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The impacts of climate change on health

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Title

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Abstract

The environment is a significant factor in people's health, and one of the major forces acting on it is climate change. This paper provides a qualitative overview of the likely impacts of climate change on health, which will vary widely between countries and between different population groups within countries. In general, those most impacted include the elderly, the poor, and those with chronic conditions. This may mean, for example, that people in long term care are more impacted than the population at large.

Most impacts will be deleterious rather than beneficial. The detailed impacts depend on many complex and interacting factors. The complexity of the interactions between climate change and other factors mean that projections of future mortality and morbidity rates will inevitably rely on many assumptions, often implicitly.

Climate change will affect many different aspects of health, both directly and indirectly through large-scale alterations to Earth's natural systems. Both water and food security are likely to be affected, and there may be major population displacements and civil unrest.

Keywords

Climate change; health; environment

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1. Introduction

The World Health Organisation (WHO) estimates that in 2012 23% of all deaths were due to environmental factors, and 22% of the disease burden (measured in DALYs – disability-adjusted life years) (Prüss-Üstün et al. 2016). The environment is clearly a significant factor in people's health, and one of the major forces acting on it is climate change. This paper is intended to provide a qualitative overview of the likely impacts of climate change on health.

In recent years there has been much research and many resulting publications focused on the linkage between climate change and human health. However, this paper does not attempt to provide a comprehensive list of references to the primary research, as thorough literature reviews have already been performed by others. Section 1.2 describes the principal sources that have been used.

Section 2 gives some background on climate change and the risks it poses. Section 3 considers the likely effects of climate change on health in general, and section 4 looks at the specific effects in the UK, USA, and elsewhere in the world.

This paper does not attempt to assess the quantitative effects on mortality or morbidity. There are several research projects currently in train that are likely to produce quantitative information that

actuaries can use: see, for example, the accompanying paper on UK mortality (Naqvi & Hall 2017), and a forthcoming paper from the IFoA's Resource and Environment and Pensions Working Party (IFoA 2017).

1.1 Summary and conclusions

The health impacts of climate change will vary widely between countries and, most likely, between different population groups within countries (see section 4). Although there are likely to be some beneficial impacts, they are minor compared with the vast majority of impacts, which will be deleterious. Although this overall picture is reasonably clear, the details are not: they depend not only on the detailed effects of climate change, which are themselves uncertain (see section 2), but also on factors such as social and political circumstances and responses to change.

As an example, the prevalence and severity of vector-borne diseases – infectious diseases transmitted by living organisms such as insects – depend on the operation of complex transmission cycles involving vectors, other intermediate hosts, and humans. The factors influencing these cycles include climate factors as well as how pathogens adapt and change, the availability of hosts, changing ecosystems and land use, demographics, socioeconomic and sociocultural factors, and prioritisation of vector control. The impacts on health are further affected by factors such as access to health care and human behavioural responses to perception of disease risk (Crimmins et al. 2016; Romero-Lankao et al. 2014).

Climate change will affect many different aspects of health (see section 3), including:

- Temperature-related illness and death
- Injuries
- Mental health
- Cardio-vascular, respiratory, skin and neurological diseases
- Vector-borne diseases
- Gastro-intestinal illnesses
- Undernutrition
- Skin cancer
- Cataracts

In addition, there are likely to be substantial indirect effects. Especially in poorer countries, the health impacts from possible large-scale alterations to Earth's natural systems may well outweigh the direct effects of climate change (Myers & Bernstein 2011). Both water and food security are likely to be affected, and there may be major population displacements and civil unrest. For example, it is thought that the 2007-2010 drought contributed to the Syrian uprising that began in 2011 (Kelley et al. 2015). In richer countries the risks to health infrastructure from climate change may be significant: in the UK, for example, many health facilities are vulnerable to flooding, and severe weather events may prevent health professionals getting to work (Kovats & Osborn 2016). In addition, in all countries there may be reduced funding available for healthcare due to adverse economic impacts of climate change.

As well as varying widely by country, the impacts will also vary between population groups within individual countries. In general, those most impacted include the elderly, the poor, and those with chronic conditions. This may mean, for example, that people in long term care are more impacted than the population at large. Also, the complexity of the interactions between climate change and other factors mean that projections of future mortality and morbidity rates will inevitably rely on many assumptions, often implicitly. Actuaries using such projections will need to consider the assumptions that have been made in the context of the situation in which they are applying the projections.

1.2 Sources

There are three recent major national and international reports that look at the risks and impacts of climate change, and that explicitly address the effects on health, and that have been especially useful in the preparation of this paper. They are based on thorough literature reviews and synthesise the

state of knowledge at the time they were written, contain much more detail than is possible here, and include extensive lists of references which are likely to be helpful to anyone wanting to explore the effects of climate change on health in more detail. They are:

- AR5
- UK CCRA evidence report
- USA NCA

AR5, published in 2014, is the Fifth Assessment Report (IPCC 2014b) of the Intergovernmental Panel on Climate Change (IPCC). The IPCC, which operates under the auspices of the United Nations Environment Programme (UNEP), is the international body for assessing the science related to climate change. The IPCC currently has 195 member countries. Its assessments are produced by hundreds of leading scientists and experts, and undergo multiple rounds of drafting to ensure they are comprehensive, balanced, and accurate. The IPCC does not conduct its own scientific research: its reports are based on published literature (Intergovernmental Panel on Climate Change 2013). AR5 consists of a *Synthesis Report*, which summarises all the findings, and the reports of three working groups: WG I on the *Physical Science Basis*, WG II on *Impacts, Adaptation, and Vulnerability*, and WG III on *Mitigation of Climate Change*. Each volume contains chapters on relevant topics, each chapter prepared by a separate group of academics and other experts. Chapter 11 of the report of WG II is on *Human health: impacts, adaptation and co-benefits* (Smith et al. 2014), and chapters 22 to 30 focus on specific regions of the world.

The CCRA is the *UK Climate Change Risk Assessment*. The 2008 Climate Change Act requires the UK government to publish a CCRA every five years, in order to assess "the risks for the United Kingdom from the current and predicted impacts of climate change". The second CCRA (HM Government 2017) was published in 2017 by DEFRA (the Department of Environment, Food & Rural Affairs). It was based on the *UK CCRA 2017 Evidence Report* (Committee on Climate Change 2016a), which was prepared by the Adaptation Sub-Committee of the Committee on Climate Change (ASC), an independent body, and which sets out the latest evidence on the risks and opportunities to the UK from climate change. The evidence report was based on a review of published literature and on four specially commissioned research projects. It consists of a synthesis report and eight technical chapters. Each technical chapter provides the detailed analysis underlying the summary in the synthesis report, and was prepared by a separate group of academics and other experts. Chapter 5 is on *People and the built environment* (Kovats & Osborn 2016) and includes analysis of health impacts.

The NCA is the *National Climate Assessment*, prepared by the US Global Change Research Program (USGCRP) every four years. The third NCA was published in 2014[1]. Like AR5 and the CCRA Evidence Report, the NCA is based primarily on published literature. As well as summary chapters, the NCA has chapters on 13 different sectors. The fourth NCA is currently being prepared, and is expected to be published in 2018. As part of the NCA process, in 2016 the USGCRP published a report on *The impacts of climate change on human health in the United States: A Scientific Assessment* (Crimmins et al. 2016).

Another especially relevant recent publication is the World Health Organization's assessment of the burden of disease from environmental risks (Prüss-Üstün et al. 2016). This does not focus specifically on climate change, but considers the links between the environment and 133 diseases and injuries. The environmental factors that are covered include man-made climate change, and the effects of climate change on many of the diseases and injuries are specifically mentioned.

2. Climate change

It is now generally accepted that the global climate is changing, and that the change is mainly caused by greenhouse gas emissions from human activity. The average global temperature rose by 0.85°C between 1850 and 2012, and the number of extreme weather events appears to be increasing. These

[1] http://nca2014.globalchange.gov/

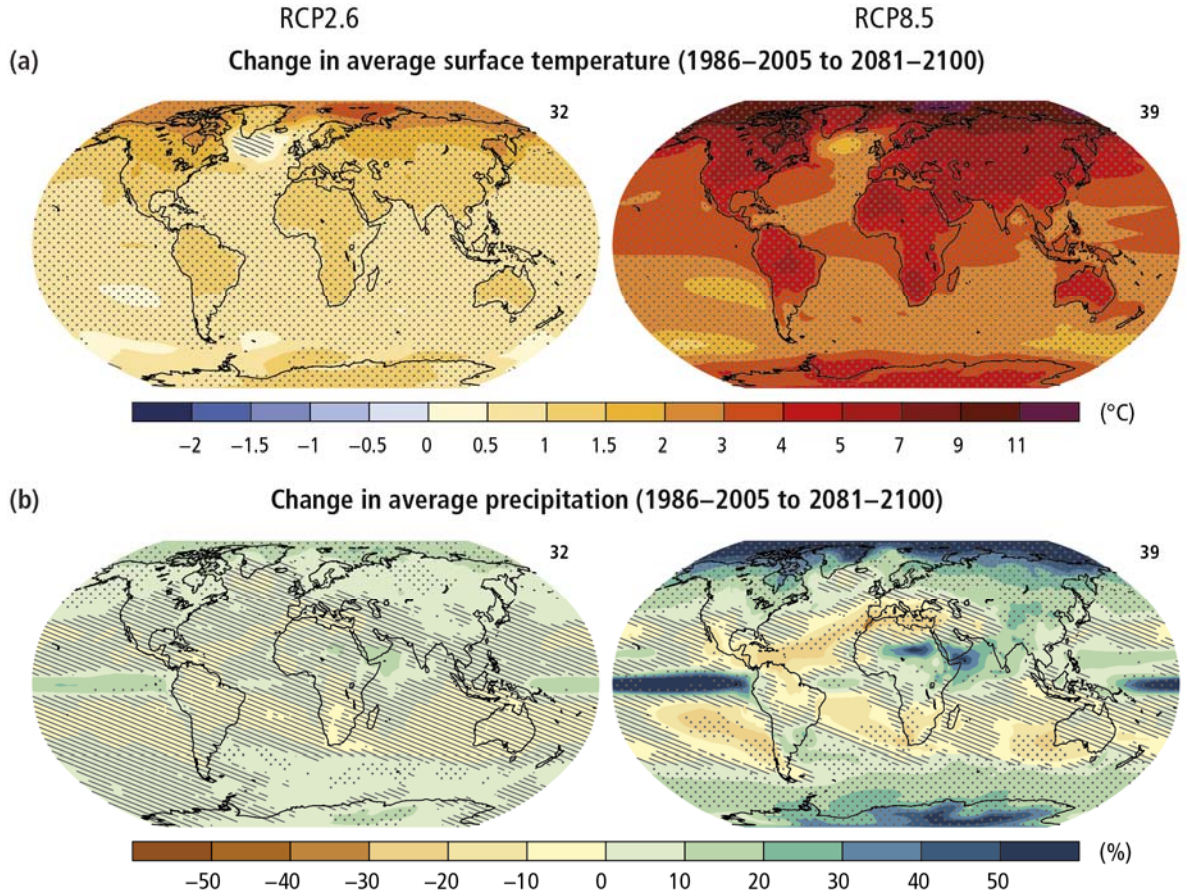
trends are likely to continue over the next century. In December 2015, at the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change (COP21) in Paris, 195 nations (including the UK) agreed to take measures to limit the increase in the average global temperature to 1.5°C above pre-industrial levels. However, the environment is slow to respond to factors that change the rate of climate change, so there will be no immediate effect from any measures that are taken, and there is considerable uncertainty surrounding the future trajectory of global temperatures (IPCC 2014a; Committee on Climate Change 2016b; European Commission 2016).

Efforts to combat climate change take two forms: mitigation and adaptation. They are defined as follows (IPCC 2001):

- Mitigation: An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.
- Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Adaptation and mitigation are both needed in order to manage climate risks. With no mitigation, the climate will change so much that no adaptation measures will be sufficient to maintain human civilisation. Even if stringent mitigation measures are applied immediately, the global temperature will continue to rise for some years because of climate inertia, so some adaptation measures will be necessary.

Figure 1: Changes in average surface temperature and average precipitation (from IPCC 2014a)



Change in average surface temperature (a) and change in average precipitation (b) based on multi-model mean projections for 2081-2100 relative to 1986-2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios. The number of models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling (ie, dots) shows regions where the projected change is large compared to natural internal variability and where at least 90% of models agree on the sign of change. Hatching (ie, diagonal lines) shows regions where the projected change is less than one standard deviation of the natural internal variability.

The detailed effects of climate change will vary by location in rather complex ways. Some locations will have greater increases in temperature than others, and some will be drier while others will have more precipitation. These effects are strongly dependent on the actual trajectory of future climate change, as shown in Figure 1, which shows projections under two different scenarios. RCP2.6 (for Representative Concentration Pathway) is a scenario illustrating a stringent mitigation pathway aiming to keep global warming to less than 2C above pre-industrial temperatures. RCP8.5 is a scenario with very high, but plausible, greenhouse gas emissions, illustrating a possible outcome if there are no additional efforts to constrain emissions (IPCC 2014a).

As the climate changes, so will the weather. The following changes are possible, though they are likely to occur to different extents in different locations:

- More frequent and longer heat waves
- Fewer and less severe winter freezes
- More frequent and more intense extreme precipitation events
- More frequent and more intense wind storms

In addition, the ocean will become warmer and more acidic, and the sea level will rise.

The extent of these changes over the last few decades in North America is shown by the Actuaries Climate Index (ACI)[2], which is composed of six components:

1. Frequency of temperatures above the 90th percentile (T90);
2. Frequency of temperatures below the 10th percentile (T10);
3. Maximum 5-day rainfall in the month (P);
4. Consecutive dry days (D);
5. Winds above the 90th percentile (W); and
6. Sea level (S).

Figure 2: Actuaries Climate Index 1961-2016. Seasonal five-year moving averages of components, Canada and the United States (from Actuaries Climate Index 2016)

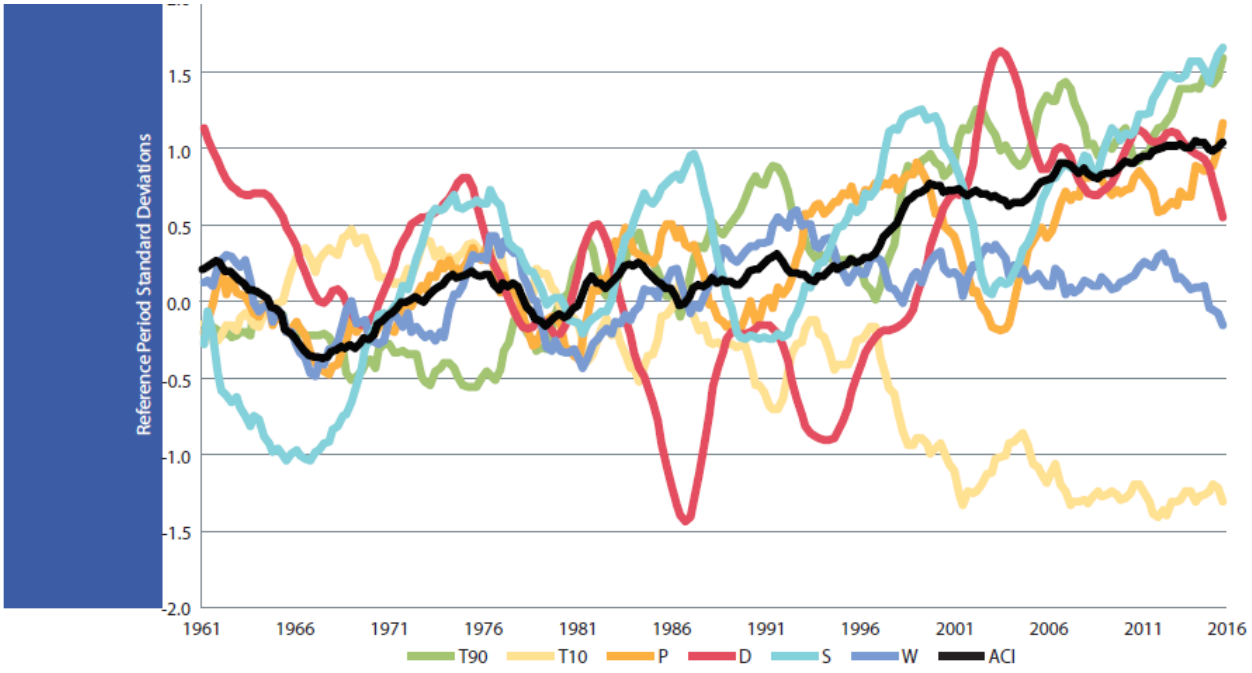


Figure 2 shows the components of the ACI since 1961. It is clear that, in North America, there have been more high temperatures and fewer low temperatures, and more episodes of extreme precipitation. The incidence of drought has been rather variable.

2.1 Types of risk

A major part of climate change adaptation involves managing the risks posed by climate change, which can be viewed as falling into three categories (Bank of England 2015; TCFD 2016):

- Physical risks: the first-order risks which arise from weather-related events, such as floods and storms.
- Transition risks: the risks which could arise from the transition to a lower-carbon economy, such as extensive policy, legal, technology and market changes, and the speed at which such changes might occur.
- Liability risks: risks which could arise when parties who have suffered loss and damage from climate change seek to recover losses from others who they believe may have been responsible.

The risks to health are both physical risks, arising from changes in the environment, and transition risks, arising from moves towards a lower-carbon economy. Transition risks are likely to have substantial indirect effects on health, for example through changes in economic conditions and the availability of funding for health care, changes in lifestyle factors such as travel and diet, and changes

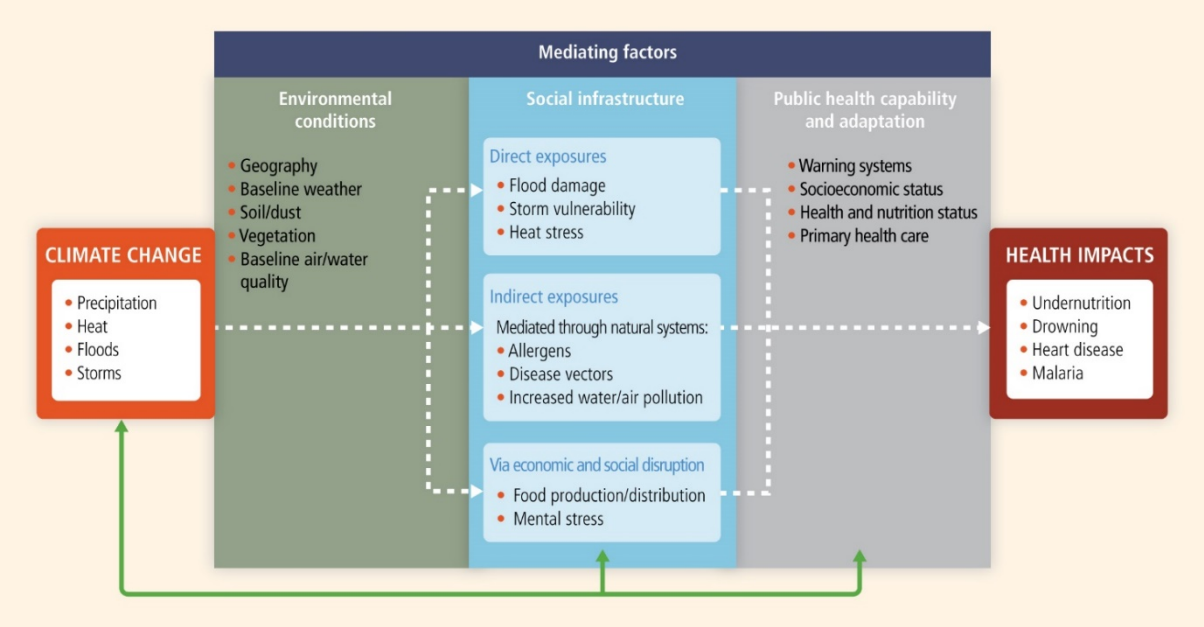
[2] http://actuariesclimateindex.org/home/

in air quality. Liability risks are unlikely to affect health, though poor health outcomes might themselves be a source of liability risks.

3. General health impacts

The pathways by which climate change affects health can be very complex, with many mediating and interacting factors (see Figure 3). As well as the environment, influences on health include social and political responses to the changing environment and to other factors, changing demographics, and economic changes. Effects can be both direct (increased temperatures leading to heat-related illness and death) and indirect (population displacement leading to undernutrition). Evidence of unexpected ways in which climate change can affect health continues to emerge – for instance, it appears that the cause of a recent epidemic of chronic kidney disease in Central America may be recurrent dehydration in the hot climate (Palmer 2017; Roncal-Jimenez et al. 2016).

Figure 3: Pathways by which climate change affects health (from Smith et al. 2014)



Conceptual diagram showing three primary exposure pathways by which climate change affects health: directly through weather variables such as heat and storms; indirectly through natural systems such as disease vectors; and pathways heavily mediated through human systems such as undernutrition. The green box indicates the moderating influences of local environmental conditions on how climate change exposure pathways are manifest in a particular population. The gray box indicates that the extent to which the three categories of exposure translate to actual health burden is moderated by such factors as background public health and socioeconomic conditions, and adaptation measures. The green arrows at the bottom indicate that there may be feedback mechanisms, positive or negative, between societal infrastructure, public health, and adaptation measures and climate change itself. [...] The examples are indicative.

As well as deleterious effects, there are some that are beneficial (for example, fewer cold-related deaths in temperate climates). In some cases, the effects of climate change on health can be nonlinear. This appears to be the case for malaria: when the temperature is already near the upper limit for the transmission vector and the pathogen, increased variations in temperature tend to reduce transmission, while if the temperature is near the lower limit increased variations tend to increase transmission (Smith et al. 2014). Moreover, mitigation and adaptation measures can themselves impact human health.

This complexity has implications for the use of projections of future mortality or morbidity rates: any model will have to make many assumptions, often implicitly, and actuaries will need to be aware of what those assumptions are.

3.1 Direct negative effects

In AR5, Smith et al (2014) assign the direct negative effects of climate change on health to three basic mechanisms:

- Direct impacts, which relate primarily to changes in the frequency of extreme weather, including heat, drought, and heavy rain;
- Effects mediated through natural systems, for example, disease vectors, water-borne diseases, and air pollution;
- Effects heavily mediated by human systems, for example, occupational impacts, undernutrition, and mental stress.

This classification indicates the range of mechanisms that is possible, though it is not necessarily complete. For instance, temperature-related deaths in the UK and USA occur over a wide range of temperatures, and are not strongly related to extreme weather (Hajat et al. 2014; Crimmins et al. 2016). It is often difficult to differentiate between the latter two mechanisms due to the extensive interactions between natural and human systems, and the distinction between direct and indirect effects is not always clear.

Table 1 summarises a range of negative impacts of climate change on human health.

Table 1: Direct negative impacts of climate change on health

Climate driver	Exposure	Health outcome
Rising temperatures, more frequent, severe and prolonged heat events	Overheating (in residential and business premises, hospitals, care homes, and other health facilities)	Heat-related death and illness. Increased risk of injury. Mental health.
	Reduced productivity from farmers	Undernutrition
	Overheating for outdoor workers	Heat strain and heat stroke. Increased risk of injury.
	Changed work patterns for outdoor workers to times when disease vectors more active	Vector-borne diseases
	Elevated exposure to toxic chemical solvents (faster evaporation)	Cardiopulmonary and neurological disease
Rising temperatures and changing precipitation patterns	Increased ozone levels	Cardiopulmonary disease
	Increased wildfires, higher particulate levels	Cardio-vascular and respiratory illnesses
	Pollen	Pollen-related allergic disorders
	Quantity and quality of food harvested	Undernutrition
Rising sea level, changing precipitation patterns, more frequent or intense storms, increased flooding	Contaminated water, infrastructure damage	Drowning, injuries, mental health, gastro-intestinal illnesses
Changing temperature extremes and seasonal weather patterns	Wider range of tick activity	Lyme disease, tick-borne encephalitis
	Native mosquitoes better able to transmit diseases; non-native mosquitoes better able to survive	Dengue, Chikungunya, West Nile virus, malaria, etc
	Other disease vectors	Haemorrhagic fever with renal syndrome, plague, leishmaniasis
Rising sea surface temperature, changing precipitation patterns affecting coastal salinity	Recreational water or shellfish contaminated with *Vibrio* or other bacteria	Diarrhoea, intestinal illness, wound and bloodstream infections

Climate driver	Exposure	Health outcome
Rising temperatures, increased humidity, changing season length	Increased growth of pathogens (eg *Salmonella*) and reduced food safety	*Salmonella* infection, gastro-intestinal outbreaks, schistosomiasis
Rising temperatures and changing precipitation patterns, increased droughts, droughts ended by heavy rainfall	Reduced water supply; lower water quality	Gastro-intestinal illnesses, mental health
Rising temperatures	Algal bloom in freshwater and marine environments, increased neurotoxins accumulating in fish and shellfish	Liver, neurological, digestive and skin diseases
Rising temperatures, fewer and less severe cold events	Increased outdoor activity, increased UV exposure	Skin cancers, eye cataracts
Droughts ended by heavy rainfall	Disease vectors such as mosquitos	West Nile virus, Zika virus

Sources: (Crimmins et al. 2016; Kovats & Osborn 2016; Smith et al. 2014; Prüss-Üstün et al. 2016)

3.2 Indirect effects

There are also more indirect impacts caused by large-scale alterations to Earth's natural systems, and these may pose a greater risk to human health than the direct impacts (Myers & Bernstein 2011). Some of these effects are summarised in Table 2.

Table 2: Indirect impacts of climate change on health

Climate driver	Exposure	Health outcome
Rising temperatures	Increased evapotranspiration leading to increasing water requirements for agriculture	Undernutrition, sanitation-related disease
	Less water available from glacial melt (irrigation and urban water supplies from rivers)	Undernutrition, sanitation-related disease
Rising sea levels, more extreme storms, changing precipitation patterns	Coastal inundation, intrusion of salt water into freshwater aquifers	Undernutrition, sanitation-related disease
	Health facilities out of action, health care staff and patients unable to travel to facilities	Reduced quality of health care
Rising temperatures and changing precipitation patterns	Increased ozone levels, curtailed agricultural yields	Undernutrition
Rising concentrations of atmospheric CO_2	Reduced nutritional quality of crops	Undernutrition
Rising temperatures and changing precipitation patterns, increased droughts and flooding, increased incidence of natural disasters, local crop failures, rising sea levels	Population displacement	Infectious diseases, respiratory infections, sanitation-related disease, undernutrition, high rates of violence, mental illness
Rising temperatures and decreasing sea ice	Changes to volatilisation and remobilisation of persistent organic pollutants, radioactivity, heavy metals	Neurological and other effects
	Increased transport to and from the Arctic, increased contaminants in wild life	Neurological and other effects,

Sources: (Myers & Bernstein 2011; Prüss-Üstün et al. 2016; Larsen et al. 2014; Kovats & Osborn 2016; Smith et al. 2014)

3.3 Beneficial effects

The effects of climate change can provide health benefits as well as adverse impacts. For instance, there are likely to be fewer cold-related deaths in winter in the future in the UK. The CCRA considers that the significance of this beneficial effect will be reduced because of the growing and aging population, which will mean an increase in the number of those who are especially vulnerable (Kovats & Osborn 2016). However, there are currently many more cold-related deaths in the UK (around 31,500 each year) than heat-related deaths (around 1,500) (Vardoulakis et al. 2014).

Table 3 summarises some of the beneficial impacts of climate change on human health.

Table 3: Beneficial impacts of climate change on health

Climate driver	Exposure	Health outcome
Rising temperatures, fewer and less severe cold events	Warmer temperatures	Fewer cold-related deaths
	Health care staff less unable to travel to work, patients less unable to travel to treatment	Increased quality of health care
	Increased outdoor activity (in winter, or in cooler climates)	Better vitamin D synthesis
Changing temperature extremes and seasonal weather patterns	Mosquitoes less able to transmit diseases (at upper end of temperature range)	Reduction in malaria
	Sources: (Crimmins et al. 2016; Kovats & Osborn 2016; Smith et al. 2014)	

3.4 Effects of adaptation and mitigation

The preceding tables ignore adaptation and mitigation measures, which can themselves have impacts on health, other than those impacts arising from their effects on climate change. Climate altering pollutants (CAPs) can affect health directly, so mitigation measures that reduce their emissions may have positive effects on health. Adaptation and mitigation measures include (Smith et al. 2014):

- Improving energy efficiency and shifting to cleaner energy sources, thus reducing local emissions of health-damaging and climate-altering air pollutants;
- Improving child and maternal health through birth spacing by providing access to reproductive health services (including modern family planning), thus reducing population growth, energy use, and consequent CAP emissions over time;
- Designing transport systems that promote active transport and reduce use of motorized vehicles, leading to lower emissions of CAPs and better health through improved air quality and greater physical activity;
- Shifting consumption away from animal products, especially from ruminant sources, in high-meat-consumption societies towards diets whose production is less CAP intensive.

Other measures could have negative effects on health. For example, efforts to reduce energy use through insulating buildings can change indoor air quality by changing ventilation rates, thus increasing the concentrations of indoor sourced pollution and allergens (although the concentrations of externally sourced pollutants are reduced) (Kovats & Osborn 2016). Modern hospitals and care homes in the UK are designed to be thermally efficient in cold weather, but this leads to overheating in heatwaves, affecting both patients and staff (Kovats & Osborn 2016). Efforts to reduce dependence on fossil fuels through the use of biofuels increase grain demand, pitting human food needs against biofuel production (Myers & Bernstein 2011).

4. Specific health impacts

Given the differing local effects of global climate change, and the differing local social and political environments, the specific effects of climate change on health are likely to vary widely by location. There are recent detailed reports on the likely effects in the UK and USA (Kovats & Osborn 2016; Crimmins et al. 2016), and the main points are summarised below in sections 4.1 and 4.2. These two sections follow the structure of the reports on which they are based, so are not necessarily directly

comparable (for example, mental health is not treated separately in the CCRA, but is seen as an outcome of phenomena such as flooding). The USA is much more geographically diverse than the UK, so the range of impacts is rather wider.

Section 4.3 gives some indication of possible impacts elsewhere in the world.

4.1 Impacts in the UK

In the UK, the ASC considers that climate change poses the most significant risks to health through the following (Kovats & Osborn 2016):

- Death and injuries from flooding
- Heat-related death and illness
- Diseases caused by vector-borne pathogens
- Worsening air quality and changes in pollen abundance and seasonality
- Poor water quality, including marine *Vibrio* infections

4.1.1 Flooding

Flooding and storms directly cause injuries and deaths, but can also have significant effects on mental health. Risks from infectious disease caused by flooding are considered to be low. The disruption to infrastructure and transport systems from flooding and storms could affect the ability of health professionals to get to work, and many hospitals and other health facilities are themselves at risk of flooding: both effects could have detrimental impacts on the health of patients (Kovats & Osborn 2016).

4.1.2 Heat-related death and illness

Future temperature increases will mean that the risk to health from warm weather will rise. These risks include cardiovascular and respiratory problems. The effect will be amplified by the ageing of the population, and the impact is likely to be greater in London and southern England than in the rest of the UK. The urban heat island effect is likely to be reinforced by climate change, resulting in increased outdoor temperatures in high density urban areas. There are also health risks to passengers from high temperatures on public transport. There is a possibility that increased temperatures could cause a shift away from non-air-conditioned public transport to private cars, with potential impacts on accident rates. Increased temperatures may also encourage more outdoor activity, with a beneficial effect from the production of vitamin D, although too much sun exposure can lead to sunburn and an increased risk of skin cancer (Kovats & Osborn 2016).

There are also likely to be beneficial effects from warmer temperatures. It is however uncertain whether the total number of cold-related deaths will decrease. There are at least two sources of uncertainty: first, the overall population is increasing and becoming older, and so more vulnerable; and second, some recent studies have indicated that there may not be a strong relationship between temperature and mortality (IFoA 2017).

4.1.3 Vector-borne diseases

Several diseases spread by insects and ticks have recently emerged in Europe, including vivax malaria, West Nile fever, dengue fever, Chikungunya fever, leishmaniasis, Lyme disease and tick-borne encephalitis. Higher temperatures will mean that non-native mosquito species are better able to survive in the UK, and may also increase the risk of indigenous species transmit diseases. For instance, *Aedes albopictus* is spreading northwards, and reached Paris in 2015. It transmits over 20 human and animal viruses (although it probably plays a large role only in the transmission of dengue, Chikungynunya and Zika). It is likely to be only a matter of time before it reaches the UK. The risk of malaria transmission in the UK is low. The numbers of several “nuisance” species of insect (including house flies and mosquitoes) are likely to increase with climate warming, which could lead to increased use of pesticides, which in turn could have adverse impacts on health (Kovats & Osborn 2016).

4.1.4 Air quality

Climate change is likely to affect air quality in both urban and rural areas although the local effects are complex and uncertain, as they depend on topography, atmospheric chemistry and emissions from transport systems. Higher temperatures can lead to increased ground-level ozone concentrations, and may also affect particulates and NO_2, both of which have deleterious health effects (see Table 1 and Table 2). However, air quality is likely to be more affected by future changes in emissions levels than by climate change. Increased temperatures may lead to greater release of pollen, but pollen release is also influenced by other factors such as water availability, and varies by pollen species (Kovats & Osborn 2016).

4.1.5 Water and food quality

The risk of salmonella increases with rising temperatures, but in the UK this effect is offset by the overall decline in its incidence. It is not clear what the effects of climate change on campylobacter will be. Although increasing sea temperatures may result in increased marine *Vibrio* infections, it is not clear whether there will be a resulting increase in human disease (Kovats & Osborn 2016).

4.2 Impacts in the USA

In the USA, the main health effects can be classified as follows (Crimmins et al. 2016):

- Temperature-related death and illness
- Air quality impacts
- Impacts of extreme events
- Vector-borne diseases
- Water-related illnesses
- Food safety
- Mental health and well-being

4.2.1 Temperature-related death and illness

There is likely to be an increase in the number of heat-related deaths and a decrease in the number of cold-related deaths. The actual numbers of deaths will depend on the adaptation measures that are taken. The increase in heat-related deaths is likely to outweigh the decrease in cold-related deaths. Hotter than average days in summer or colder than average days in winter both lead to increased illness and death, and these effects are seen for even small deviations from seasonal averages. This suggests that some of the impact of climate change will come through comparatively small changes in temperatures (Crimmins et al. 2016).

4.2.2 Air quality

Climate-driven increases in ground-level ozone are likely to result in increases in acute respiratory symptoms and deaths, as well as more hospital visits and lost school days. Increased numbers and severity of wildfires are likely to increase emissions of particulate matter and ozone precursors, resulting in additional adverse health outcomes. There are also likely to be increases in the levels of some airborne allergens, resulting in increases in asthma episodes and other allergic episodes (Crimmins et al. 2016).

4.2.3 Extreme events

Extreme events such as storms, drought, and flooding are likely to be more common, more intense, or both, in some regions of the USA, resulting in increased deaths, injuries, and adverse effects on mental health. Extreme events also affect health through their disruption of infrastructure, including infrastructure for health care and emergency response services. The risk from coastal flooding will also increase (Crimmins et al. 2016).

4.2.4 Vector-borne diseases

The geographic and seasonal distributions of existing vectors and vector-borne diseases are likely to change. Ticks will be active earlier in the year and their range will extend further to the north, so there will be greater exposure to Lyme disease. The distribution, abundance and prevalence of infection in the mosquitoes that transmit West Nile virus and other pathogens are likely to change, leading to

changes in rates of infection. New vector-borne pathogens may become prevalent, but the effects on health are likely to be limited (Crimmins et al. 2016).

4.2.5 Water-related illnesses

Both freshwater and marine harmful algae blooms are likely to become more common, as will *Vibrio* bacteria, and the risk of human exposure to their effects will increase. The problems will arise in recreational waters, shellfish habitats and sources of drinking water, and may be exacerbated by failures in the infrastructure for drinking water, wastewater and storm water caused by extreme weather events (Crimmins et al. 2016).

4.2.6 Food safety

Increased temperatures may lead to an increase in foodborne illness, as food becomes more exposed to certain pathogens and toxins. Food may contain more chemical contaminants, from a greater accumulation of mercury in seafood, due to elevated sea surface temperatures, and from increased use of pesticides. The levels of protein and essential minerals in agriculturally important food crops, such as wheat and rice, will decrease with rising levels of atmospheric carbon dioxide. Food distribution may be more disrupted by extreme weather events, leading to more food damage, spoilage, and contamination (Crimmins et al. 2016).

4.2.7 Mental health

The mental health impacts of climate change are not limited to severe weather events and other disasters. Adverse mental health outcomes may also arise from the threat of climate change, and from changes to people's local environment. Groups that may be more affected than others include children, the elderly, pregnant and post-partum women, people with existing mental illness, the economically disadvantaged, the homeless, first responders, and communities that rely on the natural environment for sustenance and livelihood (Crimmins et al. 2016).

4.3 Impacts elsewhere

Deaths and ill health that can be attributed to environmental factors vary widely between regions around the world, with sub-Saharan Africa suffering the most (Prüss-Üstün et al. 2016). It is therefore not unexpected that the impacts of climate change on health are also likely to vary widely. This variation is partly due to different climatic conditions, but also due to other factors, including (Smith et al. 2014):

- Geographic location (eg, low lying coastal areas, rural vs urban)
- Current health status (eg, baseline levels of pathogens and vectors, chronic diseases)
- Age and gender
- Socioeconomic status
- Public health and other infrastructure
- Population growth

That said, many of the impacts identified in the UK and USA are quite general and are likely to be significant in many countries around the world. For instance, the implications for food safety (section 4.2.6) will be more serious in places where refrigeration is less widely available; and the mental health issues identified in section 4.2.7 are likely to be widespread.

The report of Working Group II in AR5 contains chapters covering eight different regions of the world (and a ninth covering the Ocean). The principal impacts on human health highlighted in these chapters are summarised in Table 4.

Table 4: Regional impacts of climate change on health

Region	Principal impacts
Africa	Food security, increased malnutrition and susceptibility to infectious diseases
	Increased precipitation in areas where cholera is endemic
	Climate change is likely to counteract the beneficial consequences of socioeconomic development on child malnutrition
	Changing geographic range and incidence of malaria, leishmaniasis and Rift Valley fever
	Expanded distribution of ticks causing animal disease (with economic effects)
	Heat-related health effects
Europe	Heat-related health effects, especially in Southern Europe
	Reduced cold-related mortality
	Marine biotoxins in seafood
	Vulnerability of health system infrastructure to flooding
	Heat wave effects on patients and staff in hospitals
Asia	Heat-related health effects: aging population, urban heat islands
	Epidemics following floods
	Dust storms and wildfires
	Food security, increased malnutrition and susceptibility to infectious diseases
	Changing geographic range and incidence of malaria and dengue
Australasia	Heat-related health effects: population growth and aging population
	Increased water- and food-borne diseases
North America	Heat-related health effects, especially in the northern parts of North America
	Changes in the seasonal timing and spatial extent of pollen release
	Extreme precipitation events leading to increase in water-borne diseases
Central and South America	Increased malaria, dengue, yellow fever, schistosomiasis and other diseases
	Increases in chronic respiratory and cardiovascular diseases
	Dehydration from heat waves increases hospitalisations for chronic kidney diseases
Polar regions	Extreme weather events particularly impacting Indigenous, isolated and rural populations
	UV-B radiation, leading to immunosuppression, skin cancer, non-Hodgkin's lymphoma, cataracts
	Changing river and sea-ice conditions affect travel safety and access to critical hunting, herding and fishing areas
	Increase in contaminants in environment and food chain
Small islands	Extreme weather events
	Increased leptospirosis, malaria, dengue and other diseases
	Reduced access to adequate, safe freshwater

Sources: (Niang et al. 2014; Kovats et al. 2014; Hijioka et al. 2014; Reisinger et al. 2014; Romero-Lankao et al. 2014; Magrin et al. 2014; Larsen et al. 2014; Nurse et al. 2014)

Overall, health in the tropics and polar regions will be impacted more than in temperate regions; and health in wealthier countries will be impacted less than in less wealthy countries. The higher impact in the less wealthy countries comes about because of geographic location (many are in the tropics or near tropics), because they have less robust health and other infrastructure, and because larger proportions of their populations rely more directly on the environment for sustenance and livelihood. The major indirect impacts discussed in section 3.2 will primarily affect the less wealthy countries.

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