor countries but even the richest industrial societies are not immune. Extreme weather events are, by definition, rare stochastic events. There are two categories (*1*):

- extremes based on simple climate statistics, such as very low or very high temperatures;
- more complex, event driven extremes: droughts, floods, or hurricanes—these do not necessarily occur every year at a given location.

With climate change, even if the statistical distribution of simple extreme events remains the same, a shift in the mean will result in a non-linear change in the frequency of extreme events. The detection of change in simple climate extremes is more likely than the detection of changes in event-driven extremes.

Climate variability can be expressed at various temporal scales (by day, season and year) and is an inherent characteristic of climate, whether or not the climate system is subject to change. Much attention has focused on the influence of El Niño-Southern Oscillation (ENSO) on weather patterns in many parts of the world. In sensitive regions, ENSO events may cause significant inter-annual perturbations in temperature and/or rainfall within a loose 2–7 year cycle. However, it is important that such perturbations are not confused with climate change. In reality, these fluctuations introduce more noise into the long-term trends, making it more difficult to detect the climate change signal.

The effect of climate change on the frequency and/or amplitude of El Niño is uncertain. However, even with little or no change in amplitude, climate change is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño in many regions.

A range of physical, ecological and social mechanisms can explain an association between extremes of climate and disease (Figure 5.1, Table 5.1 and Table 5.2). Social mechanisms may be very important but are difficult to quantify: for example, droughts and floods often cause population displacement. Outbreaks of infectious disease are common in refugee populations due to inadequate public

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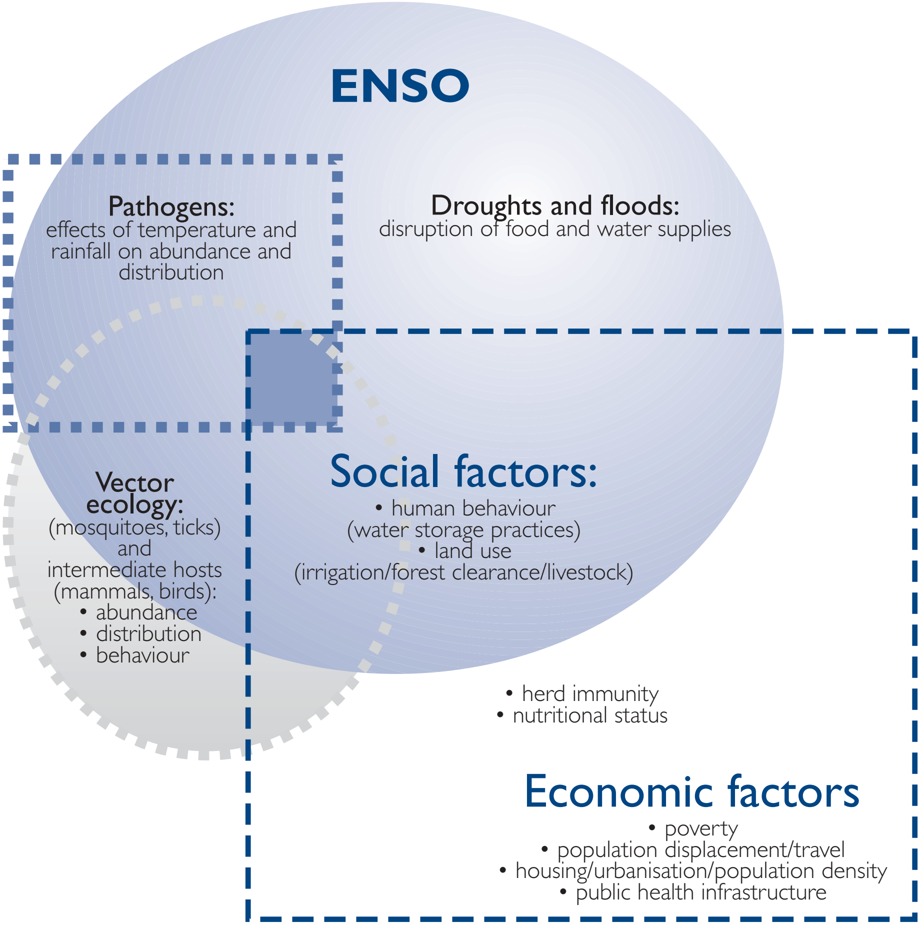
FIGURE 5.1 ENSO and disease. ENSO events cause physical effects such as droughts and floods (blue circle). Where these overlap and interact with suitable ecological and socioeconomic conditions (within dotted lines) they may cause disease outbreaks (dark shaded area).



health infrastructure, poor water and sanitation, overcrowding and lack of shelter. Climate also can affect infectious diseases that are spread via contaminated water or food. Water-related diseases are a particular problem in poor countries and communities, where water supplies and sanitation often are inadequate. Outbreaks of cholera, typhoid and diarrhoeal diseases can occur after flooding if the floodwaters become contaminated with human or animal waste, while drought reduces the water available for washing and sanitation and also tends to increase the risk of disease.

There is a web of interactions between ecosystems, climate and human societies, which influences the occurrence of infections. For example, the resurgence of communicable diseases in the past few decades is thought to have resulted primarily from social factors including population growth, urbanization, changes in land use and agricultural practices, deforestation, international travel and breakdown in public health infrastructure (*3*). From the opposite perspective, major communicable diseases such as malaria also can severely limit social development (*4*).

TABLE 5.1 Mechanisms by which above-average rainfall can affect health.

Event	Type	Description	Potential health impact
Heavy precipitation event	meteorological	"extreme event"	increased mosquito abundance or decreased (if breeding sites are washed away)
Flood	hydrological	river/stream over tops its banks	changes in mosquito abundance contamination of surface water
Flood	social	property or crops damaged	changes in mosquito abundance contamination of water with faecal matter and rat urine (leptospirosis).
Flood	catastrophic flood /"disaster"	Flood leading to >10 killed, and/or 200 affected, and/or government call for external assistance.	changes in mosquito abundance contamination of water with faecal matter and rat urine and increased risk of respiratory and diarrhoeal disease deaths (drowning) injuries health effects associated with population displacement loss of food supply psychosocial impacts

Source: reproduced from reference (*2*).

TABLE 5.2 Mechanisms by which below-average rainfall can affect health.

Event	Type	Description	Potential health impact
Drought	meteorological	evaporation exceeds water absorption, soil moisture decreases. Several indices have been developed based on meteorological variables, e.g. Palmer Drought Severity Index.	changes in vector abundance if vector breeds in dried up river beds, for example.
Drought	agricultural	drier than normal conditions leading to decreased crop production	depends on socioeconomic factors, i.e. other sources of food available and the means to acquire them.
Drought	social	reduction in food supply or income, reduction in water supply and quality	food shortage, illness, malnutrition (increases risk of infection) increased risk of disease associated with lack of water for hygiene.
Drought	food shortage/ famine/drought disaster	food shortage leading to deaths >10 killed, and/or 200 affected, or government call for external assistance.	deaths (starvation) malnutrition (increases risk of infection) health impacts associated with population displacement

Source: reproduced from reference (*2*).

This chapter summarizes what is known about the historical effects of climate extremes on human health. The following section describes studies of infectious diseases and climate extremes related to El Niño Southern Oscillation. The next considers the impacts of short-term extremes of temperature. The final section contains a discussion of climate-related disasters.

El Niño and infectious diseases

There is a well-studied relationship between rainfall and diseases spread by insect vectors which breed in water, and are therefore dependent on surface water availability. The main species of interest are mosquitoes, which spread malaria and viral diseases such as dengue and yellow fever. There is considerable evidence linking mosquito abundance to rainfall events. Mosquitoes need access to stagnant water in order to breed—conditions that may be favoured by both wet and dry conditions. For example, heavy rain can create as well as wash away breeding sites, while in normally wet regions drought conditions can increase breeding sites by causing stagnation of water in rivers. The timing of rainfall in the year and the co-variation of other climate factors also are likely to be important.

Vector-borne disease transmission is sensitive to temperature fluctuations also. Increases in temperature reduce the time taken for vector populations to breed. Increases in temperature also decrease the incubation period of the pathogen (e.g. malaria parasite, dengue or yellow fever virus) meaning that vectors become infectious more quickly (*5*). On the other hand (depending on thresholds that are species-specific) hot, dry conditions can reduce the lifetime of mosquitoes. Temperature also may affect the behaviour of the vector and human populations, affecting the probability of transmission. Warmer temperatures tend to increase biting behaviour of the vector and produce smaller adults which may require multiple blood meals in order to reproduce.

Malaria

Malaria is the world's most important vector-borne disease. Over 2.5 billion people are at risk, and there are estimated to be 0.5 billion cases and more than 1 million deaths from malaria per year (*6*). Malaria incidence is influenced by the effectiveness of public health infrastructure, insecticide and drug resistance, human population growth, immunity, travel, land-use change and climate factors.

Very high temperatures are lethal to the mosquito and the parasite. In areas where temperatures are close to the physiological tolerance limit of the parasite, a small temperature increase would be lethal to the parasite and malaria transmission would therefore decrease. However, at low temperatures a small increase in temperature can greatly increase the risk of malaria transmission (*7*).

Malaria's sensitivity to climate is illustrated in desert and highland fringe areas where rainfall and temperature, respectively, are critical parameters for disease transmission (*8*). In these regions higher temperatures and/or rainfall associated with El Niño may increase transmission of malaria. In areas of unstable malaria in developing countries, populations lack protective immunity and are prone to epidemics when weather conditions facilitate transmission. Across the globe, many such areas experience drought or excessive rainfall during ENSO events.

Drought in the previous year has been identified as a factor contributing to increased malaria mortality. There are several possible reasons for this relationship. Drought-related malnutrition may increase an individual's susceptibility to infection (*9*). Also, drought may reduce malaria transmission resulting in a reduction in herd immunity in the human population. Therefore, in the subsequent year the size of the vulnerable population is increased (*10*).

Alternatively, a change in ecology of the natural predators may affect mosquito vector dynamics; mosquito populations recover more quickly than their predator populations following a dry year. Famine conditions may have contributed to excess mortality during historical epidemics of malaria, for example following the 1877 El Niño in India. Many deaths occurred after the end of the drought; the proximate cause was malaria when drought-breaking rains increased vector abundance, exacerbated by population movement and the concentration of people in feeding camps (*11*).

Many parts of South America show ENSO-related climate anomalies. Serious epidemics in the northern countries of South America have occurred mainly in the year after El Niño (year +1). In 1983 following a strong El Niño event, Ecuador, Peru and Bolivia experienced malaria epidemics (*12*, *13*, *14*). In Venezuela and Colombia, malaria increased in the post-Niño year (+1) (*10*, *15*, *16*, *17*). A statistically significant relationship was found between El Niño and malaria epidemics in Colombia, Guyana, Peru, and Venezuela (*18*). The causal mechanisms are not completely understood. El Niño is associated with a reduction of the normal high rainfall regime in much of Colombia, as well as an increase in mean temperature, increase in dew point, and decrease in river discharges (*17*). These relationships between malaria and ENSO nevertheless can be used to predict high and low-risk years for malaria, giving sufficient time to mobilise resources to reduce the impact of epidemics (*15*).

Africa has desert fringe malaria around the Sahara (e.g. the Sudan) and the Kalahari (Namibia, Botswana). Of these areas, southern Africa and a region east of the Sahara show ENSO-related rainfall anomalies. Several recent studies have examined evidence of relationships between climate extremes and malaria in Africa (*19*, *20*, *21*).

The 1997/98 El Niño was associated with heavy rainfall and flooding in Kenya, after two years of drought. From January to May 1998, a major epidemic of falciparum malaria occurred. Brown et al. (*19*) reported an attack rate of approximately 40% in the town of Wajir, Kenya. Three districts in Kenya reported a six-fold increase in malaria cases in the first two months of 1998 compared to the same period in 1997 (*22*). The malaria epidemic was compounded by widespread food shortages.

Other researchers emphasize the significance of non-climate factors in explaining recent malaria epidemiology in Africa (*23*). A resurgence of malaria in the highlands of Kenya over the past 20 years has been attributed to resistance to antimalarial drugs (*24*). Another study did not find a relationship between climate trends and the timing of malaria epidemics in Kenya. Based on a 30-year time series of climate and disease data, it concluded: ". . . intrinsic population dynamics offer the most parsimonious explanation for the observed interepidemic periods" (*25*). One study has reported no significant meteorological trends in four high-altitude sites in East Africa where increases in malaria have been reported (*26*). This study used spatially averaged climate data that may be unreliable for this purpose. An association between rainfall, temperatures and the number of inpatient malaria cases three to four months later has been reported recently (*27*).

Dengue

Dengue is the most important arboviral disease of humans, occurring in tropical and subtropical regions worldwide. In recent decades, dengue has become an increasing urban health problem in tropical countries. The disease is thought to have spread mainly as a result of ineffective vector and disease surveillance; inadequate public health infrastructure; population growth; unplanned and uncontrolled urbanization; and increased travel (*28*, *29*). The main vector of dengue is the domesticated mosquito, *Aedes aegypti*, that breeds in urban environments in artificial containers that hold water. Dengue also can be transmitted by *Aedes albopictus*, which can tolerate colder temperatures.

Dengue is seasonal and usually associated with warmer, more humid weather. There is evidence that increased rainfall in many locations can affect the vector density and transmission potential. ENSO may act indirectly by causing changes in water storage practices brought about by disruption of regular supplies (*5*). Rainfall may affect the breeding of mosquitoes but this may be less important in urban areas: *Aedes aegypti* breed in small containers, such as plant pots, which often contain water in the absence of rain.

Between 1970 and 1995, the annual number of epidemics of dengue in the South Pacific was positively correlated with the Southern Oscillation Index (SOI) (*30*). This is plausible since, in this part of the world, high positive values of the SOI (denoting La Niña conditions) are associated with much warmer and wetter conditions than the average—ideal for breeding of mosquitoes. In a subsequent study, Hales et al. examined the relationship between ENSO and monthly reports of dengue cases in 14 island nations in the Pacific (*31*). There were positive correlations between SOI and dengue in ten countries. In five of these (American Samoa, Nauru, Tokelau, Wallis and Western Samoa) there were positive correlations between SOI and local temperature and/or rainfall. During La Niña, these five islands are likely to experience wetter and warmer than normal conditions. Local weather patterns may trigger an increase in transmission in larger, more populated islands where the disease is endemic, but infected people then carry the disease to smaller neighbouring islands. This implies that the effect of climate on vector-borne diseases is not necessarily confined to the region affected by altered climate, suggesting that forecasts may need to take account of regional social and environmental factors too.

A study of dengue in Viet Nam, found that the number of cases increased in El Niño years (*32*). In Thailand, which does not have a strong ENSO signal, there was no correlation (*25*). Many countries in Asia experienced an unusually high level of dengue and dengue haemorrhagic fever in 1998, some of which may be attributable to El Niño-related weather (*5*). Gagnon et al. reported positive associations between El Niño and dengue epidemics in French Guyana, Indonesia, Colombia and Suriname, regions that experience warmer temperatures and less rainfall during El Niño years (*33*).

These studies do not identify unequivocally the environmental risk factors for increases in dengue cases. Further regional or global scale studies are needed to determine whether El Niño is associated with a change in dengue activity and if so, what climate parameters (temperature, rainfall, humidity, sea level or wind velocity) primarily are responsible.

Rodent-borne diseases

Rodents act as reservoirs for a number of diseases whether as intermediate infected hosts or as hosts for arthropod vectors such as ticks. Certain rodent-borne diseases are associated with flooding including leptospirosis, tularaemia and viral haemorrhagic diseases. Other diseases associated with rodents and ticks include plague, Lyme disease, tick borne encephalitis (TBE) and hantavirus pulmonary syndrome (HPS).

Rodent populations have been shown to increase in temperate regions following mild wet winters (*34*). One study found that human plague cases in New Mexico occurred more frequently following winter-spring periods with above-average precipitation (*35*). These conditions may increase food sources for rodents and promote breeding of flea populations. Ticks also are climate sensitive.

Infection by hantaviruses mainly occurs from inhalation of airborne particles from rodent excreta. The emergence of the disease hantavirus pulmonary syndrome in the early 1990s in the southern United States has been linked to changes in local rodent density (*36*). Drought conditions had reduced populations of the rodents' natural predators; subsequent high rainfall increased food availability in the form of insects and nuts. These combined effects lead to a tenfold increase in the population of deer mice from 1992 (*36*) to 1993. In 1998, an increase in cases of hantavirus was linked to increased rodent populations which, in turn, were attributed to two wet, relatively warm winters in the southern United States associated with 1997/98 El Niño (*37*, *38*). A comprehensive study by Engelthaler et al. in the Four Corners region, USA, concluded that above-average precipitation during the winter and spring of 1992–1993 may have increased rodent populations and thereby increased contact between rodents and humans and viral transmission (*39*).

Diarrhoeal illness

Many enteric diseases show a seasonal pattern, suggesting sensitivity to climate. In the tropics diarrhoeal diseases typically peak during the rainy season. Floods and droughts are each associated with an increased risk of diarrhoeal diseases, although much of the evidence for this is anecdotal. The suggestion is plausible, however, since heavy rainfall can wash contaminants into water supplies, while drought conditions can reduce the availability of fresh water leading to an increase in hygiene-related diseases.

Major causes of diarrhoea linked to contaminated water supplies are: cholera, cryptosporidium, *E.coli*, giardia, shigella, typhoid, and viruses such as hepatitis A. Outbreaks of cryptosporidiosis, giardia, leptospirosis and other infections have been shown to be associated with heavy rainfall events in countries with a regulated public water supply (*40*, *41*, *42*, *43*, *44*, *45*).

An association between drinking water turbidity and gastrointestinal illness has been reported (*46*). This was one of the first studies to apply time series methods to the analysis of water-related disease. A study of waterborne disease outbreaks in the United States has shown that about half were significantly associated with extreme rainfall (*41*). Outbreak locations from an Environmental Protection Agency database were assigned to watersheds. The rainfall in the month of the outbreak and in previous months was estimated from climate records: for outbreaks associated with surface water the association was strongest for rainfall events in the same month as the outbreak.

Transmission of enteric diseases may be increased by high temperatures, via a direct effect on the growth of disease organisms in the environment (*47*, *48*, *49*). In 1997 a markedly greater number of patients with diarrhoea and dehydration were admitted to a rehydration unit in Lima, Peru, when temperatures were higher than normal during an El Niño event (*50*). A time series analysis of daily data from the hospital confirmed an effect of temperature on diarrhoea admissions, with an estimated 8% increase in admissions per 1 °C increase in temperature (*51*).

Analysis of average diarrhoea reports in the Pacific Islands (1978–1986) suggested a positive association with average temperature and an inverse association with estimated water availability (*52*). Time series analysis of diarrhoea reports in the islands of Fiji (1978–1992) confirmed a statistically significant effect of monthly temperature changes (an estimated 3% increase in diarrhoea reports per 1 °C increase in temperature). Extremes of rainfall also were associated with increases in diarrhoea (*52*).

In summary, there is good evidence of associations between several important communicable diseases and climate on several temporal and geographical scales. This is true of vector-borne diseases, many enteric illnesses and certain water-related diseases. These associations are not found everywhere—hardly surprising given the complexity of the causal pathways involved. Relationships between year-to-year variations in climate and communicable diseases are most evident where these climate variations are marked, and in vulnerable populations in poor countries. Major scientific reviews agree that El Niño can provide a partial analogue for the effects of global climate change on communicable diseases (*53*). However, the Intergovernmental Panel on Climate Change (IPCC) cautions:

"Policymakers should appreciate that although our scientific capacity to foresee and model these various health outcomes of climate change continues to evolve, it is not possible to make precise and localized projections for many health outcomes . . ." (*3*).

Temperature extremes: heatwaves and cold spells

In recent years there has been a great increase in interest in time series studies of temperature and mortality. These are seen as the most satisfactory method for

BOX 5.1 Impact of climate extremes on malaria in Irian Jaya

Beginning in late August 1997, a significant increase of unexplained deaths was reported from the central highland district of Jayawijaya. The alarming number of fatalities rapidly escalated into September, dropping off precipitously by late October. More than 550 deaths due to "drought-related" disease had been officially reported from the district during this 10-week period. The outbreaks occurred in extremely remote areas of steep mountainous terrain inhabited by shifting agriculturist populations.

Microscopic evidence and site survey data implicated malaria as the principal cause of the excess morbidity and mortality at elevations between approximately 1000 and 2200 m. The dramatic increase in malaria and associated deaths was related indirectly to the prolonged and severe drought created by the prevailing 1997–98 El Niño affecting the Australasian region.

Clinical cases of malaria were described as severe, due in large part to the low level of naturally acquired immunity in these highland populations and the predominance of *Plasmodium falciparum* infection. Disease may have been further exacerbated by the population's compromised nutritional status because of drought-related severe shortages of staple foods. Based on a retrospective investigation, an *a posteriori* epidemiological explanation of the probable interrelated causes of the epidemic is presented:

> "Beginning in late July 1997, drought conditions resulted in numerous transient pools of standing water along zones of steep gradient streams normally associated with fast-flowing water. This permitted sufficient and rapid increases in vector populations (*Anopheles punctulatus* complex) that could sustain recently introduced or intensified local low-level malaria transmission. Moreover, water and food shortages contributed to increased demographic movement and exposure to high risk malaria endemic lowlands, thus increasing the prevalence of human infections and infectious reservoirs in those populations returning to the highlands."

Source: Based on reference (54)

BOX 5.2 Cholera

Traditionally cholera is viewed as a strictly faecal–oral infection but increased attention is being paid to the environmental determinants of this disease. The discovery of a marine reservoir of the cholera pathogen and its long term persistence with various marine organisms (in the mucilaginous sheath of blue-green algae and copepods) helps to explain the endemicity in certain regions, such as the estuaries of the Ganges and Bramaputra in Bangladesh (*55*). Recent work has suggested links between the seasonality of cholera epidemics and seasonality of plankton (algal blooms) and the marine food chain. A study of *Vibrio cholerae* 01 in Bangladesh (1987–90) found that abundance increases with the abundance of copepods (which feed on phytoplankton) in coastal waters (*55*). Analysis of cholera data from Bangladesh showed that the temporal variability of cholera exhibits an interannual component at the dominant frequency of El Niño (*56*, *57*).

Several cholera outbreaks occurred in 1997 following heavy rains. Countries in East Africa were severely affected: major cholera outbreaks occurred in the United Republic of Tanzania, Kenya, Guinea-Bissau, Chad and Somalia (*2*, *58*). Outbreaks also were reported in Peru, Nicaragua and Honduras (*59*, *60*). However, the total number of cholera cases reported to WHO in 1997, globally and by region, was similar to that in 1996. Countries that experienced increased cholera incidents in 1997 are at risk of increases in cholera in subsequent years. In 1997, the regional WHO cholera surveillance team was aware of the forecasts of an El Niño-related drought in south-east Africa. The team was able to institute measures to help reduce the severity of a cholera outbreak in Mozambique by increased monitoring and heightened preparedness of health care institutions (*60*).

quantifying the short-term associations between ambient temperatures and daily mortality. Any long-term patterns in the series (e.g. seasonal cycles) are removed. The effect of a hot day is apparent only for a few days in the mortality series; in contrast, a cold day has an effect that lasts up to two weeks. In many temperate countries mortality rates in winter are 10–25% higher than death rates in summer but the causes of this winter excess are not well understood (*61*).

It is likely that different mechanisms are involved in heat and cold related mortality; cold related mortality in temperate countries is related in part to the occurrence of seasonal respiratory infections. High temperatures cause some well-described clinical syndromes such as heatstroke (*62*). Very few deaths are reported as attributed directly to heat. Exposure to high temperatures increases blood viscosity and it is plausible that heat stress may trigger a vascular event such as heart attack or stroke (*63*). Studies have shown that elderly people have impaired temperature regulation (*62*, *64*, *65*, *66*). Physiological studies in the elderly indicate that low temperatures are associated with increased blood pressure and fibrinogen levels (*67*, *68*).

The impact of heatwave events on mortality

Heatwaves can kill. In July 1995 a heatwave in Chicago, USA, caused 514 heat-related deaths (12 per 100000 population) and 3300 excess emergency admissions (*69*). The morgues were full and bodies had to be stored in refrigerated trucks. From 12 to 20 July, daily temperatures ranged from 34–40 °C, with the highest temperatures on 13 July. The maximum number of deaths occurred on 15 July (*70*).

During heatwaves, excess mortality is greatest in the elderly and those with pre-existing illness (*71*). Much of this excess mortality is due to cardiovascular, cerebrovascular and respiratory disease. The mortality impact of a heatwave is uncertain in terms of the amount of life lost: a proportion of the deaths occur in susceptible persons who were likely to have died in the near future. Nevertheless, there is a high level of certainty that an increase in the frequency and intensity of heatwaves would increase the numbers of additional deaths due to hot weather.

There is no standard international definition of a heatwave. Operational definitions are needed for meteorological services. As meteorological agencies are becoming more commercialized they are keen to develop practical applications of their forecasts and tailor them to user needs. The Netherlands meteorological bureau uses the following definition to trigger advance warnings in the media and directly to health services: at least 5 days with maximum temperature above 25 °C of which at least 3 days with maximum temperature above 30 °C. The evidence on which this is based is not clear. In the United States, the National Weather Service suggest that a heat advisory (early warning) be issued when the daytime heat index reaches 40.6 °C and a night time minimum temperature of 26.7 °C persists for at least 48 hours (*72*). Local definitions are used: in Dallas the medical examiners office define a heatwave as three consecutive days of temperatures over 37.8 °C.

It is surprisingly difficult to define a heatwave as responses to very high temperatures vary between populations and within the same population over time. A 1987 heatwave in Athens resulted in 926 deaths classified as heat-related, although the attributable excess mortality was estimated to be more than 2000 (*73*). A subsequent heatwave in 1988 was associated with a much smaller excess mortality. This has been observed also in Chicago following the 1995 heatwave (*74*).

Few analyses have looked at the impacts of heatwaves in developing countries and the evidence is largely anecdotal. A heatwave in India in June 1998 was estimated to have caused 2600 deaths over 10 weeks of high temperatures (*75*). In Ores, the temperature rose to 49.5 °C and was reported to have caused 1300 deaths. The high temperatures were exacerbated by recurrent power failures that affected cooling systems and hospital services in Delhi.

Important behavioural factors may be specific to certain countries: in Japan, young children are often affected when left in motor vehicles. Not all heat related deaths are due to weather conditions. For example, in the United States in 1994, 221 heat related deaths were recorded, but only 101 (46%) were due to ambient weather conditions. The rest were due to overexertion during exercise, for example. During the period 1979–1994, heat-related mortality due to weather conditions was 2.7–3.7 per million population in the four highest reporting states (Arizona, Arkansas, Kansas, and Missouri) (*72*). Most of these deaths occurred in the over-55 age group. Overall the impact of mortality is underestimated because death rates from other diseases increase during heatwaves. This is true in all populations where it has been investigated.

Rooney et al. estimated the excess mortality associated with the 1995 heatwave in the United Kingdom (*76*). An estimated 619 extra deaths (8.9% increase) were observed relative to the expected number of deaths, based on the 31-day moving average for that period. Excess deaths were apparent in all age groups but most marked in females and for deaths from respiratory and cerebrovascular disease. A heatwave in Belgium in 1994 was associated with excess mortality. Part of the excess was due to mortality displacement, since there was a deficit in deaths in the elderly following the heatwave (no deficit was apparent for age group 0–64 years) (*77*).

Vulnerability to temperature-related mortality

Indicators of vulnerability to heat and cold that have been investigated include:

- age and disease profile
- socioeconomic status
- housing conditions
- prevalence of air conditioning
- behaviour (e.g. clothing).

These factors also have counterparts in individuals as risk factors for heat related mortality or morbidity, such as presence of air conditioning at time of death.

Both individual and population level studies provide strong and consistent evidence that age is a risk factor for heat-related mortality. Studies vary on the age at which the vulnerability is increased. There are physiological reasons why the elderly are more vulnerable.

An important study was undertaken following the Chicago heatwave in 1995. Semenza et al. interviewed the relatives of those who died during the heatwave and controls who lived near the case, matched for age and neighbourhood (*78*). Individual risk factors for dying in the heatwave were identified: chronic illness; confined to bed; unable to care for themselves; isolated; without air conditioning. A comparison of mortality rates in three Illinois heatwaves (1966) by age group, sex and ethnic group (white vs. other) found that women and white people were at more risk (*79*).

Winter mortality

In many temperate countries there is a clear seasonal variation in mortality (*80, 81*), death rates during winter being 10–25% higher than those in summer. The major causes of winter death are cardiovascular, cerebrovascular, circulatory and respiratory diseases (*82*, *83*).

Annual outbreaks of winter diseases such as influenza, which have a large effect on winter mortality rates, are not strongly associated with monthly winter temperatures (*84*). Social and behavioural adaptations to cold play an important role in preventing winter deaths in high latitude countries. Sensitivity to cold weather (measured as the percentage increase in mortality per 1 °C change in temperature) is greater in warmer regions. Mortality increases to a greater extent with a given fall in temperature in regions with warmer winters, in populations with less home heating and where people wear lighter clothes (*85*).

The elderly (aged 75 and over) are particularly vulnerable to winter death, having a winter excess of around 30%. This vulnerability is not yet well understood but may arise through a combination of physiological susceptibility, behavioural factors and socioeconomic disadvantage. Excess winter mortality is an important problem in the United Kingdom where there has been much debate about the role of poor housing, fuel poverty and other socioeconomic issues for the elderly population (*86*). Several studies have linked routine mortality data at ward or enumeration district level with small-area indicators of housing and deprivation. A study of ischaemic heart disease morbidity in Stockport found higher winter excess in the higher social class groups although a clear gradient was not observed (*87*). A small-area study found that inadequate home heating and socioeconomic deprivation were the strongest independent predictors of ward-level variation in excess winter death in England and Wales (*88*). In general, however, studies have found only weak or absent relationship between excess winter mortality and deprivation (*86*).

The potential impact of climate change on temperature related mortality

Global climate change is likely to be accompanied by an increase in the frequency and intensity of heatwaves, as well as warmer summers and milder winters (*2*). Extreme summer heat's impact on human health may be exacerbated by increases in humidity. There has been significant warming in most regions in the last 25 years (see chapter 5) some of which the IPCC has attributed to human activities. However, it is not clear that the frequency of heatwaves has been increasing, although few studies have analysed daily temperature data to confirm this (*1*). There is much regional variation in the trends observed. Gaffen and Ross looked at data from 1961–1990 for 113 weather stations in the United States and found that the annual frequency of days exceeding a heat stress threshold increased at most stations (*89*).

Predictive modelling studies use climate scenarios to estimate future temperature related mortality. Those studies which use the empirical statistical model (based on coefficients derived from linear regression of the temperature mortality relationship) find that reductions in winter deaths are greater than increases in summer deaths in temperate countries (*84*, *90*). However, other methods indicate a more significant increase in summer deaths. Kalkstein and Green estimated future excess mortality under climate change in United States' cities (*91*). Excess summer mortality attributable to climate change, and assuming acclimatization, was estimated to be between 500–1000 for New York and 100–250 for Detroit by 2050, for example.

Populations can be expected to adapt to changes in climate via a range of physiological, behavioural and technological changes. These will tend to reduce the impacts of future increases in heatwaves. The initial physiological acclimatization to hot environments can occur over a few days but behavioural and technological changes, such as changes to the built environment, may take many years.

While it is well established that summer heatwaves are associated with short term increases in mortality, the extent of winter-associated mortality directly attributable to stressful weather is difficult to determine and currently being debated. Limited evidence indicates that, in at least some temperate countries, reduced winter deaths would outnumber increased summer deaths. The net impact on mortality rates will vary between populations. There are no clear implications of climate change for non-fatal outcomes as there is a lack of relevant studies.

Natural disasters

The health effects of disasters are difficult to quantify because secondary effects and delayed consequences are poorly reported and communicated. Information on natural disasters generally is gathered by the organisations and bodies directly involved in disaster relief and reconstruction. As a result, information usually is collected for specific operational purposes not as a database; figures are estimated, not measured directly (*92*). This is especially true of flood events and windstorms where the actual deaths and injuries directly caused by the event are small compared to the problems that arise as a result, including deaths from communicable diseases and the economic losses sustained (*93*, *94*, *95*) (see Box 5.3 on Hurricane Mitch).

El Niño has an effect on the total number of persons affected by natural disasters (*96*, *97*). Worldwide, disasters triggered by droughts are twice as frequent during the year after the onset of El Niño than other years (*97*). This risk is concentrated in southern Africa and south-east Asia. The El Niño effect on disasters is strong enough to be apparent at the global level (*96*). In an average El Niño year, around 35 per 1000 persons are affected by a natural disaster. This is over four times greater than the rate in non El Niño years, based on analysis of data from 1963 to 1992. This difference in risk is much stronger for famine disasters; El Niño's global disaster footprint is largely determined by the consequences of drought.

In 1997/98 Kenya was particularly hard hit by flooding and excess rainfall. Ecuador and northern Peru experienced severe flooding and mudslides along the coastal regions which severely damaged the local infrastructure (*98*). In Peru, 9.5% of health facilities were damaged, including 2% of hospitals and 10% of other health centres (*98*). At the other extreme, Guyana, Indonesia and Papua New Guinea were severely affected by drought. Although not all natural disasters in 1997/98 should be attributed to the El Niño event, global estimates of the impact vary from 21 000 (*99*) to 24 000 (*100*) deaths.

Trends in weather disasters

Globally, there is an increasing trend in natural disaster impacts. An analysis by the reinsurance company Munich Re found a three-fold increase in the number of natural catastrophes in the last ten years, compared to the 1960s (*94*). This is primarily from global trends affecting population vulnerability rather than changes in the frequency of climatological triggers.

Developing countries are poorly equipped to deal with weather extremes. The number of people killed, injured or made homeless by natural disasters is increasing alarmingly. This is due partly to population growth and the concentration of population in high-risk areas like coastal zones and cities. Large shanty-towns with flimsy habitations often are located on land subject to frequent flooding. In many areas the only land available to poor communities may be that with few natural defences against weather extremes. Direct hits of extreme events on towns and cities tend to cause large losses. In recent decades there has been a large migration to cities and more than half the world's population now lives in urban areas. Such migration and increasing vulnerability means that even without increasing numbers of extreme events, losses attributable to each event will tend to increase (*101*).

There are several sources of information but the largest, most used and most reliable is a database created in 1988 with support from the World Health Organization and the Belgium Government (EM-DAT). The objective of EM-DAT is:

> *". . . to serve the purposes of humanitarian action at national and international levels. It is an initiative aimed to rationalise decision-making for disaster preparedness, as well as providing an objective base for vulnerability assessment and priority setting" (92).*

The Centre for Research on the Epidemiology of Disasters (CRED) records events where at least 10 people were reported killed; 100 people were reported affected; there was a call for international assistance; or declaration of a state of emergency. There are increasing trends of economic and insured losses from disaster events, and economic annual losses have increased ten-fold since the 1950s (*102*). However, much of the upward trend in economic losses probably is due to societal shifts and increasing vulnerability to weather and climate extremes (*103*).

Data for the 1980s and 1990s are shown in Table 5.3. This shows the numbers of events, people killed and people affected by weather-related natural disasters in each decade, by region of the world. Some regions are more severely affected than others, although some show a decrease in the number of people killed (Africa and eastern Mediterranean) and the number of people affected (Africa, Americas and south-east Asia).

Reasons for the observed increases include:

- increasing concentration of people and property in urban areas
- settlement in exposed or high risk areas (e.g. flood plains, coastal zones)
- changes in environmental conditions (e.g. deforestation can increase flood risk).

There has been an apparent recent increase in the number of disasters but little change in the number of people killed (*94*). In 2000 there were over 400 disasters, with 250 million people affected (*94*). This paradox may be explained by technological advances in the construction of buildings and infrastructure along with advancements in early warning systems, especially in more developed regions. Although there are pronounced year-to-year fluctuations in the numbers of deaths due to disasters, a trend towards increased numbers of deaths and numbers of people affected has been observed in recent decades (*94*).

The health impacts of disasters

Extreme weather events directly cause death and injury and have substantial indirect health impacts. These indirect impacts occur as a result of damage to the

TABLE 5.3 Number of events, people killed and affected, by region of the world for the 1980s and 1990s.

Region	1980s			1990s		
	Events	Killed	Affected	Events	Killed	Affected
Africa	243	416851	137758905	247	10414	104269095
Eastern Europe	66	2019	129345	150	5110	12356266
Eastern Mediterranean	94	161632	17808555	139	14391	36095503
Latin America & Caribbean	265	11768	54110634	298	59347	30711952
South East Asia	242	53853	850496448	286	458002	427413756
Western Pacific	375	35523	273089761	381	48337	1199768618
Developed	563	10211	2791688	577	5618	40832653
Total	1848	691857	1336185336	2078	601219	1851447843

N.B. Regions used in this table correspond to the map of regions used in chapter 7.

TABLE 5.4 Theoretical risk of acquiring communicable diseases, by type of disaster.

Type	Person to person	Water borne	Food borne	Vector borne
Earthquake	M	M	M	L
Volcano	M	M	M	L
Hurricane	M	H	M	H
Tornado	L	L	L	L
Heatwave	L	L	L	L
Coldwave	L	L	L	L
Flood	M	H	M	H
Famine	H	H	M	M
Fire	L	L	L	L

H = High.
M = Medium.
L = Low.
Source: Reproduced from reference 106.

local infrastructure, population displacement and ecological change. Direct and indirect impacts can lead to impairment of the public health infrastructure, psychological and social effects, and reduced access to health care services (*104*). The health impacts of natural disasters include (*105, 106*):

- physical injury;
- decreases in nutritional status, especially in children;
- increases in respiratory and diarrhoeal diseases due to crowding of survivors, often with limited shelter and access to potable water;
- impacts on mental health which may be long lasting in some cases;
- increased risk of water-related and infectious diseases due to disruption of water supply or sewage systems, population displacement and overcrowding;
- release and dissemination of dangerous chemicals from storage sites and waste disposal sites into flood waters.

Floods

Floods are associated with particular dangers to human populations (*107*). Immediate effects are largely death and injuries from drowning and being swept against hard objects. Local infrastructure can be affected severely during a natural disaster. El Niño related damage may include: flood damage to buildings and equipment, including materials and supplies; flood damage to roads and transport; problems with drainage and sewerage; and damage to water supply systems.

During and following both catastrophic and non-catastrophic flooding, there is a risk to health if the floodwaters become contaminated with human or animal waste. A study in populations displaced by catastrophic floods in Bangladesh in 1988 found that diarrhoea was the most common illness, followed by respiratory infection. Watery diarrhoea was the most common cause of death for all age groups under 45 (*108*). In both rural Bangladesh and Khartoum, Sudan, the proportion of severely malnourished children increased after flooding (*109, 110*). In developed countries, both physical and disease risks from flooding are greatly reduced by a well maintained flood control and sanitation infrastructure and public health measures, such as monitoring and surveillance activities to detect and control outbreaks of infectious disease. However, the recent experience of flooding in Central Europe, in which over 100 people died, showed that floods can have a major impact on health and welfare in industrialised countries too (*111*).

Floods also cause psychological morbidity. Following flooding in Bristol, UK, primary care attendance rose by 53% and referrals and admissions to hospitals more than doubled (*112*). Similar psychological effects were found following floods in Brisbane, Australia, in 1974 (*113*). An increase in psychological symptoms and post-traumatic stress disorder, including 50 flood-linked suicides, were reported in the two months following the major floods in Poland in 1997 (*99*).

A number of studies have established a link between dampness in the home, including occasional flooding, with a variety of respiratory symptoms. For example, a Canadian study found that flooding was linked significantly to childhood experience of cough, wheeze, asthma, bronchitis, chest illness, upper respiratory symptoms, eye irritation and non-respiratory symptoms (*114*).

Windstorms and tropical cyclones

Impoverished and high-density populations in low-lying and environmentally degraded areas are particularly vulnerable to tropical cyclones, the majority of deaths caused by drowning in the storm surge (*106*, *115*).

Bangladesh has experienced some of the most serious impacts of tropical cyclones this century, due to a combination of meteorological and topographical conditions and the inherent vulnerability of a low-income, poorly resourced population. Improved early warning systems have decreased the impacts in recent years. However, the experience of Hurricane Mitch demonstrated the destructive power of an extreme event on such a region (*116*).

Droughts

A drought can be defined as "a period of abnormally dry weather which persists long enough to produce a serious hydrologic imbalance" (*118*), or as a "period of deficiency of moisture in the soil such that there is inadequate water required for plants, animals and human beings" (*92*). There are four general types of drought, all which impact on humans, but in different ways (*118*):

1. meteorological: measured precipitation is unusually low for a particular region;
2. agricultural: amount of moisture in the soil is no longer sufficient for crops under cultivation;
3. hydrological: surface water and groundwater supplies are below normal;
4. socioeconomic: lack of water affects the economic capacity of people to survive, i.e. affects non-agricultural production.

The health impacts on populations occur primarily on food production. Famine often occurs when a pre-existing situation of malnutrition worsens: the health consequences of drought include diseases resulting from malnutrition (*105*). In addition to adverse environmental conditions political, environmental or economic crises can trigger a collapse in the food marketing systems. The major food emergency in Sudan during 1998 illustrates the interrelationship between climatic triggers of famine and conflict.

In times of shortage, water is used for cooking rather than hygiene. This increases the risk of diarrhoeal diseases (due to faecal contamination) and water-washed diseases (trachoma, scabies). Outbreaks of malaria can occur due to changes in vector breeding sites (*119*) and malnutrition increases susceptibility to infection.

BOX 5.3 Hurricane Mitch

Hurricane Mitch was the worst disaster to strike Central America in the twentieth century (*95*). It began when a tropical depression, subsequently named Mitch, formed in the southern Caribbean Sea on 21 October 1998. Between 22–26 October, Mitch increased in intensity, developed into a tropical storm and then a Category 5 hurricane (*117*). Winds of up to 295 km per hour struck the coastlines of Nicaragua, Honduras, El Salvador, Guatemala and Belize, followed by heavy continuous rainfall for over 5 days (*95*).

Mitch caused around 9550 deaths; destroyed or affected around 137 851 homes; and affected a population of around 3 174 700 people (*95*, *116*). Yet the effects of the tropical storm/hurricane were worse than these high numbers indicate. This was due to the damage to infrastructure and services that worsened the secondary effects. These secondary effects and additional impacts included (*93*, *95*):

- increase in vectors leading to increased transmission of vector-borne diseases, especially malaria and dengue;
- increases in communicable diseases such as gastrointestinal and respiratory diseases; losses in the production sector: Honduras lost over 70% of banana, coffee and pineapple crops;
- set-backs to development plans: in Honduras reported to be 50 years;
- set-backs in progress in public health;
- set-backs in environmental health caused by flooding of wells and latrines, destruction of water and sanitation systems and leakage of septic tanks and sewerage systems.

Factors that increased the vulnerability of the population of these countries to the effects of this natural disaster include (*116*).

- increased population pressure;
- migration of the population to the more vulnerable areas, such as the low lying coastal areas and along river banks;
- urbanization of the population leading to increased numbers living in poorly constructed houses with little access to health, water and sanitation services;
- marginalisation of the population.

Economic losses were estimated at over US$ 7 billion for the region as a whole (*95*).

Forest fires

The direct effects of fires on human health are burns and smoke inhalation. Loss of vegetation on slopes may lead to soil erosion and increased risk of landslides, often exacerbated when an urban population expands into surrounding hilly and wooded areas.

Air pollution is linked to increased mortality and morbidity in susceptible persons, and increased risk of hospital and emergency admissions. Assessments are being undertaken of the short-term impacts on mortality and morbidity associated with the 1997 El Niño episode. However, such assessments often are limited by lack of baseline data. WHO has published health guidelines for episodic vegetation fires (*120*, *121*).

Conclusions

The increasing trend in natural disasters partly is due to more complete reporting, as well as increasing vulnerability of populations. Poverty, population growth and migration are major contributory factors affecting this vulnerability. Particularly in poor countries, the impacts of major vector-borne diseases and disasters can limit or even reverse improvements in social development; even under favourable conditions recovery from major disasters can take decades.

Quantitative public health forecasts, based on statistical associations between climate variability and health outcomes, will be highly uncertain because future social and economic trends will influence strongly the effects of climate change. It will be possible to carry out qualitative assessments for policy purposes based on less-than-perfect scientific evidence.

There is the potential to use seasonal forecasts to reduce the burden of disease. At present, seasonal forecasts are of most use in the mitigation of drought, food shortages and famine disasters, but the relationships described above could provide the basis for early warning systems for epidemics. Currently available predictive models of climate variability and communicable disease are insufficiently reliable to provide early warning of epidemics. Policy use probably should await validation of these models by analysis of prospective epidemic forecasts.

Seasonal forecasting is only part of an early warning system that must incorporate monitoring and surveillance, as well as adequate response activities. Forecasts of climate extremes could improve preparedness and reduce adverse effects. Focusing attention on extreme events also may help countries to develop better means of dealing with the longer-term impacts of global climate change.

Conversely, the pressures on the biosphere that drive climate change may cause critical thresholds to be breached, leading to shifts in natural systems that are unforeseen and rapid. Studying historical extremes of climate cannot forewarn on the consequences of such events. Rapid changes in climate during extreme events may be more stressful than slowly developing changes due to the greenhouse effect. Thus climatic variables that have the greatest influence in the short-term may not be those with the biggest impact in the longer term.

Adaptive social responses to rapidly occurring periodic extremes of climate may be less effective in the face of progressive climate shifts. For example, increased food imports might prevent hunger and disease during occasional drought, but poor countries are unlikely to be able to afford such measures indefinitely in response to gradual year-by-year drying of continental areas.

Analogue studies of extreme climate events and human health provide important clues about the interactions between climate, ecosystems and human societies that may be triggered by long-term climate trends. Whilst the short term localized effects of simple climate extremes are most readily quantifiable, studies of complex climate extremes provide important qualitative insights into these relationships and the factors affecting population vulnerability.

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