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Managing the health effects of climate change

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Executive summary

Climate change is the biggest global health threat of the 21st century

Effects of climate change on health will affect most populations in the next decades and put the lives and wellbeing of billions of people at increased risk. During this century, earth's average surface temperature rises are likely to exceed the safe threshold of 2°C above preindustrial average temperature. Rises will be greater at higher latitudes, with medium-risk scenarios predicting 2–3°C rises by 2090 and 4–5°C rises in northern Canada, Greenland, and Siberia. In this report, we have outlined the major threats—both direct and indirect—to global health from climate change through changing patterns of disease, water and food insecurity, vulnerable shelter and human settlements, extreme climatic events, and population growth and migration. Although vector-borne diseases will expand their reach and death tolls, especially among elderly people, will increase because of heatwaves, the indirect effects of climate change on water, food security, and extreme climatic events are likely to have the biggest effect on global health.

A new advocacy and public health movement is needed urgently to bring together governments, international agencies, non-governmental organisations (NGOs), communities, and academics from all disciplines to adapt to the effects of climate change on health. Any adaptation should sit alongside the need for primary mitigation: reduction in greenhouse gas emissions, and the need to increase carbon biosequestration through reforestation and improved agricultural practices. The recognition by governments and electorates that climate change has enormous health implications should assist the advocacy and political change needed to tackle both mitigation and adaptation.

Management of the health effects of climate change will require inputs from all sectors of government and civil society, collaboration between many academic disciplines, and new ways of international cooperation that have hitherto eluded us. Involvement of local communities in monitoring, discussing, advocating, and assisting with the process of adaptation will be crucial. An integrated and multidisciplinary approach to reduce the adverse health effects of climate change requires at least three levels of action. First, policies must be adopted to reduce carbon emissions and to increase carbon biosequestration, and thereby slow down global warming and eventually stabilise temperatures. Second, action should be taken on the events linking climate change to disease. Third, appropriate public health systems should be put into place to deal with adverse outcomes.

While we must resolve the key issue of reliance on fossil fuels, we should acknowledge their contribution to huge improvements in global health and development over the past 100 years. In the industrialised world and richer parts of the developing world, fossil fuel energy has contributed to a doubled longevity, dramatically

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reduced poverty, and increased education and security for most populations.

Climate change effects on health will exacerbate inequities between rich and poor

Climate change will have its greatest effect on those who have the least access to the world's resources and who have contributed least to its cause. Without mitigation and adaptation, it will increase health inequity especially through negative effects on the social determinants of health in the poorest communities.

Despite improvements in health with development, we are still faced with a global health crisis. 10 million children die each year; over 200 million children under 5 years of age are not fulfilling their developmental potential; 800 million people go to bed each night hungry; and 1500 million people do not have access to clean drinking water. Most developing countries will not reach the Millennium Development Goal health targets by 2015. In September, 2008, the WHO Commission on Social Determinants of Health reported that social inequalities are killing people on a grand scale, and noted that a girl born today can expect to live up to 80 years if she is born in some countries but less than 45 years if she is born in others. The commission concluded that health equity is achievable in a generation, it is the right thing to do, and now is the right time to do it.

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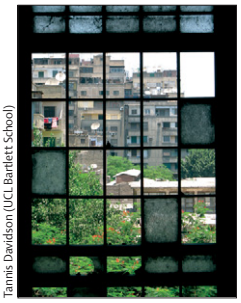
The effects of climate change on health are inextricably linked to global development policy and concerns for health equity. Climate change should catalyse the drive to achieve the Millennium Development Goals and to expedite development in the poorest countries. Climate change also raises the issue of intergenerational justice. The inequity of climate change—with the rich causing most of the problem and the poor initially suffering most of the consequences—will prove to be a source of historical shame to our generation if nothing is done to address it. Raising health status and reducing health inequity will only be reached by lifting billions out of poverty. Population growth associated with social and economic transition will initially increase carbon emissions in the poorest countries, in turn exacerbating climate change unless rich countries, the major contributors to global carbon production, massively reduce their output.

Luxury emissions are different from survival emissions, which emphasises the need for a strategy of contraction and convergence, whereby rich countries rapidly reduce emissions and poor countries can increase emissions to achieve health and development gain, both having the same sustainable emissions per person.



Tannis Davidson (UCL Bartlett School)

Key challenges in managing health effects of climate change

The UCL *Lancet* Commission has considered what the main obstacles to effective adaptation might be. We have focused on six aspects that connect climate change to adverse health outcomes: changing patterns of disease and mortality, food, water and sanitation, shelter and human settlements, extreme events, and population and migration. Each has been considered in relation to five key challenges to form a policy response framework: informational, poverty and equity-related, technological, sociopolitical, and institutional.

Our capacity to respond to the negative health effects of climate change relies on the generation of reliable, relevant, and up-to-date information. Strengthening informational, technological, and scientific capacity within developing countries is crucial for the success of a new public health movement. This capacity building will help to keep vulnerability to a minimum and build resilience in local, regional, and national infrastructures. Local and community voices are crucial in informing this process.

Weak capacity for research to inform adaptation in poor countries is likely to deepen the social inequality in relation to health. Few comprehensive assessments on the effect of climate change on health have been completed in low-income and middle-income countries, and none in Africa. This report endorses the 2008 World Health Assembly recommendations for full documentation of the risks to health and differences in vulnerability within and between populations; development of health protection strategies; identification of health co-benefits of actions to reduce greenhouse gas emissions; development of ways to support decisions and systems to predict the effect of climate change; and estimation of the financial costs of action and inaction.

Policy responses to the public health implications of climate change will have to be formulated in conditions of uncertainty, which will exist about the scale and timing of the effects, as well as their nature, location, and intensity.

A key challenge is to improve surveillance and primary health information systems in the poorest countries, and to share the knowledge and adaptation strategies of local communities on a wide scale. Essential data need to include region-specific projections of changes in health-related exposures, projections of health outcomes under different future emissions and adaptation scenarios, crop yields, food prices, measures of household food security, local hydrological and climate data, estimates of the vulnerability of human settlements (eg, in urban slums or communities close to coastal areas), risk factors, and response options for extreme climatic events, vulnerability to migration as a result of sea-level changes or storms, and key health, nutrition, and demographic indicators by country and locality.

We also urgently need to generate evidence and projections on health effects and adaptation for a more severe (3–4°C) rise in temperature, which will almost certainly have profound health and economic implications. Such data could increase advocacy for urgent and drastic action to reduce greenhouse gas emissions.

Mark Maslin

The reduction of poverty and inequities in health is essential to the management of health effects of climate change. Vulnerability of poor populations will be caused by greater exposure and sensitivity to climate changes and reduced adaptive capacity. Investment to achieve the Millennium Development Goals will not only reduce vulnerability but also release public expenditure for climate change currently consumed by basic prevention strategies (eg, malaria control). Health-oriented and climate-orientated investments in food security, safe water supply, improved buildings, reforestation, disaster risk assessments, community mobilisation, and essential maternal and child health and family planning services, will all produce dividends in adaptation to climate change.

Poverty alleviation and climate adaptation measures will be crucial in reducing population growth in countries where demographic transition (to stable and low fertility and death rates) is delayed. Population growth will increase overall emissions in the long term and expand the number of vulnerable individuals (and thus the potential burden of suffering) greatly.

The application of existing technologies is as important as the development of new ones. Nonetheless, technological development is needed to boost food output, to maintain the integrity of ecosystems, and to improve agricultural and food system practices (agriculture is responsible for an estimated 22% of greenhouse gas emissions), to improve systems for safely storing and treating water, to use alternative supplies of water, for waste water recycling and desalination, and for water conserving technologies. It is also needed to create buildings that are energy efficient and use low-carbon construction materials; to allow for planning settlements, and to develop software of planning and land use; to increase regional and local climate modelling, creating effective early warning systems, and the application of geographic information systems; and to ensure the provision of existing health and family planning services at high coverage, and thus ensure the rights of individuals and couples to have good health outcomes and access to voluntary family planning methods.

Incentives for the development of technologies are necessary to address the negative public health consequences of climate change in poor countries. In the pharmaceutical sector, rich markets generate vigorous research and drug development activities, whereas poor markets have been mainly ignored. Public funding for investment in developing green technologies for poor markets will be essential.

The biggest sociopolitical challenge affecting the success of climate change mitigation is the lifestyle of those living in rich nations and a small minority living in

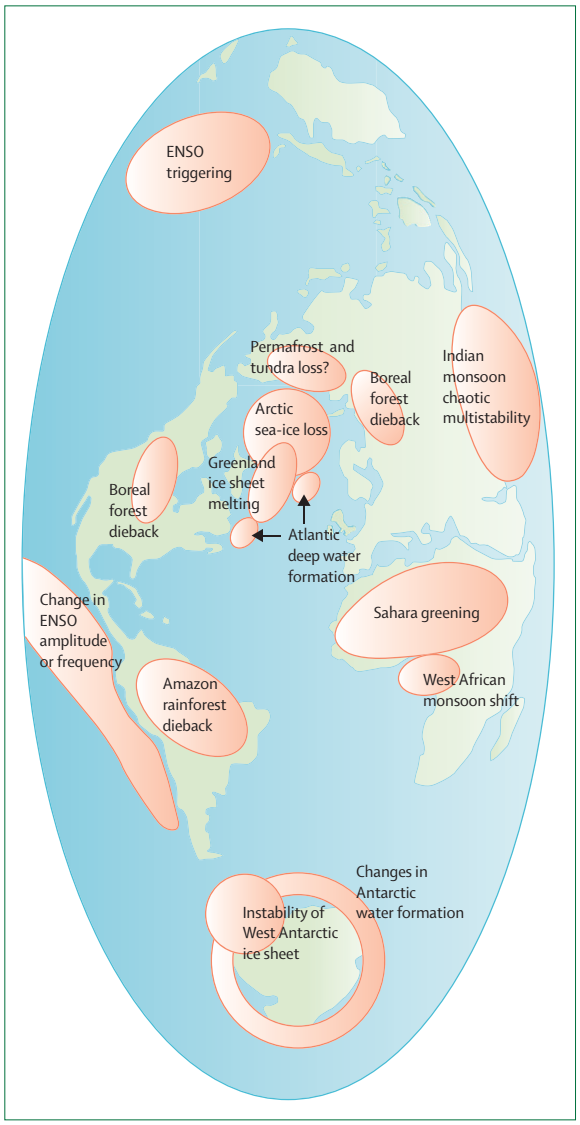


Figure 1: **Potential tipping points in climate systems**[3]
ENSO=El Niño southern oscillation. Boreal forest is the most northern woodland area. Tundra is a vast, mostly flat, treeless Arctic region of Europe, Asia, and North America in which the subsoil is permanently frozen.

poor nations, which is neither sustainable nor equitable. Behavioural change will depend upon information, incentives, and emphasis on the positive benefits of low-carbon living. Sustainable consumption requires accessible information for all about carbon footprints arising from the lifecycle of economic products and our energy usage. A step towards low-carbon living has health benefits that will improve quality of life by challenging diseases arising from affluent high-carbon societies—obesity, diabetes, and heart disease especially—and reducing the effects of air pollution.

Building social capital through community mobilisation will improve adaptation strategies in both rich and poor communities. Psychosocial health will be affected by environmental change and uncertainty about the future; therefore, public engagement about scientific findings must be undertaken with responsibility and care. Continuing population growth poses a further, important, long-term issue for climate mitigation; better health and development is the best way to ensure fertility declines, but re-energising the provision of high-quality family planning services where there is unmet need is also important.

Climate change adaptation requires improved co-ordination and accountability of global governance. Too much fragmentation and too many institutional turf wars exist. Vertical links need attention: we might need local action to prevent local flooding and global action to ensure that funding is available. Horizontal coordination requires joined up thinking across governments and international agencies. Governance at the global level, especially in UN institutions, is characterised by a lack of democratic accountability and profound inequalities. These deficiencies will be exposed by climate change negotiation with countries in the developing world. Funding initiatives are insufficient and poorly coordinated. In adapting effectively to climate change, we need to consider market failures, the role of a powerful transnational corporate sector, political constraints on both developed and developing countries, whose electorates might demand a greater focus on short-term issues or wealth creation, and the need to strengthen local government. Power and politics will enter all discussions about food security, water supply, disaster risk reduction and management, urban planning, and health and population expenditure.

A new public health movement will increase advocacy to reduce climate change

We call for a public health movement that frames the threat of climate change for humankind as a health issue. Apart from a dedicated few, health professionals have come late to the climate change debate, but health concerns are crucial because they attract political attention.

This report raises many challenging and urgent issues for politicians, civil servants, academics, health professionals, NGOs, pressure groups, and local communities. The global financial crisis has stimulated governments of industrialised countries to talk about the so-called green new deal, which brings about re-industrialisation based on low-carbon energy. Ideas such as carbon capture in power stations, carbon taxes with 100% dividends for low-carbon users, and fourth generational nuclear power are on the highest political agendas. The Copenhagen UN Framework Convention on Climate Change (UNFCCC) conference in December, 2009 (COP 15) will address the shared vision of governments about new global warming and emissions targets for 2020 and 2050. It will also address reform of the Clean Development Mechanism, reducing emissions from deforestation, technology transfer, and adaptation.

The ability of health systems to respond effectively to direct and indirect health effects of climate change is a key challenge worldwide, especially in many low-income and middle-income countries that suffer from disorganised, inefficient, and under-resourced health systems. For many countries, more investment and resources for health systems strengthening will be required. Climate change threats to health also highlight the vital requirement for improved stewardship, population-based planning, and the effective and efficient management of scarce resources.

Recommendations on management of the health effects of climate change are listed at the end of this report.

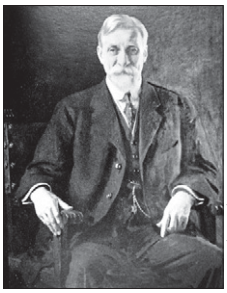
Introduction

The potential health effects of climate change are immense. Management of those health issues is an enormous challenge not only for health professionals but also for climate change policy makers. An integrated and holistic political response is vital for good social, economic, and ethical reasons. Consistent with this ambition, we have brought together a multidisciplinary group to explore this urgent issue.

Anthropogenic climate change is now incontrovertible. The amount of change and its intensity, along with the willingness and capacity to mitigate it, are subject to considerable debate and controversy. This report deliberately supports a conservative approach to the agreed facts for two reasons. First, even the most conservative estimates are profoundly disturbing and demand action. Second, less conservative climate change scenarios are so catastrophic that adaptation might be unachievable. However, although conservative on the estimates and cognisant of the possibility of pessimistic outcomes, we are optimistic on what can be achieved by a collaborative effort between governmental and non-governmental entities at all levels, and concerned citizens at the community level.

The Intergovernmental Panel on Climate Change (IPCC) reported that societies can respond to climate change by adapting to its effects and by reducing greenhouse gas emissions (mitigation), thereby decreasing the rate and magnitude of change.[1] The capacity to adapt and mitigate depends on socioeconomic and environmental circumstances, and the availability of information and technology. Less information is available about the costs and effectiveness of adaptation measures than about mitigation measures.

Climate change is not just an environmental issue but also a health issue. The ability to adapt to the health effects of climate change depends on measures that reduce its severity—ie, mitigation measures that will drastically reduce carbon emissions in the short term, but also increasing the planet's capacity to absorb carbon. This is a crucial issue that must be acted upon urgently. However, we only focus on how we might adapt to and avoid the negative health effects of climate change that, because it can take 20–30 years for carbon emissions to have a full effect, and for deforestation and ecosystem damage to become apparent, will occur even with the best possible mitigation action. In this report, we review the consensus science on climate change and then briefly explore its health implications. We address six ways in which climate change can affect health: changing patterns of disease and morbidity, food, water and sanitation, shelter and human settlements, extreme events, and population and migration. We then present a policy framework to address the major obstacles to responses to the health effects of climate change, and how policy responses might address these issues.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Climate science and the effect of climate change on health

In 1896, the Swedish scientist Svante Arrhenius suggested that human activity could substantially warm the earth by adding CO_2 to the atmosphere. His predictions were subsequently independently confirmed by Thomas Chamberlin.[2] At that time, however, such effect on human beings was thought to be dwarfed by other influences on global climate, such as sunspots and ocean circulation. However, these observations went unappreciated until recently.

The establishment of the IPCC in 1988 was a pivotal move by the world community to address this issue, and has made a huge difference to the evolution of a shared understanding of climate change and to the stimulus for more and better research and modelling.

The greenhouse effect


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The temperature of the earth is determined by the balance between energy input from the sun and its loss back into space. Indeed, of the earth's incoming solar short-wave radiation (ultraviolet radiation and the visible spectrum), about a third is reflected back into space. The remainder is absorbed by the land and oceans, which radiate their acquired warmth as long-wave infrared radiation. Atmospheric gases—such as water vapour, CO_2, ozone, methane, and nitrous oxide—are known as greenhouse gases and can absorb some of this long-wave radiation and are warmed by it. This greenhouse effect is needed because, without it, the earth would be about 35°C colder.[3] Plants take up water and CO_2 and, through photosynthesis, use solar energy to create molecules they need for growth. Some of the plants are eaten by animals. Whenever plants or animals die, they decompose and the retained carbon is released back into the carbon cycle, most returning into the atmosphere in gaseous form. However, if organisms die and are not allowed to rot, the embedded carbon is retained. Over a period of about 350 million years (but mainly in the Carboniferous period), plants and small marine organisms died and were buried and crushed beneath sediments, forming fossil fuels such as oil, coal, and natural gas. The


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industrial revolution started a large-scale combustion of these fossil fuels, releasing carbon back into the atmosphere, increasing the concentrations of greenhouse gases in the atmosphere and resulting in an increased greenhouse effect. Consequently, the temperature of the earth started to rise.

Anthropogenic climate change

Industrial human activity has released vast quantities of greenhouse gases—ie, about 900 billion tonnes of CO_2, of which about 450 billion tonnes has stayed in the atmosphere. About 80% of CO_2 is caused by industrialisation and the rest by land use such as deforestation. The first direct measurements of atmospheric CO_2 concentrations were made in 1958 at an altitude of about 4000 m on the summit of Mauna Loa in Hawaii, a remote site free from local pollution. Ice-core data indicate preindustrial CO_2 concentrations of 280 parts per million by volume (ppmv). In 1958, atmospheric CO_2 concentration was 316 ppmv, and has risen every year reaching 387 ppmv in 2008. CO_2 concentrations over the last 650 000 years have ranged between 180 and 300 ppmv, with changes of 80 ppmv between the regular waxing and waning of the great ice ages. Pollution that we have caused in one century is thus comparable to natural variations that have taken thousands of years.[3]

The increase in greenhouse gases has already substantially changed climate; average global temperatures have risen 0·76°C and the sea level has risen over 4 cm. Seasonality and intensities of precipitation, weather patterns, and substantial retreat of the Arctic sea ice and almost all continental glaciers have dramatically changed.[4] The 12 warmest years on record within the past 150 years have been during the past 13 years: 1998 was the warmest, followed by 2005, 2002, 2003, and 2004. The IPCC states that the evidence for global warming is unequivocal and is believed to be due to human activity.[4] This idea is supported by many organisations, including the Royal Society and the American Association for the Advancement of Science.

Panel 1: The precautionary principle

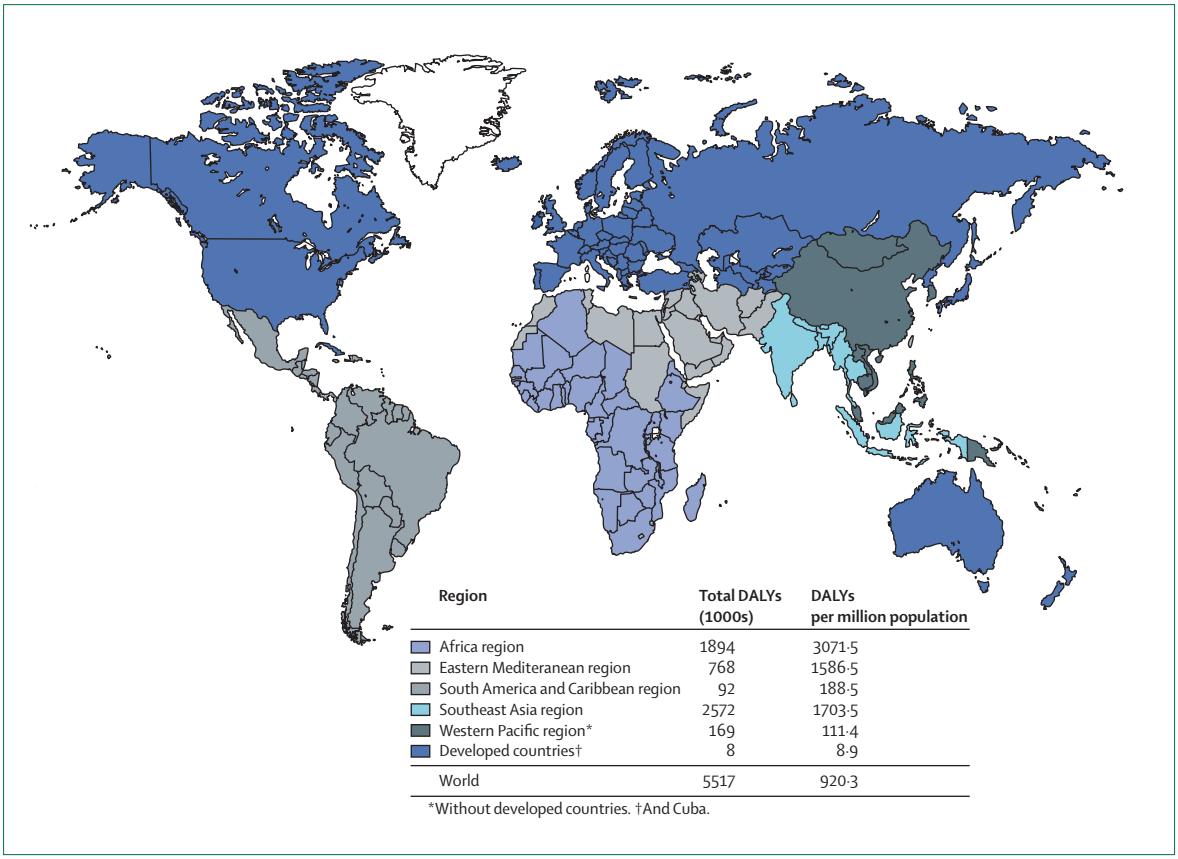
The meaning and role of the precautionary principle is unsettled and disputed, but at its core is the pervasiveness of scientific uncertainty. Whilst it never dictates a specific course of action, and often tradeoffs need to be made between costs and risks of acting and those of not acting, the precautionary principle reminds us that uncertainty is not a reason to postpone or avoid action. This principle is enshrined in Bradford-Hill's article,[10] which states that "all scientific work is incomplete—whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. This does not confer upon us a freedom to ignore the knowledge that we already have, or to postpone the action that it appears to demand at a given time". It might be objected that this principle adds little to what we expect from good decision making. However, decision making can disregard uncertain effects, taking a short-term approach and focusing instead on the certain costs of taking action.

Predicted climate change

The IPCC has synthesised the results of 23 atmosphere–ocean general circulation models to predict future temperature rises on the basis of six emission scenarios.[4] They report that global mean surface temperature could rise between 1·1°C and 6·4°C by 2100, with best estimates between 1·8°C and 4·0°C. Most variation, especially in the latter two-thirds of this century, indicates the unavoidable uncertainty over future choices, trajectories, and behaviours of human societies. Furthermore, global CO_2 emissions are rising faster than the most dire of the IPCC emission scenarios.[5] The models also predict an increase in global mean sea level of 18–59 cm. If the contribution from the melting of ice of Greenland and Antarctica is taken into account, this range increases to 28–79 cm by 2100.[4] All these predictions are based on the assumption of a continued linear response between global temperatures and ice-sheet loss. This response is unlikely because of positive feedback loops in the global warming system, and sea level rise could thus be much higher. Some leading climate scientists have raised the concern that the IPCC 2007 predictions are too conservative,[6–8] although this is still viewed as controversial. Scientists are also concerned by tipping points in the climate system. The term tipping points commonly refers to a critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system. Lenton and colleagues[9] used the term tipping element to describe large-scale components of the earth system that might pass a tipping point. They mainly looked at tipping elements that could be triggered this century. The greatest threats are the artic sea ice and the Greenland ice sheet, with other five potential elements: the west Antarctic ice sheet, the Atlantic thermohaline circulation, El Niño southern oscillation, Indian summer monsoon, Amazon rainforest, and boreal forest. Tipping points might either accelerate global warming or have a disproportionate effect on humanity (figure 1). Uncertainty in predictions however is not an excuse for inaction (panel 1).

Global warming

The effects of global warming will substantially increase as the temperature of the planet rises.[1,11] The return period and severity of floods, droughts, heatwaves, and storms will worsen. Coastal cities and towns will be especially vulnerable as sea level rise will increase the effects of floods and storm surges. Increased frequency and magnitude of extreme climate events together with reduced water and food security will have a severe effect



Region	Total DALYs (1000s)	DALYs per million population
Africa region	1894	3071·5
Eastern Mediteranean region	768	1586·5
South America and Caribbean region	92	188·5
Southeast Asia region	2572	1703·5
Western Pacific region*	169	111·4
Developed countries†	8	8·9
World	5517	920·3

*Without developed countries. †And Cuba.

Figure 2: **Estimated effects of climate change in 2000, by WHO region**[16]
DALY=disability adjusted life year.

on public health of billions of people.[11] Global warming also threatens global biodiversity. Ecosystems are already being hugely degraded by habitat loss, pollution, and hunting. The millennium ecosystem assessment[12] suggested that three known species are becoming extinct every hour, whereas the 2008 living planet report[13] suggested that biodiversity of vertebrates had fallen by over a third in just 35 years, an extinction rate 10 000 times faster than any observed in the fossil record. Global warming is likely to exacerbate such degradation. Economic consequences will be severe,[14] and mass migration and armed conflict might result.

A more pessimistic scenario could occur if the observed temperature rise approaches the higher end of the IPCC expected scenarios. Sustained global temperature rises of 5–6°C could lead to the loss of both Greenland and the western Antarctic ice sheets by the middle of the next century, raising sea levels by up to 13 m.[3,7,8] The UK Environment Agency has plans to deal with a rise of 4·5 m through construction of a barrier across the mouth of the river Thames, stretching 15 miles from Essex to Kent. However, a 13-m rise would cause the flooding and permanent abandonment of almost all low-lying coastal and river urban areas. Currently, a third of the world's population lives within 60 miles of a shoreline and 13 of the world's 20 largest cities are located on a coast. More than a billion people could be displaced in environmental mass migration. A stable coastline would not be re-established for hundreds of thousands of years. The north Atlantic ocean circulation (which includes the Gulf Stream circulation) could collapse plunging western Europe into a succession of severe winters followed by severe heatwaves during summer. An additional 2 billion people would be water stressed, while billions more would face hunger or starvation. The risk of armed conflict would rise. Public health systems around the world would be damaged, some to the point of collapse. Global biodiversity would be devastated.

Future climate targets

What level of climate change is safe? In February, 2005, the British Government convened an international science meeting in Exeter, UK, to discuss this topic. Their recommendation is that global warming must be limited to a maximum of 2°C above preindustrial average temperature.[15] Below this threshold, there are both winners and losers due to regional climate change, but above this figure everyone might lose. However, temperature rises are likely to exceed this threshold: a rise of 0·76°C has already occurred and, even if we had

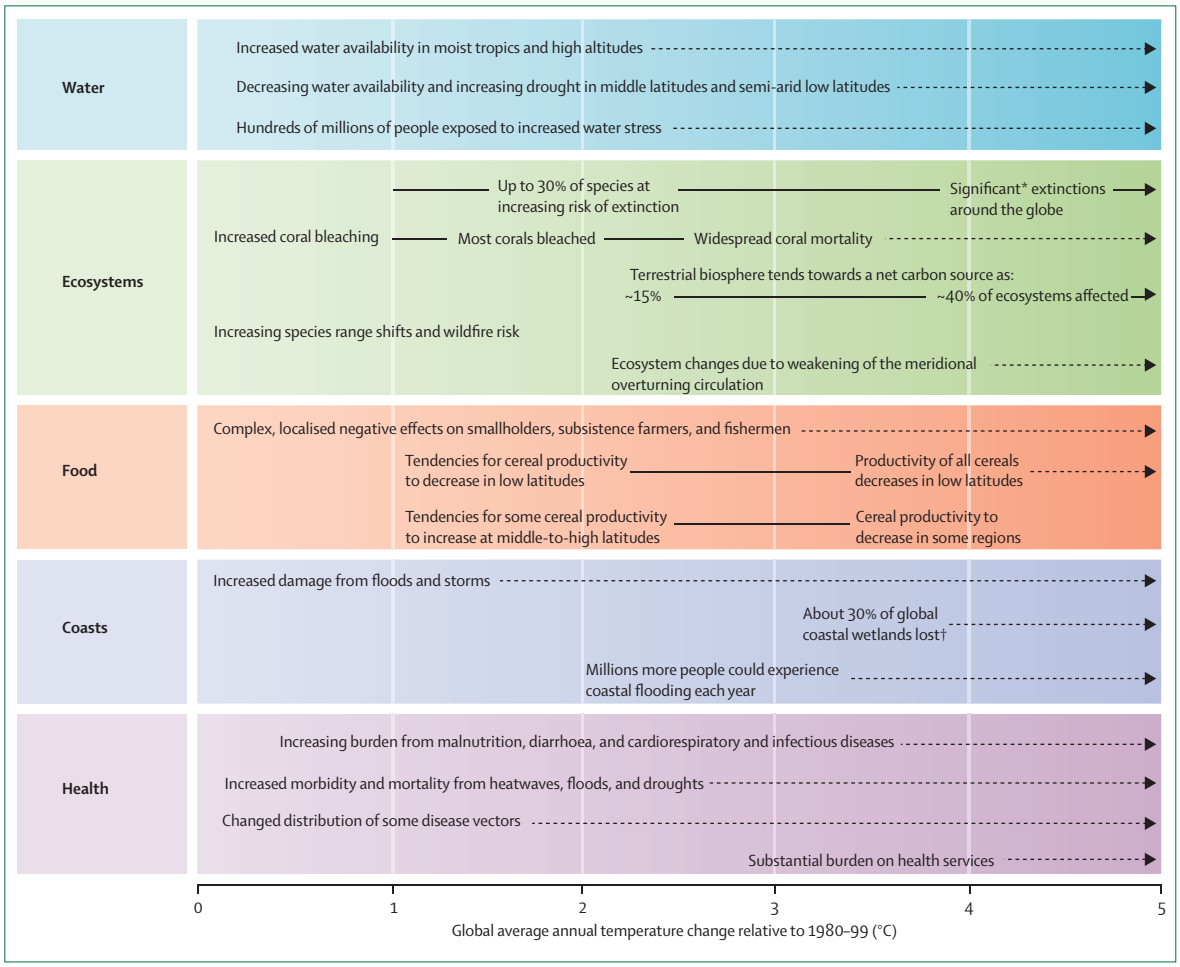


Figure 3: **Effects of global average temperature change**[1]

*Significant is defined as more than 40%. †Based on average rate of sea level rise of 4·2 mm per year from 2000 to 2080. The black lines link effects caused by climate change, whereas the broken arrows indicate effects continuing with increasing temperatures. Entries are placed so that the left-hand side of the text indicates the approximate level of warming associated with the onset of a given effect.

stopped all emissions in 2000, there would still be another 0·6°C rise by 2050.[4]

The cost of climate mitigation and adaptation

What is the cost of avoiding climate change? According to the UK Government commissioned Stern review on the economics of climate change in 2006, if we do everything we can now to reduce global greenhouse gas emissions and ensure we adapt to the future effects of climate change, the average estimated cost is 1% of the world gross domestic product (GDP) every year.[14] However, if we do nothing, the effects of climate change could cost 5–20% of the world GDP every year. These figures have been disputed. Pielke and colleagues[5] argue that the cost of converting the global economy to low carbon could be more than 1% of the world GDP because global emissions have risen faster than the worst predictions. Stern has recently revised the estimate to 2% of the world GDP. However, Parry and colleagues[12] suggest that the effects and the associated costs of global warming have been underestimated by the IPCC[1] and Stern.[14] The potential costs or benefits to global health of mitigating and adapting have not yet been established. Even if the benefit–cost ratio of solving global warming is less than that suggested by Stern, the ethical issue of preventing deaths of tens of millions of people and the increase in human misery for billions is clear.

Climate change and health

Climate change and its rapid emergence in the past decades are a major challenge to public health together with poverty, inequity, and infectious and non-communicable diseases. Furthermore, the poorest countries will suffer the greatest consequences of climate change even though they contributed the least for emissions.

Climate change has been responsible for 5·5 million disability adjusted life years (DALYs) lost in 2000 (figure 2). Although influential in stimulating action on climate change, these initial assessments of the disease

burden attributable to climate change were conservative and relate only to deaths caused by cardiovascular diseases, diarrhoea, malaria, accidental injuries in coastal floods and inland floods or landslides, and the unavailability of recommended daily calorie intake (which is an indicator of malnutrition). However, estimates show that small increases in the risk for climate-sensitive conditions, such as diarrhoea and malnutrition, could result in very large increases in the total disease burden. DALY combines the time lived with disability and the time lost due to premature mortality.

The IPCC's fourth assessment report reviewed over 500 published articles on the effects of heat and cold; wind, storms, and floods; drought, nutrition, and food security; food safety; water and disease; air quality and aeroallergens and disease; vector-borne, rodent-borne, and other infectious diseases; occupational health and ultraviolet radiation (figure 3).

In addition to these direct health effects, climate change will have indirect substantial consequences on health. Economic collapse will devastate global health and development. Mass environmental displacement and migration will disrupt the lives of hundreds of millions of people, exacerbating the growing issues associated with urbanisation and reverse successes in development. Conflict might result from resource scarcity and competition, or from migration and clashes between host and migrant groups.

From a conservative perspective, although a minority of populations might experience health benefits (mostly related to a reduction in disease related to cold weather), the global burden of disease and premature death is expected to increase progressively.[16] These projections were made using emissions data obtained before 2000. Work done after the IPCC 2007 report by Canadell and colleagues[17] compared data from the 1990s with those of 2000–06, and found that CO_2 emissions growth rate increased from 1·3% to 3·3% every year, suggesting that the current carbon cycle is generating more severe climate change sooner than expected. This finding has serious implications for health. Not only the scale of consequences of climate change on health is much larger but the period in which to implement effective adaptive strategies is shorter, threatening to widen social and health inequities even further. The countries most severely affected by climate change are often those most under-resourced in terms of financial, infrastructure, and human capacity to respond. New estimates of disease burden and comparative risk assessments are currently being developed and should provide data for relative current and future health outcomes.

Global health inequities and climate change

> "The rich will find their world to be more expensive, inconvenient, uncomfortable, disrupted and colourless; in general, more unpleasant and unpredictable, perhaps greatly so. The poor will die."[18]

Modern society has done much good for the health and wellbeing of many people. However, large health inequities within and between countries exist. In Japan or Sweden, for example, children can expect to live more than 80 years; in Brazil, 72 years; in India, 63 years; and in several African countries, less than 50 years.[19] The WHO Commission on the Social Determinants of Health reported that social inequities are killing people on a grand scale. The report suggested that "the toxic combination of bad policies, economics, and politics is, in large measure, responsible for the fact that a majority of people in the world do not enjoy the good health that is biologically possible".[19] The damage done to the environment by modern society is perhaps one of the most inequitable health risks of our time. The carbon footprint of the poorest 1 billion people is around 3% of the world's total footprint;[20] yet, these communities are affected the most by climate change (figure 4). Adverse health outcomes are likely to be greatest in low-income countries and in poor people living in urban areas, elderly people, children, traditional societies, subsistence farmers, and coastal populations.[1,22] Loss of healthy life years as a result of global environmental change (including climate change) is predicted to be 500 times greater in poor African populations than in European populations.[23] The observed variation is due to several factors: regional variation in predicted rates and types of climatic change; differing underlying vulnerabilities (such as existing levels of heat and food stress, and exposure to disease vectors); and differing capacities to adapt to changing conditions (related to governance and resources nationally and individual incomes).[24] These differences in the effects of climate change are due to existing economic, social, and heath inequities.[25]

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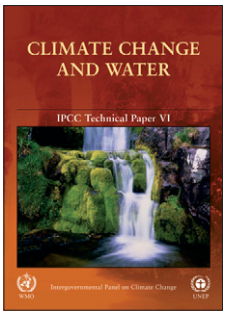
Recent scientific findings

This report is mainly based on the consensus findings from the 2007 IPCC report. Recent scientific findings, however, increased the concerns arising from the IPCC report. In March, 2009, in Copenhagen (Denmark), an international scientific congress on climate change was attended by more than 2500 delegates from about 80 countries.[26] This congress raised several concerns:

- Recent observations confirm that, because of high rates of observed emissions, the worst-case IPCC scenario trajectories (or even worse) are being realised for parameters such as global mean surface temperature, sea level rise, ocean and ice-sheet dynamics, ocean acidification, and extreme climatic events. Many parameters might worsen, leading to an increasing risk of abrupt or irreversible climatic shifts.
- Societies are highly vulnerable to even modest climate change, with poor nations and communities especially at risk. Temperature rises above 2°C will be challenging for contemporary societies to cope with and will increase the level of climate disruption through the rest of the century.



IPCC

- Rapid, sustained, and effective mitigation based on coordinated global and regional action is required to avoid dangerous climate change, regardless of how it is defined. Delay in initiating effective mitigation actions increases greatly the long-term social and economic costs of both adaptation and mitigation.
- Climate change is having, and will have, very different effects on people within and between countries and regions, on present and future generations, and on human societies and nature. An effective, well-funded adaptation safety net is required for those people least capable of coping with climate change, and a common but differentiated mitigation strategy is needed to protect the poor and most vulnerable people.

Management of the health effects of climate change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Climate change will lead to adverse health effects in many ways. If we are about to take effective action to keep health effects of climate change to a minimum, we need to understand the consequences of climate change on health and the possibilities for change or adaptation. In the case, for example, of health threats through changing patterns of disease due to insect-borne infections, various responses are possible—such as vector control, promotion of mosquito nets, new vaccines, or rapid and effective diagnosis and treatment. By contrast, in the case of malnutrition due to food shortages, public health and medical approaches can provide, at best, only temporary relief, and a sustainable solution can only be found in measures that match food supply to need and ensure economic entitlements in the most vulnerable groups.[27] The ability to mount responses in any circumstance might be limited by the degradation of infrastructure and by the economic stressors that climate change brings.

Accordingly, we consider six ways that link climate change to health. These are changing patterns of disease and mortality, extreme events, food, water, shelter, and population. There are, of course, many overlaps and common elements. However, each should be independently considered to understand the possibilities of action to adapt to climate change, and the dangers if such possibilities are not adopted.

Patterns of disease and mortality


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Climate change will affect health directly through a complex set of interdependent interactions. Regional weather changes in temperature, sea level, precipitation, and extreme weather events will cause downstream effects on the environment that lead to adverse health effects. The epidemiological outcome of climate change on disease patterns worldwide will be profound, especially in developing countries where existing vulnerabilities to poor health remain. The added pressure of climate change to the environment will worsen this burden and pose challenging questions for public and global health.

Global temperature rise will directly affect health. The heatwaves of 2003 in Europe caused up to 70 000 deaths, especially from respiratory and cardiovascular causes.[28] Rising temperatures are likely to generate heat-related stress, increasing the short-term mortality rate due to heatstroke.[29] Regions that are heavily urbanised will be more adversely affected than rural ones. Urban populations are especially vulnerable to climate change,[30] as are people with a pre-existing respiratory disease.[31] Modelling of climate change in the Gulf predicts increased mortality rates due to cardiovascular and respiratory illnesses, thermal stress, and increased frequency of infectious vector-borne diseases in 2070–99.[32] The California heatwave of 2006 showed large increases in admissions to hospitals from cardiovascular and other illnesses, and the heatwave in Germany in 2003 increased mortality rates, especially from respiratory causes.[33,34]

Furthermore, the urban population in developing countries is projected to increase from 2·3 billion in 2005 to 4 billion by 2030, which is compounded by expanding urban sprawl and poor housing.[35] This change will inevitably increase the risk of heatwaves and heatstrokes in cities in developing countries as a result of the so-called heat island effect.

Rising temperatures will also affect the spread and transmission rates of vector-borne and rodent-borne diseases. Temperature affects rate of pathogen maturation and replication within mosquitoes, the density of insects in a particular area, and increases the likelihood of infection. Therefore, some populations who have little or no immunity to new infections might be at increased risk. Vector reproduction, parasite development cycle, and bite frequency generally rise with temperature; therefore, malaria, tick-borne encephalitis, and dengue fever will become increasingly widespread. In some cases, extreme events, such as heavy rains, will wash away eggs and larvae and decrease vector populations.

Mosquitoes responsible for malaria will grow, by accessing warm high altitudes, in places once free of the disease.[36] Lindsay and Martens[37] have used models and scenarios to estimate that 260–320 million more people will be affected by malaria by 2080 as a consequence of new transmission zones. Other studies provide similar estimates.[38,39] Pascual and colleagues[40] modelled the population dynamics of mosquitoes in relation to warming in east African highlands. They found that mosquito abundance is amplified with warming, with an over ten-fold increase with every unit increase (0·1°C) in temperature.

In Kenya, meteorological factors were associated with malaria incidence, with temperature having the largest effect.[41] This finding suggests that temperature rises will increase malaria cases. Reiter and colleagues[42] have cautioned against attributing malaria dynamics to climate change and point to the uncertainties of predicting malaria epidemics nationally and locally.

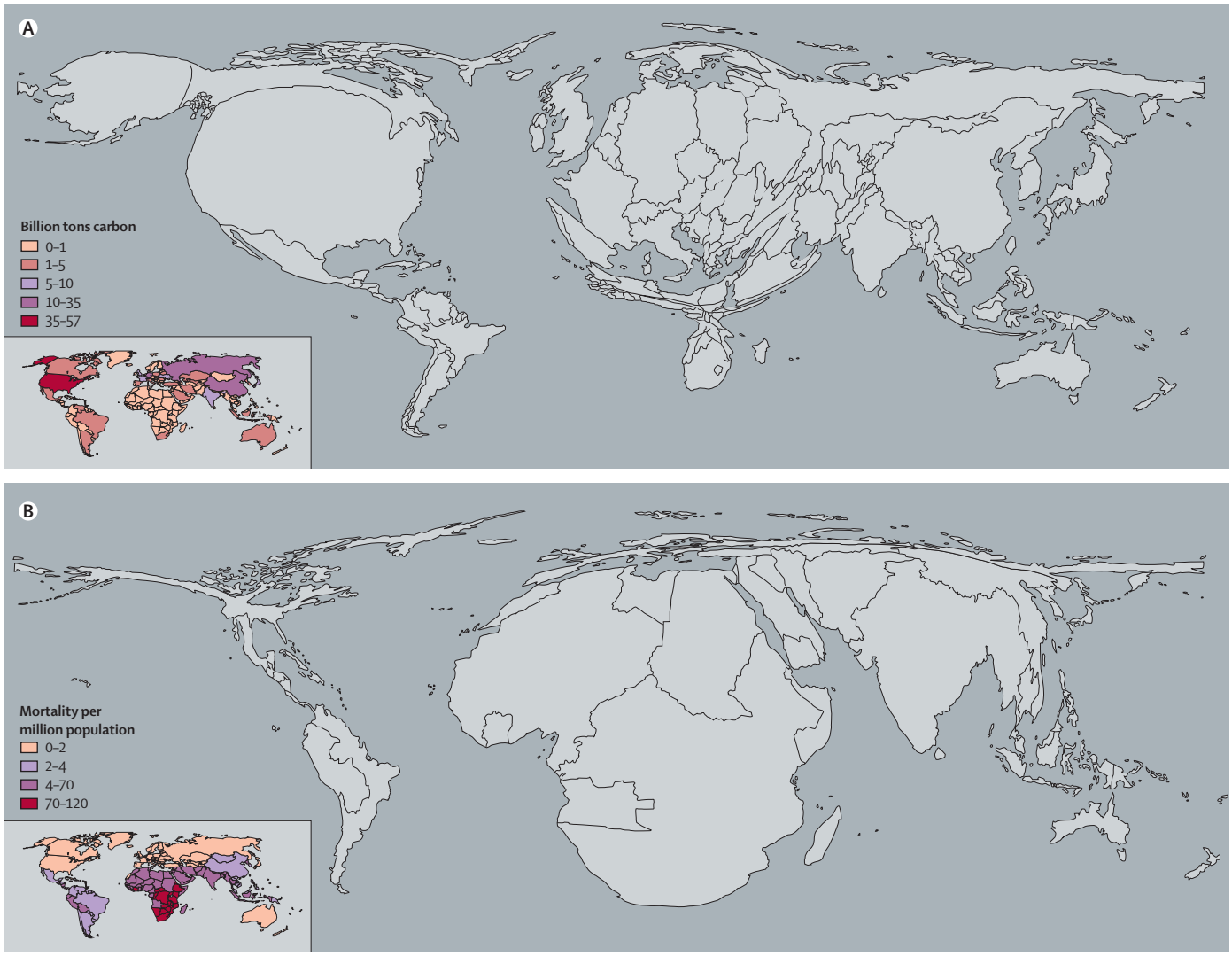

Figure 4: **Density-equalising cartogram**
Comparison of undepleted cumulative CO_2 emissions by country for 1950–2000 versus the regional distribution of four climate-sensitive health consequences (malaria, malnutrition, diarrhoea, and inland flood-related fatalities).[21]

Dengue fever is sensitive to climate. The disease is prominent in urban areas because of inadequate water storage that affects about 100 million people worldwide. Climate change will increase the number of regions affected by arbovirus, such as Australia and New Zealand. Heavy rainfall and a rise in temperature increase the rate of infection.[43] By 2080, about 6 billion people will be at risk of contracting dengue fever as a consequence of climate change, compared with 3·5 billion people if the climate remained unchanged.[1,44]

Schistosomiasis, fascioliasis, alveolar echinococcosis, leishmaniasis, Lyme borreliosis, tick-borne encephalitis, and hantavirus infections are all projected to increase as a result of global climate change.[45–49]

However, some research attributed changes in disease patterns, such as for tick-borne encephalitis, to socio-economic rather than climate change.[50,51] There is no clear evidence at present for a climate effect on influenza or avian flu.[52]

The spread of animal infections, such as blue-tongue virus and other Orbiviruses, provides further evidence of the consequence of climate change on vector-borne diseases.[53]

The extinction of species across the globe arising from habitat fragmentation, climate change, pollution, and the rapid global movement of people and other living organisms have worked synergistically to diminish ecosystem function. Ecosystem modifications through climate change and other anthropogenic changes to the environment could lead to catastrophic disease outbreaks.[54]

Climate change will strain health resources of those countries that already face the public health challenges

of poor health infrastructure, poverty, and inequality. Diminished biodiversity might reduce the risk of a disease being transmitted to human beings, a phenomenon termed the dilution effect.[55] Species might be competent or incompetent in transmitting a disease to vectors that feed upon them. Loss of biodiversity through climate change could alter the proportions of competent and incompetent hosts. Competent reservoir hosts tend to thrive in species-poor communities, therefore vectors are more likely to feed upon these competent reservoirs and become infected, and the risk of human disease is increased. This effect might occur in Lyme, West Nile, and hantavirus diseases.

As ocean temperatures rise with global warming and more intense El Niños, cholera outbreaks might increase as a result of more plankton blooms providing nutrients for *Vibrio cholerae*.[22] In 1998, increased rainfall and flooding after hurricane Mitch in Nicaragua, Honduras, and Guatemala caused a leptospirosis outbreak, and an increased number of cases of malaria, dengue fever, and cholera. Floods also promote outbreaks of cryptosporidiosis: in Wisconsin (USA) in 1993 there were 400 000 cases and 100 deaths.[56]

The ability of health systems to respond effectively to the direct and indirect health effects of climate change is a challenge worldwide, especially in many low-income and middle-income countries, which suffer from disorganised, inefficient, and under-resourced health systems.

Food

Climate change threatens human health through its effect on undernutrition and food insecurity.[57] Chronic and acute child malnutrition, low birthweights, and suboptimal breastfeeding are estimated to cause the deaths of 3·5 million mothers and young children every year.[58] Furthermore, one in three children under the age of 5 years born in developing countries suffer from stunting due to chronic undernutrition.

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Climate change will compound existing food insecurity.[59] Before the current food crisis, more than 800 million people had calorie-deficient diets, mostly in sub-Saharan Africa and south Asia. After the rise in food prices in 2008, millions more—estimates range from 100 million to 850 million—might suffer hunger or food insecurity.[60] According to the UN World Food Programme, the number of food emergencies every year has increased from an average of 15 during the 1980s to more than 30.

Lobell and Asner[61] showed that corn and soyabean yields in the USA fell by 17% for every degree rise in growing season temperature. Previous studies had predicted changes of similar magnitude for a 3°C temperature increase.[62]

Lobell and colleagues[63] used statistical crop models and climate projections for 2030 from 20 general circulation models and showed that south Asia and southern Africa, without sufficient adaptation measures, are likely to suffer negative outcomes on crops that are important to large food-insecure human populations, such as maize, wheat, and rice.

Another study[64] suggests that half of the world's population could face severe food shortages by the end of the century because rising temperatures take their toll on farmers' crops. Harvests of staple food crops, such as rice and maize, could fall between 20% and 40% as a result of increased temperatures during the growing season in tropical and subtropical regions. Battisti and Naylor[64] combined IPCC climate models with historical examples of the effects of heatwaves on agriculture, and found a 90% chance that, by the end of the century, the coolest temperatures in tropical regions during the crop-growing season would exceed the hottest temperatures recorded between 1900 and 2006. Temperate regions, such as Europe, will see previous record temperatures become the norm by 2100.

Although agricultural productivity might increase in some regions as a result of global warming (almost entirely in the rich high-latitude countries, although Sahara greening might benefit west Africa), hunger, illness, and death due to undernutrition are set to worsen as climate change affects crops, forestry, livestock, fisheries, aquaculture, and water systems. Increases in extreme weather events will damage crops and disrupt farming.[65] Sea level rise and flooding of coastal lands will lead to salination or contamination of fresh water and agricultural lands, and the loss of nursery areas for fishing. Drought, and changing patterns of plant and livestock diseases and pest infestations, reduction of income from animal production, decreased crop yields, lessened forest productivity, and changes in aquatic populations will all affect food production and security. The regions most likely to be adversely affected are those already most vulnerable to food insecurity and malnutrition, where production is undertaken by

smallholder and subsistence farmers, pastoralists, traditional societies, indigenous people, coastal populations, and artisanal fisherfolk.[59] Ironically, many food-insecure people nowadays are small farmers, fishers, and herders. Even though they grow food, many lack access to good land, adequate agricultural inputs, and access to viable markets, and thus lack the ability to meet their needs through either production or purchase.[66]

The rise in food prices has also caused an upsurge in the number of urban-based, food-insecure populations, a trend that will grow as a result of people being forced to migrate to urban areas as environmental migrants, and because almost all global population growth over the next 30 years will occur in cities of developing countries.

In 2008, Josette Sheeran, director of the World Food Programme, wrote that "in the fight against hunger we could now be facing a perfect storm of challenges, including climate change and increasingly severe droughts and floods, soaring food prices and the tightest supplies in recent history, declining levels of food aid, and HIV/AIDS, which also aggravates food insecurity".[67]

Water and sanitation

Safe and reliable access to clean water and good sanitary conditions are essential for good health. Provision of public health infrastructure has been key to economic, social, and industrial development, and remains a challenge in many parts of the world. In 2002, 21% of people living in developing countries did not have sustained access to an improved water source, and 51% did not have access to improved sanitation.[68] In 1995, almost 1·4 billion people were living in water-stressed regions, defined as rainfall runoff of less than 1000 m^3 per person per year.[69] The main health effects of lack of access to clean water and sanitation are diarrhoeal and other diseases caused by biological or chemical contaminants. Poor drainage in human settlements increases exposure to contaminated water and provides habitat for mosquitoes, leading to increased incidence of water-borne and vector-borne diseases.

In Delhi (India), for example, 15 million people face serious water shortages, with water being transported up to 300 km. The projected population of this municipality is more than 30 million by 2025.[70] Buildings in Mexico City (Mexico) are sinking as a result of overexploitation of the aquifers under the city, and the water distribution network is losing 40% of water. Consequently, the city now imports a third of its raw water, with the additional costs of pumping it up 1000 m.[71]

Changing rainfall and temperature over the next decades are likely to make provision of clean water, good sanitation, and drainage even more complicated than it is now. Average annual rainfall is forecast to decrease in some regions and increase in others, and droughts and floods are likely to become more frequent and intense. Regional temporal patterns of rainfall might also be altered: the problem is not simply sustained drought, but also severe rainfall all at once followed by less rainfall, thus annual rainfall might rise, but still cause drought.

Increased rainfall could reduce absolute water scarcity in some regions. However, the health benefits of increased rainfall in regions such as southeast Asia depend on the capacity to store additional runoff, which is predicted to occur during the wettest rather than driest seasons.[69] In other regions, such as the Mediterranean, southern and central Africa, Europe, and the southern USA, reduced annual rainfall and growing populations are likely to increase the number of people living under water stress.[69] Water scarcity might result in greater conflict between and within countries and communities.

More than a sixth of the world's population currently live in glacial-fed water catchments, which are vulnerable to climate change.[14] Increasing rates of glacial melting are predicted to lead to great reductions of water availability. In the near future, high peak flows in glacial-fed rivers are expected, as the rate of glacier-mass loss increases, followed by dramatic reductions in river flow and freshwater availability as glaciers progressively disappear. Rising temperatures are also likely to result in earlier snow thawing and increased rain relative to snow precipitation, bringing peak river flows earlier in the year, potentially exacerbating dry season water scarcity.[72] In August, 2008, when the Kosi river changed course, the Bihar flood (India) was probably partly caused by increased river flow from glacial melting. The flood affected 4·4 million people, destroyed 290 000 hectares of land, and costed an estimated US$6·5 billion.

Reduced river flows and increased water temperature will lead to declining water quality as the dilution of contaminants is reduced, less oxygen is dissolved in water, and microbiological activity increases.[1,72] These effects could lead to major health problems for vulnerable people, especially during drought, and might increase the risk of conflict and major population migration.

Shelter and human settlements

The management of health effects of climate change related to shelter and human settlements requires not only secure emergency shelter for those displaced or affected by climate variability events, but also human settlements prepared for the future climate-changed environment. The process of urbanisation in the developing world is structurally linked to increased environmental vulnerability, with a high percentage of the urban population exposed to climate-related hazards, such as floods and landslides, as well as to related health problems, such as disease and injury. Climate change increases this vulnerability, especially for the poorest and most powerless groups in society, as they often have not been given opportunities to adapt. Thus, poverty reduction needs to be placed at the forefront of the debate on adapting human settlements to climate change.

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Adaptation can prevent only some damage. Synergies between development and climate change adaptation exist: successful, well-governed cities that focus on improved housing, living conditions, and infrastructure will reduce poverty and, at the same time, adapt to climate change.[73]

Urban settlements, especially cities, need to be adapted in two ways. First, changing and designing settlements that contribute less to the causes of climate change (eg, building energy efficient and green housing). Second, adapting settlements to be climate resilient and able to cope with the increasing risks of climate change.

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The need to improve the lives of 2·4 billion people who rely on biomass for cooking and heating and 1·6 billion people who have no access to electricity presents a major developmental challenge in many developing countries.[74] Those without access to electricity for cooking, lighting, transport, communications, and refrigeration are exposed to adverse health risks. Poor people who have access to energy currently do so in the worst way—ie, they have access to energy that is expensive, polluting, limited, and disadvantageous to women and children, both in terms of health risks and the time spent in the collection of energy fuels. Reliance on unclean burning of coal and biomass fuels is a cause of much ill-health in developing countries.[75] Therefore, a need exists to improve access to secure, clean, reliable, affordable, and sustainable sources of energy that can provide essential services for a healthy, productive, and safe life, strengthening the positive relation between poverty reduction, health, energy security, and ecological sustainability. Energy security is also an issue of growing concern to many governments in both developed and developing countries, and a potential source of international tension and conflict.[75]

Extreme events

Major disasters caused by extreme natural events and health are directly linked, especially in relation to weather-related disasters, which can be expected to increase in number and severity in a warmer planet. Associated health problems[72] can arise from the loss or contamination of potable water leading to disease, destruction of crops resulting in food shortages, poor nutrition, and malnutrition. Health problems are compounded by general infrastructure breakdown, notably with respect to water supply, sanitation, and drainage. In the long term, mental health conditions after a disaster, such as depression and anxiety, can also present serious problems.

In recent years, more than 2 billion people were affected by natural disasters,[76] many of which were directly or indirectly related to extreme meteorological phenomena, including heatwaves and coldwaves, floods, droughts, and windstorms. A few examples of cities at risk from floods or sea level rise include Alexandria (Egypt), Cotonou (Benin), Dhaka (Bangladesh), Lagos and Port Harcourt (Nigeria), Abidjan (Côte d'Ivoire), Mombasa (Kenya), Buenos Aires (Argentina), and Bamenda (Cameroon).[73]

Between 2004 and 2008, 40% of the 1062 disasters in this period were the result of floods and tropical cyclones, whereas 52% of disasters in 2007 were related to the weather. Most susceptible are those populations living in developing nations that occupy coastal tropical regions. 70% of natural disasters between 2004 and 2006 occurred in Asia, the Pacific region, Africa, and the middle east,[76] where most of the world's vulnerable and exposed populations reside. As defined by the reinsurance group Munich Re, in 2007 there were 960 major natural disasters (the highest ever such figure),[77] with more than 90% being the result of extreme weather-related or climate-related events, together accounting for 95% of the 16 000 reported fatalities and 80% of the total $82 billion economic losses.

Of the 238 great natural catastrophes that occurred between 1950 and 2007, two-thirds resulted from extreme weather or climate-related events, mainly floods and windstorms.[77] According to Munich Re,[77] the number of great weather-related disasters has climbed from an average of less than two per year in 1950 to more than six in 2007. Over the same period, average annual economic losses have risen from less than $5 billion to more than $60 billion.

According to the IPCC fourth assessment report,[4] the frequency of heavy precipitation events has increased over most land areas; more intense and longer droughts have been observed across wide areas since the 1970s; widespread changes in extreme temperatures over the past 50 years have seen less frequent cold spells and more frequent and intense heatwaves than ever before; intense tropical cyclone activity has risen in the north Atlantic since about 1970; and the incidence of extreme high sea levels has also risen.

Observed climate-related hazard trends are held by the IPCC to be likely or more likely than not to indicate human contribution.[4]

On the basis of projections for the 21st century with special report on emissions scenarios,[78] the frequency of most meteorological extreme events is expected to continue to rise.[4] Hot conditions, heatwaves, and heavy precipitation events will continue to become more frequent.[4] According to Sterl and colleagues,[79] by 2100 northeast India and Australia can expect summer temperatures to peak over 50°C, and the southwest, central west, and southern Europe over 40°C. This warming is expected to have serious health implications for vulnerable groups such as elderly people with cardiovascular conditions. Precipitation intensity is predicted to increase across most regions,[1] which could result in increased river and flash flooding, including those related to the south Asian monsoon.[80] Although the total number of tropical cyclones might decrease, more powerful, and therefore potentially more destructive,

storms could become increasingly frequent.[81] Future trends in extratropical storm activity remain difficult to predict, but a consensus exists that changes will become apparent. Ulbrich and colleagues[82] forecast increasing storm-track activity in the eastern north Atlantic, western Europe, and parts of Asia, which might intensify extreme cyclones. Jiang and Perrie[83] predict that Atlantic middle-latitude storms will increase in radius and tend to become more severe and faster, whereas Rockel and Woth[84] estimate a future increase of up to 20% in the number of storm peak events over central Europe. Coastal flooding arising from powerful storms causing high storm surges are projected to increase. According to the IPCC fourth assessment,[1] this event could triple (from the current 200 million) the number of people vulnerable to extreme surges.

Population and migration

Population growth will interface with climate change in ways that intensify several other mechanisms, especially shelter, food, and water scarcity. Population growth also puts additional stress on already weak health systems and exacerbates vulnerability to the adverse health effects of climate change. Independent of population growth, large-scale population movement is likely to intensify as changing climate leads to the abandonment of flooded or arid and inhospitable environments. The resulting mass migration will lead to many serious health problems both directly, from the various stresses of the migration process, and indirectly, from the possible civil strife that could be caused by chaotic movement of people.

According to the UN 2006 revision of the world population prospects, the world population is likely to increase from the current 6·7 billion to 9·2 billion in 2050.[85] This increase is equivalent to the total global number of people in 1950, and it will be absorbed mostly by the less developed regions, whose population is projected to rise from 5·4 billion in 2007 to 7·9 billion in 2050. By contrast, the population of developed regions is expected to remain mainly unchanged at 1·2 billion, and would have declined if it was not for the projected net migration from developing to developed countries, which is expected to be 2·3 million persons every year after 2010. Modest changes in fertility have large effects on population growth. Current projection is that the world population will grow to 9·2 billion by 2050 but, if fertility is half a birth higher or lower than that expected between 2005 and 2050, the world population will be 10·8 or 7·8 billion, respectively, in 2050.[85] Furthermore the current median projection assumes that fertility will continue to decline, which is threatened by the reduction in funding over recent years for family planning services.

Population growth will increase pressure and competition for scarce resources, such as food, water, and land. To compensate, production will rise, resulting in even greater environmental degradation of arable land.

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Panel 2: International law on climate change

The agreement of the UN Framework Convention on Climate Change (UNFCCC) in 1992 was the first major step in the development of international law on climate change. This agreement, which provided only minor targets and ambitions, crucially puts in place institutions and procedures for global debate and action on climate change. It also set the stage for the more ambitious Kyoto protocol in 1997, which aimed to cut developed-country greenhouse gas emissions by 5% below 1990 levels in 2008–12. The protocol provided for three market-based mechanisms (emissions trading, clean development mechanism, and joint implementation) to contribute to emission reduction. Within the overall 5% target, the obligations of individual developed countries vary greatly. Developing countries undertook no emission reduction targets in Kyoto, and the USA did not ratify the protocol. In the recent meeting in Poznan (Poland), discussions focused on an ambitious response to climate change mitigation that would include targets for the large developing countries, such as China, India, and Brazil. The negotiations on the Kyoto protocol's adaptation fund were also moved forward. The fund is a legal entity that provides grants to help developing countries to adapt to the consequences of climate change. International negotiations to set targets beyond 2012 are ongoing, and will be concluded in Copenhagen at the end of 2009.

Both demand and compensatory rises in food production will be complicated by high land loss, a result of industrialisation, urbanisation, and sea level rises and increased flooding. Also, an expansion of the global population will eventually bring a substantial rise in CO_2 emissions.

Rising sea levels, which result from oceanic thermal expansion and ice-cap melting, will be a major contributing factor to population displacement.[4] The recent doubling of sea level rise projections from the March, 2009, Copenhagen conference are especially worrying. As mentioned previously, a third of the world's population lives within 60 miles of a shoreline, and a high number of these live at low altitudes. The rising of the sea level will be most intensely felt in densely populated, low-lying river deltas, such as the delta region of Bangladesh or the Nile delta in Egypt. In Bangladesh, for instance, over 120 million people populate the complex delta region: a 0·5-m sea level rise will account for 10% land loss and a displacement of 6 million people; a rise of 1·0 m will cause 20% land loss and a population displacement of 15 million people.[86]

Drought and desertification frequency and intensity will increase, causing health problems and also influencing population migration. Droughts, especially in rural areas, have a tendency to affect migration into cities,[1] increasing urbanisation and stressing the socio-economic conditions already exacerbated by high population growth. It is estimated that 72% of the dwellers in African cities live in slums, which, having poor drainage facilities, are especially prone to flooding and ill health.[87] Action Aid ran analyses of slum dwellers in six African cities and found intracity flooding and the consequence on hygiene and sanitation to be a major health concern.[88]

Although it is impossible to predict with any certainty what climate change will mean for human population migration,[89] the number of climate-change-related migrants that could exist by 2050 is estimated to be in the hundreds of millions.[90]

Climate change, population growth, migration, and conflict are contentious issues. Climate change might be one of many factors influencing violence,[91] but where conflict occurs between migrant and host populations, it is a result of national identity clashes rather than of migration.[92] This association, however, has been observed for example in Darfur. Coinciding with warming of the Indian ocean, average rainfall in southern Sudan dramatically fell in recent decades, prompting the UN Environment Programme to recognise that climate change and desertification have been an additional stressor to the population, influencing migration to the south and thus might have contributed to the initiation of the conflict.[93]

A policy response framework

Climate change is a real threat to global health and wellbeing, and is contributing to mortality, especially for people living in poverty and lacking access to essential health care. A 2°C rise will result in insecurity for millions of people in terms of food, water, or shelter, with the risk of many additional deaths.

No countries will be immune from the health effects of climate change. For example, the hurricane Katrina in the USA and the deaths caused by the 2003 heatwave in Europe show that rich countries cannot always protect themselves from the adverse health consequences of climate-related events.

An integrated approach to attempting to reduce the adverse effects of climate change requires at least three levels of action. First, policies must be adopted to reduce carbon emissions, and thereby slow down global warming and eventually stabilise temperatures. Second, action must be taken on the links connecting climate change and adverse health. Third, appropriate public health systems should be put into place to deal with adverse outcomes.

Slowing down carbon emissions presents daunting challenges, requiring coordinated action on a global scale (panel 2). However, many adaptation strategies can be pursued by a combination of local, national, regional, and global strategies, and hence important steps can be taken requiring less demanding forms of cooperation and therefore with greater speed. This does not mean that adaptation will be easy or straightforward. Common challenges exist that make, and will make, the process of

adjustment to climate change difficult. Here, we highlight five overlapping challenges. These are not the only five and they might not even be the most important. Our goal is simply to promote creative thinking on how to respond to them.

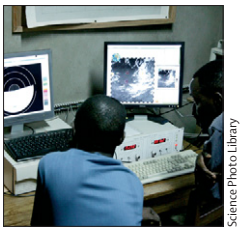
Informational challenge

The generation of reliable, relevant, and up-to-date information will be essential to respond to the negative health effects of climate change. Information is worthless without political will or institutional capacity; however, without information, political will or institutional capacity will achieve little. This challenge is about the generation and dissemination of relevant information about the public health effects of climate change and how to address them. In developed countries, at least, general awareness of the issue seems well established. Yet, much more detailed and specific information is necessary if an intelligent response is to be made. Information pertaining to specific regions, countries, and localities is an important resource, which is not yet sufficiently available for poor countries.[17] Building the capacity of governments and universities in the poorest countries could take a long time to accomplish, therefore new operational systems for vulnerability assessments are needed especially in Africa and Asia. South America and Caribbean countries have done much to assess the effect of climate change, but a lot remains to be done.

WHO has identified key gaps in knowledge—notably, a lack of region-specific projections of changes in health-related exposures and a lack of research on health outcomes concerning various future emissions and adaptation scenarios. WHO has also noted the issues of models that generalise health outcomes between locations because important local factors, such as transmission dynamics, might not be well captured.

Varying capacity for research and adaptation in low-income and middle-income countries is likely to deepen the inequality of health effects. The geographical distribution of the 16 national health impact assessments of climate change done between 2001 and 2007 is indicative. Only five assessments were in low-income or middle-income countries—India, Bolivia, Panama, Bhutan, and Tajikistan—and none were in Africa. Local capacities for research must be strengthened with local responses to climate change.

Little modelling has been done outside developed countries despite the effects on health being skewed towards developing countries. Information that is reliable, accurate, and disseminated is fundamental for effective adaptation and to avoid the so-called adaptation apartheid. For example, heatwaves are silent killers. Although we have good data for the effects of heatwaves in the USA and Europe, almost no reliable data for heatwave-induced mortality exist in Africa or south Asia.[94,95] Disease monitoring, surveillance, and health early warning systems depend on reliable information provided by meteorological stations worldwide. However, the number of these stations in Africa, for example, is eight times lower than the minimum recommended by the World Meteorological Organisation, and reporting rates are the lowest in the world.[96] A key challenge is the financial and technical constraints that prevent developing countries from wide-scale implementation of these stations.[14]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The 61st World Health Assembly resolution—passed unanimously in May, 2008—lays out five priorities for research and action: extensive documentation of the risks to health and differences in vulnerability within and between populations; development of health protection strategies; identification of health co-benefits of actions to reduce greenhouse gas emissions or to adapt to climate change; development of decision support systems to predict the effects of climate change for member states; and estimation of the financial costs of action and inaction.

Better modelling of basic climate–health association and a comprehensive assessment of current and future climate-related burdens of disease are needed. Some climate–health associations cannot be formally modelled (eg, mental health or infectious disease consequences on population displacement), therefore alternative qualitative and longitudinal studies will be needed.[97]

Assessment of the burden of disease associated with climate change is challenging because of the unusually wide range of health outcomes (and inputs) affected.[16] However, detailed estimates are essential both in strengthening understanding of the consequences of failed attempts at emission mitigation and in formulating policies to improve adaptation in those most at risk.

The challenge to disseminate information is about ensuring that the necessary information is available and easily accessible in the right place at the right time. Mechanisms to ensure that the lessons of experience and experiments in one place can be learned in other, perhaps distant, places are essential. Several databases have been established to facilitate learning, such as the UK Climate Impacts Programme database (panel 3) and the UNFCCC database on local coping strategies. It gathers and disseminates knowledge and experience from communities that have had to adapt to specific hazards or climatic conditions.[100] It is searchable by hazard (eg, floods), outcome (eg, decreased food security), and strategy (eg, appropriate crop selection), and new case studies can be added. The current examples come from various developing countries, including China. There are a few contributions from developed countries, such as a heatwave strategy in Philadelphia (USA) and typhoon preparedness in Japan.

Policy responses to the public health effects of climate change will have to be formulated in conditions of uncertainty. The complexity of uncertainty partly indicates that climate change is not a stand-alone risk factor but, rather, an amplifier of existing health risks. The unavoidability of uncertainty refers to the unusual

future projection of health risks, and not something that is much, if ever, done in routine environmental epidemiology and public health. Therefore, uncertainty will always exist about the scale and timing of the effects, as well as their nature, location, and intensity. Regardless of any lack of clarity about what the precautionary principle means (panel 1), action will have to proceed in spite of scientific uncertainty. Policy responses must be able to adapt to new information or unexpected events.

Changing patterns of disease and mortality

A fundamental requisite for health adaptation to climate change is to improve monitoring and surveillance of disease and mortality in sensitive regions. In developing countries, disease surveillance systems are inconsistent and poorly managed. The challenge is to incorporate a strong public health infrastructure and empower communities to achieve effective disease surveillance.

Health early warning systems are especially important in the context of heatstroke, extreme weather events, and disease outbreaks for developing and developed countries. The effectiveness of health early warning systems depends on the past and current disease monitoring and surveillance, and accurate and reliable meteorological and climatic forecasts. Health early warning systems are a win-win strategy that reduces the risk of disease whilst increasing adaptive capacity that is most essential in the context of developing countries.

In the developing world, no region-specific projections of changes in health-related exposures and no research projecting health outcomes under various future emissions and adaptation scenarios compared with many parts of developed countries exist.[1,101] Recent reports have highlighted the urgent need for improved surveillance systems and technologies, especially for infectious diseases in developing countries and for increased cooperation between states in the identification and public health response to outbreaks and epidemics.[102]

Food

Prediction on how climate change will affect agricultural production is lacking. Some of the negative effects of climate change on agriculture could be offset by better practices, more irrigation, and use of genetically modified crops. However, in some areas a complete change of agricultural practices and type of crops grown will be needed. This is both an informational and social challenge. With climate change, many areas might become unsuitable for cash crops; however, because of market forces, high use of irrigation and pesticides might still make it financially viable. But the land might be more suitable and more environmentally sustainable if used for mixed food crops. These important decisions need information to ensure a region's or country's food security in spite of climate change.

One suggestion of multinational biotechnology corporations and some governments is that the effects of

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climate change on food can be dealt with by technological solutions, especially genetically modified plants. This idea places a corporate, technological, and commercial approach against one that questions the claims that genetically modified plants will increase food security and be able to cope with climate change, and that instead calls for more ecologically sustainable forms of farming that will also provide direct benefits to organisations of small-scale farmers, fisherfolk, and indigenous people, while strengthening national food sovereignty in poor countries. The 2008 international assessment of agricultural science and technology for development (also known as the world agriculture report), which was written by over 400 scientists and is similar to the reports of the IPCC, states: "To address expected climate change challenges and impacts, a major role for agricultural knowledge, science and technology is to increase adaptive capacity and enhance resilience through purposeful biodiversity management. Options include irrigation management, water harvesting and conservation technologies, diversification of agriculture systems, the protection of agrobiodiversity and screening germplasm for tolerance to climate change".[103] It also states that there is no evidence that genetically modified plants will increase food security in a changing climate and indicates some dangers related to an over-reliance on such plants.[103]

Water and sanitation

At present, water resource and infrastructure management have been based on data for a stable climate.[71] No assessment exists on how effective currently recommended interventions (from hygiene promotion to infrastructure) will be in a different climate. The key issue with the management of water in the future is not only that climate change predictions are uncertain but also that the climate will be unstable and unpredictable on the basis of long-term historical data. Water-resource managers and policy makers need to shift from risk-based approaches based on historical climate and hydrological data to decision making in an uncertain setting. Improved data collection and modelling will provide useful ways to guide decision making, but the nature of decision making under climate change will be fundamentally different.

The quality and availability of data and climate models are variable worldwide. This variability poses substantial challenges in understanding regional climate systems to improve climate and hydrological modelling. Improved observation and modelling of climate and hydrology are a challenge, especially for developing regions including Africa, Asia, and South America. Observation and modelling are needed to provide baseline scientific input for planning and managing water resources and infrastructure. Furthermore, policy makers are faced with the issue that water scarcity indexes currently only include surface water. Many populations rely on ground and stored water resources, which are not currently taken into consideration.[104]

Panel 3: The UK climate impacts programme

The UK experience offers a positive example for generating local information about climate change adaptation. The UK climate impacts programme (UKCIP) is mainly funded by the UK Government through the Department for Environment, Food and Rural Affairs (DEFRA). Its aim is to provide information through models and interactive systems for stakeholders in the UK. At present, UKCIP is a unique global resource helping individuals, companies, and governments to assess their vulnerabilities and to build adaptation strategies. Similar programmes, if copied by other countries, would help policy makers to design adaptation policies. The models can predict decadal changes in water and food security, extreme events, as well as changes in the extent of potential disease vectors.[98,99]

For more on **UKCIP** see http://www.ukcip.org.uk/

For more on **DEFRA** see www.defra.gov.uk/environment/climate-change/uk/ukccp/pdf/ukccp-ann-report-july08.pdf

Shelter and human settlements

There is growing evidence, through simulations and empirical studies, that human settlements, both rural and urban, will be greatly affected by the irreversible outcomes of climate change, even in the most optimistic scenarios.[105] Research and debate should focus on how settlements will be affected and how to best adapt to climate change.[14] The social and economic effects of climate change will increase inequalities worldwide. Most vulnerable people live in urban settlements in developing countries that have limited resources to adapt to climate change and are already affected by several natural-related risks, such as floods and landslides.[106,107] Paradoxically, urban areas in high-income nations, which are the greatest contributors to greenhouse gas emissions, have much more resource capacity to adapt. Climate change debates on urban settlements tend to be focused on mitigation and, consequently, are limited.

Extreme events

Better assessment of the health effects of extreme climatic events requires improved modelling of their pace and spatial distribution and more thorough and sophisticated models of the demographic, social, and economic trends that increase human vulnerability to hazards. Also, adaptation and mitigation will require a new approach to management of extreme events, focusing on improved early warning, effective contingency planning, identification of the most vulnerable and exposed communities, and, in some cases, permanent resettlement. Such challenges are only likely to be met successfully where disaster risk reduction is actively incorporated as a mainstream activity of social and economic development.[108]

Current knowledge of the health effects of extreme events is limited by scarce (especially related to subjectivity) data collection and analysis, and epidemiological and longitudinal studies.[109,110] Two principal challenges can be identified: first, expansion of knowledge of the factors making populations vulnerable through improved climate modelling and vulnerability assessments at the regional and local scale; and second, identification of the most appropriate actions and approaches for reducing extreme-event disaster risk and, consequently, limiting resulting health effects.[108,111]

Population and migration

The connection between population growth and climate change is complex; because the main cause of climate change lies in the rate of carbon emissions in developed countries, developing countries cannot be blamed for the issue of population growth. However, developing countries with rapid population growth might become substantial contributors to climate change.

Accurate models of the number of environmentally displaced people because of uncertainty of the effects of climate change are not feasible. The association between climate change and migration is complex, and environmentally induced migration should be viewed as a consequence of a multicausal system that includes political, social, and economic factors.[112] Similar to migration, the association between climate change and conflict is difficult to quantify. Climate change is not the only factor leading to migration or violence but high population densities and growth, inequality, and underdevelopment are also responsible.[113]

For example, the effect of rising sea levels on migration is uncertain, as sea level rise does not only depend on the rate of global temperature rise but also on the rate of natural processes such as subsidence. The World Bank has estimated that, by the end of the 21st century, the sea level in Bangladesh could rise by as much as 1·8 m. In the worst-case scenario, they estimated that this would result in a loss of up to 16% of land supporting 13% of the population and producing 12% of the GDP.[3]

Investment in voluntary family planning programmes can make a great contribution to mitigation and adaptation programmes. Policy formulation to develop a new plan that combines reduced child mortality with access to family planning will be a major challenge.

Panel 4: Contraction and convergence

Climate change requires two possibly conflicting actions. Carbon emissions must be reduced to avoid the worst outcome of climate change. Poor countries need rapid economic development so that no country, community, or individual is too poor to adapt to climate change. The concept of contraction and convergence, developed by the Global Commons Institute, considers the need to pursue both these actions simultaneously.[114] Contraction and convergence reduce overall carbon emissions to a sustainable level but do so according to an equal share of emissions per person globally. Industrialised countries would dramatically reduce their emissions whilst developing countries would increase theirs to allow for, and stimulate, development and poverty reduction.

The challenge of poverty and inequality

Many of the most serious public health consequences of climate change will be experienced by the world's poorest nations, increasing global health inequities.[20] Basic infrastructure for much of the world's population is inadequate to meet essential health care needs, and our ability to cope effectively with the aftermath of natural disasters is insufficient. Overall, all the underlying social, economic, and ecological determinants of global illness and premature death will be exacerbated by climate change.[20] Progress towards the Millennium Development Goals and achievement of the 2015 targets might be impaired or reversed. Because climate change acts mostly as an amplifier of existing risks to health, poor and disadvantaged people will experience greater increments in disease burden than rich, less vulnerable populations.[24,26]

The current financial crisis raises doubts about a global model to reduce inequities based on economic growth. Contraction and convergence (panel 4) increase the need for new economic approaches, which place sustainability and equity at the centre of the economic debate.[115]

Nobody doubts that efforts to adapt to the negative health effects of climate change will be expensive. Even the conservative UNFCCC estimates that by 2030 tens of billions of dollars every year will be required to meet the costs.[116] Funds dedicated through international bodies are much less than these estimates.[117]

UNFCCC funds aim to reduce vulnerability to climate change and to help build adaptive capacity. These are very modest relative to need, being around $275 million. The Kyoto adaptation fund, managed by the Global Environment Facility is larger.[118] However, even the most optimistic estimates predict that the fund could yield only $1–5 billion every year. Even if the same amount could be contributed by the World Bank's new climate change funds, it would not be enough.[119]

Additionally, the adaptation fund is not yet operational, and developing countries are unhappy about the management of existing funds.

Not only is raising more funds to support adaptations to climate change needed, but also ensuring appropriate management and control of this finance internationally, and by national and local governments. Although redistribution through government aid and fiscal policy is crucial, private funds and private investment are also important in funding climate change adaptation.

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Patterns of disease and mortality

Poor people are greatly affected by disease worldwide. Whether in a developed or developing country, health outcomes are worst for those on low incomes[20] because they lack access to the health system. HIV/AIDS, tuberculosis, and malaria have perpetuated poverty in developing countries because of the cost of treatment and the loss of productivity.

Infectious and vector-borne diseases related to climate change will have their greatest effect in resource-poor settings through poor housing, poor water supplies and sanitation, and increased vulnerability.

Gender inequity is another important factor. In developing countries, women are among the most vulnerable to climate change; they not only account for a large proportion of the agricultural workforce but also have few alternative income opportunities. Women manage households and care for family members, which limit their mobility and increase their vulnerability to natural disasters and other local sudden climate changes. Efforts to keep the adverse effects of climate change to a minimum should ensure that policies address issues of women's empowerment.

Individual assets that bring benefits to a woman's family and community, such as health and education, are easily attainable with good reproductive health. In particular, adequate birth spacing improves maternal and infant health and resilience, and contributes significantly to women's ability to be economically productive. Gender differences must be taken into account not just in terms of differential vulnerability but also as differential adaptive capacity. During a natural disaster, for example, women have a key role in protecting, managing, and recovering lost household resources, and often develop innovative strategies to address climate change.[120] Case studies in Senegal, Bangladesh, and Ghana showed grassroots women's groups developing strategies to cope with issues related to energy and forestry, agriculture, water resources, and trade. Women should be perceived as powerful contributors of change and should be fully integrated into climate change mitigation and adaptation strategies at all levels.

Vulnerability will exist to both climate change and poverty, especially in developing countries.[121] The vulnerability of poor people to climate change is manifested in three main ways: exposure, sensitivity, and adaptive capacity. The world's poor nations are exposed to the effects of climate change due to their geographical location.[122] Also, low education, income, health, and other contextual factors reduce the adaptive capacity of developing countries. Therefore, future vulnerability to the health effects of climate change depends on development and climate change itself.

The challenge is to reduce not only poverty but also the diseases related to poverty, such as water-borne and vector-borne diseases, which require sustainable development with a functioning primary and secondary health system. This challenge should be underpinned by a strong public health infrastructure, incorporating

surveillance and monitoring of diseases, access to technologies at an affordable cost, access to health professionals, access to health centres especially in rural areas, and sustainable education and training of future health professionals.

The limited research and structural adaptation in low-income and middle-income countries are likely to deepen social inequality related to climate change. Public sector financial constraints and national infrastructure and human capacity should be improved.

Food

The present structure, organisation, and control of the globalised food and agricultural system are failing to address the needs of both poor people and the environment. For example, profits of giant agricultural and food corporations increased greatly in 2008, when the number of hungry people grew.[123,124]

Most farms are smallholder operations of less than 2 hectares. 0·5% of world's farms that exceed 100 hectares claim a disproportionate share of global farming income, enjoy privileged access to land and policy makers, and receive a share of tens of billions of dollars of public subsidies every year.[125]

Direct payments to farmers of the Organisation of Economic Cooperation and Development amounted to $125 billion in 2006. For the past 25 years, many low-income countries had to adopt trade and agriculture reforms, including: dismantling or privatisation of public instruments such as marketing boards, farmer credit schemes, input subsidies, and extension programmes; shifting from food to export crops; and opening up to competition with the heavily subsidised agricultural businesses in developed countries.[61] At the same time, development assistance to the agricultural sector has fallen. The aid of the Organisation of Economic Cooperation and Development to farmers in developing countries was only $3·9 billion in 2006, and now accounts for 3·4% of aid budgets, even though 75% of the world's poor people live in rural areas.

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Water management will be crucial to future food security.[126] Co-management of water for agriculture and ecosystems is a precondition for ecological sustainability, requiring ways to value water socially, economically, and ecologically.

Geographic, satellite, and food price monitoring have an important role as early warning systems for famine and food insecurity, but a functioning primary health care system is probably the best and most effective way.

Water and sanitation

Climate change requires urgency to deliver water, sanitation, and drainage to the world's poor nations, which need fair financial and regulatory mechanisms, allowing for delivery of affordable services whilst providing resources for construction, maintenance, and operation of water and sanitation systems. Public, private, and community sectors are important in providing specific systems and delivery services locally.

River basins and water catchment areas that cross political boundaries require policies and regulations to provide fair access to water resources and to avoid conflict.

Access to good primary health care is essential for populations vulnerable to climate change, also for water-borne diseases. People who are in good health are less likely to be vulnerable to water-borne diseases during extreme events. Good primary health care will not only improve the resilience of local populations to water-related and sanitation-related diseases but also is the best early warning system for epidemics of water-borne diseases.

Shelter and human settlements

Reductions in poverty, including improvements in housing and living conditions, and in provision for infrastructure and services, would reduce climate change hazard vulnerability. Moreover, an articulation of the brown and the green agenda perspectives in dealing with human settlements could reduce vulnerabilities and mitigate climate change.[127] For example, reforestation and afforestation can reduce risks of flooding. Indirect effects on settlements (eg, health, lack of water, migration, and livelihoods) and how urban dwellers develop mechanisms to cope with these effects need to be assessed to understand how these mechanisms could be mainstreamed into urban planning responses to climate change adaptation.[128]

Current risks linked to climate change and variability are due to the large proportion of urban dwellers lacking protective infrastructure and little land-use planning. When buildings and infrastructure are developed in urban centres, environmental effects are often not taken in consideration. These are responsibilities of local governments, whose institutional capacity varies widely.

Those settlements with little economic diversification—where most income comes from climate-sensitive primary resource industries such as agriculture, forestry, and fisheries—are more vulnerable than diversified settlements. 99% of households and businesses in low-income countries do not have disaster insurance.[129] As climate change intensifies, the housing issue (eg, affordability and availability) is aggravated both in developed and developing countries, mostly affecting poor people.

With half of the population of urban centres in low-income countries lacking piped water, waste collection, paved roads, sewers, and storm drains, their vulnerability has not been reduced by existing mechanisms that focus on social and economic development.[73] With persistent vulnerability, poor people living in urban areas are more susceptible to increasing frequency and intensity of climate change.

Extreme events

An effective assessment of the increasing climate-change-driven extreme events requires that national governments embrace the idea that natural disasters are related to the particular societal context within which these events take place. In other words, those affected are in a position of risk as a consequence of a portfolio of economic, social, and political institutional factors that can and should be addressed by decision makers.[130] Control of climate-change-related extreme events has to be achieved through developmental and humanitarian responses, and through increased preparedness and response that come from integrating the disaster risk reduction paradigm (defined by the UN international strategy for disaster reduction as "the broad development and application of policies, strategies and practices to minimise vulnerabilities and disaster risks throughout society") with a nation's future development.[108,111]

Population and migration

Because contraceptive use in a population is the major determinant of birth rate and hence population growth or decline, family planning is not just an adaptation to climatic change but also a mitigation strategy to achieve a sustainable population (panel 5). The predicted population increase is unsustainable and will severely exacerbate the issues of urbanisation in developing nations. Obstacles to effective use of family planning are complex, but much experience exists in providing family planning services that can meet the needs of about one in six women worldwide who want to delay or cease childbearing but cannot access effective contraceptive methods. According to the UN Population Fund, many women in every country report that their last birth was unwanted or mistimed.

The 1994 international conference on population and development in Cairo (Egypt) emphasised the importance of reproductive health and of empowering women to take charge of their reproductive lives. The poorest people have the least access to, and greatest need for, contraceptive services; however, since 1994, funding for family planning programmes has been reduced, partly because of the diversion of funds to HIV/AIDS. Additionally, US Agency for International Development (USAID) funds under Republican administrations have been subject to the gag rule, which stipulated that, to be eligible for USAID funding, an organisation could not spend any funding from any other source on abortion-related activities. This rule was repealed by President Obama in early 2009, so family planning service delivery is hoped to improve in the future in the poorest countries.

***Panel 5:* Family planning**

Family planning is a unique solution among medical interventions. It reduces poverty, and maternal and child mortality; increases primary schooling, and women's education and empowerment; increases environmental sustainability; and mitigates the effects of climate change through stabilisation of global populations. Family planning is not simply about technology; female literacy and education should be as important as the provision of family planning services. Although the issue of climate change is mainly due to high consumption and greenhouse gas emissions in developed countries, population growth is highest in developing countries where it will compromise efforts to achieve sustainable development and the transition to low-carbon economies. We can neither reverse environmental degradation nor respond to the health challenges presented by climate change in a context of continuing rapid or even moderate population growth.

The technological challenge

The UNFCCC identifies technology transfer (along with funding and insurance) as key actions for adaptation to climate change by developing countries. Appropriate technologies are adapted to local economic and ecological conditions, and take into account local knowledge, skills, and culture. The technological challenge is not only about high-technology solutions but also about understanding biodiversity to develop appropriate policy responses, and the contribution that less developed communities can make in sharing their knowledge of sustainable low-carbon technologies and ways of life.

UN Photo/Martine Perret

Technological challenge requires incentives for the development of technologies needed to address the negative public health consequences of climate change in poor countries. Experience in the pharmaceutical sector has shown that rich markets generate vigorous research and development activities, whereas poor markets are mainly ignored. Public funding for investment in developing technologies for poor markets

***Panel 6:* Changing consumption patterns**[137]

Governments should not simply indicate public preferences but also offer leadership in shaping public priorities on important issues. Global political leadership has paid too much attention to the need for consumption-led economic growth and too little to issues of equity and fulfilment of basic rights. Global taxation and trade regimes foster a global culture that results in a global luxury market of cosmetics of around US$25 billion (which is part of a broader cosmetics market worth $200 billion) and a global pet-food market projected to grow to $40 billion by 2010. This spending would comfortably fund basic social protection for low-income countries.

is required. Furthermore, although intellectual property rights have a role in rewarding innovation and scientific discovery, most people realise that these can also hinder scientific development by reducing sharing of knowledge and lead to excessive prices. Technological challenges require a rebalancing of the benefits and costs of the current intellectual property regime. Currently, the World Trade Organisation's agreement on trade-related intellectual property rights has put in place a global system for patent protection for a minimum period of 20 years. The exceptions in the agreement are not sufficient to accommodate the needs of poor countries with limited capacities to produce their own versions of patented technologies. Therefore, a waiver has been agreed to facilitate access to essential medicines for poor countries.[131] Although the framework is in place, the waiver has been relied upon only once by Rwanda in the 5 years since its adoption. Serious efforts need to be made to ensure that intellectual property protection does not constitute an impediment to climate change adaptation in poor countries.

UN Photo/Eskinder Debebe

The technological challenge also requires development of knowledge in poor countries. The educational and scientific base of a country will have an important role in increasing or constraining any individual country's capacity to adapt. Because of the scale and complexity of the technological challenge, and its many dimensions, fostering multidisciplinary collaborations to capacitate development in all areas will be essential.

Patterns of disease and mortality

No effective vaccines exist for many climate-sensitive communicable diseases (eg, malaria, dengue fever, schistosomiasis, and leishmaniasis). The international community must promote research and development for vaccines that can be made accessible to the most vulnerable people. They must also find a sustainable and ethical solution to the trade-related intellectual property rights (TRIPS) agreement that allows developing countries to buy medical supplies without a substantial burden on their budgets. Large-scale vaccination programmes in the developing world would also require a strong public health infrastructure, knowledge, and finance and political will.

Low-cost and low-technological solutions, such as mosquito nets and water filters, provide effective public health systems for responding to health effects of climate change.

Satellite mapping and geographical information systems are useful analytical ways for local, regional, and national surveillance to project future health outcomes. For example, such systems for malaria in the developing world could allow health-care professionals to reallocate resources and prevent predicted future outbreaks. However, to maximise the effect of this technology requires accessibility of finances, knowledge, and expertise in poor countries. Existing or new technologies to reduce the effects of climate change on health cannot create secondary negative outcomes or contribute to further climate change. For example, air conditioning units can be introduced in homes, offices, and public buildings to reduce risk from heatstrokes. However, air conditioning units are highly energy inefficient and contribute to climate change, therefore producing an adverse secondary effect. New technology should aim to be carbon neutral, inexpensive, and easily manufactured worldwide.

Food

The technological challenge in this area is to ensure food security mainly by environmentally friendly ways of increasing food availability. Future temperature rises might have an especially strong effect in tropical regions because crops grown there are less resilient to changes in climate than those grown in non-tropical regions. A major technological challenge is to develop new crops to withstand higher temperatures.[65] The key task, attuned to local culture and economy, is to find ways of lessening adverse health risks from changes in food yield, quality, and accessibility.

Although industrialised and intensive agricultural production has helped to boost food output, it has also undermined the integrity of ecosystems by, for example, impairing nutrient cycling in soils, overusing pesticides, and disrupting natural pollination. Such sustained high agricultural output has also depended on fossil fuel use to generate fertilisers. Agricultural mismanagement can also result in salination and water-logging of soils, and in land degradation and soil erosion.[132,133]

Technological changes in agriculture will also be important for climate change mitigation. Agricultural practices and aspects of the current global food system are major contributors to global warming. Agriculture has been estimated to be responsible for 14% of total greenhouse gas emissions. According to the International Food Policy Research Institute and the Food and Agriculture Organisation, agriculture, land use, and waste account for 35% of greenhouse gas emissions.[60] The major causes are the production and use of fertilisers; methane production from wetlands (especially

rice production) and methane emissions from livestock; and carbon released from deforestation and land clearance. Global increase in consumption of meat and dairy products also augments methane production. Furthermore, the global transportation of food causes additional greenhouse gas emissions.

Water and sanitation

Less than 4% of Africa's groundwater resources are currently exploited. Although climate change threatens accessibility to water resources in general, the magnitude of this threat could be reduced with the development and availability of appropriate technology to exploit groundwater resources. Approaches to provide access to safe drinking water and sanitation have conventionally followed either large-scale, centralised infrastructure systems or small-scale, locally affordable, and maintainable technologies. Resilience to climate change might require new approaches that provide the universal public health benefits of large infrastructure systems while avoiding high water consumption at a cost that is affordable for all. Water and sanitation systems need to be appropriate to local geography, culture, knowledge, and resources, and able to withstand high intensity rainfalls and drought conditions, and keep wastage of clean water to a minimum. Ecological sanitation systems and low or no flow toilets that do not require water to dispose human waste safely are likely to be of increasing importance in delivering good public health outcomes under water-scarce conditions.

Systems for safely storing and treating water and technologies for using alternative supplies of water, such as waste-water recycling and desalination, are also likely to be important, although the development and implementation of these systems might undermine climate change mitigation efforts if they result in increased carbon emissions. Urban drainage systems, which incorporate principles of sustainable design (such as rainwater harvesting), will provide resilience to high rainfall events while removing standing water that can become contaminated, and act as habitat for vectors such as mosquitoes. Water and sanitation technologies, which can be easily deployed during emergency situations, such as floods or hurricanes, will be increasingly important.

Water-conserving technologies, which deliver good public health outcomes but consume little water, will need to be implemented greatly in households and settlements. Design and management of water and sanitation infrastructure need to account for resilience to droughts and floods, and changing annual average rainfall.

For example, the IPCC has compiled data for technological adaptations that have already been implemented in areas of Africa aimed at promoting climate resilience in rain-based farming systems for drought stress. These adaptations include: water harvesting systems, dam building, water conservation and agricultural practices, drip irrigation, and development of drought resistant crops.[1] These observed adaptations should be spread across different regions, nationally coordinated and locally implemented.

Shelter and human settlements

The design of houses and settlements could affect health through protection against thermal extremes, disaster-proofing, barriers and deterrents to infectious disease vectors, and energy efficiency.

Development of technological adaptations to cope with climate change and its health-related problems has three dimensions: first, technology for new building structures (eg, energy efficient and built with low-carbon material); second, planning of settlements, including

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building appropriate infrastructure for flooding control (eg, Netherlands), having green areas as flood buffers (eg, Brazil), and designing multiland-use compact cities to ease transportation (eg, new urbanism initiative in the USA); and third, acquisition and dissemination of information, land-use planning, and management systems for dealing with vulnerability (eg, to natural disasters), and making city services climate friendly, such as giving priority to affordable and efficient public transportation and access to affordable adequate housing for the population.

Even though technology for settlements to adapt to climate change has been developed (eg, building standards to use less energy) and building technologies to adapt to climate change already exist, the challenge is to make them available where they are needed by providing knowledge and financing. Thus, we need to create institutional mechanisms for making those technologies accessible to people who will suffer most from climate change and adjust those existing technologies to the conditions of developing areas (eg, adapted to environmental conditions, local affordability, and culture).

Technology does not need to be highly advanced to be effective. Many basic technologies and planning devices could be implemented in cities to relieve the strains and health consequences of urbanisation. Hygienic frameworks must be put in place: public toilets with adequate drainage; proper waste disposal; and sanitation policy enforcement. Local city planning should be done in collaboration with, and aided financially by, high-level entities.

Extreme events

Technological challenges to reduce the effects of extreme events include improvements in regional and local climate modelling, development of effective early warning systems, and application of the geographic information system to improve vulnerability assessment, hazard and risk zonation, and land-use planning in an increasingly warm planet. In many developing countries, cost and expertise shortage limits capacity to undertake major physical and structural works, such as improved flood defences, protection of crucial infrastructure, and modifications to housing construction, but in many cases low-cost alternative technologies are applicable.[134]

Population and migration

Climate change will progressively affect populations in vulnerable areas, with unpredictable effects on sudden migration or temporary displacement. Limiting population growth will help to mitigate climate change and expedite progress towards poverty alleviation and development.

Huge progress has been made since 1950 in both contraception and service delivery, but much remains to be done, especially in Africa. Worldwide, around

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200 million women wish to delay or prevent pregnancy, but are not using effective contraception. Meeting their needs would cost about $3·9 billion a year, and could prevent 23 million unplanned births, 22 million induced abortions, 142 000 pregnancy-related deaths (including 53 000 from unsafe abortions) and 1·4 million infant deaths.[135] Demand for family planning is expected to increase in the next 15 years as millions of young people become sexually active. But funding for family planning is declining for reasons such as a premature sense that the overpopulation issue has been solved, criticisms of inept and sometimes coercive programmes in Asia, and displacement by HIV/AIDS programmes.[136] Family planning is a low-cost, safe, and acceptable intervention, with proven benefits that encompass health, education, and reduction of poverty and environmental degradation.

Panel 7: The sustainability agenda and intergenerational justice

The concept of sustainable development was formulated to address issues of intergenerational equity in resource availability. It has been condemned as lacking definition and conceptual rigour. However, it offers the possibility of fundamental changes to the way we consume and produce, the way we arrange our functionally fragmented institutions, and the way we distribute resources globally and locally. Most importantly, sustainable development not only posits environmental degradation and poverty as interconnected issues, but it gives an example of how mainstream politics might be brought into a debate that demands a complete rethink of our institutions, resources, and environmental outcome, and also assumes that these issues can be solved with political will.

The sociopolitical challenge

Lifestyle commitments and consumption patterns, whether in rich or poor countries, need to be understood in the context of diverse social and political structures through which individuals and groups assure their survival and status. Different factors define the matrix within which human–ecological interactions take shape. Three key elements of this interaction include: life–work patterns, time and space relations, and prestige and value systems. The intersection of these and other factors gives rise to practices that might support, or in some cases hinder, the ability of some groups to respond to climate change. We have indications, from early phases of environmental stress, that these different dimensions need to be carefully disaggregated and that there are complex feedback systems between them. We urgently need to develop new models of human socioecological interaction to address these issues.

Governments should address climate change and its consequences. The present financial crisis has emphasised the importance of global governance, regulation, and government cooperation in providing security. Baer and Singer[115] have analysed the systemic structures of inequality underlying global warming and argue that fundamental changes are essential to the mitigation of several emerging health crises linked to anthropogenic climate and environmental change.

The move to a low-carbon economy will have global health benefits from both reduction in the health effects of climate change and improvement in human lifestyles, and these must be emphasised through health promotion. Public health messages in high-carbon economies should point to the health benefits of actions to address climate change through reduced use of cars, less air travel, and lower meat consumption. Climate has no respect for national borders or nation-specific government. Global governance will, therefore, be a central feature of any discussion of climate change and health. Issues will, similarly, not be solved by any single discipline. For example, rising rates of malaria in the Peruvian Amazon are caused by deforestation increasing the short-term risk of malaria by creating areas of standing water in which mosquitoes can lay their eggs.[134] Health here depends on responsible forestry practices. A structural change, at the political level, is needed to redistribute resources between rich and poor countries. Whatever their geographical location, rich individuals are likely to be better protected than poor people against negative health effects through their access to mobility, insurance, and health care. To meet the new targets of 80% reduction in carbon emissions in industrialised countries by 2050, for example, substantial reduction in consumption levels and change in the value associated with some kinds of luxury consumption are needed (panel 6).

Patterns of disease and mortality

Changing patterns of illness for gradual and extreme forms of climate change will have sociopolitical consequences. All epidemiological problems associated with modernity, mobility, and resource consumption are exacerbated when climate-related social instabilities are put in motion. As people migrate away from areas deteriorated by gradual warming or destroyed by extreme weather events, they not only place substantial demands on the ecosystems and social infrastructures into which they migrate, but also carry illnesses that emerge from shifts in infectious-disease vectors.

New epidemics are serious issues. Care facilities in increasingly warm climates, for instance, currently relegate tropical-disease treatment to specialty (sometimes exclusive and exclusionary) medical facilities. New disease vectors, therefore, are not only a problem for those who suffer, but for professionals educationally or clinically unprepared to respond to them. Many hospital facilities in industrialised countries lack experience in

managing malaria, and even infections or parasitic diseases that have emerged in previously cold climates (eg, dengue fever) are rarely well understood by practitioners.

Extreme weather events are not always handled well by rich nations. During hurricane Katrina, for example, many people were trapped in New Orleans (LA, USA) because the hurricane occurred at the end of a pay period when poor people had no money to pay for the bus fares.[138] Increased access to wealth is only an effective deterrent to disease at income levels that developed nations have far exceeded and that developing nations still work to achieve.[139] Social stabilities created by closing the gap between rich and poor in both developing and developed nations will therefore become a crucial element in a new capacity building that allows for better adjustment to the sociocultural consequences of climate change. Actively building social capital can be a strong deterrent to migration away from epidemic-ridden areas, and provides socially stable populations with infrastructures needed to deal with unexpected change.

WaterAid

Food

International priorities for food issues related to climate change include: willingness to ensure fairly distributed global food security, better use of local resources, preservation of sustainable ecosystems that provide local sources of nourishment, and revision of disaster-relief efforts from emergency food distribution to long-term capacity rebuilding after climate-related natural disasters. However, we focus more on immediate effects of disasters than on improvement of local and sustainable forms of food production before and after a disaster. A shift is needed from disaster response to risk reduction where the capacities of local populations are strengthened to anticipate and plan for risks ahead of their occurrence.

Food aid must be coupled with forms of sustainable reconstruction that are less formulaic and more locally sensitive. Often, food distribution creates dependencies without being coupled with locally relevant forms of reconstruction. Aid organisations that partly or completely withdraw food aid once a disaster setting has been identified as in recovery phase must rethink how the desperation of now-dependent groups is increased when food aid is withdrawn or fought over in resettlement camps. Social programmes that educate consumers about healthy diets and that try to limit the effects of unhealthy food might have an effect on disease burdens. Nevertheless, such burdens are mainly carried by poor people who are likely to face severe constraints to access high-quality food or to modify their food choices.

Building local social capital around food supply is a major challenge. More attention needs to be given to the global agrifood system, to the added value of industrial processing, refining, and sweetening, and the economies of scale created by multinational and transnational operations. Local food movement might only come when the crisis has deepened. A generalised reorientation to locally sourced produce would need both economic change and political intervention.

Finally, distribution systems that transport food over long distances not only contribute directly to climate change but also might decrease immunity when non-local foods are consumed.[140]

Water and sanitation

The misuse of water by creating inappropriate climates to improve specialised forms of agriculture (eg, to water beef and dairy cattle and other livestock in arid environments where they are not indigenous and to service waste disposal systems that use excessive amounts of water) might undermine efforts to tackle climate change through positive social action. Farmers use about three-quarters of the world's water supply: to grow 1 kg of wheat requires around 1000 L of water, whereas 1 kg of beef takes as much as 15 000 L. American or European diets require around 5000 L of water per person every day, whereas African or Asian vegetarian diets use about 2000 L per person every day.[141] The social and political challenge of shifting dietary practices is enormous, especially as populations start to eat more meat as they climb out of poverty.

Issues of desertification are well documented and potentially catastrophic. Tidal surges that salinate and pollute fresh-water reservoirs and wells cause mass migrations as changes in monsoon patterns necessitate the movement of populations out of areas where fresh water was once available. However, because water is essential, its misuse has remarkable knock-on effects. Deforestation and logging create pools of water that, when exposed to sun, allow mosquitoes and other vectors to flourish. Vectors might unexpectedly bring new infections to formerly temperate climates (eg, dengue fever in North America).

More troubling, however, is the way in which water is increasingly being used as a cultural weapon. Diverting water for personal benefit is ancient. But nowadays water has become a powerful way to oppress vulnerable populations. Some evidence indicates that the forceful movement of vulnerable populations against their will into camps that have limited access to water leads to oppression of women and abduction of children into military splinter groups and armies.[142] Stress and post-traumatic stress are increasingly a result of climate-change-induced conflict.

Shelter and human settlements

The effects of climate change on human settlements can increase vulnerability to several kinds of health-related problems. Adaptation of societies to respond to the causes and consequences of those problems poses huge

sociopolitical challenges both in developing and developed countries.

Health vulnerability of urban settlements is not distributed evenly worldwide.

Some climate-vulnerable countries (eg, small-island developing states) and poor countries with limited resources to adapt to climate change tend to suffer most consequences. Their health systems, already under stress, have limited ability to respond adequately to climate-change-related problems. The poorest and weakest groups, such as elderly people, persons with disabilities, children, and minorities, would be the most exposed to climate change consequences. As these groups have traditionally been more excluded from adequate housing and from access to adequate health systems, climate change tends to increase the inequalities in our society.

How to tackle climate-change-related health problems in urban settlements is a great political challenge because it involves the creation of an improved governance system at all levels. First, the most vulnerable populations need to participate in the decision-making processes at all levels, from local to global, to ensure adequate health policies to reduce their vulnerability. Second, local political will is needed to develop institutional capacity to create strong public health systems. Third, coordination at different levels of governance is necessary to distribute resources and expertise for adapting to climate change in human settlements and its health consequences.

As climate change is still a far-away issue in the political agenda in most local governments, especially in developing countries, framing climate change as a health issue can bring political interest in improving public health systems. The political challenge is to create governance structures that combine top-down and bottom-up approaches to change health governance structures towards efficient and fair processes and outcomes.

Extreme events

The challenge to respond to extreme climatic events not only for social destabilisation but also in terms of knowledge can be overwhelming. When governments attempt to educate populations about the dreadful consequences of extreme events, they might incite the panic that their efforts seem to limit. The so-called duck and cover programmes of the US Atomic Energy Commission during the Cold War era, which were designed to educate the public about an unimaginable catastrophe, have been blamed by social psychologists for contributing to the presence of panic-related disorders in children.[143] Planning for extreme events has secondary psychological implications that are rarely addressed by health practitioners. Indeed, education of the general public about uncertainty is no simple matter and must be carried out with responsibility and care, and with recommendations for alternative forms of adjustment that are real and feasible.

Black Coffee Project

Social illnesses related to environmental uncertainty cannot be underestimated because extreme events are by definition destabilising. Social uncertainty might cause increased levels of psychological stress because of instabilities that are both perceived and real.[144] Climate change will, therefore, have an effect on psychosocial health.[97] Increased spending on appropriate counselling or sympathetic health promotion, and the initiation of such services in poor countries, could be as important as planning to reduce new disease vectors.

Population and migration

Although effective measures to achieve demographic transition through family planning are available and work, they are not always wanted in either rich or poor countries. Whether increased consumption is the result of the rich consuming more or simply more people consuming, population growth is a factor that needs to be taken into account in climate change. Paradoxically, fertility decline has been associated with economic growth and development. Economic instabilities associated with climate change might exacerbate, rather than diminish, population expansion that is not amenable to education, exhortation, or improved delivery systems alone.

There is no discussion of models of sustainability derived from indigenous cultures or from ideologies not devoted exclusively to the concept of development as a growth-oriented and progress-oriented ideal. Although many have benefited from development in terms of life expectancy, and human development indices and agricultural productivity have improved dramatically, these gains are unbalanced across populations and might be unsustainable. The discussion of urban population growth worldwide, but especially in developing countries, makes a strong

connection between population growth and environmental change.

Modern spatial epidemiology has mapped migration caused by extreme climatic events, and the subtle effects, from desertification in what is now Saharan Africa to tsunami-related mass migration and resettlement in south and southeast Asia. Because extreme weather events do not respect national boundaries, there are limits to what individual nation states can do to mobilise disaster responses, and migrants could become vulnerable to the sentiments of uncertain hosts.

The institutional challenge

The final and overarching challenge is institutional. Our current institutional arrangements, both private and public, seem unlikely to be able to guarantee an effective and equitable policy response to the health consequences of climate change. Our institutions of government must reach out to listen and respond to the poorest communities in ways that have not been previously achieved. The institutional challenge is one of coordination with a vertical and a horizontal dimension.

Intervention should occur at different levels of government, as appropriate to the scale of the issue. These different levels of government must work together to support one another and to reinforce the positive benefits of intervention. Overlapping rather than exclusive jurisdiction between levels of government is preferred, with activities at different levels constituting multiple experiments from which we can learn, and safety nets to guard against inaction or unsuitable action at any level. In the USA, for example, individual states have to take actions to tackle climate change in the absence of an effective policy response at the federal level.[145]

Coordination should form joined-up governments. Governments are often organised sectorally, segmented in specialised policy domains. Environment is separate from health, and health is separate from agriculture. This is true at all levels of government, including internationally, where fragmentation and policy contradictions are a serious problem. WHO deals with health, whereas the World Trade Organization (WTO) deals with trade. Each is implicated in the adjustment process and their actions will need to be coordinated.

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Responding to the health effects of climate change extends beyond the environmental sector, but also involves the health sector, which needs to have a major role in the discourse around climate change.

Other institutional challenges relate to power and politics.[146] Global governance is characterised by a lack of democratic accountability and profound inequalities. This is most obviously true for organisations such as private funding bodies, but it is also true of intergovernmental organisations, including UN bodies and the World Bank and the International Monetary Fund. Although these organisations might operate to increase the accountability of states, to whom the relevant international organisations are accountable is not always clear. Also, developing countries are under-represented.[20] Difficult choices will have to be made by these institutions in relation to climate change, and these decisions are intensely political with important distributive effects.

International organisations are not blind to the need to respond to perceived accountability deficits. The WTO, for example, has recently opened its hearings to the public for the first time. Also, the World Bank established an inspection panel in 1993 to address the concerns of people affected by the bank projects and to ensure that the bank adheres to its operational policies and procedures during the design, preparation, and implementation phases of projects. Although these small steps have many limitations, they are an acknowledgment that good governance matters internationally and that a response to accountability problems is possible.

An agenda for developing countries must be put in place through global cooperation. Representation on global task forces to assess the health effects of climate change is heavily skewed in favour of institutions of developed countries. In poor countries, health assessments and climate science and health surveillance research are a priority.

Our ability to develop an effective and fair institutional framework to respond to climate change will need to consider market failures and the role of a powerful transnational corporate sector. Whether in the policy domain of energy, food, water, or medicines, transnational corporations are important and mainly unaccountable entities. We will need to design institutions that are more responsive to the needs of the poor and less to the financial demands of big businesses.[147] We will also need to reduce population growth, and help developing nations to fund services that will ensure that children are born by choice, not chance.

Nationally, governments face three main challenges. First, reduction of carbon-emitting activities needs to be managed. This is likely to come from strengthened public awareness of climate change and its potential effects on health. In the developing world, climate change issues are perceived by many as distant, diffuse, and uncertain.[148] Developing countries are preoccupied with the current high burden of disease due to non-climatic factors and, at the same time, problems related to health-care delivery in the public systems. Citizens of the poorest countries should understand the links between these constraints and climate change.

Second, locally relevant adaptation technologies that do not compromise growth need to be identified. Discussion needs to extend to locally relevant adaptation technologies that do not harm health.

Third, to support both these goals and to underpin national adaptation efforts, health effects of climate change need to be integrated into national plans across sectors and tiers of government. This action will require improved understanding of health and climate change at regional, national, subnational, community, and individual levels, from the primary sector to public finance. National plans must financially support key shifts in policy, facilitate access to better technologies, and protect health outcomes. Frumkin and colleagues[147] have proposed a public health approach to climate change based on the essential public health services, which extends to both clinical and population health services, and emphasises the coordination of government agencies (federal, state, and local), academia, the private sector, and NGOs.

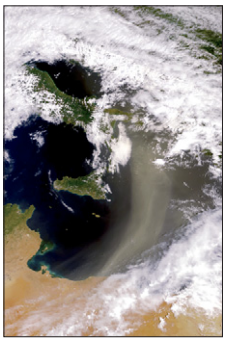
There are institutions to undertake these challenges (eg, in South America and the Caribbean), from capable national governments to effective regional financial and research organisations. Such institutions are likely to gain from cooperation, both from opportunities for sharing adaptation technologies and from presenting a unified front when bargaining for increased development assistance in spite of costly adaptation. Those that do not have such capabilities must be assisted to face each of these challenges.

The institutional challenge of adjusting to the adverse public health effects of climate change is closely tied to the general challenge of sustainable development, with its emphasis on equity and environment, and on wellbeing instead of relentless economic growth.[24] Climate change adds new urgency to this challenge, not least because of the clear disjuncture between cause and effect; responsibility for climate change is mainly of rich nations and, although the negative public health effects of climate change will not be confined to poor nations, they will be worse there, both in absolute terms and in terms of relative capacity to cope. Whether viewed as an ethical imperative or an example of enlightened self-interest in an interconnected world, a vigorous anticipatory response to the challenge of adjustment is urgently needed.

Climate change demands political action and social mobilisation. However, individuals, organisations, and governments all have an important role in advocating and implementing change. Although a complete response requires a holistic global approach, this should not be a reason to delay changes that are beneficial to human health and can be implemented immediately. Equally, the possibility of partially effective local strategies should not be seen as a substitute for a full-scale global response.

Putting climate change at the centre of government policies enables a number of win-win solutions in achieving implementation of policies across government departments. For example, the UK Government energy policy to cut greenhouse gas emissions by 80% by 2050, to increase the use of renewable energies, and to ensure that every home is adequately and affordably heated will increase the achievement of policy objectives in the departments of agriculture, transport, and health.

Our findings are in agreement with the main messages from the international scientific congress on climate change in Copenhagen in March, 2009. These messages suggested that, to achieve the societal transformation to meet the climate change challenge, we need to: reduce inertia in social and economic systems; build on a growing public desire for governments to act on climate change; remove implicit and explicit subsidies; reduce the influence of vested interests that increase emissions and reduce resilience; enable shifts from ineffective governance and weak institutions to innovative leadership in government, the private sector, and civil society; and engage society in the transition to norms and practices that foster sustainability.



European Space Agency

Patterns of disease and mortality

WHO has acted to transform some of its organisational objectives and structures to support ministries of health in their efforts to develop and implement national policy on many of the societal factors that affect health, health equity, and, implicitly, climate change. In May, 2008, the 61st World Health Assembly placed climate change and health on the global agenda, mandating a more active WHO engagement in responding to climate change.[150]

Some national and regional governments have begun to embrace the health-in-all-policies approach championed recently by the Finnish Government during its EU presidency.[151] Extending this to include environment as a core consideration would be a positive development.

Food

The effect of climate change on food security worldwide is a public health priority that requires a holistic and multisectoral policy approach. Tackling both climate change and food insecurity will not just be a case of

looking for solutions to provide more food but also will require policies that can manage ecosystems and produce food sustainably and effectively, and with the added goal of improving the lives of poor people. The Indian Government has recently taken steps to address a crisis in rural communities, which became manifest by high rates of farmer suicides, through a programme of subsidy and increased investment. India, along with other governments, has considered regulation of financial systems in which speculation in futures markets might contribute to food price rises.[152,153] Small changes in food production or crop yields can initiate big changes in price, especially where unregulated speculation is possible on commodity exchanges. Increase in food prices is a major cause of hunger and malnutrition, which in turn might increase child mortality rates; therefore, these issues could emerge over the next 20 years as early indicators of the effects of climate change on health.

Furthermore, governments need to address patterns of food consumption. One starting point is to define and promote a sustainable diet, which could mean reductions of the incidence of heart disease, cancer, diabetes, and obesity. R K Pachauri, chair of the IPCC, recently suggested that a reduction in meat consumption would be a practical and helpful way for an individual to contribute to lower greenhouse gas emissions.[154] Such policy would lead to reductions in colorectal cancer and, probably, ischaemic heart disease.[155]

According to the South Centre, an assessment should be done on: the growing use of intellectual property rights in the agri-food sector and its effect on local markets and farmers in developing countries; the displacement of the public sector by the private sector as the lead investor in agricultural research; and the way in which profits are disproportionately allocated to the private sector while negative externalities and risks are mainly borne by governments and communities.[156] Many similarities exist between agricultural research and development and the challenges experienced by the health community within the pharmaceutical research and development sector. At the same time, the agri-food sector has an important role in ensuring high crop yields and increased food production to meet the needs of a global population of more than 9 billion people.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Also, a shift in the way in which humanitarian emergencies are dealt with needs to be accelerated. The response still often comes in the form of food aid, which undermines long-term food security in famine-prone regions. Instead, in-kind food aid should be replaced, where possible, with cash donations to agencies that can purchase food from regional or local markets, making more efficient use of scarce resources while supporting local and regional food producers.

The preferences of affluent consumers are shaping global food and agricultural systems in many developing countries towards producing export commodities. Developing countries can use their comparative advantage in low-labour costs to capitalise on lucrative American and European markets, while benefiting from the import of cheap, subsidised grains produced by agri-business. However, although some countries have been able to do this (with some even meeting domestic demand for food despite import surges and growing participation of transnational companies in the local market), many countries formerly self-sufficient for food have become net food importers and susceptible to the volatility of unregulated and speculative commodity markets.

A new commitment to rural development is required to reduce urban drift and rural degradation by both subsistence communities and industrialisation. Investments need to be made in rural roads, telephones, and electricity connections; access to education and health services is important to allow farmers to produce food efficiently and effectively; forms of organisation such as associations, cooperatives, and microcredit groups can help to reduce costs for agricultural inputs and create useful economies of scale; and microfinance services targeted at low-income and poor households need to be expanded.

Promotion of biodiversity within the agro-ecosystem is also an important strategy for enabling agriculture to adapt to the anticipated changing weather patterns and maximise yield over the medium to long term.[157–160] The 2008 world agriculture report highlights a major role for purposeful biodiversity management in responding to climate change. A mix of crops and varieties in one field increases resilience to erratic weather changes, drought, and flood; reduces the vulnerability to pests and diseases; and can help to prevent soil erosion and desertification.

Water and sanitation

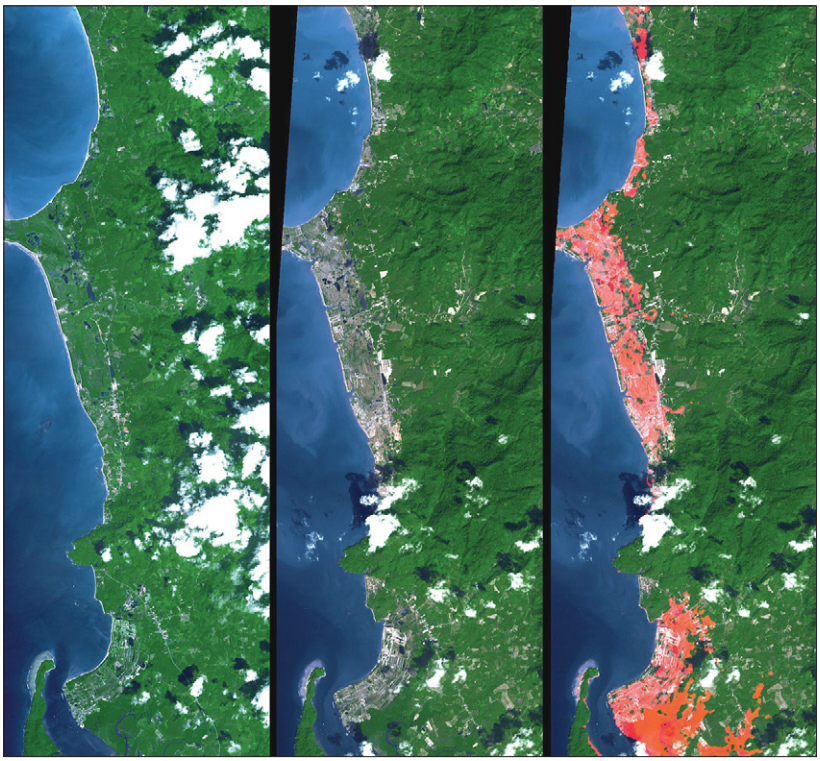
Integrated water resource systems aim to manage water for various uses including agriculture, industry, domestic consumption, and the environment, and have been implemented in some catchments in Europe, North America, and Australia. Managing competing demands for water from various sectors will become more contentious under conditions of water scarcity and drought that are likely to increase under climate change. Reforming existing water management institutions and creating new authorities will be important to allow for integrated control of increasingly scarce water resources, especially in planning for, and managing, drought, and, where appropriate, in encouraging transitions to forms of agriculture and industry with low water requirements.

Water utilities and regulators need to incorporate climate change predictions and uncertainties when planning and managing water resources and operations, including planning for resilience to drought and floods. Disaster management planning will also be required to ensure rapid and coordinated responses to floods and

droughts to avoid outbreaks of disease and maintain good public health.

Global donors and financial institutions have a key role in financing the construction and extension of water and sanitation infrastructure. Funds for water and sanitation projects should consider equity and affordability for the system users in ensuring the long-term viability and appropriateness of infrastructure systems to provide universal public health benefits under a changing climate.

Good management of water resources is crucial. Transboundary management of water resources requires intergovernmental dialogue, and is important for regional governance to avoid conflict and allow for integrated water-resource management. Governmental authorities need to ensure that utilities, water-resource managers, and public health authorities are taking into account climate change in their planning and operations. Integrated management of water resources might require national governments to reform existing institutions to allow for authorities that can implement decision making together with hydrological rather than political boundaries. Integrated water resource management and planning under uncertainty might need local authorities that share water resources to work closely together and to participate in regional and catchment-scale management institutions.



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The Indian Ocean coastline north of Phuket,Thailand, before and after the tsunami in 2004

Shelter and human settlements

Only a few countries (such as Netherlands) have seriously initiated any activities related to adaptation to climate change. Most countries and subnational governments might have political, financial, and operational difficulties establishing effective institutions to deal with climate change.

The vulnerability of human settlements, especially of poor people, has not been properly articulated in adaptation strategies, partly because of the way in which climate change has been framed, nationally and internationally, with a bias towards mitigation and with adaptation analyses limited to rural areas and agricultural systems. Although efforts put into developing strategies to assist poor people living in rural areas to adapting to climate change are crucial and necessary, more effort is needed to deepen the understanding of equivalent strategies adopted by poor people in the urban context. There has been some focus on climate resilience in urban planning. The UNFCCC local coping strategies database allows users to search for examples of successful local coping strategies by type of hazards and effects, but features almost no information about documented local strategies within the urban context.[100]

A need also exists to look at responses not only to climate-change-related disasters but also to move to prevention approaches and gradual adaptation to a new world shaped by climate change, adapting institutions and promoting innovative organisations. Within human settlements, planning processes need to adapt to climate change at all levels (eg, cities, regions, and infrastructures) to avoid both the short-term inevitable consequences of climate change during the next 20–30 years due to the inertia in the climate system and the potential consequences of non-action or late response. Thus, information and systems for better planning under climate change conditions need to be developed, and land-use planning and building regulations need to be rethought. Moreover, climate change policies should not be self-contained but need transversal responses integrated with other policies (eg, housing, health, and poverty reduction), and policy responses and efforts vertically (at the different levels of governance) and horizontally (within the structure of government, and with civil society, NGOs, and the private sector).

Adaptation requires local knowledge, skills, and capacity. Households, community organisations, and local government need to have the will and capacity to take action. Simply giving money is not the solution. A strategy to benefit poor people will not work if local government refuses to work with them or sees them as the issue. The vulnerability of both urban and rural poor people is not simply due to their poverty but, often, to the failure of local government. Good governance initiatives are often focused on central rather than local or municipal governments, and international agencies fail to understand the limitations and constraints on local government.

Mark Maslin

Private enterprise can potentially unleash significant investment for adaptation in cities; local government must encourage local financial services, insurance, and provision of appropriate supplies to encourage adaptation, but major infrastructural investment will remain the duty of the government. The attraction of local governments into climate change adaptation investment is complementary to development of goals.

Although much of the policy efforts have been made to reduce climate change, adaptation in human settlements has gained momentum in the past few years among international development organisations. UN HABITAT has held conferences to discuss global responses to climate change concerning human settlements. ICLEI (local governments for sustainability) launched the cities for climate protection programme involving many cities worldwide. However, many initiatives lack sufficient funding for implementation at a large scale and links to other related international initiatives, such as the Millennium Development Goals.

Regional initiatives to cope with adaptation to climate change exist, but few yield results. The European Commission has organised conferences on the theme and produced a paper indicating policy options for adaptation to climate change in Europe in 2007.[161] There are also UN-led initiatives for small-island countries in the Pacific region and the Caribbean (some of the most vulnerable regions to climate change), such as the Pacific Island Adaptation Initiative and the Caribbean Adaptation to Climate Change and Sea Level Rise, both started in 2003. In the highly urbanised South America and rapidly urbanising Asia and Africa, some initiatives also exist. However, most of these are in the early stages of execution and might funding for implementation in the medium and long term.

National governments are still reticent to tackle the adaptation challenges of human settlements. Netherlands has done a lot to advance adaptation policies. This country has high vulnerability to climate change because of its low altitude, but also has a strong capacity to adapt to natural adversities. Netherlands has assessed the best adaptation strategies to cope with the consequences of climate change, mainly by implementing large infrastructure projects and making adaptations in land-use planning. However, island states such as Vanuatu have started adaptation policies with a priority on evacuation of the population because they lack the resources to adapt. Countries have issues engaging in climate change policies when they conflict with their national development interests.[162]

Even though coordination with high-level policies is lacking, many cities and subnational governments have

started to include adaptation measures in their planning processes. One example is the climatic future for Durban project, which tries to raise people's awareness about climate change and integrates adaptation measures into the development planning process. There are also initiatives in the civil society. In the Philippines, the Red Cross has assessed how programmes for community-based disaster preparedness can cope with vulnerability due to climate change.[163] However, more initiatives are needed locally, as many local governance structures (such as local governments) hold responsibility for adaptation policies (ie, land-use planning, health, and transportation), but also link those local initiatives to national and international efforts to gain scope in coordination.[164]

Extreme events

Improved climate modelling will help to constrain future expectations of extreme meteorological events in terms of frequency, scale, and temporal and spatial distribution. Developments in global monitoring, especially satellite technology and improved communications, can help to provide short-term alerts of windstorms and floods and early warnings of droughts and heatwaves, allowing effective emergency management planning and water resource and supply arrangements. Improved coordinated responses by international agencies to extreme droughts and floods will help to reduce the public health effects of these events and ensure a rapid return to normality. The 2005 UN world conference on disaster reduction and its output, the Hyogo Framework for Action (HFA) 2005–15, articulated for the first time a common international perspective on interventions and priorities. The HFA outlines a broad-based vision of disaster risk reduction, encompassing governance, risk assessment and warning, knowledge and education, risk management and vulnerability reduction, and disaster preparedness and response.[165] This vision is perfectly applicable to the future threats presented by climate-change-related extreme events, and is now being developed to produce concrete indicators for disaster risk reduction and disaster resilience nationally and locally.[166,167]

With the HFA, disaster risk reduction is becoming mainstreamed internationally and nationally at policy level. Also, bilateral donors and international financial institutions such as the World Bank are beginning to take disaster risk reduction seriously with respect to their grant-awarding and lending practices. Growing evidence exists that national governments are updating pertinent legislation and disaster management structures. Although the main aim currently is to improve resilience of at-risk communities, rather than concerns over coping with and adapting to climate-change-related extreme events, the concepts and practice of disaster risk reduction and climate change adaptation substantially overlap, with potential for fruitful convergence.[168–170] The importance of governance issues and the idea that the effects of many natural disasters arising from extreme events are a function of government policies, structures, and decision making in development and emergency management spheres, rather than being technical failures or simple acts of God, are starting to be recognised.[130,171]

Much of the burden of managing extreme events falls on affected communities and local organisations. The ability to cope with extreme events locally is highly variable, although often weakly linked to high-level disaster management systems. Although community-based disaster risk reduction is widely promoted and practised, and highly effective in some instances, systematic analysis of its effectiveness remains limited.[134] Frequently, initiatives are blocked or watered down by a lack of political will, insufficient funds, or the absence of expertise or guidance.

Population and migration

For population growth, there are three major institutional challenges. First, acknowledgment by governments in developing countries and in the donor community, by intergovernmental and non-governmental institutions, civil society groups, philanthropic foundations, the women's health movement, and health-care providers that population growth is important in climate change and that, addressing it through global reinvestment in voluntary family planning services, is both crucial and in agreement with the requests of developing countries themselves. Second, all family-planning programmes require political commitment, clear management and supervision, sound logistics, and competent staff. Beyond these basic requirements, it is clear that success in family planning depends on dismantling the barriers to contraception. This means considering mobile services, in addition to static clinics, commercial outlets, and social marketing schemes to suit local requirements. Equally important is the removal of conservative (attitudinal) barriers, combined with education of lawyers, health-care providers, and religious leaders about the importance of reproductive health.

Third, policy should be evidence based, and services should take a life-span approach, aiming to meet the needs of women throughout their reproductive lives, through good sex education, contraceptive services, and, where the law permits, safe abortion services that respect and protect the rights of people seeking to access those services.

Reuters

Asserting that population issues are central to adaptive responses to climate change is not about blaming the victim. Lower fertility and smaller families will accelerate the escape from poverty,[172–174] and thus reduce the background rates of climate-change-related mortality. Population is the denominator of everything we do. Increases in population size, whether through migration or fertility, in regions vulnerable to the effects of climate change (such as coastal areas) means that

more people are at risk. Ignoring high rates of population growth in parts of the world is likely to jeopardise the success of other responses to climate change and limit our ability to intervene in ways that respect and protect human rights.

Conclusions and recommendations

This report raises many challenging and urgent questions for politicians, civil servants, academics, health professionals, NGOs, pressure groups, and local communities. Climate change is potentially the biggest global health threat in the 21st century. Our response requires a new public health movement that is multidisciplinary and multisectoral, and that leads to coordinated thinking and action across governments, international agencies, NGOs, and academic institutions. Any adaptation interventions must sit alongside the need for primary mitigation: reduction in greenhouse gas emissions. Indeed, recognition by governments and electorates that climate change has enormous health implications should assist the advocacy and political change to tackle mitigation and adaptation.

Whichever mitigation strategies are chosen by governments or agreed at the Copenhagen conference, the move to a low-carbon economy will have global health benefits and these must also be emphasised. More research is needed on win-win solutions, which are equally important in developed and developing countries.

We have proposed a framework for responding to the health effects through adaptation strategies, which in turn embeds mitigation strategies to improve human health worldwide. This framework raises several important issues for action:

- Climate change mitigation and adaptation are essential elements to overall development policy. They are not separate issues that can be divided from the agenda for poverty alleviation or for closing the gap on social inequalities and health.
- The most urgent need is to empower poor countries, and local government and local communities everywhere, to understand climate implications and to take action. Health professionals and university academics have an important catalytic role. Multidisciplinary groups from higher education institutions can have a forceful role in engaging with community leaders, civil society organisations, and students in these debates. There is a need for new financing for global links between developed and developing countries that create a two-way dialogue. Developed countries can help to strengthen capacity for high-quality research and information collection in developing countries, and developing countries can strengthen the ability of developed countries to understand sustainability and low-carbon living. Empowerment is as much about community mobilisation as high-level political action. The empowerment process is likely to be pluralistic and chaotic, but health and academic communities can do much to support and catalyse these processes.
- An agenda for developing countries must be developed through global cooperation. Representation on global task forces to assess the health effect of climate change is heavily skewed in favour of institutions in developed countries. In poor countries, health assessments and high-level climate science and health surveillance research are a priority. New research and advocacy groupings in Africa and south Asia are needed, and the academic community of developed countries must have a role in lobbying for resources and support. Food and water insecurity are early effects of climate change and will be a high priority for poor communities. Distilling academic findings into simple language, policy briefs, and user-friendly media is essential.
- Climate change should be integrated into the entire discourse of our present and should be taken into consideration for all governance actions. An advocacy movement must ensure that the health effects of climate change are placed high on the agenda of every research and development funder, philanthropist, academic journal, scientific conference, professional meeting, and university or school curriculum. Academics should lead advocacy within their own spheres of influence.
- Accountability mechanisms are crucial. We hope that this report will initiate or stimulate new funding and networks to monitor what is happening in government, civil society, academia, local government, and communities, especially in the most vulnerable populations. Accountability indicators should be monitored by the academic community and civil society organisations. It should be possible to agree upon health and climate change goals and targets for the processes of engagement and empowerment. Global and regional conferences and working groups to develop these outputs would be valuable in the same way that previous reports published in *The Lancet* have stimulated action on child survival, nutrition, and maternal health through the countdown to 2015. A biennial review of progress towards agreed targets would help to accelerate progress through celebration of success and identification of areas where progress is lagging.
- Awareness of health risks can have an important role in strengthening carbon mitigation debates and targets. Joint statements from national institutes of medicine, representative bodies such as royal colleges, journal editors, organisations such as the Climate and Health Council,[175] and university leaders worldwide, drawing upon a growing evidence base, can create a solidarity and authority that politicians will find hard to resist. The priority is to send clear messages to the Copenhagen conference in December,

2009, emphasising the health consequences of climate change, even with a 2°C increase in temperatures (which is now broadly accepted as inevitable), with estimates of the severity of health effects at warming up to 4°C. Public and policy maker recognition of the profound meaning of the existence of threats from climate change to nature's life processes, to the productive and stabilising ecosystems upon which we depend, and hence to human health and survival, will have great effect on the seriousness and urgency with which we approach this unprecedented challenge.

- The frequently observed state of fragmented health systems, with little attention paid to long-term sustainability, must give way to the development of coherent, population-based, and bottom-up health planning. Health systems must not act only as a platform for the delivery of clinical services but also provide the foundation for an effective public health response to the many climate-induced threats to health. This action will require more attention being paid to the organisational and management deficiencies of ministries of health, including subnational health governance and management structures. Long-term strategies and investments will be needed to develop the clinical and management human capacity of health systems. Some countries will also need to address the currently unregulated and disorganised private sector to harness existing resources to better serve the public interest. Many countries currently lack any coherent long-term and sustainable development agenda for their health systems. This needs to change.
- The move to a low-carbon economy will have global health benefits from both a reduction in the health effects of climate change and improvement in human lifestyles, and these must be emphasised. There must be more research on win-win solutions, which are equally important in rich and poor countries. For example building new green cities in the developed world, which minimise the need for cars and maximise exercise, will contribute to the fight against obesity. In poorer countries, developing water and energy systems, which are operated by local renewable sources of power, cuts reliance on imported fossil fuels and empowers local community groups.
- Building low-carbon and climate-resilient cities in emerging economies that adapt to continuing rural–urban migration, driven both by economic development and climate effects, is important. More than a third of the world's population now live in urban areas in low-income or middle-income nations. Even Africa has 40% of its population in urban areas, a number that is larger than that in North America. Worldwide, the numbers of people injured or killed by storms and floods, and the amount of economic damage caused and insurance claims made, especially in these urban areas, have increased.
- Three priorities for action in urban areas are to improve the capacity and accountability of local and municipal government, to change their relation to informal settlers, and to ensure that government policies encourage rather than hinder the contributions to adaptation made by individuals, community organisations, and private enterprise.[70] Urban developments could use climate-resilient engineering on sites at low risk of water or food stress, and provide sustainable low-carbon transport and other infrastructure. A new approach to urban planning to ensure healthy food supplies, adequate exercise, clean air, clean water, devolved health service structures, and education might provide a model of what we mean by a climate-adapted public health response.

High-income countries have caused almost all the anthropogenic climate change that has occurred to date, and they must now face extremely challenging political and economic choices if climate change mitigation is to be achieved. The UCL *Lancet* Commission has recognised Antonio Gramsci's pessimism of the intellect and optimism of the will in tackling this issue. The academic community has a crucial role in facing up to the challenge of climate change, the health consequences we shall bequeath to our children and grandchildren (panel 7), and in helping to inform and support a policy process that will challenge us all.

What is a practical way to take the challenge forward? We call for a collation of global expertise on the health effects of climate change leading up to a major conference within the next 2 years, which will define the priorities for management, implementation, and monitoring. Representation from developing countries should be emphasised. The conference should bring representatives of all interested groups together to share experiences, and to discuss and endorse a set of key indicators and targets (climate and health adaptation goals developed by an international expert working group) for concerted global action. A key element of this action programme should focus on ways in which the poor nations can develop their own capacity to monitor problems, and to improve the evidence base for policy makers and planners. We believe a biennial review of progress towards agreed targets would help to accelerate progress through celebration of success and identification of areas in which progress is lagging.

Contributors

Members of the UCL *Lancet* Commission contributed to the development of the structure of the report, writing, and commenting on drafts. All authors have seen and approved the final version of the report.

Conflicts of interest

We declare that we have no conflicts of interest.

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