Harben Lecture

Climate change and human health: impacts, vulnerability, and mitigation

A Haines, R S Kovats, D Campbell-Lendrum, C Corvalan

It is now widely accepted that climate change is occurring as a result of the accumulation of greenhouse gases in the atmosphere arising from the combustion of fossil fuels. Climate change may affect health through a range of pathways—eg, as a result of increased frequency and intensity of heat waves, reduction in cold-related deaths, increased floods and droughts, changes in the distribution of vector-borne diseases, and effects on the risk of disasters and malnutrition. The overall balance of effects on health is likely to be negative and populations in low-income countries are likely to be particularly vulnerable to the adverse effects. The experience of the 2003 heat wave in Europe shows that high-income countries might also be adversely affected. Adaptation to climate change requires public-health strategies and improved surveillance. Mitigation of climate change by reducing the use of fossil fuels and increasing the use of a number of renewable energy technologies should improve health in the near term by reducing exposure to air pollution.

Lancet 2006; 367: 2101–09

See **Comment** page 2039

London School of Hygiene and Tropical Medicine, London, UK (Prof A Haines MD, R S Kovats MSc); **and WHO, Geneva, Switzerland** (D Campbell-Lendrum DPhil, C Corvalan PhD)

Correspondence to:
Prof A Haines, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK
Andy.Haines@lshtm.ac.uk

Published simultaneously with *Public Health*; DOI:10.1016/j.puhe.2006.01.002

Introduction

It has been known for thousands of years, at least since the time of Hippocrates, that climate has wide ranging impacts on health. Increasing recognition of the process of climate change has led to a growing interest by health researchers in assessing the potential mechanisms by which changes in climate could influence health (figure 1). Such health effects will be modulated by factors such as socioeconomic development and by the degree to which effective adaptation measures are implemented. Although most studies have assessed the potential impacts of climate change in isolation from other environmental changes, in reality climate change will be experienced against a background of other global changes—eg, population growth, urbanisation, land use changes, and depletion of fresh water resources—that themselves have implications for health and that could, in some instances, interact with climate change to magnify the impacts.

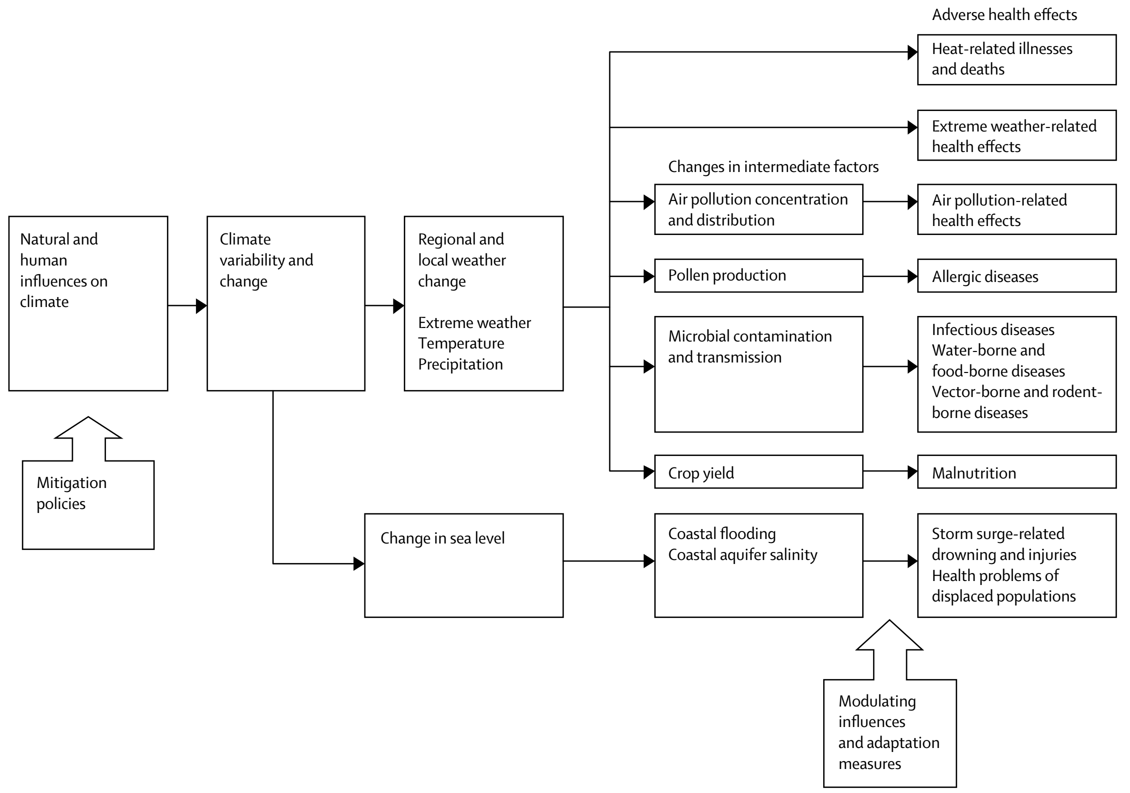
This article was the subject of the 2005 Harben Lecture of the Royal Institute of Public Health given by one of us (AH). It covers some of the ground of previous overviews[1,2] but adds discussion of adaptation options and the potential use of "mitigation strategies"—eg, energy efficiency and renewable technologies—to contribute to near-term reductions in mortality.

There are several mechanisms by which climate can affect health. Extremes of temperature and rainfall—eg, heat waves, floods, and drought—have direct immediate effects on mortality as well as longer-term effects. For example, populations that have experienced flooding may suffer from sustained increases in common mental disorders.[3] Climate change is also likely to affect biodiversity and the ecosystem goods and services that we rely on for human health. Changes in temperature and rainfall may also affect the distribution of disease vectors—eg, those of malaria and dengue—and the incidence of diarrhoeal diseases. Climate can affect levels of air pollutants—eg, tropospheric ozone pollution may be higher in some areas of Europe and lower in others—but the relations are still imperfectly understood.[4] Sea level rise is likely to threaten low lying coastal populations, particularly in countries where economic conditions do not allow construction of sea defences and other counter measures. There are also concerns that flooding, drought, and environmental degradation associated with climate change may lead to population displacement and more environmental refugees.

Research on the health impacts of climate change addresses three main topics: current associations between climate and disease, the effect of recent changes in climate, and the evidence base for projecting the future impacts of climate change on health (figure 2). Temperatures have been increasing globally for the past two to three decades. The detection and attribution of health effects to these changes has become a key research challenge.[5] This climate warming is projected to continue and accelerate, so that by the end of this century global mean temperature will have increased by 1·4–5·8°C.[6] Effects at the upper end of the range are more difficult to predict and likely to be more seriously adverse.[7]

Has observed climate change already been affecting human health?

A growing number of studies present evidence for the effects of observed climate change on vector-borne and other infectious diseases. Although the literature to date does not constitute strong evidence of an impact of climate change on human vector-borne diseases (eg, malaria), there is now evidence of vector species responding to recent climate change in Europe.[8] There have been latitudinal shifts in ticks that carry tick-borne encephalitis in northern Europe,[9,10] although alternative explanations—eg, changes in confounding factors like land use or in socioeconomic, demographic, and other environmental factors—remain plausible.



Mitigation policies for reduction of greenhouse gas emissions
Energy efficiency
Use of renewable energy sources
Forest preservation and replanting

Modulating influences
Population density and growth
Level of technological development
Standard of living and local environmental conditions
Pre-existing health status
Quality of and access to health care
Public-health infrastructure

Adaptation measures
Vaccination programmes
Disease surveillance
Protective technologies
Weather forecasting and warning systems
Emergency management and disaster preparedness
Public-health education and prevention
Legislation and administration

Figure 1: **Potential health effects of climate variability and change**
Reproduced from reference 1, with permission from the American Medical Association.

There is some evidence for changes in the frequency of weather extremes over recent decades.[6] Many health outcomes are sensitive to isolated extreme events (eg, heavy rainfall, high temperatures). Analyses of the 2003 heat wave in Europe have concluded that it was a truly extreme event and the summer of 2003 was probably the hottest in Europe since 1500.[11] Climatologists now consider it "very likely" that human influence on the global climate has at least doubled the risk of a heat wave such as that experienced in 2003.[12] Recent evidence has also emerged about a possible causal role of climate change (and specifically the warming of sea surface temperatures) in increasing the intensity of tropical cyclones,[13,14] although a single event such as Hurricane Katrina, which caused major or catastrophic damage along the coastlines of Louisiana, Mississippi, and Alabama in 2005, cannot be definitely attributed to climate change.

Where health surveillance data are available for several decades up to the present day, it may be possible to determine whether any observed changes in disease might be related to changes in climate. Interpretation is complicated by potential competing explanations due to changes in important health determinants over time, as well as changes in the way in which diagnoses may be recorded. Empirical observation of the health consequences of recent climate change, followed by formulation, testing, and then modification of hypotheses would require long time-series (probably several decades) of careful monitoring. Although this process may accord with the principles of empirical science, it would not provide the timely information needed to inform current policy decisions on greenhouse gas emission abatement, so as to offset possible health consequences in the future. Nor would it allow early implementation of policies for adaptation to some level of climate change, which is now inevitable owing to past greenhouse gas emissions. Therefore, the best estimation of the future health effects of climate change will necessarily come from risk assessment based on our current understanding of the effects of climate variation on health from observations made in the present and recent past, acknowledging the influence of a large range of modulating factors.

Observations of short-term variations in climate or weather show that even small temperature increases and precipitation changes can result in measurable impacts on malaria, diarrhoeal episodes, injuries related to floods, and malnutrition. Knowledge of these relations allows approximate estimates of the health effects of past and future climate change to be made.

Heat waves

Mortality rises in hot weather, especially in elderly people. It is very likely that climate change will be associated with increases in the frequency of heat waves.[15] More than 2000 excess deaths were reported in England and Wales[16] during the major heat wave that affected most of western Europe in 2003 (table 1).[16–23] The greatest impact on mortality occurred in France, where it was estimated that 14 800 excess deaths occurred during the first 3 weeks of August 2003 than would be expected for that time of year.[18] Deaths in Paris increased by 140%.[24] The sustained period of extreme high temperatures (including the minimum temperature), unique in the recorded history of Paris, together with housing designed for cooler summers, caused a major public-health crisis.

Much of the excess mortality from heat waves is related to cardiovascular, cerebrovascular, and respiratory causes and is concentrated in elderly people. A proportion of these deaths occur in susceptible people who would probably have died in the near future, but there are likely to be substantial numbers of potentially preventable deaths. In the August 2003 event, the mortality patterns indicate that the contribution of short-term mortality displacement was relatively small.[25]

Urban centres are often particularly affected because of the urban heat island effect, which results in the temperatures being somewhat higher than the surrounding suburban and rural areas. Air pollution concentrations may also rise during heat waves and may contribute to the raised death rates. The recent experience of the heat wave in Europe demonstrated that, even in high-income countries, such events can cause large numbers of deaths in the absence of a coordinated response to ensure that elderly people are kept cool and well hydrated.

The impact of extreme summer heat on human health may be exacerbated by increases in humidity. A central question in estimating future heat-related and cold-related mortality is the rate at which populations will adapt to a warmer climate. Populations are likely to acclimatise to warmer climates via a range of behavioural, physiological, and technological adaptations. The initial physiological acclimatisation to hot environments can occur over a few days, but complete acclimatisation may take several years. The rate at which changes will take place in infrastructure is likely to be much slower.

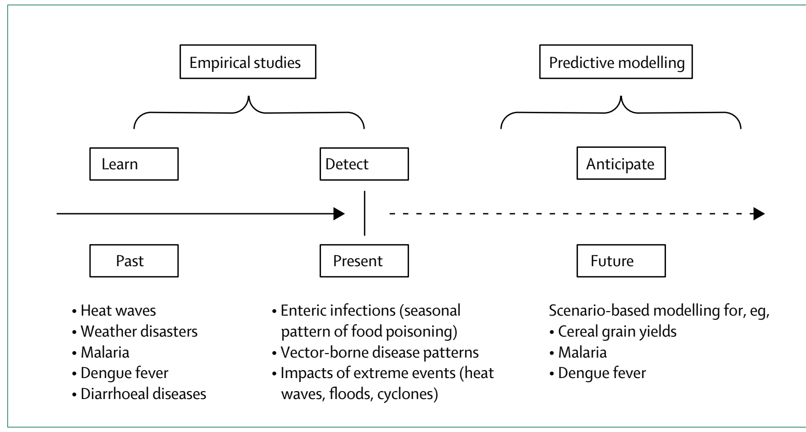


***Figure 2:* Three important research paths with examples of relevant topics**
Original figure by A J McMichael (National Centre for Epidemiology and Population Health, Australian National University, Canberra, Australia). Reproduced with permission.

Floods, droughts, and storms

Natural disasters have a variety of health impacts,[3,26] ranging from immediate effects of physical injury and morbidity and mortality through to potentially long-lasting effects on mental health. Most flood-related deaths can be attributed to rapid rise floods,[27] due to the increased risk of drowning. In October 1988, a flash flood occurred in the Nimes region of France.[28] Although the homes of 45 000 people were damaged and more than 1100 vehicles destroyed, only nine deaths by drowning (including two people who tried to rescue others) and three severe injuries were reported. In 1996, 86 people died from a flood in the town of Biescas in Spain as a consequence of the stream of water and mud that suddenly covered a campsite located near a channelised river.[29]

Many slow-rise river flood events have also been associated with fatalities. In central Europe, the Meuse, Rhine, Elbe, and Danube rivers have flooded in recent years. In 1997, river floods in central Europe left over 200 000 people homeless, and more than 100 people were

Location (date)	Excess mortality (% increase)	Reference
England and Wales (Aug 4–13)	2091 deaths (17%)	Johnson et al[16]
Italy (Jun 1–Aug 15)	3134 (15%) in all Italian capitals	Conti et al[17]
France (Aug 1–20)	14 802 (60%)	Anon[18]
Portugal (Aug)	1854 (40%)	Botelho et al[19]
Spain (Jul–Aug)	4151 deaths (11%)	Simon et al[20]
Switzerland (Jun–Sept)	975 deaths (6·9%)	Grize et al[21]
Netherlands (Jun–Sept)	1400–2200 deaths (not reported)	Garssen et al[22]
Germany (Aug 1–24)	1410 deaths (not reported)	Sozialministerium Baden-Wuerttemberg[23]

***Table 1:* Excess mortality attributed to the 2003 heat wave in Europe**

killed. Floods in Dresden, Germany, in 2002 left large parts of the city without power and freshwater for several days.[30] Four of the six main hospitals in Dresden were sited near the river Elbe and affected by the flooding. Over 1300 deaths, approximately 2000 injuries, and more than 1 million displaced people resulted from Hurricane Katrina, which is now the most expensive "natural" disaster in US history.

In some cases flooding may lead to mobilisation of dangerous chemicals from storage or remobilisation of chemicals already in the environment—eg, pesticides. A case study of heavy metal soil contamination after the flooding of the river Meuse during the winter of 1993–94 concluded there was a potential health risk for river-bank inhabitants as a consequence of lead and cadmium contaminations of the flood plain soils.[31] Hazards may be greater when industrial or agricultural land adjoining residential land is affected. However, there is insufficient research on flooding that causes chemical contamination to detect any causal effect on the pattern of morbidity and mortality in the affected populations.[32]

Following floods, increases in diarrhoeal and respiratory diseases are reported in both high-income and low-income countries;[3,33] transmission is increased where there is crowding of displaced populations. In industrialised countries, although infections are much less of a problem, the impact on the local economy may still be severe and increases in common mental disorders such as anxiety and depression are common. These increases are probably related to damage to the home environment and economic losses and may persist for more than a year after flooding.

Increased vulnerability of populations in low-income countries may be related to the habitation of high-risk areas such as flood plains and coastal zones, the presence of a limited public-health infrastructure, and the substantial damage to local and national economies, which is proportionally much greater than in industrialised countries.[34] Inevitably, low-income populations are also less likely to be covered by insurance.

Droughts may have wide ranging effects on health including on nutrition, infectious diseases, and on forest fires causing air pollution, particularly in low-income countries. The number of people worldwide affected by drought is influenced strongly by the El Niño cycle.[35]

Infectious diseases

Transmission of many infectious disease agents is sensitive to weather conditions, particularly those spending part of their life cycle outside the human body. Pathogens that are carried by insects are exposed to ambient weather. Vector-borne diseases typically exhibit seasonal patterns in which the role of temperature and rainfall is well documented. Some vector-borne diseases, such as malaria, also display considerable year-to-year variation in some regions that can also be partly explained by climatic factors.[36]

Changes in climate that can affect the transmission of vector-borne infectious diseases include temperature, humidity, altered rainfall, soil moisture, and sea level rise. It is a complex task to determine how these factors may affect the risk of vector-borne diseases. In addition to climatic factors, the incidence and geographic distribution of vector-borne diseases are influenced by many demographic and societal factors. Transmission requires that the reservoir host, a competent vector, and the pathogen be present in an area at the same time, and in adequate numbers to maintain transmission.

Global climate change could cause increases or decreases in the overall incidence of vector-borne diseases, and the duration of the transmission season, in particular sites. Small changes in seasonality may be important, since transmission rates tend to increase non-linearly in relation to the transmission season. Furthermore, increases or decreases in the geographic distribution of disease transmission may occur, since climate-driven changes in vectorial capacity cause transmission to become unsustainable in previously endemic areas, or sustainable in previously non-endemic areas. Even small increases in disease distributions may mean that new populations are exposed. New populations often lack acquired immunity, which can result in more serious clinical disease.

There is now a substantial body of literature on the association between the El Niño cycle, a major determinant of global weather patterns, and some infectious diseases. For example, there is reasonably strong evidence for an association with El Niño and malaria epidemics in parts of south Asia and South America and with cholera in coastal areas of Bangladesh.[36]

The relations between climate and disease distribution and transmission have been investigated for many vector-borne diseases (table 2), including the development of predictive models. Predictive models can be broadly classified as "biological" (based on aggregating the effect of climate on the individual components of the disease transmission cycle) or "statistical" (derived from direct correlations between observed geographic or temporal variations in climate, and associated variations in disease incidence or distribution). Most modelling of the effects of climate change has focused on malaria,[37–39] but the

Vector	Major diseases
Mosquitoes	Malaria, filariasis, dengue fever, yellow fever, West Nile fever
Sandflies	Leishmaniasis
Triatomines	Chagas disease
Ixodes ticks	Lyme disease, tick-borne encephalitis
Tsetse flies	African trypanosomiasis
Blackflies	Onchocerciasis
Snails (intermediate host)	Schistosomiasis

Table 2: **Examples of vector-borne diseases likely to be sensitive to climate change**

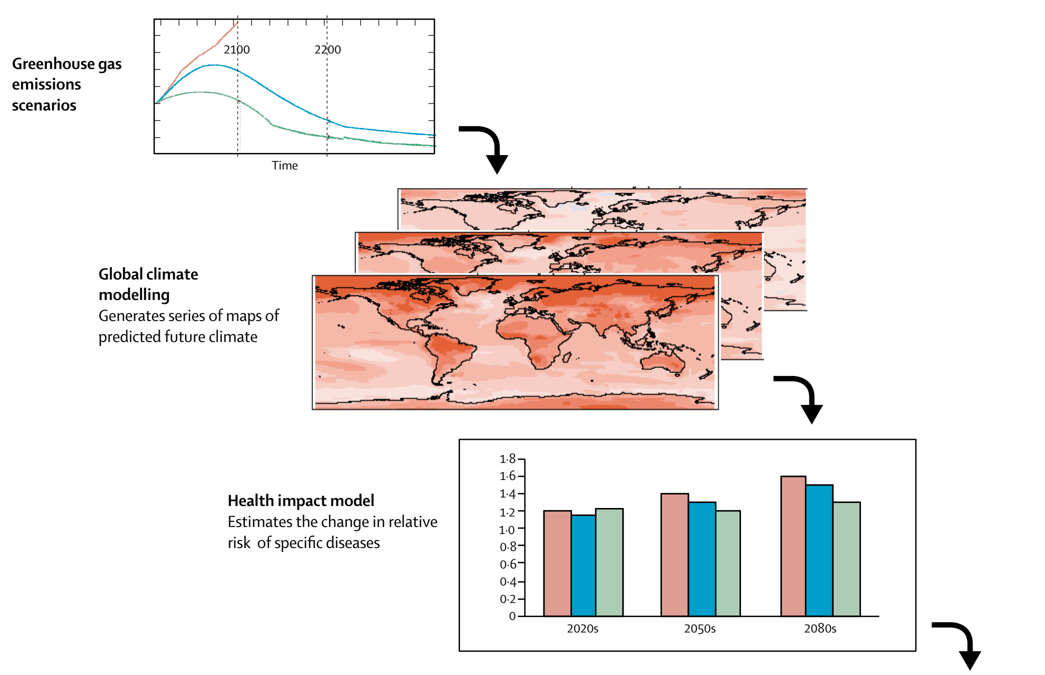
potential impact on the global distribution of dengue has also been estimated.[40] The calibration and validation of global dynamic models is difficult because the underlying systems are never closed. The requisite historical data are not often available with sufficient spatial coverage. The use of assumptions and simplifications potentially decrease the quantitative accuracy of the assessment. Hence, research is now focused on the development of regional models that can allow for validation and adequate prioritisation and estimation of risk.

It is likely that additional populations put at risk by climate change will be in low-income countries, since it is generally assumed that more developed countries, which currently control malaria, will remain able to do so. Malaria in poorer countries is currently only restricted by climate factors in specific arid and highland regions. The ability of these countries to manage any climate-induced increase in malaria will depend on their capacity to develop and sustain malaria control programmes.

The effect of climate change will vary geographically. Malaria transmission may decrease in many areas where decreases in precipitation are projected, particularly around the Amazon and in Central America. The overwhelming majority of the burden of malaria currently occurs in sub-Saharan Africa. Study of the effects of climate changes over much of the past century suggests that areas showing a statistically significant trend towards increasing suitability for malaria are broadly countered by areas showing a decrease.[41] The most detailed study, verified against a large database of historic malaria surveillance data, suggests that climate change will cause a small (5–7%) increase in the population at risk in Africa, mainly through expansion into higher altitudes. The study indicates that climate change will also lengthen the transmission season in many areas, causing a 16–28% increase in the total number of person-months of exposure.[42]

Estimating the global burden of disease due to climate change

WHO has recently undertaken an exercise to estimate the global burden of disease that could be due to climate



Subregion	Malnutrition	Diarrhoea	Malaria	Floods	All causes	Total DALYs/million population
AFR-D	293	154	178	1	626	2185·78
AFR-E	323	260	682	3	1267	3839·58
AMR-A	0	0	0	4	4	11·85
AMR-B	0	0	3	67	71	166·62
AMR-D	0	17	0	5	23	324·15
EMR-B	0	14	0	6	20	147·57
EMR-D	313	277	112	46	748	2145·91
EUR-A	0	0	0	3	3	6·66
EUR-B	0	6	0	4	10	48·13
EUR-C	0	3	0	1	4	14·93
SEAR-B	0	28	0	6	34	117·19
SEAR-D	1918	612	0	8	2538	2080·84
WPR-A	0	0	0	1	1	8·69
WPR-B	0	89	43	37	169	111·36
World	2846	1459	1018	193	5517	925·35

Figure 3: **Overview of the comparative risk assessment process for climate change and health**

change in terms of disability adjusted life years (DALYs) lost. This measure makes it possible to take into account impacts that do not necessarily lead to death but cause disability. Climate scenarios are derived from the output of global climate models that are, in turn, driven by scenarios of future greenhouse gas emissions (figure 3). The attributable burden of climate change was estimated in relation to three (future) climate scenarios relative to the baseline climate (ie, the average climate from 1960 to 1991) representing little or no anthropogenic climate change. Epidemiological models were used to estimate the degree to which these climatic changes are likely to affect a limited series of health outcomes (malaria, diarrhoeal disease, malnutrition, flood deaths, direct effects of heat and cold). These measures of proportional change can be applied to projections of the burden of each of these diseases in the future to calculate the possible impacts of climate change on the overall disease burden. The methods have been described more fully elsewhere.[43]

To generate consistent estimates, the analysis attempted to account for current geographic variation in vulnerability to climate, where not already incorporated into the predictive models. It also attempted to account for future changes in disease rates due to other factors (eg, decreasing rates of infectious diseases due to technological advances or improving socioeconomic status), and for changes in population size and age structure (eg, potentially greater proportion of older people at higher risk of mortality related to cardiovascular disease in response to thermal extremes). These potential future changes can be addressed by applying the estimates of relative risks under alternative climate change scenarios to the global burden of disease projections of disease rates, population size, and age structure. These alternative scenarios attempt to take into account the effects of changing gross domestic product (GDP), "human capital" (as measured by average years of female education), and time (to account for trends such as technological development)[44] on the overall "envelope" of cause-specific mortality and morbidity for diseases affected by climate change. The assumptions made about future adaptation and vulnerability are outlined in table 3.

The analyses suggested that climate change will bring some health benefits, such as lower cold-related mortality and greater crop yields in temperate zones, but these benefits will be greatly outweighed by increased rates of other diseases, particularly infectious diseases and malnutrition in developing regions. A small proportional increase in cardiovascular disease mortality attributable to climate extremes is likely in tropical regions, and a small benefit in temperate regions, caused by warmer winter temperatures. Since there is evidence that some temperature-attributable mortality represents small displacements of deaths that would occur soon in any case, no assessment was made of the associated increase or decrease in disease burden. Climate change is estimated to increase the burden of diarrhoea in regions made up mainly of developing countries by approximately 2–5% in 2020. Richer countries (GDP>US$6000/year), either now or in the future, were assumed to suffer little or no additional risk of diarrhoea. Much larger proportional changes are likely in the numbers of people killed in coastal floods (approximately a doubling in the former socialist economies), and inland floods (up to five times greater risk in developed regions). Although the proportional change is much larger than for other health outcomes, the baseline disease burden is much lower, so that the aggregate effect is comparatively small. Substantial proportional changes were estimated in the risk of falciparum malaria in countries at the edge of the current distribution. However, most of the estimated attributable disease burden is associated with small proportional increases in regions that already suffer heavily from malaria, principally through extensions in the altitudinal and latitudinal range in Africa.

On aggregate, it was estimated that climate change may already (by 2000) be causing in the region of 150 000 deaths (0·3% of global deaths per year) and 5·5 million lost DALYs/year (0·4% of global DALYs lost per year).[45] Even taking into account increasing wealth and some level of behavioural and socioeconomic adaptation, the disease burden caused by climate change is likely to increase substantially over time. Overall, the effects are predicted to be heavily concentrated in poorer

	Biological* adaptation affecting relative risks	Socioeconomic adaptation affecting relative risks
Direct effects of heat and cold	Yes. Temperature associated with lowest mortality was assumed to change directly with temperature increases driven by climate change	None
Diarrhoea	None	Assumed RR=1 if GDP per capita rises above US$6000/year
Malnutrition	None	Food-trade model assumed future increases in crop yields from technological advances, increased liberalisation of trade, and increased GDP
Disasters: coastal floods	None	Model assumed the relative risk of deaths in floods decreases with GDP
Disasters: inland floods and landslides	None	Model assumed the RR of deaths in floods decreases with GDP
Vector-borne diseases: malaria	None	None (for RR)

GDP=gross domestic product; RR=relative risk. *Physiological, immunological, and behavioural.

Table 3: **Assumptions on adaptation and vulnerability for each health outcome, as applied in the WHO global burden of disease exercise**

Health outcome	Public health	Surveillance
Mortality and morbidity due to heat waves	Public-health education Heat health warning systems Emergency preparedness	Enhance health surveillance of routine data for early detection of heat wave effects (eg, monitoring from funeral homes, calls to NHS Direct)
Floods	Public-health education—eg, boil water notices Emergency preparedness Check list for post-flood activities	Surveillance for flood effects, with long-term follow-up Coordinated national surveillance for flood deaths, injuries, and illnesses
Air quality	Warnings for high pollution days	Daily air pollution measurements
Vector-borne diseases	Public education, especially to avoid contact with ticks	Monitoring of vectors and reservoir host Integrated surveillance for human and animal diseases
Food-borne disease	Maintenance and strengthening of food hygiene measures	Integrated surveillance for human and animal diseases
Water-borne diseases	Risk assessment for extreme rainfall events Risk assessment of health effects of algal blooms	Increased microbiological monitoring of public water supplies and private wells, and enhanced surveillance during and following heavy rainfall events

Table 4: **Summary of public-health adaptation measures in relation to the health impacts of climate change (applicable to European populations)[46,47]**

populations at low latitudes, where the most important climate-sensitive health outcomes (malnutrition, diarrhoea, and malaria) are already common, and where vulnerability to climate effects is greatest. These diseases mainly affect younger age groups, so that the total burden of disease due to climate change appears to be borne mainly by children in developing countries.

Considerable uncertainties surround these estimates and the range of impacts included is not comprehensive. There is, for example, uncertainty over future climate change (particularly future greenhouse gas emissions), uncertainty about climate/health relations, and most importantly, uncertainties around the degree to which current climate/health relations will be modified by socioeconomic adaptation in the future. These uncertainties could be reduced in subsequent studies by (1) applying projections from a range of climate models and/or their probability distributions, (2) relating climate and disease data from a wider range of climatic and socioeconomic environments, (3) more careful validation against patterns in the present or recent past, and (4) more detailed longitudinal studies of the interaction of climatic and non-climatic influences on health.

Climate change and public health

The current state of knowledge about climate change is such that some specific measures for health protection can now be recommended. The summer of 2003 illustrated a lack of public-health capacity in Europe to deal with heat waves. A recent WHO publication encourages public-health decision makers to act now to address climate hazards, as well as address adaptation strategies in the longer term.[46] Although there is uncertainty about future climate change, failure to invest in adaptations may leave a nation poorly prepared to cope with adverse changes and increase the probability of severe consequences.[47]

A number of important factors related to the design and implementation of strategies must be considered in the assessment of health policies, measures, and strategies, including: (1) the variation of appropriateness and effectiveness of adaptation options by region and across demographic groups; (2) how to exploit opportunities, as well as to reduce risks; (3) the cost of adaptation and the potential to exacerbate climate change (eg, extensive use of air conditioning); (4) the need for adaptation to multiple factors, including climate change; (5) the systemic nature of climate impacts that means that many sectors will need to be involved to reduce public-health impacts; and (6) maladaptation—ie, policies that increase vulnerability to climate change can result in serious negative effects. Some examples of public-health adaptation strategies to climate variability and change are given in table 4.

Mitigation strategies and health

Climate change poses a major threat to sustainable development because adverse effects are likely to be directed particularly at poor populations that currently also suffer disproportionately from a lack of reliable energy at the level of the household and the community. The easy availability of cheap energy from fossil fuels has underpinned the economic development of industrialised countries and has therefore contributed substantially to the dramatic advances in health observed over the past century or so. With current energy sources, recent and continuing patterns of economic development contribute more to climate change than population growth.[48] During the 20th century the world population grew almost fourfold, at the same time emissions of carbon dioxide grew around 12-fold. Population growth in low-income and middle-income countries poses major challenges for greenhouse gas emissions in the future if economic growth is based on fossil fuel use.

Although the Kyoto protocol is an important political initiative to engage countries in developing policies to reduce greenhouse gas emissions, the modest targets in the protocol would not have much impact on some of the major adverse impacts.[49] For example, to keep the concentration of carbon dioxide from exceeding the doubling of the pre-industrial concentration of 275 parts per million, reductions of more than two-thirds in emissions would be needed, assuming a population of 9 billion by 2050.[50] The industrialised nations, which have benefited so much from fossil fuels, should take the lead and their proportional reductions will need to be much greater than the less developed nations to converge on a much lower level and more equal distribution of emissions.

Approximately 2 billion people lack access to electricity and suffer substantial ill health as a result. Around half the global population cook daily with traditional biomass fuels (eg, dung, crop residues, wood, and charcoal), resulting in exposure to very high concentrations of air pollutants indoors and extensive time spent in collection of wood or other fuel and the attendant opportunity costs, particularly for women. Improved energy efficiency cook stoves are becoming increasingly available in a number of countries and can substantially cut the use of biomass fuels with subsequent health, environmental, and economic benefits.[51] These populations would also obviously benefit from access to affordable electricity.

A WHO publication has demonstrated the potential near-term benefits to health of strategies to reduce greenhouse gas emissions applied in China.[52] The authors concluded that the benefits to human health arising from changes in energy use in the housing sector are many times larger than those in the electric power sector. Economic benefits of reducing exposure to indoor air pollution were thought to be substantially larger than the cost of reducing greenhouse gas emissions, particularly when this was achieved by improving energy efficiency.

Fossil fuel combustion is a cause of both local air pollutants (especially particulates, ozone, methane, nitrogen oxides, and sulphur dioxide) and greenhouse gases. Policies that aim to address global anthropogenic climate change can therefore also benefit health in the near term by reducing the concentration of urban air pollutants. A recent paper demonstrates the potential benefits of converting all US on-road vehicles to hydrogen fuel-cell vehicles.[53] Such vehicles powered by hydrogen from renewable energy sources (eg, wind power) could save 3700–6400 lives annually from reduced air pollution as well as benefiting climate change. “Ancillary benefits” are the monetised secondary (or side) benefits of mitigation policies on problems such as reductions in local air pollution associated with the reduction of fossil fuels. Multiple, wider health ancillary benefits of mitigation are possible by improving transport policies in both developed and developing countries. Transport is projected to have the fastest proportional growth in greenhouse gas emissions of any sector from 1990–2020, and there are direct connections with urban air pollution (around 800 000 deaths per year globally), road traffic accidents (1·2 million deaths per year), and physical inactivity (1·9 million deaths a year).[45] There are therefore potentially major synergies in terms of reduced greenhouse gas emissions and direct health benefits from sustainable transport systems that make more use of public transport, walking, and cycling, especially in rapidly developing countries such as China and India.

Sources of renewable energy such as photovoltaic, solar thermal, wave, and wind power do not appear to have any important adverse effects on health and their overall impacts are likely to be overwhelmingly beneficial.[54] The barriers to their uptake relate particularly to the cost of electricity generated in these ways. However, there is substantial evidence that dams for the generation of hydropower may have adverse effects, for example, by affecting the distribution of vector-borne diseases and displacing populations.[55,56] The health impact assessment of dams is therefore an important aspect of the planning process. The assessment of the impacts of the expansion of nuclear power is complex and beyond the scope of this article. Increasing costs and concerns about the security of fossil fuels provide added impetus to seek alternatives.

Conclusions

The effects of climate change on health are likely to be predominately negative and impact most heavily on low-income countries where capacity to adapt is weakest, but also on the most vulnerable groups in developed countries. Adaptation strategies should blunt some of the adverse impacts but will pose difficulties of implementation, particularly in low-income countries. With climate change already underway, there is a need to assess vulnerabilities and identify cost-effective intervention/adaptation options in the health sector and in other sectors that have direct links to human health. Early planning can help reduce future adverse health impacts and mitigation strategies—eg, using a number of renewable energy sources—can improve health by reducing air pollution as well as addressing climate change.

Conflict of interest statement

AH is a reviewer and RSK a participant in the UN Intergovernmental Panel on Climate Change for the Fourth Assessment Report. DC-L and CC declare that they have no conflict of interest.

Acknowledgments

This article is based on a paper presented to the World Climate Change Conference (Moscow, Russian Federation, Sept 29–Oct 3, 2003), which has been updated for the 2005 Harben Lecture of the Royal Institute of Public Health. We thank Tony McMichael for permission to use figure 2 and acknowledge the contributions of many scientists to the Comparative quantification of health risks: global and regional burden of disease due to selected major risk factors report. The views expressed in this article are those of the authors and do not necessarily reflect the position of the WHO.

References

1 Haines A, Patz J. Health effects of climate change. *JAMA* 2004; **291:** 99–103.

2 McMichael AJ, Woodruff RE, Hales S. Climate change and human health: present and future risks. *Lancet* 2006; **367:** 859–69.

3 Ahern M, Kovats RS, Wilkinson P, Few R, Matthies F. Global health impacts of floods: epidemiologic evidence. *Epidemiol Rev* 2005; **27:** 36–46.

4 Langner J, Bergstom R, Foltescu V. Impact of climate change on surface ozone and deposition of sulphur and nitrogen in Europe. *Atmos Environ* 2005; **39:** 1129–41.

5 Kovats RS, Campbell-Lendrum D, McMichael AJ, Woodward A, Cox J. Early effects of climate change: do they include changes in vector-borne disease? *Philos Trans R Soc Lond B Biol Sci* 2001; **356:** 1057–68.

6 Intergovernmental Panel on Climate Change. Climate change 2001: impacts, adaptation and vulnerability. Contribution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, 2001.
7 Kovats RS, Campbell-Lendrum D, Matthies F. Climate change and human health: estimating avoidable deaths. *Risk Anal* 2005; **25:** 1409–18.
8 Purse BV, Mellor PS, Rogers DJ, Samuel AR, Mertens PP, Baylis M. Climate change and the recent emergence of bluetongue in Europe. *Nat Rev Microbiol* 2005; **3:** 171–81.
9 Lindgren E, Tälleklint L, Polfeldt T. Impact of climatic change on the northern latitude limit and population density of the disease transmitting European tick *Ixodes ricinus*. *Environ Health Perspect* 2000; **108:** 119–23.
10 Skarphedinsson S, Jensen PM, Kristiansen K. Survey of tick borne infections in Denmark. *Emerg Infect Dis* 2005; **117:** 1055–61.
11 Luterbacher J, Dietrich D, Xoplaki E, Grosjean M, Wanner H. European seasonal and annual temperature variability, trends and extremes since 1500. *Science* 2004; **303:** 1499–1503.
12 Stott PA, Stone DA, Allen MR. Human contribution to the European heatwave of 2003. *Nature* 2004; **432:** 610–14.
13 Emanuel K. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* 2005; **436:** 686–88.
14 Webster PJ, Holland GJ, Curry JA, Chang HR. Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science* 2005; **309:** 1844–46.
15 Hulme M, Jenkins GJ, Lu X, et al. Climate change scenarios for the United Kingdom: the UKCIP02 Scientific Report. Norwich, UK: Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, 2002.
16 Johnson H, Kovats RS, McGregor G, et al. The impact of the 2003 heatwave on mortality and hospital admissions in England. *Health Stat Q* 2005; **25:** 6–11.
17 Conti S, Meli P, Minelli G, et al. Epidemiologic study of mortality during the summer 2003 heat wave in Italy. *Environ Res* 2005; **98:** 390–99.
18 Anon. Impact sanitaire de la vague de chaleur en France survenue en août 2003. Paris: Institut de Veille Sanitaire, 2003.
19 Botelho J, Caterino J, Calado R, Nogueira PJ, Paixao E, Falcao JM. Onda de calor de Agosto de 2003. Os seus efeitos sobre a mortalidade da populacao portuguesa. Lisbon: Instituto Nacional de Saude Dr. Ricardo Jorge, 2005.
20 Simon F, Lopez-Abente G, Ballester E, Martinez F. Mortality in Spain during the heat waves of summer 2003. *Euro Surveill* 2005; **10:** 156–60.
21 Grize L, Hussa A, Thommena O, Schindlera C, Braun-Fahrlandera C. Heat wave 2003 and mortality in Switzerland. *Swiss Med Wkly* 2005; **135:** 200–05.
22 Garssen J, Harmsen C, de Beer J. The effect of the summer 2003 heat wave on mortality in the Netherlands. *Euro Surveill* 2005; **10:** 165–67.
23 Sozialministerium Baden-Wuerttemberg. Gesundheitliche Auswirkungen der Hitzewelle im August 2003. Freiburg, Germany: Sozialministerium Baden-Wuerttemberg, 2004
24 Vandentorren S, Suzan F, Medina S, et al. Mortality in 13 French cities during the August 2003 heat wave. *Am J Public Health* 2004; **94:** 1518–20.
25 Le Tertre A, Lefranc A, Eilstein, D, et al. Impact of 2003 heat wave on all cause mortality in 9 French cities. *Epidemiology* 2006; **17:** 75–79.
26 Noji EK. The public health consequences of disasters. New York: Oxford University Press, 1997.
27 French J, Ing R, Von Allmen S, Wood R. Mortality from flash floods: a review of national weather service reports, 1969–81. *Public Health Rep* 1983; **98:** 584–88.
28 Duclos P, Vidonne O, Beuf P, Perray P, Stoebner A. Flash flood disaster—Nimes, France, 1988. *Eur J Epidemiol* 1991; **7:** 365–71.
29 Estrela T, Menéndez M, Dimas M, et al. Sustainable water use in Europe – part 3: extreme hydrological events: floods and droughts. Copenhagen: European Environment Agency, 2001.
30 Meusel D, Kirch W. Lessons learned from the 2002 flood in Dresden, German. In: Menne B, Bertollini R, Kirch W, eds. Extreme weather events and public health response. Berlin: Springer-Verlag, 2005: 175–84.
31 Albering HJ, van Leusen SM, Moonen EJ, Hoogewerff JA, Kleinjans JC. Human health risk assessment: a case study involving heavy metal soil contamination after the flooding of the river Meuse during the winter of 1993–1994. *Environ Health Perspect* 1999; **107:** 37–43.
32 Euripidou E, Murray V. Public health impacts of floods and chemical contamination. *J Public Health* 2004; **26:** 376–83.
33 Siddique A, Baqui A, Eusof A, Zamon K. 1988 flood in Bangladesh: pattern of illness and cause of death. *J Diarrhoeal Dis Res* 1991; **9:** 310–14.
34 Few R, Matthies F, eds. Flood hazards and health: responding to present and future risks. London: Earthscan, in press.
35 Bouma MJ, Kovats SR, Goubet SA, St H Cox J, Haines A. Global assessment of El Niño's disaster burden. *Lancet* 1997; **350:** 1435–38.
36 Kovats RS, Bouma MJ, Hajat S, Worrell E, Haines A. El Niño and health. *Lancet* 2003; **361:** 1481–89.
37 Martin PH, Lefebvre MG. Malaria and climate—sensitivity of malaria potential transmission to climate. *Ambio* 1995; **24:** 200–07.
38 Rogers DJ, Randolph SE. The global spread of malaria in a future, warmer world. *Science* 2000; **289:** 1763–66.
39 Thomas CJ, Davies G, Dunn CE. Mixed picture for changes in stable malaria distribution with future climate in Africa. *Trends Parasitol* 2004; **20:** 216–20.
40 Hales S, de Wet N, Macdonald J, Woodward A. Potential effect of population and climate changes on global distribution of dengue fever: an empirical model. *Lancet* 2002; **360:** 830–34.
41 Small J, Goetz SJ, Hay SI. Climatic suitability for malaria transmission in Africa, 1911–1995. *Proc Natl Acad Sci USA* 2003; **100:** 15341–45.
42 Tanser FC, Sharp B, le Sueur D. Potential effect of climate change on malaria transmission in Africa. *Lancet* 2003; **362:** 1792–98.
43 McMichael AJ, Campbell-Lendrum D, Kovats RS, et al. Global climate change. In: Ezzati M, Lopez AD, Rodgers A, Murray CJ, eds. Comparative quantification of health risks: global and regional burden of disease due to selected major risk factors, vol 2. Geneva: WHO, 2004: 1543–649.
44 Murray CJL, Lopez AD, eds. The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries and risk factors in 1990 and projected to 2020. Cambridge, MA, USA: Harvard School of Public Health/WHO, 1996.
45 WHO. The world health report 2002: reducing risks and promoting healthy life. Geneva: WHO, 2002.
46 Menne B, Ebi KL, eds. Climate change and adaptation strategies for human health Hessen, Germany, Dr Dietrich Steinkopff Verlag GmbH & Co. KG, 2005.
47 Smith JB, Lenhart SS. Climate change adaptation policy options. *Climate Research* 1996; **6:** 193–201.
48 McMichael AJ, Powles JW. Human numbers, environment, sustainability, and health. *BMJ* 1999; **319:** 977–80.
49 Parry ML, Arnell NW, Hulme M, Nicholls RJ, Livermore MT. Adapting to the inevitable. *Nature* 1998; **395:** 741.
50 Wigley TML, Richels R, Edmonds JA. Economic and environmental choices in the stabilization of atmospheric CO_2 concentrations. *Nature* 1996; **379:** 240–43.
51 Kammen DM. Cookstoves for the developing world. *Sci Am* 1995; **273:** 72–75.
52 Wang X, Smith KR. Near-term health benefits of greenhouse gas reductions: a proposed method for assessment and application in two energy sectors of China. Geneva: WHO, 1999. WHO/SDE//PHE/99.01.
53 Jacobson MZ, Colella WG, Golden DM. Cleaning the air and improving health with hydrogen fuel-cell vehicles. *Science* 2005; **308:** 1901–05.
54 Haines A, Kammen D. Sustainable energy and health. *Global Change and Human Health* 2000; **1:** 2–11.
55 Diop M, Jobin WR. Senegal River Basin Health Master Plan Study. Water and Sanitation for Health (WASH) Field Report number 453. Washington, DC: US Agency for International Development, 1994.
56 Ghebreyesus TA, Haile M, Witten KH, et al. Incidence of malaria among children living near dams in northern Ethiopia: community based incidence survey. *BMJ* 1999; **319:** 663–66.

Copyright of Lancet is the property of Lancet and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.