Introduction: climate change – the need for regional assessments

While uncertainty persists about the pace of climate change, there is scientific consensus that the build-up of greenhouse gases has resulted in global warming and climate change. The Intergovernmental Panel on Climate Change (IPCC), an effort of a global collective of scientists, projects that the Earth’s temperature could rise by as much as 4°C by the year 2100 depending on future trends of greenhouse gas emissions [1, 2]. The magnitude of the health consequences resulting from climate change will reflect the actual increase in temperature. The consequences of greenhouse gas emissions for climate are not simply a warming uniformly across the globe, but rather the warming is anticipated to be variable by place and over time, and extremes of weather will be enhanced. The direct weather consequences of climate change include warmer temperatures and more extreme conditions, and an associated sea-level rise, whereas the indirect consequences are broad with implications for human health (see Table 20.1). Beyond the adverse consequences listed in Table 20.1, some regions may benefit from warming through expanded agriculture and less need for heating.

The health implications of climate change reflect both direct and indirect pathways (see Figure 20.1). Climate change will not lead to new causes of morbidity and mortality, but will change the distributions of some causal factors that affect the occurrence of morbidity and mortality. For vector-borne infectious diseases (e.g. malaria), changes in the geographic distributions of vectors may lead to the emergence of diseases in places that have been previously free from the particular diseases. There is concern, for example, about the potential for malaria to re-enter places where it has long been eliminated if the range of its vector, the Anopheles mosquito, expands. Changes in flora may bring new allergens and crop yields may drop. Air pollution may worsen from fossil fuel combustion for power generation to meet increasing cooling needs due to warming and other energy demands to adapt to climate change. Rising sea levels and weather changes with consequences for agriculture and availability of water may displace people and lead to social and economic disruption with diverse potential implications for health.

The consequences of climate change for human health will be manifested differentially across broad regions of the world. The extent of change is projected to be variable, at least on
Table 20.1 Potential threats and health consequences of climate change

<table>
<thead>
<tr>
<th>Threat</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased frequency and intensity of heatwaves</td>
<td>Increased mortality from heatwaves, particularly in elderly</td>
</tr>
<tr>
<td>Altered distributions of aeroallergens</td>
<td>Increased frequency and severity of allergic diseases and symptoms</td>
</tr>
<tr>
<td>Altered distributions of vectors of infectious diseases</td>
<td>Spread of infectious diseases and increased frequency</td>
</tr>
<tr>
<td>Increased air pollution</td>
<td>Increased morbidity and premature mortality</td>
</tr>
<tr>
<td>Changing agricultural yields</td>
<td>More undernourished people in low-income countries</td>
</tr>
<tr>
<td>Social and economic disruptions, displacement</td>
<td>Various, with acute and chronic consequences</td>
</tr>
</tbody>
</table>

Figure 20.1 Schematic diagram of pathways by which climate change affects health, and concurrent direct-acting and modifying (conditioning) influences of environmental, social and health-system factors [2]
the regional scale – populations vary in their vulnerability and resilience, and adaptive capacity and resources also differ. Consequently, the IPCC provides regional assessments giving specific insights into anticipated impacts of climate change, including effects on human health. In its Fourth Assessment Report, the IPCC includes a chapter on Asia that offers findings used in this chapter [1, 2]. Additionally, in 2012, the World Health Organization (WHO) and the World Meteorological Organization (WMO) collaborated in the publication of the *Atlas of Health and Climate*, which provides useful maps that highlight the geographic diversity of the health consequences of climate change [3].

This chapter begins with an overview of the health consequences of climate change, covering effects that result through both direct and indirect paths. It considers not only the health consequences, but also the specific measures that might be taken to reduce impact. We then turn to the health consequences of climate change that are projected for South/East Asia. Of necessity, our coverage of this wide-ranging set of topics is brief. For further information, we recommend the reports of the IPCC, as well as the series in *Lancet* on climate change and health [4, 5].

**Mechanisms by which climate change affects health**

Climate change has been labelled as ‘the biggest global health threat of the 21st century’. In so labelling it, the *Lancet* and the University College London Institute for Global Health Commission cited the far reach of climate change and its diverse threats to human health [6]. Estimates of the potential burden of premature mortality and additional morbidity from climate change, while subject to great uncertainty, indicate a looming, substantial impact. For the year 2000, climate change was estimated to have caused the premature loss of about 150,000 lives and about 5.5 million disability-adjusted life-years (DALYs), representing 0.3 per cent of total deaths and 0.4 per cent of all DALYs, respectively [7].

Climate change affects health within the complex, multilevel system that determines the health of individuals and populations, including social, economic and health systems and governmental determinants (see Figure 20.1). The time domains of the stressor and adaptive and mitigative responses are also relevant. The acute stress of a catastrophic and large-scale weather event may overwhelm countering responses and mitigating mechanisms – the devastation caused by Hurricane Sandy to the East Coast of the United States (US) in 2012 is exemplary. The health status of the population affected is also a key consideration, as is the adequacy of its health system. Responses to the stressors associated with climate change may vary with the age structure of the population, the prevalence of chronic diseases and the capacity of the health system to provide care for the burden of disease that might arise from a climate-change driven event. There is concern that climate change could cause large-scale social and economic disruption through drought, famine and sea-level rise, and migration could lead to instability and conflict. For such consequences, the geopolitics of the world at the time will be critical [8].

There is the additional conceptual complexity of determining that health consequences are attributable to climate change. The assignment of causation is based on the concept of comparing actual events to scenarios of what might have happened absent climate change – the so-called counterfactual. For weather events, for example, a comparison is between the number of extreme events with health consequences, compared with the number generated by climate models in the absence of human-forced climate change. Such comparisons are conceptually challenging and not readily communicated to decision-makers and the public.
Heat stress and heatwaves

Temperature has long been associated with adverse effects on health and mortality. At extreme temperatures, the well-known clinical entities of hypothermia and hyperthermia are documented causes of death [9]. For climate change, exposure to heat and hyperthermia are of particular concern, given the resulting warming and increased frequency of extreme events with dangerously high temperatures. Hyperthermia occurs when temperatures are high among persons carrying out physical activities that lead to thermal stress, as well as among people who are susceptible to heat because of limited adaptive capacity, such as infants, the elderly and persons taking medications that impair responses to thermal stress (e.g. medications widely used for hypertension and heart disease). Even in developed countries, excess deaths from heat and heatwaves remain common and dramatic heatwaves with large numbers of deaths continue to occur. For example, in recent decades, the dramatic and well-documented epidemics of death associated with heatwaves in Chicago in 1995 (about 750 excess deaths [10]) and in Europe in 2003 (about 35,000 or more excess deaths [11, 12]), have alerted the public to the dangers of heatwaves and led to protective actions by governments and public health agencies.

Warmer temperatures are associated with mortality even in times when heatwaves are not in progress [9, 12]. The relationship between temperature and mortality has been characterized as ‘J-shaped’, such that mortality increases with both colder and warmer temperatures from an optimum temperature at which it is the lowest [13, 14]. Figure 20.2 provides

![Figure 20.2](image-url)

**Figure 20.2** Temperature-mortality relative risk functions for 11 US cities, 1973–1994 [13]

Note

°C = 5/9 x (°F – 32)
Climate change and health

illustrative analyses from 11 US cities. In almost all cities, the temperature with the lowest risk for mortality is evident and the upturn with higher temperature is more prominent in northern cities. The optimum temperature varies inversely with average temperature, and hence latitude, as well as the extent to which adaptive measures, such as air conditioning, are in place for buffering warmer or colder temperatures [12, 13, 15]. This J-shaped relationship has implications for the potential overall effect of global warming consequent to climate change on heat-associated mortality. Warming would reduce the cold-associated mortality while increasing heat-associated mortality, minus the new adaptive measures [13]. However, beyond the rise in average temperature, climate change is also projected to increase the variability of temperature and the frequency of heatwaves [1, 2]. There is an effect of heatwaves per se and the temperature profile of heatwaves seems to be a critical determinant of excess mortality [16].

Evidence suggests that the risk of heat-related excess mortality has declined on longer time frames. Carson and colleagues [17] examined weekly mortality in London during the twentieth century and assessed temperature-associated mortality over a period during which a major shift occurred in the underlying causes of death, the population became progressively older and the proportion affected by chronic diseases increased. They found declines in susceptibility to dying from both cold and heat. Carson et al. attributed this finding to factors related to social and environmental conditions, behaviour and health care. Davis et al. [18] examined heat-related mortality over the period between 1964 and 1998 in the US and also found declining heat mortality, which they attributed to various adaptations, including the increased availability of air conditioning. Barnett [19] found that the association of warm temperature with cardiovascular mortality during the summer declined substantially over the period between 1987 and 2004.

Population characteristics also affect the impact of heatwaves. The elderly and persons with underlying chronic diseases, such as coronary heart disease and congestive heart failure, are particularly at risk. Additionally, individuals taking diuretics, or taking some drugs used for blood pressure control and/or other drugs may have impaired cardiovascular responses to thermal stress, as may those who are obese. In the ageing populations of the more developed countries, these at-risk groups are increasing. Epidemiological analyses have identified additional risk factors for mortality during heatwaves, including a lack of social support, socioeconomic status and housing characteristics. In urban areas, the ‘urban heat island’ phenomenon tends to increase the risk of mortality associated with heatwaves [20]. Determinants of risk in less developed countries have received little research attention. In such countries, there is a very low prevalence of air conditioning.

Because the elderly and people with underlying chronic diseases are particularly susceptible, the hypothesis has been advanced that the excess mortality associated with heatwaves comes from a brief advancement of the time of dying, a phenomenon sometimes referred to as ‘mortality displacement’ or ‘harvesting’. If such mortality displacement is occurring, a reduction in mortality would be anticipated following the excess associated with the heatwave and, indeed, analytical approaches have been developed for assessing mortality displacement [21, 22]. Regarding the 2003 heatwave in France, the extent of mortality displacement was found to be modest [23]. Parallel analyses of heat-related deaths in Delhi, São Paulo and London, using distributed lag models, found some mortality displacement in London and a lesser indication of this phenomenon in Delhi [24], with the pattern being intermediate for São Paulo. These results, as well as descriptive observations on the ages of individuals dying during heatwaves, suggest that heatwaves do not affect only the most vulnerable.
Where there is little evidence on temperature-associated mortality in developing countries, greater excess mortality might be anticipated because of limited penetration of air conditioning, the density of megacities and limited attention to the problem by public health authorities. The ISOTHURM project examined the temperature–mortality relationship in 12 urban areas, including several in low- and middle-income countries [14]. The data from most of the cities showed the typical J-shaped relationship with temperature. In Delhi and Salvador, mortality did not increase at colder temperatures, nor did an increase occur at hotter temperatures in Chiang Mai and Cape Town.

Aeroallergens and allergic diseases

Aeroallergens – biological agents associated with allergic responses – are ubiquitous in indoor and outdoor environments. The two principal and most prevalent diseases associated with aeroallergens are allergic rhinitis, also referred to as hay fever and asthma [25]. Aeroallergens are known to exacerbate asthma and trigger attacks of allergic rhinitis.

For persons with allergic rhinitis and asthma, climate change might increase the risk of exacerbation through altered local and regional pollen production. Warming has already caused an earlier onset of the spring pollen season in the Northern Hemisphere [1, 2]. It may also lengthen the pollen season, change the spatial distribution of vegetation and possibly alter pollen production [1, 2, 26, 27]. Evidence suggests that climate change has changed exposures of populations to aeroallergens [1, 2, 28]. Vegetation patterns have changed and pollination is occurring earlier for some species in some places. New species could potentially become successful in additional areas, leading to exposures of populations to new antigens. More prolonged and intense exposure to aeroallergens could result in more severe disease and greater morbidity, and even increased mortality from asthma. Beggs and Bambrick [27] have proposed that climate change could be contributing to the global rise in asthma as a consequence of greater pollen exposure.

Changes in endemic and epidemic infectious diseases

Worldwide, in both developed and developing countries, infectious agents remain a leading cause of disease and death [29]. Warming from climate change has the potential to affect the transmission of infectious diseases across the globe. The transmission of these diseases is conceptually described by the ‘epidemiological triangle’ (see Figure 20.3), which captures the interplay between its components: the agent, the environment and the vector. Environmental conditions that promote or extend the geographic range of the vector increase the potential for infection. In addition to potentially affecting vector-borne diseases, climate change may also extend or change the geographic regions in which an infectious agent is present. Climate change may affect both endemic disease (i.e. disease generally occurring in a population) and epidemic disease (i.e. disease occurring in excess of normal expectancy). The time frames over which climate change could affect infectious diseases extend from relatively short, as even the temperature rise to date has had apparent impact, to relatively long, as continued temperature increases would be predicted to continue to alter vector distributions and densities.

Mathematical models of infectious disease transmission provide quantitative insight into the potential for climate change to increase rates of vector-borne diseases. The potential for transmission of infectious diseases is characterized by the basic reproductive rate ($R_0$) which describes the number of new cases of infection arising from one case in a population of
susceptible persons [30]. Values above unity imply the possibility of epidemic disease – a value of unity means that endemic disease will be maintained and a value below unity means that the disease will decline. Warming can increase $R_0$ through its effect on vector numbers, transmission probabilities and biting rates for insect vectors [30]. The geographic spread of vectors may also be affected by the extension of their ranges resulting from warmer conditions. Several vector-borne diseases are considered to be potentially sensitive to climate change [31] (see Table 20.2).

Waterborne and airborne diseases may also be affected by climate change. For diseases transmitted by water, warming may enlarge the geographic area in which conditions are suitable for survival of disease-causing organisms and for propagation of infection [32, 33]. The occurrence of waterborne infections has also been linked to extreme weather events [34]. Increased air conditioning and more time spent indoors, because of warming, might affect patterns for diseases that are transmitted in indoor environments by droplets or by contact, such as influenza and the common cold.

<table>
<thead>
<tr>
<th>Vector</th>
<th>Major diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mosquitoes</td>
<td>Malaria, filariasis, dengue fever, yellow fever, West Nile fever</td>
</tr>
<tr>
<td>Sandflies</td>
<td>Leishmaniasis</td>
</tr>
<tr>
<td>Triatomines</td>
<td>Chagas disease</td>
</tr>
<tr>
<td>Ixodes ticks</td>
<td>Lyme disease, tick-borne encephalitis</td>
</tr>
<tr>
<td>Tsetse flies</td>
<td>African trypanosomiasia</td>
</tr>
<tr>
<td>Blackflies</td>
<td>Onchocerciasis</td>
</tr>
<tr>
<td>Snails (intermediate host)</td>
<td>Schistosomiasia</td>
</tr>
</tbody>
</table>

Source: [31].
Cholera illustrates the complexity of understanding how climate change can alter the occurrence of infectious diseases [32, 33]. The disease-causing organism, *Vibrio cholera*, is endemic and widely found in water. Multiple global cholera pandemics have been documented—the seventh, which began in 1961, is still ongoing. The present epidemic began with the emergence of a new biotype, the El Tor biotype of *V. cholerae* 01, in Indonesia. In 1991, the pandemic moved to South America, with outbreaks along the Pacific coast. The epidemic’s occurrence was linked to a plankton bloom that was driven by the El Niño Southern Oscillation (ENSO). The planktonic copepod organism harbours the *V. cholerae* organisms on its surface. Consequently, a higher concentration of plankton increases the dose of the infectious agent received from drinking contaminated water. A time-series analysis of cholera in Bangladesh found a link with the ENSO phenomenon [35]. Lipp and colleagues [33] propose that climate change could affect each step in their model for cholera transmission. Checkley and colleagues [36] carried out a time-series analysis of temperature changes associated with the ENSO and all hospital admissions for diarrhoea in children in Peru. Over the period between 1993 and 1998, they found that the numbers of admissions were positively associated with temperature and also with the ENSO, which had an effect on the admissions rate beyond that expected from the temperature increase alone.

Changes in the epidemiological characteristics of other infectious diseases have been examined in relation to climate change. Dengue transmission was addressed in the IPCC report [1, 2] and in specific studies [37]. In Western Australia, Woodruff et al. [38] found that climate data predicted epidemics of the Ross River virus disease (which is spread by mosquitoes) reasonably well, particularly if data on mosquitoes were incorporated into the model. Studies have also addressed tick-borne disease [39, 40] and food-borne disease [41]. The potential for malaria to increase as a consequence of climate change has been controversial and malaria is receding globally in spite of some predictions that it would intensify as the world warms [42] (see chapters 18 and 19).

Many factors determine susceptibility to infection and the severity of the resulting illness, including mortality risk. In developed countries, key factors include age, immunocompetence, presence of comorbid chronic diseases (e.g. coronary heart disease, chronic obstructive pulmonary disease and diabetes), access to vaccines and to medical care, and the quality of the medical care available. In developing countries, additional determinants of severity include general nutritional status and specific micronutrient deficiencies. The level of sanitation, the availability and use of preventive measures (such as bed nets and vector control), and the availability of vaccinations determine transmission probabilities. In both developed and developing countries large populations are at risk for more severe infections and mortality.

**Ambient air pollution**

Climate change may worsen air pollution, either directly (through increased tropospheric—ground-level—ozone production) or indirectly (through greater power plant emissions as power generation increases to meet the demand for air conditioning capacity). Ozone is a secondary pollutant formed via sunlight-driven photochemical reactions involving precursor hydrocarbons and oxides of nitrogen. Together with ozone, other secondary products are generated, forming the complex mixture of photochemical smog. Ozone pollution is projected to increase because warmer temperatures increase ozone production [1, 2]. Warmer temperatures enhance the chemical reactions that generate ozone. Under various scenarios, increases of several parts per billion are projected over the next two decades [43] and up to a range of 10 to 30 parts per billion by the end of this century [44]. Fossil fuel combustion...
contaminates the atmosphere with the primary particles generated by combustion and with the secondary particles formed from gaseous components of power plant emissions through complex chemical and physical processes. Increased fossil fuel burning could also worsen particulate air pollution, beyond predictions from climate change scenarios [1, 2, 45].

The health risks of both ozone and airborne particles have been characterized in numerous epidemiological studies, with supporting evidence coming from in vivo and in vitro toxicological research [46, 47, 48]. Both ozone and particulate matter (PM) air pollution have been associated with an increased risk of mortality in time-series studies of daily mortality [49, 50, 51] and airborne particles have also been associated with an increased risk of death on longer time frames [47, 51, 52]. Both types of pollution are also associated with morbidity, including an increased risk for hospitalization [51, 53] and other adverse outcomes [48]. A quickly expanding body of evidence links particulate air pollution to adverse cardiovascular effects [52]. As for temperature and infection, a substantial proportion of the population is at increased risk because of older age and comorbidity, particularly respiratory and cardiac diseases.

Analyses that link climate change model outputs to ozone concentrations have been carried out for cities in the US. Knowlton et al. [54] projected future increases in ozone concentration for 31 counties of the New York metropolitan region. Considering the impact of climate change alone on ozone concentration, they estimated a median 4.5 per cent increase in summertime ozone-related, acute, all-cause mortality for all the counties. Bell et al. [55] performed a similar modelling for 50 cities in eastern US. They estimated the average increase in daily one-hour maximum concentration as 4.8 parts per billion. Depending on the concentration–response relationship used, the increase in ozone concentration corresponded to an increase in daily, all-cause mortality of 0.11 to 0.27 per cent.

Analyses have also addressed particulate air pollution, considering potential risks of increased fossil fuel combustion and benefits for health of reducing air pollution through greenhouse gas mitigation [45, 56]. In one assessment, enhanced energy consumption based on fossil fuel combustion was projected as leading to substantial increase in premature mortality [45]. In a scenario of business as usual that results in increased exposure to PM air pollution, an additional 700,000 premature deaths were forecast. Similarly, in an analysis of four of the world’s major cities (Mexico City, New York City, Santiago and São Paulo), Cifuentes et al. [56] predicted that reductions of ozone and particles from mitigation would substantially reduce premature mortality.

In addition, air pollution and thermal stress may act synergistically: both affect the same susceptible populations and mean that hot temperatures will increase ozone production. A few studies have addressed such synergism. In Athens, the short-term effect of sulphur dioxide on daily mortality was independent of temperature over the period between 1975 and 1982 [57]. An analysis of mortality in Athens during a 1987 heatwave suggested synergism of air pollution with higher temperatures [58]. Filleul and colleagues [59] examined the contributions of ozone and temperature to the excess mortality observed in nine French cities during the 2003 heatwave. They estimated that both ozone and heat contributed to the excess and found that the relative contributions varied from city to city. Fischer et al. [60] published similar findings for the Netherlands during the 2003 heatwave. Neither analysis tested for synergism between ozone and temperature. Synergistic effects of aeroallergens and urban air pollutants (such as ozone and particulate matter) on asthma and allergenicity have been examined in epidemiological and toxicological studies [61, 62]. A recent study showed that ragweed pollen collected along high-traffic roads induced higher allergenicity than ragweed pollen sampled in vegetated areas, suggesting that traffic-related pollution enhances pollen allergenicity [63].
Climate change and social and economic disruption

The possibility of social and economic disruption from climate change looms large for much of the world, including Asia. Climate change can threaten food security, lead to desertification and threaten water supplies [5]. Agricultural productivity is likely to suffer as a result. Sea-level rise may force migration from coastal areas, leading to crowding and potentially to cross-border migration. In Asia, sea-level rise would cause large-scale inundation along the vast Asian coastline and recession of flat sandy beaches. The ecological stability of mangroves and coral reefs around Asia would be put at risk. The potential implications for health of the social and economic impacts of these broad consequences of climate change are enormous, including inadequate food and water supplies, breakdown of governmental services and failure of health systems. There is also potential for conflict over resources, possibly water access and agricultural land.

Specific health outcomes and adaptation measures

The inevitable consequences of climate change, as described above, require responsible actions to mitigate the problem. Central to the mitigation debate is the reduction of CO₂ emissions by using renewable energy sources, cleaner fossil fuels and improving energy efficiencies. Given that CO₂ has a long-term half-life in the atmosphere, proposals to mitigate short-lived warming pollutants such as methane and black carbon have gained support in recent years, especially under the notion of ‘co-benefits’. In addition to having a larger warming potential than CO₂ on a per-molecule basis, methane is a precursor of troposphere ozone and black carbon (BC) is considered to be a more toxic component of airborne fine particulate matter. In a recent assessment of 14 specific emission control measures targeting BC and methane to reduce the rate of climate change over the next 20–40 years, Anenberg et al. [64] found that in addition to climate benefits, the methane and BC emission control measures would have substantial co-benefits for air quality and public health worldwide, potentially reversing trends of increasing air pollution concentrations and mortality in Africa, and South, West and Central Asia. The projected benefits are independent of CO₂ mitigation measures.

Perhaps more urgent than mitigating greenhouse pollutants is developing adaptation strategies. We consider a number of adaptation measures, at both societal and individual levels, that are specific to pathways through which climate change affects health outcomes. Across all pathways, assessment of the impact of climate change is the first step for exploring adaptation strategies. In general, disease surveillance systems are essential for acquiring data needed for impact assessment. Specifically, monitoring of diseases, along with related meteorological data and ecological factors, is needed to track the impact of weather factors by each pathway, as shown in Table 20.3. Disease monitoring is also necessary for assessing the effectiveness and efficiency of adaptation measures [65]. For example, heat watch and warning systems implemented in the US have proven effective in helping to minimize the impact of heatwaves [66]. A similar system has been recently initiated in Shanghai, China [67].

Other adaptation strategies include improvements in assuring safe water and food distribution, disaster preparedness and management, and improvements in public infrastructure, such as healthcare facilities and emergency shelters [68]. Improving socio-economic status through sustainable and equitable socio-economic development can substantially enhance social capital and reduce the vulnerability of developing countries of Asia to climate change. Adaptations to deal with sea-level rise, potentially more intense cyclones and threats to
Climate change and health

Table 20.3 Examples of climate change-related health outcomes and possible adaptation measures

<table>
<thead>
<tr>
<th>Pathways</th>
<th>Health outcome</th>
<th>Adaptation measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct effects of heat</td>
<td>Mortality, dehydration, hypothermia, hyperthermia</td>
<td>Using air conditioners, heat warning systems and shelters for the public</td>
</tr>
<tr>
<td>Effects of urban air pollution</td>
<td>Cardio-respiratory mortality and morbidity, adverse birth outcomes</td>
<td>Staying indoors, adding filters to building ventilation systems</td>
</tr>
<tr>
<td>Effects of aeroallergens</td>
<td>Asthma, allergic rhinitis, sinusitis, allergies</td>
<td>Staying indoors, using filters, medical therapies</td>
</tr>
<tr>
<td>Water-borne/food-borne diseases</td>
<td>Diarrhoeal diseases, bacillary dysentery</td>
<td>Enhancing monitoring of water and food quality, enhancing personal hygiene practices</td>
</tr>
<tr>
<td>Vector-borne diseases</td>
<td>Malaria, dengue, Japanese encephalitis, West Nile virus</td>
<td>Enhancing mosquito controls, enhancing disease surveillance and infectious disease controls</td>
</tr>
<tr>
<td>Disasters (drought, floods, forest fires, etc.)</td>
<td>Drowning, injury, mental health problems, increased susceptibility to infections</td>
<td>Improving public infrastructures (e.g. forecast and evacuation capacities) in response to natural disasters</td>
</tr>
<tr>
<td>Malnutrition</td>
<td>Underweight, increased susceptibility to disease and infections</td>
<td>Advancing technologies to improve crop yields, especially in poor agriculture communities; implementing policies and other means to reduce poverty</td>
</tr>
</tbody>
</table>

Ecosystems and biodiversity are recommended as high-priority actions in coastal areas of temperate and tropical countries [1, 2].

Climate change in South/East Asia

In the following sections, we focus on several sub-regions of Asia: South Asia and Southeast Asia based on the definition in the IPCC report [1, 2]. We use the term 'South/East Asia' when referring non-specifically to South Asia and Southeast Asia.

Asia is the most populous continent, covering 30 per cent of the Earth’s land surface, but home to over 4 billion people in 2010 or about 60 per cent of the world’s total. During the twentieth century, Asia’s population nearly quadrupled. The majority of the region’s population growth is projected to come from South Asia, which is anticipated to add 570 million people in India, 200 million in Pakistan and 130 million in Bangladesh over the next 50 years [69]. The projected population growth, especially in regions with high baseline population densities, implies increased pressure on the natural resources and the environment (e.g. deforestation, floods, droughts and disrupted ecosystems) [70]. For example, in the developing regions of Asia, the remaining natural flood plains are disappearing at an accelerating rate, due primarily to changes in land use and hydrological cycle. The most threatened flood plains may be those in South and Southeast Asia [71], and this loss of flood plains makes the region more vulnerable to climate change.

Southeast Asia is characterized by tropical rainforests, monsoon climates with high and constant rainfall, and heavily leached soils. The coastlines in monsoon Asia are cyclone-prone with approximately 40 per cent of the world’s total tropical cyclones occurring in this region [72]. This region has reportedly undergone a 0.1°C to 0.3°C increase per decade from 1951
to 2000 [73]. Furthermore, extreme weather events associated with El Niño were reported to be more frequent and intense in the past 20 years [74, 75]. For example, increased occurrence of extreme rains caused flash floods in Vietnam, landslides and floods in 1990 and 2004 in the Philippines and floods in Cambodia in 2000 [76, 77]. Since 1970, the frequency and intensity of tropical cyclones originating in the Pacific have increased [78], while cyclones originating from the Bay of Bengal and Arabian Sea have decreased in frequency but increased in intensity [79]. In both cases, the damage caused by intense cyclones has risen significantly in the affected countries, particularly India, the Philippines, Vietnam and Cambodia, as well as Japan and China [1, 2].

Temperature projections for the twenty-first century, based on the Fourth Assessment Report of IPCC [1, 2], suggest a significant acceleration of warming over that observed in the twentieth century [80, 81]. Given that South/East Asia has vast coastlines and consists of many islands, sea-level rise due to warming is a practical and serious concern. Fundamental thermodynamics and climate models suggest that dry regions will become drier and wet regions will become wetter in response to global warming [82]. These model results suggest that the absence of climate mitigation will further increase the intensity and frequency of typhoons, tropical storms, floods and landslides in South/East Asia.

**Health impacts of climate change in South/East Asia**

Compared to the ‘global average’, several of the pathways through which climate change affects human health may be amplified in South/East Asia, with some areas already experiencing a scarcity of resources, environmental degradation and high rates of infectious disease, in the context of weak infrastructure and overpopulation [83, 84]. In particular, tropical regions of South/East Asia will experience significant changes in human–pathogen relationships due to climate change [85, 86]. Changing temperatures and precipitation patterns linked to climate change will further affect health by changing the ecology of various vector-borne diseases, such as malaria, dengue, chikungunya, Japanese encephalitis, kala-azar and filariasis [87, 88]. The numbers within the vulnerable groups are large [89, 90].

**Impact on urban populations and population migration**

Major cities, including Bangkok, Jakarta, Manila and Ho Chi Minh City, are at risk as the sea rises [91]. In general, cities are vulnerable to the health impacts of climate change, partly because of urban heat island effects and urban air pollution. Long heatwaves and urban smog are indeed a potent and injurious combination to which urban areas in South/East Asia are vulnerable [83, 91].

Additionally, populations in cities throughout South/East Asia are growing rapidly. Rapid population growth and urbanization force poor people to move to fragile and high-risk areas prone to natural hazards. Moreover, the rapid growth of industries in urban areas drives people to migrate from rural areas to urban/industrialized areas. Such population migration brings substantial challenges for implementing many of the adaptation measures described earlier in this chapter because it is difficult to expand the infrastructure at a pace matching the speed of population growth. A further complication to this socio-economic-driven migration is the expected population movement following extreme weather events. Such unplanned migration has significant public health implications at its origins, along the migration routes and in the receptor areas [92]. The countries/areas that can be potentially affected by climate-induced population migration (often accompanied by pathogen migration) need to develop
preparedness and adaptation strategies to minimize the potential for resulting catastrophic damage [93].

**Impact on vector-borne and infectious diseases**

Mortality and morbidity from diarrhoeal diseases and malnutrition attributable to climate change were already the largest in South/East Asian countries including Bangladesh, Bhutan, India, Maldives, Myanmar and Nepal in 2000 [94]. In this region, endemic morbidity and mortality due to diarrhoeal disease have been linked to poverty and hygiene behaviour, accelerated by the effect of high temperatures on bacterial proliferation [36]. Incidence rates and frequency of outbreaks of diarrhoeal and other infectious diseases (e.g. cholera, hepatitis, malaria, dengue fever) have also been linked to climate-related factors, such as floods, droughts, rising sea-surface temperatures and rainfall. Other relevant factors include the scope of the susceptible population, e.g. children, the elderly and the impoverished; lack of access to safe drinking water; and inadequate sewer systems [1, 2, 95]. Increases in sea-surface temperature due to climate change will increase the growth of phytoplankton along the coastlines of South/East Asia. Phytoplankton blooms are excellent habitats for survival and spread of bacteria responsible for infectious diseases such as cholera [96]. Increases in the frequency and intensity of floods from increased precipitation and sea-level rise in the future, absent of adequate mitigation/adaptation measures, will lead to drinking water contamination and consequently increased water-borne infectious diseases. Based on the trends in temperature and rainfall, it is projected that the frequency of vector-borne and water-borne infectious diseases in Southeast Asia will remain the highest in the world in 2030 [94].

The distribution of vector-borne diseases such as malaria and dengue fever is influenced by the spread of vectors (e.g. mosquitoes) and the climate dependence of the infectious pathogens. A warmer and more humid climate is favourable for propagation and invasiveness of infectious insect vector. For example, evidence shows that dengue incidence in metropolitan Manila varies with changing rainfall patterns [97]. As Singapore experienced higher weekly mean temperatures and cumulative precipitation in the years 2004–2007, a significant increase in intensity and number of dengue fever cases could be attributed to climate factors [98]. As the increasing trends in surface temperature and rainfalls are likely to continue in the South/East Asia, intensified surveillance and control of mosquitoes during periods with high rainfalls are recommended [97].

**Poverty and vulnerability**

A significant portion of the Asian population is living below social and economic poverty thresholds [99]. Most of the world’s poor reside in South Asia and, within the region, the majority resides in rural areas [100], although rural-to-urban migration continues to increase. The poor are highly vulnerable to climate change because of their limited access to stable livelihood opportunities and limited access to areas that are fit for safe and healthy habitation. Consequently, those who are impoverished are more likely to be at increased risks from floods, droughts, and contaminated water and foods [101]. Without appropriate measures, climate change will likely exacerbate the poverty situation and increase social inequity [102], as those who live in poverty contribute far less greenhouse gases on a per capita basis than wealthier persons. Consequently, there needs to be equity in assuring that those living in poverty advance economically in order to have enhanced capacity for adaptation. Crucial infrastructure should be designed and constructed to withstand extreme events for all who
will be potentially affected. Health care and education should be strengthened, inequality addressed, and resources directed to communication and surveillance systems/technologies. Intensive development in very low-lying areas should be avoided, although large numbers of people are living at sea level in South/East Asia [91].

**Conclusion**

South/East Asia, with vast coastal areas and vector-prone climate, is one of the most vulnerable regions, facing a range of adverse health outcomes of climate change. It has many impoverished inhabitants and its coastal cities and megacities are at risk from the direct and indirect stressors associated with climate change. For the short-term, adaptive strategies are needed for heatwaves and other extreme weather events. For the longer term, the success of global mitigation strategies will be critical, particularly if sea-level rise is to be slowed, and the threat to agriculture and water security minimized.

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**References**


Climate change and health

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Climate change and health


Climate Change
Challenges and Opportunities for Global Health

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IMPORTANCE Health is inextricably linked to climate change. It is important for clinicians to understand this relationship in order to discuss associated health risks with their patients and to inform public policy.

OBJECTIVES To provide new US-based temperature projections from downscaled climate modeling and to review recent studies on health risks related to climate change and the cobenefits of efforts to mitigate greenhouse gas emissions.

DATA SOURCES, STUDY SELECTION, AND DATA SYNTHESIS We searched PubMed from 2009 to 2014 for articles related to climate change and health, focused on governmental reports, predictive models, and empirical epidemiological studies. Of the more than 250 abstracts reviewed, 56 articles were selected. In addition, we analyzed climate data averaged over 13 climate models and based future projections on downscaled probability distributions of the daily maximum temperature for 2046-2065. We also compared maximum daily 8-hour average with air temperature data taken from the National Oceanic and Atmospheric Administration National Climate Data Center.

RESULTS By 2050, many US cities may experience more frequent extreme heat days. For example, New York and Milwaukee may have 3 times their current average number of days hotter than 32°C (90°F). The adverse health aspects related to climate change may include heat-related disorders, such as heat stress and economic consequences of reduced work capacity; and respiratory disorders, including those exacerbated by fine particulate pollutants, such as asthma and allergic disorders; infectious diseases, including vectorborne diseases and water-borne diseases, such as childhood gastrointestinal diseases; food insecurity, including reduced crop yields and an increase in plant diseases; and mental health disorders, such as posttraumatic stress disorder and depression, that are associated with natural disasters. Substantial health and economic cobenefits could be associated with reductions in fossil fuel combustion. For example, the cost of greenhouse gas emission policies may yield net economic benefit, with health benefits from air quality improvements potentially offsetting the cost of US carbon policies.

CONCLUSIONS AND RELEVANCE Evidence over the past 20 years indicates that climate change can be associated with adverse health outcomes. Health care professionals have an important role in understanding and communicating the related potential health concerns and the cobenefits from reducing greenhouse gas emissions.
Current science highlights serious worldwide adverse health outcomes related to climate change. Although uncertainty remains regarding the extent of climate change, this uncertainty is diminishing.\(^1\) Consensus is substantial that human behavior contributes to climate change: 97% of climatologists maintain that climate change is caused by human activities, particularly fossil fuel combustion and tropical deforestation.\(^2\)\(^-\)\(^4\) Questions remain concerning risks, vulnerabilities, and priorities for policies to promote adaptation (reducing adverse outcomes) and mitigation (reducing heat-inducing emissions).

About half of anthropogenic greenhouse gas emissions between 1750 and 2010 occurred since 1970. The increase in greenhouse gas emissions has been greatest in the last decade (2.2% per year) compared with 1.3% per year between 1970 and 2000.\(^5\) Emissions continue to increase; 2011 emissions exceeded those in 2005 by 43%.\(^1\) Carbon dioxide from fossil fuels and industrial processes accounted for approximately 78% of the total increase from 1970-2010. Economic and population growth contribute most to increases in emissions globally and have outpaced improvements in energy efficiency. The trend toward decarbonization (cleaner fuels) of the world’s energy since the 1970s has been reversed by increased coal combustion since 2000.\(^5\)

Climatologists calculate that to avoid heating the earth more than 2°C from preindustrial levels, anthropogenic carbon dioxide emissions must be significantly reduced. Some of the projected earth system changes—which include changes in temperature and precipitation, the rise in sea levels, and acidification of the ocean—are widely accepted as the consequences of increasing carbon dioxide concentrations in the earth’s atmosphere (Box 1).\(^1\) Although evidence on global trends and the extent that climate change is related to human behavior are substantial, necessary actions on emission reductions have lagged.

### Framing Climate Change and Health

Climate change is happening: the relationship of heat-waves, floods, and droughts along with adverse health outcomes is evident.\(^7\)\(^8\) Two broad approaches are needed to protect public health: mitigation, or major reductions in carbon emissions, corresponding to primary prevention; and adaptation, or steps to anticipate and reduce threats, corresponding to secondary prevention (or public health preparedness).

A wide range of solutions is available to mitigate the problem of climate change. Many of them would improve health immediately. From decreasing rates of chronic diseases to reducing motor vehicle crashes, there are many good solutions for climate disasters and health risks. Reducing greenhouse gas, deploying sustainable energy technologies, shifting transportation patterns, and improving building design—many of which yield multiple benefits—are feasible, cost-effective, and attractive to multiple parties. Health care professionals are uniquely positioned to develop policies that simultaneously serve both planet and people.\(^9\)

Climate change, as a global disturbance, can exacerbate many environmental health risks familiar to clinicians and public health professionals.\(^10\)\(^11\) The nature of risks and population vulnerability will vary by region; indirect consequences such as ecosystem collapse may overshadow more direct health effects, yet are more difficult to estimate.

Recent reviews on health effects of climate change have been published by the Intergovernmental Panel on Climate Change\(^7\) and the US National Climate Assessment.\(^8\) Our goals in this Special Communication are to provide new US-based temperature projections from downscaled climate modeling and to review recent studies on climate change health risks and the cobenefits of mitigating greenhouse gas emissions. A brief list of key findings is summarized in Box 2.

### Methods

We reviewed the literature of international studies on climate change and health and disease risk or the cobenefits of reducing fossil fuel emissions by searching the PubMed database and Google Scholar from January 2009 to April 2014. Priority for inclusion was based on peer-reviewed articles published within the past 3 years that focused on climate and heat-related disorders, reduced work capacity, respiratory disorders, infectious diseases, food insecurity, mental health disorders, climate change communications, and health cobenefits. We identified more than 250 abstracts, and 56 articles are the basis of this review component of this article. In addition, we included our original analysis of US-based risks from heat waves and ozone air pollution (Figure 1 and Figure 2). Extreme heat data were obtained from the University of Wisconsin Probabilistic Downscaled Climate Data\(^12\) according to methods described in Kirchmeier et al.\(^13\) (Downscaling) is the process of providing locally specific information based on large-scale data. We took large-scale climate data from the global climate models and made it regionally specific using a statistical...
method.) Data were averaged over 13 climate models, which are required by the World Climate Research Programme’s coupled model intercomparison project phase 3 multimodel data set to accommodate the intercomparison nature of the program.\textsuperscript{14} Present-day estimates of the number of hot days are based on downscaled probability distributions—used for future climate modeling to establish uncertainty ranges—of daily maximum temperature for the years 1960 through 1999 from the Climate of the 20th Century simulations. Future projections are based on downscaled probability distributions of daily maximum temperature for the years 2046-2065 from the IPCC A1B emissions scenario that assumes “business as usual” or rapid economic growth and a global average temperature increase of 2.8°C.\textsuperscript{12-14}

For ozone and temperature analysis, we used ground-level ozone measurements from the US Environmental Protection Agency Air Quality System database. The maximum daily 8-hour average for each city—based on the number of monitoring sites within the city in operation between 1980 and 2002 during the May through October period, when ozone concentrations are highest—were calculated. If any monitor was higher than the 75 ppb threshold, selected as the current health-protective ozone limit from the EPA National Ambient Air Quality Standards, then the day was counted in the yearly total. Air temperature data were taken from the US National Oceanic Atmospheric Administration (NOAA) National Climate Data Center. In an analysis approach modeled after the Connecticut Department of Energy and Environmental Protection,\textsuperscript{15} annual values were compared and demonstrated that relationships existed between the number of high-ozone days each year and the number of hot-temperature days each year.

### Heat-Related Disorders

The most direct effect of a warming planet is heat stress and associated disorders. Heat-related deaths are routinely attributed to causes such as cardiac arrest without citing temperature as the underlying factor.\textsuperscript{26} Thus, the actual death toll attributable to heat is greater than certified on death certificates. Annual certified heat-related deaths averaging 658 in the United States between 1999 and 2009, represent more fatalities than all other weather events combined.\textsuperscript{17,18} More accurate risk estimates have compared observed vs expected mortality during heat events; for example, 70 000 excess deaths were estimated for the 2003 European heat wave and 15 000 for the 2010 Russian heat wave.\textsuperscript{19,20}

Although air conditioning has reduced heat-related deaths and illness in the United States, climatic and demographic trends suggest that risks may persist.\textsuperscript{21,22} Estimates from 7 climate models for the years 2081-2100 project that more than 2000 excess heat wave–related deaths per year may occur in Chicago, Illinois.\textsuperscript{23} More frequent and persistent heat waves are forecast, especially in the high latitudes of North America and Europe.\textsuperscript{24,25} Mega heat waves (as occurred in Europe and Russia) are projected to increase in frequency by 5- to 10-fold within the next 40 years.\textsuperscript{26} Figure 1 shows projected days with temperatures exceeding 32°C (90°F) per year by midcentury for Milwaukee, Wisconsin, New York, New York, and Atlanta, Georgia, and days of temperatures exceeding 38°C (100°F) for Dallas, Texas. Data were averaged across 13 climate models for this analysis. Frequency of hot days markedly increases across all cities; for example, New York City is projected to experience 3 times the current average number of 32°C (90°F) days by the midcentury (from 13 to 39 days).

High-risk groups include elderly persons, those living in poverty or social isolation, and those with underlying mental illness.\textsuperscript{27,28} Depression may be aggravated; suicide has long been observed to vary with weather.\textsuperscript{29-32} Dementia is a risk for hospitalization and death during heat waves.\textsuperscript{33,34} Psychotic illnesses such as schizophrenia,\textsuperscript{35-43} as well as substance abuse,\textsuperscript{44} also are associated with an increased risk of death during extremely hot weather. Increased frequency of kidney stones (likely precipitated by dehydration) also occurs during heat waves.\textsuperscript{45}

Cities with investments in early warning and response programs have seen some success. For example, after Milwaukee implemented an extreme heat conditions plan following 91 fatalities during the 1995 heat wave, a subsequent heat wave in 1999 resulted in only 10 deaths, or 49% less than expected.\textsuperscript{46} It is estimated that more proactive health adaptations in cities, such as enhanced tree canopies and more reflective, less heat-absorbing surfaces, could reduce heat-related mortality by 40% to 99% in Atlanta, Philadelphia, Pennsylvania, and Phoenix, Arizona.\textsuperscript{47}

**Might fewer cold-related deaths balance mortality from heat waves?** This is a topic of active research and current uncertainty, with results likely differing for climate zone and infrastructure characteristics. Although relative increases in heat-related deaths may exceed relative decreases in cold-related deaths, this may not apply in absolute terms because the balance may depend on location, population structure (proportion of older residents), and amount of warming.\textsuperscript{48,49} and the Intergovernmental Panel on Climate Change expressed low confidence that modest reductions in cold-related mortality would occur.\textsuperscript{7} Reasons for this include the observation that
many deaths related to cold temperatures do not occur during coldest times and that there is a lag between exposure to cold temperatures and increased risk of death typically much longer than 1 or 2 days.50

**Occupational Health**

Outdoor workers are affected by heat, so economic consequences on work capacity can be substantial.51 Modeling by Kjellstrom et al52 projected that by the 2050s workdays lost due to heat could reach 15% to 18% in South-East Asia, West and Central Africa, and Central America.

Using industrial and military guidelines, Dunne et al53 estimated that ambient heat stress has reduced global population-weighted labor capacity by 10% in summer’s peak over the past few decades. Projected reduction may double by 2050 and may be even larger in the latter half of the 21st century. Locations already with hot ambient conditions are particularly susceptible to heat stress losses in labor capacity, a potential liability for fragile economies.

**Respiratory Disorders**

The majority of research on the climate change–pollution connections has focused on ground-level ozone and particulate matter, both of which vary with the weather.55 Even in the face of improving emissions, a climate penalty or temperature-related worsening of pollution may be anticipated.56

We compared ground-level ozone measurements from the US EPA Air Quality System with temperature data from NOAA’s National Climate Data Center. The analysis displayed in Figure 2 suggests a direct relationship between temperature and ozone. The summers with the highest number of hot days (>32°C) in Chicago, for example, strongly correlated ($R^2=0.57$) with summers with the highest number of days when ozone levels exceeded 75 parts per billion by volume (ppbv), the US threshold level for ozone.

Models demonstrate increased ground-level ozone concentrations by the midcentury across the eastern United States,57-60 suggesting that further reductions in ozone precursors would be needed to offset the effect of climate change on ground-level ozone. Fine particulate matter less than 2.5 μm is a pollutant posing health risks and is influenced by weather. Fine particulate matter is formed as part of diesel exhaust, forest fire smoke, windblown dust, and chemical products of gaseous release from power plants, vehicles, and industry. Forty-three million people in the United States inhabit areas that exceed EPA health-based standards for fine particulate matter,61 and nearly a third of the earth’s
population inhabit areas that fail World Health Organization standards. Fine particulate matter exposure is highest in low-income countries, where regulations to limit particulate emissions are lacking or unenforced.

In many regions, future temperatures most likely will increase wildfire risk by causing increased drought. A study on worldwide mortality estimated that 339,000 premature deaths per year (range, 260,000-600,000) were attributable to pollution from forest fires, especially particulates.

In some cases, health adaptations to one hazard, eg, air conditioning for heat stress, may exacerbate another risk, such as air pollution. For example, electricity demands during more frequent heat waves, and associated power plant emissions may compound direct temperature effects on atmospheric chemistry.

Allergies and Pollen
Climate change may exacerbate allergies by enhancing pollen production and other allergens from nature. Fifty-five percent of the US population tests positive for allergens, and more than 34 million have asthma. Climate shifts alter abundance and seasonality of aeroallergens, eg, earlier flowering of oaks over the past 50 years, and increased pollen production by ragweed (Ambrosia) with warmer temperatures and higher ambient carbon dioxide. Data along a 2560-km (1600-mile) north-south sampling of monitoring stations through mid-North America indicate that the ragweed season has been lengthening by as much as 13 to 27 days north of the 44th parallel since 1995.

Infectious Diseases
Vectorborne Diseases
Vectorborne diseases are sensitive to climate through multiple mechanisms: first, through geographic shifts of vectors or reservoirs; second, through changes in rates of development, survival, and reproduction of vectors, reservoirs, and pathogens; and third, through increased biting by vectors and prevalence of infection in reservoirs or vectors. All affect transmission to humans, such that exposure to vectorborne disease will likely worsen in a warmer world.

Demographic trends influence the risk of vectorborne diseases. Warmer ambient temperatures in both the Ethiopian and Colombian highlands are projected to increase malaria in densely populated locations. Similar results occur in North America: warmer temperatures increase the development rate of the Lyme disease vector, Ixodes scapularis, and climate models predict expansion of Lyme disease into Canada. Modeling shows northern and central Europe at risk for the Chikungunya virus due to warmer, wetter weather. Policy responses can yield major health benefits, and the Intergovernmental Panel on Climate Change found overall malaria declining in East Africa due to improved control programs, such as use of bed nets.

Waterborne Diseases
Waterborne diseases are expected to worsen, especially due to heavier precipitation events (>90th ile) projected to occur with climate changes. Childhood gastrointestinal illness in the United States and India have been linked to heavy rainfall. In the Netherlands, a 33% increase in gastrointestinal illness was associated with sewage overflow following heavy rain. Flood waters contained Campylobacter, Giardia, Cryptosporidium, noroviruses, and enteroviruses. In the United States, by 2100, Great Lakes climate modeling projects a 50% to 120% increase in overflow events. A meta-analysis of 87 waterborne communicable disease outbreaks occurring worldwide from 1910 to 2010 showed that communicable disease is associated with heavy rainfall and flooding; Vibrio and Leptospira were most often cited.
Waterborne diseases can be reduced with improved management infrastructure to better handle heavy rainfalls and through urban design by reducing impermeable surface areas. Improved monitoring can also help reduce many climate-sensitive infectious disease risks. The National ArboNET surveillance system tracks 8 mosquito-borne diseases, eg, West Nile virus in humans, birds, mosquitoes, and other animals.87

**Food Security**

Undernutrition is one of the most important health concerns related to climate change. Three mechanisms affect food security: reduced crop yields, increased losses, and decreased nutrient content. On average, climate change is projected to reduce global food production by 2% per decade, even as demand increases by 14%.88 More than 800 million people currently experience chronic hunger,89 concentrated where productivity could likely be most affected.90 Climate change is projected to reduce wheat, maize, sorghum, and millet yields by approximately 8% across Africa and South Asia by 2050.88 One estimate suggests that globally, by 2050 approximately 25 million more children might be undernourished through climate change,91 and rates of growth stunting92,93 could increase substantially. Climate change–related rapid increases in food prices, especially for staples such as corn and rice, could more than double by midcentury, placing impoverished populations at further risk.94

Plant diseases caused by fungi, bacteria, viruses, and oomycetes, already responsible for a 16% crop loss, may substantially increase with climate change.95 Moreover, the nutrient value of some crops may diminish. Whereas carbon dioxide fertilization can enhance growth, protein content can decline in wheat and rice, as can iron and zinc content in crops such as rice, soybeans, wheat, and peas.96

Preventive measures range from drought or salt-resistant crops to improved technology such as drip irrigation and hoop houses (inexpensive greenhouses). Other potential adaptation strategies include changing planting dates, increasing crop diversity, and combining different strategies.

**Mental Health**

Depression, anxiety, and related disorders cause major morbidity worldwide.9798 Besides vulnerability to adverse effects from heat exposure, climate change may threaten mental health in other ways.99–102

**Climate-Related Disasters**

**Posttraumatic stress disorder, anxiety, and depression are common following disasters, sometimes a major part of the health burden.**103107 Several months after Hurricane Katrina, 49.1% of those surveyed in New Orleans and 26.4% in other affected areas developed a *Diagnostic and Statistical Manual of Mental Disorders* (Fourth Edition) *(DSM-IV)* anxiety mood disorder; 1 in 6 had posttraumatic stress disorder (PTSD) (with considerable overlap between the 2 diagnoses).108 Similar outcomes have been documented following other disasters likely to increase with climate change, including floods,109110 dam collapses,111 heat waves,112113 and wildfires.113 Psychopathology typically declines over time following disasters,114 but may persist for years,115 especially among vulnerable groups.116 Risk factors include little social capital (networks of relationships that build trust within a community) or support,112 physical injury,103 property loss,103 witnessing others with illness or injury while they were in pain or were dying during the disaster, loss of family, displacement, and history of psychiatric illness.98,113 Children may be at special risk.114 These findings suggest a variety of protective strategies,115 including strengthening social support networks,116 providing postdisaster mental health services, and prompt insurance compensation for loss.

Slow-moving disasters may also threaten mental health. Research in Australia during the recent decade-long drought revealed increases in anxiety, depression, and possibly suicidality among rural populations.114115 Strategies to reduce this burden included raising mental health literacy, building community resilience through social events, and disseminating drought-related information.107

**Climate-Related Displacement**

Displacement may mean degradation of a familiar environment; the resulting distress has been documented among Alaskan natives in villages endangered by climate-related changes.117 More typically, displacement means relocation forced by disaster or resource scarcity,118 creating considerable mental health effects.118 An important protective strategy is keeping families, even entire communities, united.120

**Anxiety and Despair Related to Climate Change**

Researchers have noted that climate change may engender despair, anxiety, and hopelessness, although few empirical data are available.100101 Although social circumstances and political views help determine cognitive and emotional processing of climate change information, there is an essential role for communication—presenting the problem and solutions in ways that engender engagement rather than despair.121 Climate adaptation and mitigation can therefore be considered, in part, a psychological task,122 one that includes effective communication.

**Other Climate Health and Societal Impacts**

Variation in precipitation, including increased severe rainfall events and increased frequency of droughts could create major risks or could have major consequences. Too little rainfall creates “dust bowl” conditions and worsens particulate matter exposure. Too much rainfall can overwhelm sewage systems, leading to increased waterborne diseases. Too much or too little can destroy crops.123

From 2003 to 2012, an average of 115 000 people died each year due to natural disasters.124 For every person killed by natural disaster, an estimated 1000 people are affected physically, mentally, or materially, through loss of property or livelihood.125 Floods are the most common severe weather event worldwide, and the frequency of river floods has been increasing.126 Conservative estimates report 2.8 billion people were affected by floods between 1980 and 2009, with 500 000 cumulative deaths estimated, even as death rates declined.127

Uncertainty exists over whether hurricane frequency might increase, but evidence suggests that extreme hurricanes (categories
4 and 5) may occur more frequently. Sea level rise will exacerbate storm surges, worsen coastal erosion, and inundate low-lying areas. Salinization of aquifers most likely will augment coastal settlements.

Health Effects of Social Disruption and Civil Conflict
In developing regions, climate-related disasters may trigger broad dislocations, often to places ill prepared for refugees who are overwhelmed by undernutrition and stress. Displaced groups commonly experience violence, sexual abuse, and mental illness. Increasing, but still inconclusive, evidence links climate change and violence, from self-inflicted and interpersonal harm to armed conflict. A 2013 meta-analysis found that each standard deviation of increased rainfall or warmer temperatures increases the likelihood of intergroup conflict by 14% on average. The Centers for Naval Analyses Military Advisory Board, comprising retired generals, warned that climate change could catalyze instability and conflict.

Communicating Climate Change and Health

Public Belief in Climate Change
Views on climate change range widely. Two decades of polling suggest that about two-thirds of US residents believe that climate change is occurring; of these about two-thirds (or about 40% of the total) believe humans cause it. About half (or about 1 in 3 overall) believe it will pose a serious threat in their lifetimes. Compared with other wealthy nations, US residents generally see the issue as remote in time and space (eg, affecting the next generation and in developing countries) and of low priority, well behind such concerns as jobs, health care, and even other environmental issues.

Researchers have segmented the US population along a spectrum ranging from “alarmed” (≈16%) to “dissmissive” (≈10%), according to climate change belief, concern, and motivation. Many factors shape views of climate change: economic trends, cultural norms, beliefs of family and friends, and values and political ideology, often exercised through cognitive shortcuts called heuristics that bypass evidence. Media coverage matters. Deliberate, well-funded attempts to deceive the public and sow confusion have succeeded.

In addition, many people are unduly influenced by personal experience, such as short-term weather perturbations. A heat wave may strengthen belief in climate change, a snowy winter may undermine it; interpretation of weather rests heavily on prior beliefs and social cues.

Communicating Climate Change and Health
Effective communication may shift knowledge, attitudes, and behavior toward reducing the risks of climate change. Research indicates several principles of effective climate communication that closely resemble those used in health. Themes include 2-way communication, gearing messages to the audience, limiting use of fear-based messages, issuing simple lucid messages repeated often from trusted sources, and making health-promoting choices easy and appealing.

Health may be a compelling frame for communication about climate change, reflecting views that change threatens health. Although further research is needed to define the role of health in climate communication, practical communication resources are becoming available, implying an important role for health care professionals.

Approach to Climate Change Adaptation
Persistent elevated atmospheric carbon dioxide will continue to warm the planet for decades even after implementation of mitigation strategies. A full range of adaptation options is reviewed elsewhere. In 2008, for the first time, more people worldwide resided in urban than in rural environments. Increasing urbanization, especially in low- and middle-income countries, presents opportunities to redesign habitats that promote public health, climate resiliency, and sustainability.

Essential infrastructure improvement could help adaptation to climate change. For example, vegetation, building placement, white roofs, and architectural design can reduce the urban heat island effect and therefore electricity demands for air conditioning. A recent study found that waste heat from air conditioning can warm outdoor air more than 1°C, so limiting the need for air conditioning use has a direct influence on urban heat islands.

In most US cities, infrastructure for potable water and wastewater management is more than 50 years old; in some cases more than a century. These systems, which serve 80% of the population, received an average near-failing grade of D+ on the 2013 Infrastructure Report Card of the American Society of Civil Engineers. Under projected increases in extreme weather, cities face a daunting but timely opportunity to establish healthier, environmentally sustainable infrastructure.

Optimal adaptation strategies achieve multiple objectives. Green spaces—forests and parks—not only reduce heat islands; they also are linked to stress reduction, neighborhood social cohesion, and reductions in crime and violence. A recent cross-sectional study of 2427 Wisconsin individuals found that neighborhood green space and tree canopy percentage had strong inverse correlation with objective measures of depression, anxiety, and stress. The magnitude of this influence was comparable with other contributors to depression, including socioeconomic status and health insurance. Tree species composition of the canopy presents another strategy; red maples, for example, emit 70% fewer biogenic volatile organic compounds than do oaks, an opportunity to develop green space while minimizing ozone-forming compounds.

Multiple benefits and cost savings may be gained through an ecological approach rather than by engineering single solutions. As sea level rises, seawalls have frequently served to stabilize shorelines. But in Vietnam, planting mangroves for storm surge protection incurs one-seventh the cost of building and maintaining seawalls or dikes for this purpose. This coastal ecosystem also preserves wetlands and marine food chains that support local fisheries.
Preparing for Tail Risks

The uncertainty regarding effects of climate change can be expressed in probability distributions. Tails of such distributions contain catastrophes—rare high-consequence events.\textsuperscript{198,199} Economists and risk managers have focused on tail risk in climate change, asking how much society should spend to reduce these risks.\textsuperscript{200} This question is familiar to homeowners who insure against the small but devastating possibility of a house fire and to physicians who treat patients when withholding treatment entails even a small risk of catastrophic outcome. Although some issues in public health decision making require a trade-off among risk management options, many existing climate mitigation measures have no adverse consequences to health or the economy (eg, energy conservation, crop land management, waste recycling).\textsuperscript{201} This thinking asserts that the possibility of catastrophic outcomes not only justifies but compels preventive action now.

Health Cobenefits From Mitigating Climate Change

There are many social, economic, and political barriers to realizing reductions in global greenhouse gas emissions. These include difficulties of behavior changes; costs of implementing energy and industrial policies; opposition of vested interests, especially fossil fuel industries; and challenges of coordinating a worldwide solution among countries at different economic stages.

Thus, it is essential to design carbon reduction policies with ancillary benefits, often referred to as cobenefits, such as improved air quality or fitness-promoting urban design. These may be viewed as more near-term and politically attractive strategies than climate mitigation alone.\textsuperscript{202} Articulating multidimensional aspects of carbon reduction strategies also helps avoid poorly designed policies that may have adverse effects on public health. For example, biofuels that compete with crop production may contribute to increased food costs and insecurity.\textsuperscript{203}

Economic Advantages of Reducing Fossil Fuel Combustion

Concern remains over the cost of policies to shift to renewable energy and reconfigure transportation systems. However, a 2014 US-based full life-cycle analysis—consideration of full supply chains for energy, eg, from processes associated with production to transportation—shows the contrary. For example, monetized human health benefits stemming from air quality improvements are estimated to potentially offset the cost of US carbon policies by 26% to 1050%.\textsuperscript{204} Global average monetized health cobenefits from avoided mortality are projected to range from $50 to $380 per ton of carbon dioxide removed and exceed abatement costs in 2030 and 2050.\textsuperscript{205} Estimated cobenefits are $30 to $600 for the United States and Western Europe, $70 to $840 for China, and $20 to $400 for India. For East Asia, air quality–related health benefits are projected to be 10 to 70 times the abatement costs in 2030.\textsuperscript{205} These large benefits are not surprising, given EPA estimates of a return of $30 for every dollar spent on reducing air pollution through the Clean Air Act.\textsuperscript{206}

Further economic benefits likely will accrue from enhanced opportunities for physical fitness. If active transport scenarios reached the levels of those in Copenhagen, costs averted for the England and Wales National Health Service would approximate $25 billion over a 20-year period\textsuperscript{207}; also for just 1 region of the United States, $3.8 billion per year (95% CI, $2.7-$5.0 billion) would be saved through physical fitness benefits stemming from increased biking.\textsuperscript{208}

Energy Sector

Increasing use of wind, solar, wave, and geothermal energy can yield benefits for both health and climate. A Wisconsin study found that increased efficiency and renewable generation in electrical power, designed to reduce carbon at low cost, could reduce statewide emissions of nitrogen oxides by 55% and sulfur dioxide by 59%.\textsuperscript{209} Regarding biofuels, if sugar cane, fast-growing tree species, and Miscanthus are used instead of corn, competition for food production could be eliminated, thus avoiding food price shocks especially affecting the poor.\textsuperscript{5}

Strategies to address short-lived climate pollutants, especially tropospheric ozone and black carbon, complement those that address carbon dioxide. Shindell et al\textsuperscript{210} screened 400 potential control measures and identified 14 that both mitigate warming and improve air quality, such as reducing emissions from coal mining, oil and gas production, and municipal landfills. The measures are estimated to reduce global mean warming by approximately 0.5°C by 2050. Health cobenefits include prevention of between 0.7 million and 4.7 million premature deaths annually, while crop yields would benefit from reduced ozone damage.

Retrofitting buildings with improved insulation, ventilation, efficient appliances, and renewable sources for electricity and heating could improve health and reduce greenhouse gas emissions.\textsuperscript{211} Health care is among the most energy-intensive commercial sectors. It represents nearly one-fifth of the US gross domestic product. Health care facilities that reduce energy use can therefore contribute to climate mitigation, reduce operating costs, and demonstrate leadership. More than 6700 health care facilities have shifted to environmentally sustainable practices and formed “Hospitals for a Healthy Environment.”\textsuperscript{212}

Transportation and Community Design

Major health cobenefits accrue from increased urban walking and cycling, so-called active travel. This approach may offer the most direct benefits by reducing health-damaging pollution emissions and enhancing personal fitness simultaneously. Physical inactivity is a risk factor for many noncommunicable diseases and may be responsible for 3.2 million deaths annually.\textsuperscript{213} An increasing number of studies show significant global health benefits from shifting to environmentally sustainable practices (key findings are summarized in the Table). For example, active commuting in Shanghai, China, was associated with a reduction of colon cancer by 48% in men and 44% in women,\textsuperscript{222} and across sample populations from Europe and Asia, active transport led to an 11% reduction in cardiovascular risk.\textsuperscript{217} For the United States, comparing cities with highest vs lowest levels of active transport, obesity rates were 20% lower and diabetes rates were 23% lower,\textsuperscript{222} and 1295 lives could be saved annually in the upper Midwest of the United States by replacing short (<4 km) car trips with bike transport.\textsuperscript{208}

Developed countries, including the United States, could benefit from greater levels of exercise,\textsuperscript{208,215,216,222,229} whereas low-
<table>
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<tr>
<th>Source</th>
<th>Location</th>
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<td><strong>Cardiovascular Diseases</strong></td>
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<td>Woodcock et al,214,215,2013</td>
<td>England (outside London) and Wales</td>
<td>All age groups living in urban areas outside London</td>
<td>Reductions in IHD disease from increased physical activity, with a reduction in the total population disease burden of ≤4.1%</td>
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<td>Maizlish et al,215, 2013</td>
<td>San Francisco Bay area</td>
<td>All age groups</td>
<td>14% Decrease in cardiovascular disease (32 466 DALYs), increased traffic injury burden by 39% (5907 DALYs), and decreased greenhouse gas emissions by 14% with 20 min/d of active transportation</td>
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<td>Hankey et al,216, 2012</td>
<td>Southern California</td>
<td>30 007 Residents</td>
<td>Lower IHD mortality rates in high- vs low-walkability neighborhoods (24.9% vs 12.5%) and 7 fewer IHD deaths/100 000/y</td>
</tr>
<tr>
<td>Hamer et al,217, 2008</td>
<td>8 Countries in Europe and Asia</td>
<td>173 146 Participants</td>
<td>Active commuting was associated with an overall 11% reduction in cardiovascular risk, especially among women</td>
</tr>
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<td>Hu et al,218, 2007</td>
<td>Finland</td>
<td>47 840 Finnish participants aged 25-64 y</td>
<td>Active commuting in Finland reduces 10-y risk of chronic heart disease events</td>
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<td>Forrest et al219, 2001</td>
<td>Benin, Nigeria</td>
<td>799 Civil servants</td>
<td>Commuting to work vs leisure activities contributed more to reported physical activity time and was associated with reduced coronary heart disease risk</td>
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<td><strong>Chronic Diseases</strong></td>
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<td>Jarrett et al,220, 2012</td>
<td>England and Wales</td>
<td>Urban populations across the United Kingdom</td>
<td>Reductions in prevalence of 7 chronic diseases associated with physical inactivity; would save US $26 billion within 20 y</td>
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<td>Rabl and de Nazelle,221, 2012</td>
<td>Europe</td>
<td>Large cities across the European Union</td>
<td>For every driver who switches to bicycling for a commute of 5 km (1 way) 5 d/wk 46 wk/y, the annual benefit would be €1 300 from improved physical fitness and €30 from improved air quality</td>
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<td>MacDonald et al,222, 2010</td>
<td>Charlotte, North Carolina</td>
<td>Individuals before and after light rail system construction</td>
<td>Light rail transit for commuting was associated with a 1.18 reduction in BMI and an 81% reduced odds of becoming obese over time</td>
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<td>Pucher et al,223, 2010</td>
<td>47 Large US cities</td>
<td>Adults ≥18y</td>
<td>US cities with highest active transport have 20% diabetes rate vs 23% in lowest active transport</td>
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<td>Hou et al,224, 2004</td>
<td>Shanghai, China</td>
<td>931 Colon cancer cases vs 1552 controls</td>
<td>High levels of daily active commuting result in reduced risk of colon cancer by 48% in men and 44% in women</td>
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<td><strong>Mortality and/or Economic Benefits</strong></td>
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<td>Macmillan et al,225, 2014</td>
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<td>Rojas-Rueda et al,225, 2012</td>
<td>Metropolitan Barcelona, Spain</td>
<td>All age groups</td>
<td>Shifting 40% of car trips to cycling and public transportation would avoid approximately 99 deaths and reduce carbon dioxide emissions by 251 tons per year</td>
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<td>Grabow et al,226, 2012</td>
<td>Upper midwestern United States</td>
<td>All age groups, 11 metropolitan areas</td>
<td>1295 Avoided annual deaths from automobile emissions reduction and fitness benefit from bicycling</td>
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<td>Lindsay et al,227, 2011</td>
<td>Auckland, New Zealand</td>
<td>Residents of urban Auckland</td>
<td>Shifting 5% of vehicle kilometers to cycling would save 22 million L of fuel, avoid 122 deaths annually, and save New Zealand $200 million per y</td>
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<tr>
<td>de Hartog et al,227, 2010</td>
<td>The Netherlands and England</td>
<td>500 000 Dutch</td>
<td>Fitness benefits of cycling were 9 times more in life-years than losses due to increased inhaled air pollution doses and traffic crashes</td>
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<td>Andersen et al,228, 2000</td>
<td>Copenhagen, Denmark</td>
<td>Men and women in all age groups</td>
<td>Commuter cyclists have 39% lower mortality rate</td>
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Abbreviations: BMI, body mass index; DALY, daily activities of living; IHD, ischemic heart disease.

* Active commuting: walking or biking to work.
income countries with air quality problems may benefit more from reduced pollution.\textsuperscript{229} Commuting to work by biking or walking reduces prevalence of obesity and diabetes in the United States, with states showing more variability in levels of active transport than cites (Figure 3).\textsuperscript{222}

Agricultural Sector and Food Systems

Health cobenefits also emerge from decreased meat consumption in high-consuming populations. Emissions from agriculture, livestock production, and forestry constitute approximately 24% of global greenhouse gas emissions,\textsuperscript{5} resulting principally from animal products. A review of 25 studies\textsuperscript{230} using the life-cycle analysis concluded that beef (14-32 kg of carbon dioxide emission equivalents per kilogram of meat produced) had the highest carbon footprint, followed by pork (3.9-10 kg of carbon dioxide emission equivalents per kg), then chicken (3.7-6.9 kg of carbon dioxide emission equivalents per kg). If consumption of meat, dairy products, and eggs were halved, nitrogen and greenhouse gas emissions could be reduced by 25% to 40% and intake of saturated fat may decrease by 40%.\textsuperscript{231} A 30% reduction in livestock production could lead to a reduction in ischemic heart disease of 15% in the United Kingdom and 16% in Sao Paulo, Brazil.\textsuperscript{232}

Figure 4 compares greenhouse gas emissions from various diets.\textsuperscript{233} Greenhouse gas emissions to support a high–red meat diet (>100 g/d) are nearly twice that of vegetarian diets.

Household Energy

Improved cook stoves in the developing world offer another opportunity for significant health cobenefits. In India, a program to introduce 150 million improved stoves over 10 years may prevent 2 million premature deaths.\textsuperscript{231} Additionally, rural electrification, for example, through microgrid systems (from solar, wind, small hydropower, or biogas) could provide lighting that may enhance childhood reading and learning, and improve food and medicine cold storage.

Access to contraception can address unmet reproductive health needs and improve the health of both mother and child by increasing birth spacing.\textsuperscript{234} Historical trends demonstrate a close relationship between carbon dioxide emissions from energy use and country-specific population size. Comparison of a United Nations low population growth scenario (7.4 billion) with a high population
growth (10.6 billion) suggests a difference in global carbon dioxide emissions of 32% by 2050.\textsuperscript{174}

**Future Challenges**

The relationship between climate change and health has been based on laboratory studies, observational data, and modeling studies. Traditional experimental designs to assess the effects of climate change are not possible. This often contributes to a political and scientific atmosphere of debate. Because climate change may have important implications for the health of the world’s population, high-quality research must be conducted, and responsible, informed debate needs to continue. However, given that evidence over the past 20 years suggests that climate change can be associated with adverse health outcomes, strategies to reduce climate change and avert the related adverse effects are necessary.

Development of effective future policies will require understanding the relationship between climate change and health and developing approaches to ensure a sustainable future while protecting health. Accounting for co-benefits may document that reducing greenhouse emission yields net economic benefits,\textsuperscript{205,235} that labor productivity increases,\textsuperscript{218} and that health system costs are reduced.\textsuperscript{207} Co-benefits can provide policymakers with additional incentives, beyond those of curtailing climate change, to reduce the emissions of both carbon dioxide and short-lived climate pollutants.

Any policy to reduce greenhouse gas emissions should include an assessment to ensure that potential benefits or risks are included in cost estimates and that unintended harm is avoided. Herein lies a special role for health professionals in policy decisions involving energy, housing, transportation, urban planning, agriculture, food systems, and more.

**Conclusions**

Evidence over the past 20 years indicates that climate change can be associated with adverse health outcomes. Health professionals have an important role in understanding and communicating potential health concerns related to climate change, as well as the co-benefits from burning less fossil fuels.

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**ARTICLE INFORMATION**


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**Study concept and design:** Patz, Frumkin, Haines.

**Acquisition, analysis, or interpretation of data:** All authors.

**Drafting of the manuscript:** Patz, Frumkin, Holloway, Haines.

**Critical revision of the manuscript for important intellectual content:** All authors.

**Statistical analysis:** Holloway, Vimont. Administrative, technical, or material support: Patz, Vimont, Haines.

**Study supervision:** Patz, Holloway, Vimont.

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Climate Change and Global Health Challenges


