CHAPTER 3

International consensus on the science of climate and health: the IPCC Third Assessment Report

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Introduction

In the early 1990s, there was very little awareness of the risks posed to the health of human populations by global climate change. In part this reflected epidemiologists' limited conventional approach to environmental health. The environment was viewed predominantly as a repository for specific human-made pollutants: in air, water, soil and food, each of which was suspected of posing particular risks to human communities and individual consumers. This was compounded by a general lack of understanding of how the disruption of biophysical and ecological systems might pose threats to the longer-term health of populations. There was also little awareness among physical and natural scientists that changes in their particular objects of study—climatic conditions, biodiversity stocks, ecosystem productivity, and so on—were of potential importance to human health. Indeed, this was clearly reflected in the content of the first major report of the United Nation's Intergovernmental Panel on Climate Change (IPCC), published in 1991. That report devoted just several paragraphs to the possibility that global climate change might affect human health.

Things have changed. The Second Assessment Report of the IPCC (1996) contained a full chapter assessing the potential risks to human population health. The Third Assessment Report (*1*) did likewise, including discussion of the emergence of actual health impacts as well as the larger issue of potential health effects. The Third Assessment Report also included a review of health impacts in regional populations around the world.

The IPCC

Recognizing that global climate change posed a range of potentially serious, often new, hazards to human societies, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The role of the IPCC is to assess published scientific literature on how human-induced changes to the gaseous composition of the lower atmosphere, caused by an increase in the emission of greenhouse gases, are likely to influence world climatic patterns; how this in turn would affect a range of systems and processes important to human societies (including human health); and what range of economic and social response options exists.

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Box 3.1 The IPCC has three Working Groups and a Task Force

Working Group I assesses the scientific aspects of the climate system and climate change.

Working Group II addresses the vulnerability of socioeconomic and natural systems to climate change, the resultant negative and positive impacts of climate change and the options for adaptations to lessen the impacts.

Working Group III assesses options for limiting greenhouse gas emissions and otherwise mitigating climate change.

The Task Force on National Greenhouse Gas Inventories defines and disseminates standardized methods for countries to calculate and report GHG emissions.

The IPCC does not carry out research, neither does it monitor climate-related data or other relevant parameters. Assessments are based on peer-reviewed and other accessible published scientific and technical literature.

A prime source of this chapter is the recent work of Working Group II of the IPCC (WGII), as this was set up as the internationally authoritative scientific review body in climate change and its impacts. Its work has been authorized by national governments through the processes of the United Nations' system; membership has been extensive, international and representative of world scientific skills and opinions, and its review processes have been open to external review by other scientific peers and government scientific advisors.

The scale of the IPCC endeavour is reflected in the size of the reports produced by its working parties and the number of scientists who take part. For instance, the most recent report from WGII is almost a thousand pages long; the list of authors and reviewers includes more than 650 names from 74 countries. Given the number of scientists involved, the formal review processes required and the need to reach consensus, the IPCC is by nature a conservative body.

WGII builds on the reports of Working Group I, in which climatologists describe the evidence that climate is changing due to human intervention, and construct and test the computer models on which future projections of climate are based. Such climate models are based on physical understanding of the climate system and build upon first principles of dynamic systems. Climatic changes due to a specified, plausible, rise in greenhouse gas concentrations can be forecast with greater confidence at global and regional scales than can changes occurring at a local level. How quickly greenhouse concentrations actually rise in future will depend on many factors, including future trends in fertility, economic development, resource consumption levels and technological choices. As a guide to policy-makers, scientists therefore must devise plausible scenarios that include these features of the future world.

It has been usual to view this topic area as comprising three kinds of health impacts. First, those that are relatively direct and foreseeable. Second, the effects that arise via indirect processes of environmental change and ecological disruption, occurring in response to climate change. Third, diverse health consequences—traumatic, infectious, nutritional, psychological and other—that occur in demoralized and displaced populations in the wake of climate-induced economic dislocation, environmental decline and conflict situations.

Our understanding of the impacts of climate change and variability on human health has increased considerably in recent years. However, research in this area faces three main difficulties:

1. It is difficult to describe clearly the main environmental and biological influences on health, while at the same time including important interactions with ecological and social processes. There must be a balance between complexity and simplicity.
2. There are many sources of scientific and contextual uncertainty. The IPCC has sought a satisfactory way to describe the level of confidence that can be assigned to each statement about a particular health impact (see Box 3.2).
3. Climate change is one of several global environmental changes that affect human health. Various large-scale environmental changes now simultaneously impinge on human population health, often interactively (*2*). An obvious example is the transmission of vector-borne infectious diseases. These are affected by: climatic conditions; population movement; forest clearance and land-use patterns; freshwater surface configurations; human population density; and the population density of insectivorous predators (*3*).

The effects of climate on the transmission biology of human diseases

Climate change involves a change in both the mean meteorological values and variability of these values. The anticipated change in mean climatic conditions is expected to be a slow process, occurring over many decades. Climate variability, however, occurs on a time-scale from weeks or months (e.g. storms and floods) to years (e.g. the ENSO cycle, oscillating with an approximately 5-year periodicity).

The health impacts of climate variability are, in general, likely to be more pronounced over the near term than are those of climate change. For example, large

Box 3.2 Dealing with uncertainties

Since the First and the Second IPCC Assessment Reports (1991, 1996), substantial advances have been made in understanding the impacts on health of climate change. Furthermore, the IPCC scientist-authors have attempted to assign a degree of confidence to each of the conclusions in the Third Assessment Report (2001).

In the Summary for Policy-makers for Working Group II, the IPCC (2001) used the following terms to indicate levels of confidence (based upon the collective judgment of the authors):

- ***very high* (95% or greater)**
- ***high* (67–<95%)**
- ***medium* (33–<67%)**
- ***low* (5–<33%)**
- ***very low* (less than 5%)**

In some other evaluative judgements within the Third Assessment Report, the IPCC used a qualitative scale to convey the level of scientific understanding. The scale comprised these categories: *well established*, *established—but-incomplete*, *competing explanations*, *and speculative*.

anomalies in temperature and rainfall in a particular season could cause a number of vector-borne and water-borne epidemics, thereafter the weather could return to normal. Extremes of heat can cause heat exhaustion, cardiovascular disease (heart attacks and strokes) while cold spells can lead to hypothermia and increase morbidity and mortality from cardiovascular disease. Storms, tropical cyclones and extreme rainfall can cause immediate death and injuries, as well as increased risk of water-borne diseases in the medium-term and psychological stress on affected communities in the long-term.

Slow changes in climatic conditions may allow human populations time to adapt. For example, people or communities may develop new ways of coping with, or attenuating, rising residential temperatures. In contrast, abrupt climate changes due to anomalous seasonal climate variability do not allow such opportunities.

The complexities of interactions between environment and host are best shown by the example of vector-borne diseases. The success of pathogens and vectors is determined partly by their reproductive rate. Malaria-carrying mosquito populations can increase tremendously within a very short time. Equally the *Plasmodium* parasite species proliferates rapidly in both mosquito and human hosts. In contrast, tsetse flies have a low reproductive rate and their populations take much longer to increase under favourable conditions. Hence, infectious diseases transmitted by the tsetse fly (including human sleeping sickness) respond less rapidly to variations in climate than do many mosquito-borne infections. Vectors' ability to transmit disease is also affected by feeding frequency. Hard ticks (such as the vectors of Lyme disease) feed more frequently and for shorter periods than soft ticks. Hard ticks therefore tend to be much more efficient vectors of human diseases. Overall, high vector and pathogen reproductive capacity; preference for humans as a source of blood meals; low life cycle complexity; and high sensitivity to temperature changes result in an infectious disease that has high sensitivity to climate variability.

While climate and environmental factors often initiate changes in the rate of disease (e.g. triggering an epidemic) health service interventions often play a major role in containing the spread of disease. Therefore, in disease outbreaks it is often unclear whether the outcome is a result of either altered climatic and environmental conditions or intervention failures. This is an example of the general problem, it is known that climate has an effect on infections and other health problems but it is difficult to tell *how much* disease and injury can be attributed to this factor.

Mathematical models provide one important means to answer the "what if?" question about the future effects of climate change on infectious disease occurrence. Both biologically based and statistical-empirical models have been used in recent years. More sophisticated integrated models are being developed to take into account the effects of other determinants such as economics and human behaviour. Historical examples of the health correlates of climate variability, such as the El Niño phenomenon, also provide insights into possible future climate and health scenarios.

The traditional role of surveillance in epidemiological assessment of diseases may not stand up to the speed with which epidemics evolve under climate change. Quite often it is difficult to tell whether a rise in the number of cases of malaria is simply normal seasonal variation or the beginning of a large-scale epidemic. At first the number of cases grows slowly, but may rapidly move into a phase of exponential growth, in which case the health care system may be over-

whelmed. Hence the value of disease forecasting methods that can estimate the size of a developing epidemic depending on the level of climate anomaly.

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Bearing in mind the general caveat that they are necessarily operating within a penumbra of uncertainty, scientists have estimated the likely range of future health impacts of climate change on human health. For the moment, the most comprehensive and widely reviewed estimates come from the work of the IPCC and the remainder of this chapter therefore provides an overview of that assessment. Unless otherwise specified, all references are to the contribution of WGII to the Third Assessment Report.

The Third Assessment Report included sectoral and regional analyses of published literature related to impacts of climate change. The Report considered the weight of evidence supporting its conclusions and attributed levels of confidence to the conclusions (these can be found in the technical summary of the IPCC-TAR: see Box 3.2 above).

The health chapter in the WGII report included a discussion of specific diseases and regions that have been impacted upon by climate variability, vulnerable populations and their adaptation options and capacity. The overall conclusion was that global climate change will have diverse impacts on human health—some positive, most negative. Changes in the frequencies of extreme heat and cold, of floods and droughts, and the profile of local air pollution and aeroallergens would affect population health directly. Other indirect health impacts would result from the effects of climate change on ecological and social systems. These impacts would include changes in occurrence of infectious diseases, local food production and under-nutrition, and various health consequences of population displacement and economic disruption.

As yet, there is little firm evidence that changes in population health status have occurred in response to observed trends in climate over recent decades. A recurring difficulty in identifying such impacts is that the causation of most human disorders is multi-factorial, and the background socioeconomic, demographic and environmental contexts change over time, so that conclusively proving (or disproving) a link with climate change is highly problematic.

Direct effects on health

Heatwaves and other extreme events

Human populations have, over time, acclimatized and adapted to local climates and also are able to cope with a range of weather changes. However, within populations, there is a range of individual sensitivity to extreme weather events. If heatwaves increase in frequency and intensity, the risk of death and serious illness would increase principally in the older age groups, those with pre-existing cardio-respiratory diseases, and the urban poor. The effects of an increase in heatwaves often would be exacerbated by increased humidity and urban air pollution. The greatest increases in thermal stress are forecast for mid to high latitude cities, especially in populations with unadapted architecture and limited air conditioning.

Modelling of heatwave impacts in urban populations, allowing for acclimatization, suggests that many United States' cities would experience, on average, several hundred extra deaths each summer (*4*). Although climate change may

have considerable impact on thermal stress-related mortality in cities in developing countries, there has been little research in such populations. Warmer winters and fewer cold spells will decrease cold-related mortality in many temperate countries. In some instances in the temperate zones, reduced winter deaths probably would outnumber increased summer deaths (*5*).

Any increase in frequency of extreme events such as storms, floods, droughts and cyclones would harm human health through a variety of pathways. These natural hazards can cause direct loss of life and injury and affect health indirectly through loss of shelter; population displacement; contamination of water supplies; loss of food production (leading to hunger and malnutrition); increased risk of infectious disease epidemics (including diarrhoeal and respiratory diseases); and damage to infrastructure for provision of health services. If cyclones were to increase regionally, there might be devastating impacts particularly in densely settled populations with inadequate resources. Over recent years climate-related disasters have caused hundreds of thousands of deaths in countries such as China, Bangladesh, Venezuela and Mozambique.

Air pollution

Weather conditions can influence the transportation of air-borne pollutants, pollen production and levels of fossil fuel pollutants resulting from household heating and energy demands. Climate change may increase the concentration of ground level ozone but the magnitude of the effect is uncertain (*6*). For other pollutants, the effects of climate change and/or weather are even less well known.

Climate change is expected to increase the risks of forest and rangeland fires and associated smoke hazards. Major fires in 1997 in south-east Asia and the Americas were associated with increases in respiratory and eye symptoms (*7*). In Malaysia, a two to three fold increase in outpatient visits for respiratory disease and 14% decrease in lung function in school children was reported.

Aeroallergens

Experimental research has shown that doubling CO_2 levels from about 300 to 600 ppm induces a four-fold increase in the production of ragweed pollen (*8*, *9*). Pollen counts from birch trees (the main cause of allergies in northern Europe) rise with increasing temperature (*10*).

Indirect effects on health

Food production and supply

Climate change will have mixed effects on food production globally. Most of the research to date has focused on cereal grain production—an important indicator of total food production, since it accounts for around 70% of global food energy. The probability of reduced food yields is, in general, greatest in developing countries where it is estimated that approximately 790 million people currently are undernourished (*11*). Populations in isolated areas with poor access to markets will be particularly vulnerable to local decreases or disruptions of food supply.

Vector-borne infectious diseases

Recent studies of disease variations associated with inter-annual climate variability (such as those related to the El Niño cycle) have provided much useful

evidence of the sensitivity to climate of many disease processes. This is particularly so for mosquito-borne diseases. The combination of knowledge from such empirical research; the resultant theoretical understanding of biological and ecological processes; and the output of scenario-based modelling; leads to several conclusions about the future effects of climate change on human populations.

Higher temperatures, changes in precipitation and climate variability would alter the geographical range and seasonality of transmission of many vector-borne diseases. Mostly, range and seasonality would be extended; in some cases reduced. Currently 40% of the world population lives in areas in which endemic malaria occurs (*12*). In areas with limited or deteriorating public health infrastructure, increased temperatures will tend to expand the geographical range of malaria transmission to higher altitudes and latitudes. Higher temperatures in combination with conducive patterns of rainfall and surface water will extend the transmission season in some locations. Changes in climate mean conditions and variability would affect many other vector-borne infections (such as dengue, leishmaniasis, Lyme disease, and tick-borne encephalitis) at the margins of their current distributions. For some vector-borne diseases in some locations, climate change will decrease the likelihood of transmission via a reduction in rainfall, or temperatures that are too high for transmission.

A range of mathematical models, based on observed climatic effects on the population biology of pathogens and vectors, indicate that climate change scenarios over the coming century would cause a small net increase in the proportion of the world population living in regions of potential transmission of malaria and dengue (*13*, *14*, *15*). An alternative modelling approach, based on a direct correlation of the observed distribution of disease distribution against a range of climate variables, suggests that there will be little change in malaria distributions, as areas that become permissible for transmission are balanced by others that become unsuitable for at least one climatic factor. Neither approach attempts to incorporate the effects of socioeconomic factors or control programmes on the distribution of current or future disease.

Water-borne infectious diseases

There are complex relationships between human health and water quality, water quantity, sanitation and hygiene. Increases in water stress are projected under climate change (see chapter 4, IPCC –TAR WG II), but it is difficult to translate these changes into risk of water-related diseases.

Heavy rainfall events can transport terrestrial microbiological agents into drinking-water sources resulting in outbreaks of crytosporidiosis, giardiasis, amoebiasis, typhoid and other infections (*19*, *20*, *21*, *22*). Recent evidence indicates that copepod zooplankton provide a marine reservoir for the cholera pathogen and thereby facilitate its long-term persistence and disseminated spread to human consumers via the marine food-web (*23*). Epidemiological evidence has pointed to a widespread environmental cause for recent outbreaks of cholera, rather than a point source contamination as seen in Peru in 1991 and East Africa in 1997/98. Strong links are found between cholera infections, bathing and drinking water from east African lakes (*24*). Cholera epidemics also are associated with positive surface temperature anomalies in coastal and inland lake waters (*23*).

Global warming is expected to lead to changes in the marine environment that alter risks of bio-toxin poisoning from human consumption of fish and shellfish. For example, bio-toxins associated with warm waters, such as ciguatera in

TABLE 3.1 Main vector-borne diseases: populations at risk and burden of diseases. *Based on data from reference 1, with updated DALY estimates from reference* (16).

Disease	Vector	Population at risk	Number currently infected or new cases per year	Disability adjusted life years lost[a]	Present distribution
Malaria	Mosquito	2400 million (40% world population)	272 925 000	42 280 000	Tropics/subtropics
Schistosomiasis	Water snail	500–600 million	120 million	1 760 000	Tropics/subtropics
Lymphatic filariasis	Mosquito	1000 million	120 million	5 644 000	Tropics/subtropics
African trypanosomiasis (Sleeping sickness)	Tsetse fly	55 million	300 000–500 000	1 598 000	Tropical Africa
Leishmaniasis	Sand Fly	350 million	1.5–2 million	2 357 000	Asia, Africa, Southern Europe, Americas
Onchocerciasis River blindness	Black fly	120 million	18 million	987 000	Africa, Latin America, Yemen
American trypanosomiasis (Chagas' disease)	Triatomine bug	100 million	16–18 million	649 000	Central and South America
Dengue	Mosquito	3000 million	Tens of millions	653 000[b]	All tropical countries
Yellow fever	Mosquito	468 million in Africa	200 000	Not available	Tropical South America and Africa
Japanese encephalitis	Mosquito	300 million	50 000	767 000	Asia

[a] The Disability–Adjusted Life Year (DALY) is a measure of population health deficit that combines chronic illness or disability and premature death (17). Numbers are rounded up to nearest 100 000.
[b] Other analyses suggest this value could be as high as 1 800 000 (*18*).

tropical waters, could extend their range to higher latitudes. Higher sea surface temperatures also would increase the occurrence of algal blooms that may affect human health directly, and which are also ecologically and economically damaging.

Changes in surface water quality and quantity are likely to affect the incidence of diarrhoeal diseases (*25*). This group of diseases includes conditions caused by bacteria such as cholera and typhoid as well as parasitic diseases such as amoebiasis, giardiasis and cryptosporidium. Infections with cholera and typhoid bacteria are dependent on the concentration of the pathogens in water or food. Currently the World Health Organization (WHO) estimates more than one billion people worldwide to be without access to safe drinking water, and that every year approximately 1.7 million die prematurely because they do not have access to safe drinking water and sanitation (*16*). Climate can increase directly the amount of pathogen in the water through increasing the biotic reservoir of the infectious agent (cholera) or by decreasing the amount of water in a river or a pond and thus raising concentration of the bacteria (typhoid). Floods can cause contamination of public water supplies with both bacteria and parasites as surface discharge flows into rivers and reservoirs, while drought can increase the concentration of pathogens in the limited water supplies. A reduction in the availability of clean water increases the risk of drinking contaminated supplies and also reduces the amount of water available for personal hygiene thus leading to skin infections.

Effects of social and economic disruptions

In some settings, the impacts of climate change may cause severe social disruptions, local economic decline and population displacement that would affect human health (*26*). Of particular concern is the impact of a rising sea level (estimated, with a wide band of uncertainty, at around 0.5 m over the coming century) on island and coastal populations currently living not far above the shoreline. Population displacement resulting from sea level rise, natural disasters or environmental degradation is likely to lead to substantial health problems, both physical and mental.

Assessments of health impacts by IPCC region

Africa

Africa has a number of climate-sensitive diseases, the most prominent being malaria, meningitis and cholera.

Malaria epidemics in the past 15 years have been reported mainly in the highlands of east Africa, Rwanda and Zimbabwe, associated with inter-annual climate variability (such as the occurrence of El Niño events). Following flooding in the arid regions of Somalia and Kenya, malaria outbreaks were reported during the 1997/98 El Niño event. Meanwhile, in the Sahel region malaria transmission has declined in the past 30 years due to long-term drought.

From 1931 (when Rift Valley Fever was first described) until the end of the 1970s, the disease was considered to be a relatively benign zoonosis that developed periodically in domestic animals (especially sheep) following heavy rains (*27*). Thereafter extensive research on mosquito vectors of Rift Valley Fever in Kenya (mainly *Aedes* and *Culex* species) clearly has linked the risk of outbreaks with flooding (*28*). Following the 1997/8 El Niño event in East Africa, a Rift Valley Fever outbreak in Somalia and northern Kenya killed up to 80% of livestock and affected their owners (*29*). In West Africa the disease is linked to epizootic diseases with increased risks during the wet season. The IPCC (2001) concluded that increased precipitation as a consequence of climate change will increase the risk of infections of this kind to livestock and people.

Currently the seventh cholera pandemic is active across Asia, Africa and South America. During the 1997/98 El Niño, the rise in sea-surface temperature and excessive flooding (*29*) provided two conducive factors for cholera epidemics which were observed in Djibouti, Somalia, Kenya, Mozambique and the United Republic of Tanzania, all of which border the Indian Ocean. Cholera epidemics also have been observed in areas surrounding the Great Lakes in the Great Rift Valley region. A significant association between bathing, drinking water from Lake Tanganyika and the risk of infection with cholera has been found (*24*). It is likely that warming in these African lakes may cause conditions that increase the risk of cholera transmission.

TABLE 3.2. Summary of the number of countries in Africa that reported disease outbreaks to WHO from January 1997 to June 1999 (*1*).

Disease	1997	1998	1999 January–July
Malaria	0	2	2
Rift Valley Fever	0	4	1
Yellow Fever	1	1	0
Meningitis (bacterial)	3	2	4
Plague	2	1	2
Cholera	8	10	7
Dengue	0	0	0

Major epidemics of bacterial meningococcal infection

usually occur every five to ten years within the African meningitis belt, and typically start in the middle of the dry season and end a few months later with the onset of the rains (*30*). Between February and April 1996, the disease affected thousands of people in parts of northern Nigeria, many of whom died (*31*). This epidemic spread from the traditional meningitis belt to Kenya, Uganda, Rwanda, Zambia and the United Republic of Tanzania (*32*). One of the environmental factors that predispose to infection and epidemics is low humidity (*33*). To date this disease has been limited to the semi-arid areas of Africa, suggesting that future distribution could expand due to increased warming and reduced precipitation.

Plague is a flea-borne disease and the major reservoirs of infection are rodents such as the common rat. Rodent populations fluctuate widely with the availability of food which in turn depends on rainfall. Exceptionally heavy rainfall can increase food abundance; as a consequence the population of rodents and fleas may multiply rapidly. During severe droughts, rodents may leave their wild habitats in search of food in human houses and this can also increase the risk of plague transmission. Plague outbreaks in Africa have in the last few years been reported in Mozambique, Namibia, Malawi, Zambia and Uganda (See Table 3.2 above).

Asia

In Asia, as in Africa, the main health concerns under climate change and variability are malaria and cholera, but thermal stress and air-pollution related illnesses also are important. Malaria still is one of the most important vector-borne diseases in India, Bangladesh, Sri Lanka, Thailand, Malaysia, Cambodia, the Lao People's Democratic Republic, Viet Nam, Indonesia, Papua New Guinea and parts of China. Vector resistance to insecticides, and parasites' to chloroquine, compound the problem of malaria control. The IPCC concluded that changes in environmental temperature and precipitation could expand the geographical range of malaria in the temperate and arid parts of Asia.

Water-borne diseases such as cholera, and various diarrhoeal diseases such as giardiasis, salmonellosis and cryptosporidiosis, occur commonly with contamination of drinking water in many south Asian countries. These diseases could become more frequent in many parts of south Asia in a warmer climate.

The direct effects of heat are important public health issues in this region. The heat index (derived from daily mean temperature, and humidity) is closely related to the occurrence of heat stroke in males aged 65 years and above residing in Tokyo. In the city of Nanjing, China, a marked increase in the number of heat stroke patients and mortality was observed when the maximum daily temperature exceeded 36 °C for 17 days during July 1988. Similar events were observed when the temperature exceeded 31 °C in Tokyo, Japan.

Australia and New Zealand

In Christchurch, New Zealand, an increase of 1 °C above 21.5 °C was associated with a 1.3% increase in all-cause mortality. There were more than the expected numbers of deaths in winter also, although this was not statistically significant. Since 1800, deaths specifically ascribed to climate hazards have averaged about 50 per year in Australia (*34*), of which 60% are estimated to be caused by heat-waves, 20% by tropical cyclones and floods. Climate change would increase the

number of heatwaves in Australia but the future frequency of storms and floods is less certain.

In Australia the number of notified cases of arbovirus infections (caused by insect-borne virus) appears to have increased in recent years. Exotic species such as *Aedes albopictus* and *Aedes camptorhynchus*, competent vectors of (respectively) the dengue and Ross River viruses, have been detected in New Zealand. Outbreaks of Ross River virus disease and Murray Valley encephalitis in south-eastern Australia tend to follow heavy rainfall events. In south-western Australia the major vector for Ross River virus is the salt-water breeding mosquito *Ae. camptorhynchus,* and variations in sea level have been associated with outbreaks. Climate scenarios suggest that conditions in some parts of Australia and New Zealand will become more favourable for the transmission of several vector-borne diseases. However, whether this potential risk will translate into an increase in cases of disease will depend on other factors such as the maintenance and expansion of the public health surveillance and response system.

Ozone and other photochemical oxidants are a concern as air pollutants in several major Australian cities and in Auckland, New Zealand (*35*). In Brisbane, Australia, current levels of ozone and particulates have been associated with increased hospital admission rates (*36*). Warm weather promotes formation of these pollutants, although other factors such as wind speed and cloud cover are also important, if more difficult to anticipate.

Europe

The major impacts of climate change and variability on health in Europe are mainly via thermal stress and air pollution, vector and food-borne diseases, water-related diseases and flood effects.

In many European cities total daily mortality rises as summer temperatures increase. Heatwaves in July 1976 and July–August 1995 were accompanied by a 15% increase in mortality in Greater London and particularly from cardio-respiratory diseases at older age (*37*, *38*). A major heatwave in July 1987 in Athens was associated with 2000 excess deaths (*39*, *40*). Warmer winters, however, would result in reduced cold-related mortalities. It has been estimated that 9000 deaths per year could be avoided by 2025 in England and Wales under a 2.5 °C increase in average winter temperature (*41*).

With deteriorating health systems, the recent resurgence of malaria in south-eastern Europe could be amplified by a warmer climate. Small numbers of locally transmitted cases currently occur in the Mediterranean region (*42*). However, existing public health resources and reduction of breeding habitats for *Anopheles* mosquitoes make it unlikely that malaria will re-emerge on a large scale in western Europe, whatever changes take place in the climate. There has been no dengue transmission in Europe in recent times, but the appearance of the vector *Aedes albopictus* in Italy and Albania is a matter of concern.

The two common forms of leishmaniasis: visceral and cutaneous, are transmitted to humans and dogs in all the Mediterranean countries by phlebotomine flies (*43*). This disease is associated with dry habitats. Higher temperatures are likely to shift northwards the range of the disease.

Lyme disease and tick-borne encephalitis (TBE) are transmitted by hard ticks such as *Ixodes ricinus* and *I. persulcatus* found in the temperate regions of Europe. Recent observations in Sweden suggest that the incidence of TBE has increased following milder winters in combination with extended spring and autumn in

two successive years (*44*). There is also some evidence that the northern limit of the tick's distribution in Sweden has shifted northwards as a result of a higher frequency of milder winters (*44*, *45*, *46*), although this relationship remains contentious (*47*). Climate change may extend the tick-borne disease transmission season and also its range towards the north, but disrupt transmission in more southerly regions (*48*).

Some countries in eastern Europe with restricted access to water at home could be affected by any climate-related decrease in supplies. For instance, an increase in the frequency and intensity of extreme precipitation could increase the risk of transmission of cryptosporidiosis.

The distribution of carriers of food-borne diseases such as flies, cockroaches and rodents could change due to climate change. In the United Kingdom of Great Britain and Northern Ireland, a study of food-borne illness found a strong relationship between incidence and temperature in the month preceding the illness (*49*).

Leptospirosis, a disease associated with flooding, is a major concern in some parts of Europe. Outbreaks of the disease have been reported following floods in Ukraine and the Czech Republic in 1997 (*50*, *51*) and Portugal in 1967 (*52*). As well as the direct injuries and infections resulting from flooding, psychological distress including cases of suicide has been associated with the event.

Latin America

Like other regions located in the tropics, some parts of Latin America are home to many tropical infectious diseases such as malaria, dengue, leishmaniasis, yellow fever, Chagas' disease and cholera. The regional assessment of health impacts in the region indicated that the main concerns are heat stress, malaria, dengue, cholera and other water-borne diseases. The region also has been particularly affected by extreme weather events, notably those associated with El Niño.

Although Latin America is home to many vector-borne diseases, few cases of climate driven diseases outbreaks were reported in the Third Assessment Report of the IPCC. However, it was noted that near the equator in Iquitos, Peru, the seasonality of malaria transmission is driven by small temperature fluctuations of 1–2°C (*53*). Changes of this magnitude can be expected to occur with global warming and this may drive disease transmission to higher altitudes and lower latitudes in Latin America. However, in some parts of the region, increases in temperature could reduce malaria transmission as has been observed in the southern part of Honduras.

In semi-arid zones in Mexico, rainfall has been observed to cause outbreaks of bubonic plague (*54*), probably as a result of an increase in the rodent reservoirs. Rodents escaping floods in Colombia are suspected to have been the primary cause of leptospirosis outbreaks. The effects of water-borne diseases are well documented in this region. Between 1991 and 1996 cholera affected 21 counties in Peru resulting in almost 200 000 cases and 11 700 deaths. Climate variability was linked to later outbreaks in Peru and Ecuador during the 1997/98 El Niño event. Besides cholera in Peru, other diarrhoeal diseases such as *Salmonella typhi* have been linked to environmental change, climate and sanitary conditions.

Considering all causes of disease and injury, it is apparent that the El Niño weather phenomenon has particularly strong effects on health in Latin America.

In 1983, during a particularly strong event, total mortality increased by 40% and infant mortality by 103% in Peru (*55*).

North America

The direct impacts of climate change and variability in this region include heat stress, injury and mortality due to convective storms, floods, hurricanes, tornadoes and ice storms.

Photochemical smog and fine particulate matter are important environmental health issues in this region. It is unclear precisely what effect climate change will have on urban air quality in North America, but higher temperatures increase the risk of significant photochemical smog. In 1997, approximately 107 million people in the United States lived in counties that did not meet air quality for at least one regulated pollutant (*56*), while more than half of Canadians live in areas where ground level ozone may reach unacceptable levels during summer months (*57*). In the United States floods are the most frequent, and the leading cause of death from, natural disasters. The mean annual loss of life has been estimated to be 147 deaths (*56*). In Canada the Red River flood of 1997 displaced more than 25 000 people (*58*).

The areas of the United States most vulnerable to heat-related illnesses appear to be the north-east and mid-west. Recent examples of heat-related deaths include 118 persons in Philadelphia in 1993 (*59*), 91 persons in Milwaukee and 726 in Chicago in 1995 (*60*). In Canada, the urbanized area of south-eastern Ontario and Quebec could be affected very negatively by warmer temperatures as shown by modelling studies (*61*). However, warmer winters could result in fewer cold related deaths.

The frequency of natural disasters may be increasing in the United States. There were less than 20 natural disasters reported annually in the 1950s and 1960s, but more than 40 per year in the 1990s (*62*). Ice storms can have very large negative impacts, as demonstrated by the January 1998 event—this left 45 dead and nearly 5 million people without electricity in winter in Ontario, Quebec and New York (*63*).

Several vector-borne diseases are endemic in North America. The World Health Organization declared the United States free of malaria in 1970, while in Canada the disease disappeared at the end of the nineteenth century. However, other climate sensitive vector-borne diseases in the United States include Lyme disease, Rocky Mountain spotted fever, St Louis encephalitis (SLE), western equine encephalitis (WEE) and snowshoe hare virus (SHV). Dengue transmission occurs in Mexico and to a much lesser extent in Texas. Hantavirus is now the major rodent-borne disease, and cryptosporidiosis and giardiasis the most common water-borne diseases.

Lyme disease is the most common vector-borne condition in the United States, approximately 10 000 cases being reported in 1994. However, in Canada where the tick vector has been reported, no disease transmission has been detected. It is expected that, with climate change, Lyme disease and Rocky Mountain spotted fever could spread to Canada.

Hantavirus infection (in humans a severe disease with a mortality rate around 40%) was associated with unusually prolonged rainfall in the 1991–92 El Niño (*64*), and by 1999, 231 cases had been reported in the United States (*56*). A number of cases subsequently have been reported in Canadian provinces of British Colombia, Alberta and Saskatchewan. This disease is sensitive to changes

in climate and ecology, but because of difficulties in predicting local rainfall it is difficult to predict the likely changes in the prevalence of hantavirus pulmonary syndrome in the United States and Canada (*57*).

Of the water-borne diseases, giardia cysts are fairly common in treated water in Canada (18.2%) and very frequent in raw sewage samples (73%) (*65*). The pathogen cryptosporidium also is widely distributed and capable of causing large-scale outbreaks. For example, in 1993, more that 400 000 cases (including 54 deaths) from a cryptosporidium outbreak were reported in Milwaukee, Wisconsin (*66*). A positive correlation between rainfall, concentration in river water and human diseases has been noted for both cryptosporidiosis and giardiasis.

Polar regions

At the time of the Third Assessment Report of the IPCC no studies were available on the impacts of climate change on human health in the polar region. A number of studies have been conducted subsequently and a summary report, the Arctic Climate Impact Assessment, is being prepared by the Arctic Council (an intergovernmental forum of countries making up the Arctic region), and the International Arctic Science Committee (a non-governmental organization for research and co-operation in the region).

Small island states

Many tropical islands report outbreaks of vector-borne and water-borne infectious diseases that are attributed, in part, to changes in temperature and rainfall regimes. In some regions, e.g. the Pacific, it has been noted that extreme weather events appear to be occurring at a greater frequency than elsewhere (*67*). As a consequence, physical injuries arising from these events can be expected to increase. Some of the small island states such as the Bahamas, Kiribati, the Marshall Islands and the Maldives are a mere 2–4 m above sea level, which predisposes them to inundation with seawater and consequent salinization of fresh water supplies and flooding from sea level rise.

Post-TAR assessments

The IPCC TAR assessment ended in 2001, however other regional and country specific assessments have since begun. In Europe and a number of developing countries, a post TAR assessment on adaptation strategies is being carried out 2001–2004. The results of these assessments will be reviewed in the fourth assessment of the IPCC.

Conclusions

The IPCC found that global climate change will affect human health in many ways. Overall, negative effects are expected to outweigh positive impacts. Important influences on health will include changes in the frequency and intensity of extremes of heat, cold, droughts, floods, hurricanes, tornadoes and other forms of extreme weather. Climate change also will impinge on health by disrupting ecological and social systems, resulting in changes in infectious disease transmission, food production, air pollution, population displacement and other forms of social disruption.

Climate change impacts on health that were judged to be of high confidence included increased heat-related mortality and morbidity; decreased cold-related mortality in temperate countries; greater frequency of infectious disease epidemics following floods and storms; and substantial health effects following population displacement from sea level rise and increased storm activity.

For each of the potential impacts of climate change it is possible to identify groups that will be particularly vulnerable to disease and injury. For instance, those most at risk of suffering harm from thermal extremes will include socially isolated city dwellers, the elderly and the poor. Populations living at the present margins of malaria and dengue, and without effective primary health care, will be most susceptible if these diseases expand their range in a warmer world.

The IPCC report shows that understanding of the links between climate, climate change and human health has increased considerably in the last ten years. However, there are still many uncertainties. There are many gaps in knowledge of exposure, vulnerability and adaptability of physical, ecological and social systems to climate change. The next chapter explores the challenges faced by researchers as they strive to fill these gaps and provide a stronger information base for responses to climate change.

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