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Extreme high temperatures

– a threat to human health
A summary of knowledge

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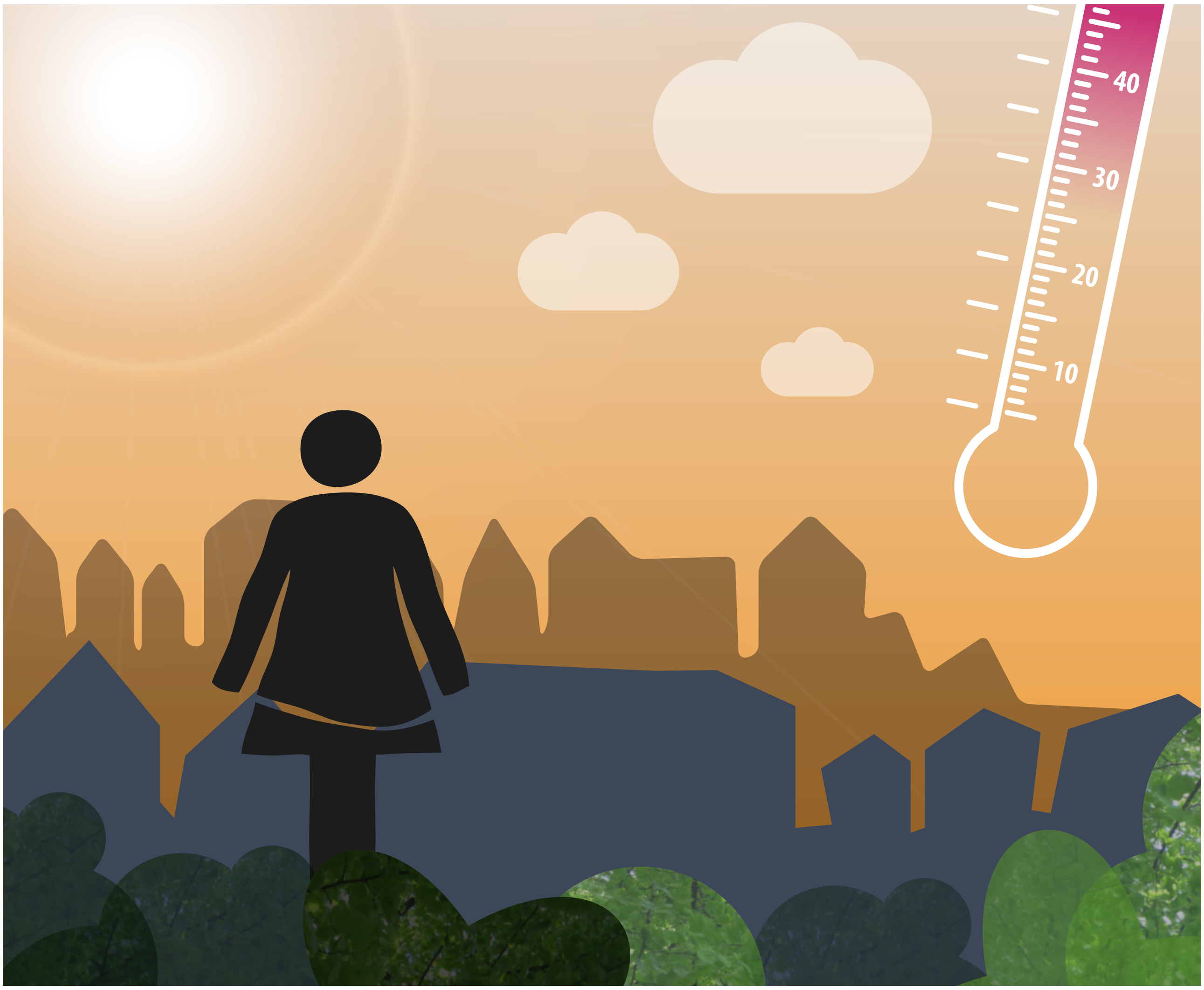

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Background

The health effects of climate change are becoming increasingly clear, and the impact of high temperatures is felt universally. Without action, a very different future awaits many of us. In some regions around the world the rising temperatures will result in summers with even more frequent and severe heatwaves (1) and limitations on what today are seen as normal outdoor activities. In other regions, populations risk facing year-round deadly heat if no mitigation efforts are put in place, according to the Intergovernmental Panel on Climate Change (IPCC) (2). The effects of anthropogenic climate change are already noticeable, as global warming of around 1°C has generated an increase in heat-related morbidity and mortality around the world (2-4). The most affected populations are those that are already marginalised, with limited access to adaptive capacities to cope with temperature rises. In order to protect planetary and human health as much as possible it is vital to act – urgently. Keeping global warming at 1.5°C would reduce climate hazards and health risks, but cannot eliminate them all (2). Hence it is, even in the best future scenario, necessary to prepare for increased exposure to extreme heat. At the current pace of global decarbonisation we are, however, unlikely to meet the Paris Agreement ambitions to keep global warming well below 2°C (4). Instead, we are heading towards a future that endangers the health of us all. Nevertheless, there is still time to change direction – there is still time to act.

The objective of this report is to give a concise summary of heat-related health effects, the most vulnerable populations, the regions that are most exposed to extreme heat, and different future scenarios of global warming. The report will not cover the burden of indirect health effects due to extreme heat, such as increased risk of wildfire, droughts putting food and water security at risk and the spread of certain infectious diseases. Nor will the co-exposure of fine particulate matter (PM2.5) and extreme heat be further discussed, although synergistic effects on mortality have been observed (5).

What is extreme heat?

The definition of extreme heat depends on the context; it is considered extreme in relation to the local climate – generally exceeding the local 95th percentile value (1, 6). If extreme heat lasts for a period of at least two to three days, the event is normally called a heatwave, but there is no universal definition (6). Heatwaves may be dry or humid, and occur primarily in temperate areas with a distinct hot season or variable summer climate. Global warming will lead to a geographical spread of heatwaves, likewise an increase in their frequency and duration. The Swedish National Expert Council for Climate Adaption highlights in its first report that heatwaves are expected to have the greatest impact on human health, among the various climate events to come (7). Heatwaves are often particularly dangerous when they occur in the early months of the season simply because the population is not acclimatised to high temperatures (6).

The urban heat island effect

Within urban environments, microclimates arise as a result of high-rise buildings, the high density of buildings and hard urban surfaces, such as roofs and pavements. Daytime heat is absorbed and stored in urban materials, and then slowly released at night, resulting in higher urban nocturnal temperatures than in adjacent rural areas (1, 6, 7). This phenomenon is called the urban heat island effect and is further amplified, primarily by heat from vehicles and building energy waste, and a small contribution of human metabolic heat (7, 8). High nocturnal temperatures increase the risk of heat-related death since they may prevent recovery from heat stress (9). With rising urbanisation there is an increased risk of heat vulnerability in regions that have previously been considered relatively tolerant to heat (6).

Wet-bulb temperature of 35°C

There is a finite temperature at which the direction of heat flow in the human body switches from heat loss to heat gain. This is reached when the ambient temperature exceeds that of fully vasodilated skin, at 35°C (10). The core body temperature may however be kept within its normal range around 37°C for a healthy individual by shedding heat, mainly through sweating (11). In humid conditions, however, sweat evaporates slower from the skin due to the humid air having less capacity to hold additional water, making the human cooling system ineffective. For this reason, the wet-bulb temperature, read by a thermometer covered in a wet cloth, is often preferred for identifying the conditions under which human health may be put at risk, since it considers both the ambient temperature and relative humidity. The wet-bulb temperature is the temperature to which the thermometer is cooled due to the evaporation of moisture, and thus mirrors the body's cooling mechanism of sweat evaporation. The wet-bulb globe temperature index is widely used as a heat stress index, and accounts for radiant temperature and air velocity in addition to air temperature and humidity (12).

The upper wet-bulb temperature limit for survival is 35°C (13) over an exposure period of at least six hours (14), but this limit may be reduced by numerous vulnerability factors (8). In some regions, this deadly threshold has already been exceeded. According to an article published by NASA Climate in 2022, wet-bulb temperatures exceeding 35°C have been observed nine times for short durations – up to 1–2 hours per occasion, since the year 2005 (15) in regions such as Pakistan and the Persian Gulf (14). Considerably lower wet-bulb temperatures can still be deadly, for example the heatwaves that resulted in at least 70,000 excess deaths in Europe in 2003 (16) did not exceed a wet-bulb temperature of 28°C (15). There has been a rapid increase in dangerously high wet-bulb temperatures in recent decades, and events of extreme heat and humidity now occur at least twice as often as they did four decades ago (13).

Health effects of hot temperatures

The core body temperature is regulated by temperature centres in the brain that attempt to maintain this temperature within the normal range around 37°C, which requires a balance of heat gain and heat loss. On one side of the heat equation is the heat gain from metabolic heat, being the sum of the metabolic rate (total metabolic energy production) minus the energy required for physical movement, which is normally a small proportion of the metabolic rate – usually around 10%. The metabolic rate increases during physical activity, thereby increasing the heat gain. The metabolic heat gain is balanced by the sum of heat gains and losses on the other side of the equation. Those include air temperature, radiant temperature, air velocity, humidity, clothing, sweat evaporation, breathing, convection (warming of the surrounding air or water) and conduction (warming of clothes and surfaces in contact with the body). Releasing heat through convection and conduction is only possible if the skin temperature exceeds that of the environment. Clothing is an important parameter to consider since it may hinder convection and sweat evaporation (11, 12).

Heat stress occurs when heat exposure is of such magnitude that it outbalances heat losses and exceeds what the human body can manage without affecting the physiological systems (17). In order to assess heat stress a minimum of six parameters should be considered, consisting of four environmental factors – air temperature, radiant temperature, air velocity and humidity, and two personal factors – activity level and clothing (12). The physiological response to heat stress is called heat strain, and includes redistribution of blood to the skin (vasodilation) and increased sweat production (6). Through these mechanisms, body heat is first transferred out of the body core by skin vasodilation, and then removed by evaporation of sweat from the skin (18). The redistribution of blood results in increased cardiac demand, to pump faster and harder in order to maintain blood pressure. The increased sweat production, on the other hand, leads to dehydration if the deficits are not adequately compensated (8). The heat strain may reduce performance capacities and provoke damage to organs – resulting in heat illnesses ranging from low blood pressure and minor heat-related headache to heatstroke and death (17).

Heat illness

Heat illnesses may be caused by heat stress that puts strain on physiological systems and organs, such as the heart and circulatory system, disturbing electrolyte and water balance or increasing the internal body temperature, which affects cellular functions (12). Classic examples of heat illnesses are heat fatigue, syncope, exhaustion and heat stroke, which are all due to failure of the thermoregulatory system. Heat syncope (fainting) is caused by low blood pressure and insufficient oxygen supply to the brain. Heat exhaustion may be due to losses of water and/or salt. This condition is associated with symptoms such as intense thirst, weakness, dizziness and headache, and the core body temperature may be subnormal to slightly elevated (6). Heat stroke is defined as the combination of core body temperature exceeding 40°C and central nervous system dysfunction, such as delirium, convulsions, or coma (18). The condition may be divided into two different types: classic and exertional heatstroke. The classic heatstroke results from an individual being passively exposed to extreme environmental heat. It has a rapid onset and without treatment will progress to death within 24 hours. Exertional heatstroke, on the other hand, appears in individuals exercising in hot or temperate environments who develop heat stress due to inadequate removal of metabolic heat. According to data from the USA and Europe, heatstroke accounts for 9–37% of the mortality that occurs during heatwaves (18). Since the measurement of core body temperature is essential for heat stroke diagnosis, the number of fatalities may be greater due to the risk of underestimated incidence of heat stroke. Individuals who survive heatstroke may experience persistent functional impairments due to organ damage (11).

Exacerbation of pre-existing medical conditions

Heat may induce exacerbations of pre-existing medical conditions, where cardiovascular disease is of particular concern as it is the primary cause of death during heatwaves (8). The underlying causes of heat-related cardiovascular events include heat-induced systemic inflammation, losses of fluid and salt during sweat production that increase the risk of coronary and cerebral thrombosis, and increased cardiac effort which results in greater demand for cardiac oxygen, increasing risk of cardiac ischemia (11).

Pulmonary diseases are the second greatest cause of heat-related morbidity and mortality during heatwaves (8). Extreme heat may trigger exacerbations of pre-existing pulmonary conditions, such as chronic obstructive pulmonary disease (COPD) and asthma, for example by inducing hyperventilation in order to disperse heat and affecting bronchoconstriction. The extreme heat may hence induce both systemic and local inflammation in airways (1). Other medical conditions that may worsen in hot temperatures include mental health disorders and kidney disease (6).

Effects of long-term exposure to heat

The long-term effects of heat are not yet completely understood, but a rising incidence of kidney fibrosis and kidney failure has been observed in outdoor workers exposed to occupational heat in Mesoamerica and India. The cause is debated, but may be due to repetitive heat stress and chronic dehydration (8). Extreme heat may also place limitations on exercise, which can affect mental health and increase the risk of several diseases, such as diabetes type II (4).

Acclimatisation

When living in a hot climate, the body will acclimatise to the heat, resulting in the individual better tolerating the high temperatures through adjustments in cardiovascular, endocrine and renal systems. The effects of this physiological adaption process include, for example, expansion of blood volume, increased maximal stroke volume, and sweating initiated in greater volume but with reduced salt level. The adaptation normally takes around two to six weeks, and is lost after a few weeks of non-exposure (6). Even if acclimatised and healthy, there are limitations on the level of heat the human system can tolerate.

Vulnerable populations

Even if the health effects of rising temperatures may be felt universally, some populations are more at risk than others. Populations that are vulnerable to extreme heat include the elderly, infants, patients with pre-existing medical conditions, outdoor workers and people with low socioeconomic status (further discussed below) – as well as pregnant women and urban inhabitants. At an individual level one person may possess several vulnerability factors that act in combination, putting the individual at particular risk of extreme heat. The Lancet Countdown report from 2021 underlines that heat vulnerability is increasing around the world due to an ageing population, increasing urbanisation and high prevalence of chronic diseases (4).

There is a clear difference between vulnerability and exposure to heat, but hotspots for vulnerability often coincide with hotspots for exposure to extreme heat, where the high temperatures may exacerbate the vulnerability of the already marginalised by amplifying health and social injustices (4).

Elderly and infants

Age is one important vulnerability factor, where both advanced age and very low age are associated with increased risk of negative heat-related health outcomes. In the older population, thermoregulatory capacity decreases with age as a result of limited skin vasodilation, sweat production and cardiovascular function (6). Thermal perception is likewise reduced, resulting in compromised behavioural responses to heat stress (1). Advanced age is also associated with changes in renal function, physical decline, frailty, certain medical conditions, use of medication, and in some cases dependence on others (6, 19). Infants, on the other hand, have a higher body surface area to volume ratio, making them especially vulnerable to heat stress and dehydration (1).

Patients with pre-existing medical conditions

Chronic cardiovascular disorders, respiratory disorders, mental health disorders and kidney disorders are examples of medical conditions associated with increased morbidity and mortality during heatwaves (1). Heat vulnerability may be related to the pathophysiology of the disease, or the medication used to treat the condition. Medications may for example increase heat vulnerability by impairing the ability to sweat, which is the case for anticholinergic medication, or by directly affecting the thermoregulatory centres in the brain (8). Heart medication, blood pressure medication, medication that alters renal function as well as medication that affects cognitive alertness are other examples that increase the risk of negative heat-related health outcomes. Dehydration due to heat may conversely increase medication toxicity (6). For some conditions, e.g. some mental health disorders, reduced behavioural adaptive capacities, such as ensuring sufficient fluid intake and wearing appropriate clothing, also contribute to heat vulnerability (1, 8).

Outdoor workers

Occupational heat is a health hazard that is growing in magnitude as global warming progresses, and is likely to lead to a decrease in the number of safe working hours. Reduced productivity will push people into poverty and affect economics on a societal level (17, 20). The populations at the highest risk of extreme workplace heat can be found in tropical low and middle-income countries (21), where outdoor workers are particularly vulnerable due to the risk of working in direct sunlight (1). The need for personal protective equipment and clothing, combined with a high physical activity level, are other factors contributing to heat stress (1, 10, 21). Ensuring sufficient rehydration is extremely important when workers are exposed to occupational heat, but is often a challenge, especially if they are also exposed to high temperatures in their free time, including high nocturnal temperatures (8, 16). Vulnerability to occupational heat is concentrated in areas of working poverty, precarious employment and limited social security. Low-wage agricultural and construction workers are among the worst affected by extreme heat (22).

People with low socioeconomic status

There is indeed a pronounced socioeconomic gradient in health and vulnerability to climate change – high temperatures not being an exception. Both social and economic deprivation are associated with increased heat-related mortality (1). For the financially vulnerable it is difficult to undertake the right protective measures to combat extreme heat, such as building designs adapted to heat, cooling systems and access to medical assistance when needed (6, 16). Poorer health status is associated with low socioeconomic status and may further contribute to vulnerability (7). More frequent and regularly occurring heat events may deplete personal resources, forcing people into poverty (16).

Future scenarios

Different regions around the globe are getting warmer at different rates, with the poles warming the fastest (23). Overall, the temperature is rising more quickly in the northern hemisphere than in the south (24), and in Europe people are now experiencing heat events that were previously seen as extreme as the new normal. This *new normal* became especially apparent in the summer of 2022, with several heatwaves, wildfires and heat-related health impacts putting pressure on healthcare (25). The populations that will be most affected by rising temperatures are, however, found in already hot regions where even small changes in temperature will have a severe impact on health, since many people are already living near their upper thermal limits (26). In addition, factors such as an ageing population, the spreading of chronic non-communicable diseases and rapid urbanisation are increasing vulnerability in regions that were previously seen as relatively tolerant to heat (6). In Europe, on the other hand, the rise in heat-related mortality may initially offset cold-related mortality (26). WHO emphasises however, that the health benefits of milder winters are likely to be outweighed by the rise in heat-related health impacts as early as the mid-21st century (1). European areas that are at particular risk of increasing heat-related mortality attributed to the progression of global warming include central and southern parts of Europe, and urban environments (2). The Eastern Mediterranean has been identified as a hot spot for climate change, and can expect a much dryer and warmer climate. Nicosia, the capital of Cyprus, is for example projected to experience the same climate conditions now seen in Cairo, by the end of the century (27).

Future predictions are depending on how we act now, and to clarify the impact of our actions, different modelling scenarios are used in the Assessment Reports of the IPCC (Box 1). Even if strong mitigation efforts are put in place it is *more likely than not* that we will reach global warming of 1.5°C (23). In a scenario of intermediate to very high greenhouse gas (GHG) emission, global warming of 2°C is *more likely than not* to *very likely* to be exceeded by the middle of the 21st century. In a low GHG emission scenario on the other hand, it is *unlikely* that global warming of 2°C will be exceeded during the 21st century.

Heat-related morbidity and mortality will continue to rise with increasing temperatures, but the future burden of extreme heat is not exclusively affected by climatic factors. Other factors are also of great importance, such as demographic changes in vulnerability, mitigation and adaption efforts (8). Projections of future heat-related mortality are therefore challenging and may vary greatly when accounting for the above-mentioned factors in different future scenarios, as shown by a study projecting annual heat-related deaths in New York City in the 2080s. When accounting for different Representative Concentration Pathways (RCPs, Box 1.), and different patterns of adaption and demographic change, the results ranged between 167 and 3331 annual heat-related deaths in the 2080s, compared with 638 annual heat-related deaths between the years 2000 and 2006 (28). Projections of future heat-related health impacts may also be challenging due to climate change seemingly happening faster than originally thought (2), leading to research quickly becoming outdated. This is important to keep in mind when reading the following sections.

Box 1. Representative Concentration Pathways (RCPs)

For the Fifth Assessment Report of IPCC (29), a new set of future emission scenarios was modelled – the Representative Concentration Pathways (RCPs), describing different radiative forcing scenarios by the year 2100 in comparison with preindustrial levels. Radiative forcing is a quantification of drivers of climate change, e.g. greenhouse gas emissions, and is measured in watts per square metre. It may be explained as the difference in incoming and outgoing energy on earth, where positive radiative forcing results in global warming.

RCPs include four scenarios: a very low emission scenario (RCP2.6 – indicating a radiative forcing of 2.6 watts per square metre), two medium emission scenarios (RCP4.5 and RCP6.0) and one high emission scenario (RCP8.5). Projections of global warming for each RCP are presented in table 1, and further illustrated in figure 1. The Sixth Assessment Report of the IPCC (23) focused on another new set of future scenarios in which levels of radiative forcing were combined with Shared Socioeconomic Pathways (SSPs), in order to integrate the influence of socioeconomic factors.

Table 1. Projections of global warming relative to year 1986–2005 (29).

Scenario	Increase in global mean surface temperature °C, mean (likely range)	
	Year 2046-2065	**Year 2081-2100**
RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
RCP4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
RCP6.0	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)
RCP8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)

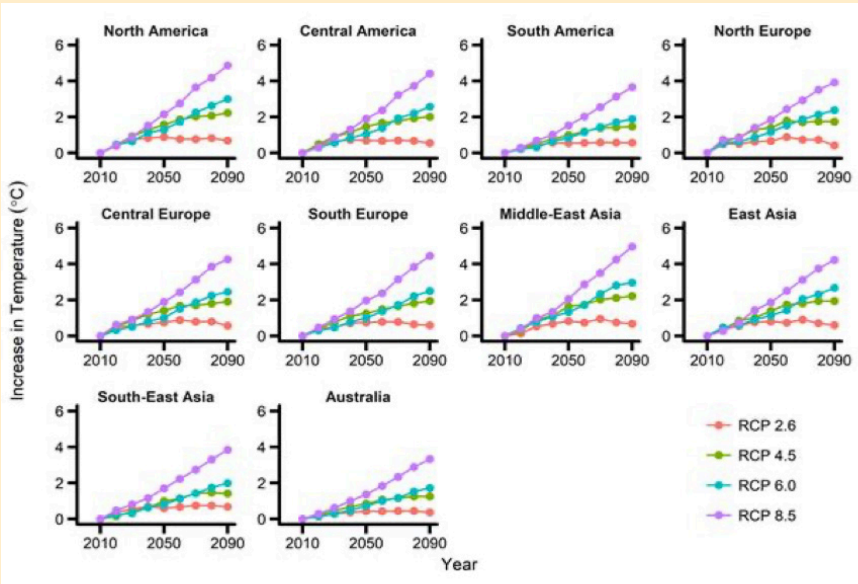

Figure 1. *Projections of increase in temperature for ten continental regions from the 2010s to the 2090s.*

Note. From Lee JY, Kim H, Gasparrini A, Armstrong B, Bell ML, Sera F, et al. Predicted temperature-increase-induced global health burden and its regional variability. Environment International. 2019;131:105027. https://doi.org/10.1016/j.envint.2019.105027 (30)

Which regions will be the most affected by extreme heat by 2050?

South Asia, the Persian Gulf and the Red Sea are already hot regions that are most likely to regularly exceed the wet-bulb temperature of 35°C by the year 2050 (14). Other regions at risk of surpassing the deadly threshold over the next 30–50 years include parts of Mexico and West Africa (31). Southeast Asia and West Africa are projected to be particularly vulnerable to higher temperatures, on account of widespread poverty and rapid urbanisation (16). In the Middle East and North Africa, *super-extreme* and *ultra-extreme* heatwaves with air temperatures exceeding 56 degrees are forecast by 2050 in a RCP8.5 scenario. In urban areas, the temperatures may be even higher due to the climate model not accounting for the urban heat island effect (32).

Which regions will be the most affected by extreme heat by 2100?

Besides South Asia, the Persian Gulf, the Red Sea, Mexico and West Africa – Eastern China and Brazil will be added to the list of regions likely to regularly surpass the wet-bulb temperature of 35°C (14) by the year 2070. If climate action is delayed, the eastern United States and northern Australia will also be exposed to dangerously high wet-bulb temperatures exceeding at least 32°C (33). In 60 % of the Middle East and North Africa, super- and ultra-extreme heatwaves are projected to become annually occurring events by the end of the century in a RCP8.5 scenario. In a RCP4.5 scenario, with medium mitigation efforts, the effects are expected to be comparable with the mid-century impacts of RCP8.5. The heatwaves will not only be hotter, but in addition last longer – several weeks in the most affected areas inland (32).

How many will be affected?

Today, around 68 million people are living in areas exposed to extreme heat, with wet-bulb globe temperatures exceeding 32°C. This number will grow to one billion people if global warming reaches 2°C, according to the Met Office (34). By 2050, global warming of 1.5°C will expose more than 350 million more urban inhabitants living in 44 megacities around the world to annually dangerously high temperatures (35).

A study published in Nature Climate Change (36) made projections of the global land area exposed to possible life-threatening extremely hot and humid conditions in different RCP scenarios. They found that by 2100 – in a RCP2.6 scenario, 27% of the global land area will be affected by extreme heat and humidity for more than 20 days per year, affecting 48% of the world population. In a RCP4.5 scenario, this area is likely to expand to cover 34% of the global land area, exposing slightly more than half the global population. In a RCP8.5 scenario, it was calculated that 47% of the planet's land area will be affected, exposing more than 70% of the global population. In this scenario, some tropical regions are projected to be exposed to life-threatening climates for almost the entire year, including parts of South America, South Asia and West Africa.

Measures to undertake

In order to keep the heat-related morbidity and mortality as low as possible it is absolutely critical to reduce greenhouse gas emissions, aiming to keep the temperature rise as low as possible. As already mentioned in this report, rising temperatures can still be expected even with strong mitigation. It is therefore crucial to develop adaption strategies to extreme heat, with special focus on protecting the most vulnerable from hot climates. To this date, most of the research regarding how to prevent heat-related health impacts has been done from the perspective of high-income countries (8). However, 80% of the global population live in low- or middle-income countries which are home to some of the most heat-affected populations (19). Research on the effects of extreme heat must therefore be extended to a broader perspective that includes all regions.

Another area requiring further research is investigation of more sustainable passive cooling interventions in addition to air conditioning. Air conditioning provides effective protection against extreme heat and as global warming progresses its cooling potential becomes increasingly vital. Unfortunately, it also has negative effects and is not a robust solution to the increasing threat of deadly hot climates. First of all, air conditioning is not affordable for many of the most vulnerable populations. Second, it contributes to a vicious spiral by driving an increasing demand for electricity, which is currently mainly generated from fossil fuels. Third, most air conditioners contribute to air pollution (4) and the urban heat island effect by producing waste heat localised outside the buildings. Fourth, people are left defenceless, and not acclimatised to heat, during power outages (1, 10).

Summary

The health consequences of climate change are many, and this small report has focused on the health effects of exposure to extreme heat. It has been shown that anthropogenic climate change has generated an increase in heat-related morbidity and mortality, and will continue to do so as global warming progresses. Worst affected are populations in hot areas, already living near their upper thermal limits, but no region will be safe from the effects of rising temperatures. With urgent climate action, it is possible to spare some regions from experiencing deadly hot and humid conditions. Strong mitigation can thereby save lives and prevent a significant number of people from being forced into poverty or to migration due to extreme heat.

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