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TECHNICAL REPORT

HEAT WAVES AND HUMAN HEALTH

EMERGING EVIDENCE AND EXPERIENCE TO INFORM RISK MANAGEMENT IN A WARMING WORLD

February 2019

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Cover Photo: Mahesh Kumar/Associated Press, May 2015. An Indian man cools off in the heat in Hyderabad, India.

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Prepared for:

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Adaptation Thought Leadership and Assessments (ATLAS)

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FIGURES AND TABLES

ACRONYMS

GHHIN	Global Heat Health Information Network
HEWS	heat wave early warning system
HHAP	heat-health action plan
IPCC	Intergovernmental Panel on Climate Change
NASA	National Aeronautics and Space Administration
NOAA	National Oceanographic and Atmospheric Administration
UHI	urban heat island
WASH	water, sanitation and hygiene
WHO	World Health Organization
WMO	World Meteorological Organization

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KEY MESSAGES

The World Health Organization defines heat waves as sustained periods of uncharacteristically high temperatures that increase morbidity and mortality. The extent and severity of health effects from a heat wave depend not only on its characteristics but also on the vulnerability of the affected populations. Around the world, the number and intensity of heat waves are on the rise. Of the warmest years on record across the globe, all were in the last three decades, and 2017 was the third warmest year in recorded history. According to both the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA):

- The five warmest years have all come in the 2010s.
- The 10 warmest years have all come since 1998.
- The 20 warmest years have all come since 1995 (Climate Central 2018).

These high temperatures, combined with other conditions, such as relative humidity, give rise to heat waves that can claim the lives of thousands of people, destroy crops and damage infrastructure. In addition, heat waves can strain basic services. Rising temperatures cause demand for water and electricity for cooling to grow and hospital admissions to increase, often at rates that overwhelm hospital capacity. As climate change intensifies, more heat records will be broken every season, increasing risks to the world's population, especially the elderly, infants and young children, pregnant women, those with chronic health challenges or disabilities and those who work outside. Furthermore, much of the global workforce works outside—including, for example, farmers, agricultural laborers and construction workers. In addition, a significant portion of the global population now lives in cities, where pavement and buildings trap and gradually release absorbed thermal energy, exposing urban residents to higher temperatures.

The direct and indirect impacts of heat waves are largely dictated by the vulnerability and exposure of the population affected. When health systems are unprepared to cope with heat extremes, the most vulnerable can suffer devastating consequences. The impacts of extreme heat can be both direct, affecting the human body's physiological responses and functions, as well as indirect, decreasing food and water security and jeopardizing hard-fought gains not only in health, nutrition, and water, sanitation and hygiene (WASH), but also in health systems strengthening and activities more broadly.

While heat waves may not bring about sweeping damage to natural, social and physical assets the way other climate stressors such as floods and droughts might, they are among the deadliest natural disasters. Heat waves throughout Europe claimed some 70,000 lives in 2003 (Robine et al. 2008). India, which routinely faces warm temperatures throughout most of the year, saw a heat wave in May 2010 that caused an excess of 1,344 deaths in the city of Ahmedabad (Azhar et al. 2014). In 2015 alone, four of the top 10 natural disasters producing the most fatalities were heat waves (United Nations Office for Disaster Risk

Reduction 2016). While data for Africa and other regions of the world are limited or considered dubious by many scientists, in 2018 a heat wave with temperature records exceeding 40°C was recorded in northern Kenya, further drying already stressed catchment areas and putting pressure on the country's vulnerable livestock communities.

Heat waves pose a range of health risks, from minor heat rashes to heat exhaustion and potentially deadly heat stroke. They are also linked to other health problems such as respiratory and cardiovascular disease, kidney disorders and mental illness. As temperatures rise and climate variability increases, most of the world is expected to experience increased impacts from heat extremes, even while taking into account gradual acclimatization to higher temperatures—both physiological adjustment and deliberate adaptation interventions (Huang et al. 2011).

Almost the entire world experiences—and will continue to experience—heat waves, but climate models show expanding risk in higher latitudes and even greater risk in places that already experience warm weather. Many of these places, for example, South and Southeast Asia and West Africa, already face challenges to climate change adaptation, including relatively low adaptive capacity, rapidly growing populations, inadequate cooling infrastructure such as air conditioning or cold supply chains that preserve vaccines, essential medicines and food. In addition, our rapidly urbanizing world will become more sensitive to extreme heat due to the urban heat island effect found in cities and other built environments, the heat effect of energy absorbed and retained in surfaces such as pavement, concrete and glass. The increasing number and intensity of heat waves will require countries to ramp up preparedness and improve heat interventions.

Efforts to better understand and manage the risks of extreme heat have emerged in the wake of recent and deadly heat waves around the world. For example, the World Health Organization (WHO) and the World Meteorological Organization (WMO) established a Joint Office for Climate and Health, which released guidance on warning system development for heat waves in 2015. Increases in injuries, illnesses and deaths from high temperatures resulted in increased research on identifying 1) thresholds for adverse health outcomes; 2) populations particularly vulnerable to heat exposures; and 3) effective interventions to prevent adverse health outcomes. While this research has been a valuable contribution to the field of climate risk management, more needs to be done to ensure that thresholds are accompanied by appropriate interventions and response mechanisms to address and adaptively manage risks, particularly among the most vulnerable populations. Around the world, communities, cities and countries have begun pilot interventions to mitigate the impact of heat waves, but more systematic and robust assessment of these interventions is needed. Several networks and communities of practice have begun to coalesce around risk management practices for addressing extreme heat, for example, the Global Cool Cities Alliance, the C40 Cities Climate Leadership Group, the Cool Cities Network, the Climate Services for Resilient Development partnership (CSRD) and the Global Heat Health Information Network (GHHIN). These networks and communities provide opportunities for exchanging knowledge and raising awareness that can lead to interventions and investments that can be brought to scale in the medium and long term.

The public health burden of heat waves in particular can be eased by building resilience into health systems through 1) advancing preparedness by improving forecasting skill and investing in vulnerability assessments to inform risk management and communication of actionable recommendations, especially to the most vulnerable populations, for minimizing heat risks, and 2) improving heat interventions by prioritizing intersectoral collaboration and implementing responsibility and accountability mechanisms for extreme heat preparedness, response and adaptation. Many cities across the world are developing heat-health action plans (HHAPs), which include a heat wave early warning system (HEWS) and emergency public health measures.

This report provides a starting point to inform risk management in a warming world with a specific emphasis on experiences in the developing world. It is structured as follows:

- *What are heat waves?* describes the physical characteristics of extreme heat, including heat waves, and common indices used to assess and measure heat stress.
- *How do heat waves impact health?* summarizes how heat waves directly and indirectly impact mortality and morbidity, describing dimensions of heat vulnerability.
- *Heat waves under a changing climate* summarizes the likely changes to spatial and temporal aspects of heat waves under changing climatic conditions.
- *What is being done to manage heat risk?* summarizes the global experience in developing robust preparedness, response and adaptation mechanisms, including HHAPs and HEWSs.
- *Moving forward* identifies critical gaps in managing heat risk and considers actions that can enrich the global response to heat waves.

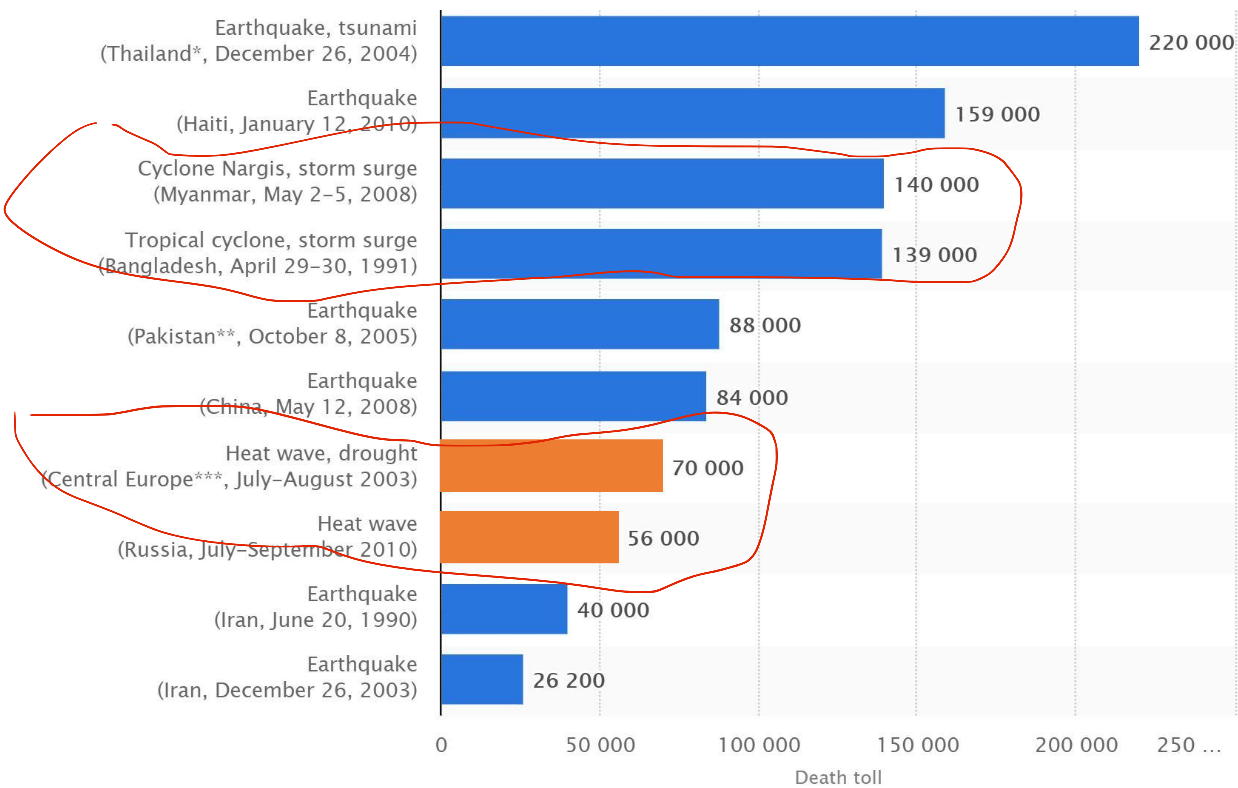
WHAT ARE HEAT WAVES?

HIGHLIGHTS

- Heat waves are sustained periods of uncharacteristically high temperatures that decrease productivity and increase morbidity and mortality.
- When health systems are unprepared for heat extremes, the most vulnerable suffer devastating consequences.
- The extent and severity of impacts from heat waves depend not only on the characteristics of heat waves themselves but also on the vulnerability of the affected population.
- A variety of indices combining temperature, humidity and other conditions are used to track heat risks across the world.

Extreme weather events bring about staggering loss of life, and heat waves are no exception (Figure 1). Although mortality from heat is highly episodic, heat waves have caused more than 150,000 deaths globally within the last 20 years (EM-DAT 2018). Nine out of 10 heat waves with the greatest number of fatalities have occurred since 2000, based on records from 1900. The year 2018 may be one of the warmest on record. Between June and July alone, heat waves swept through Asia, Europe and North America, hospitalizing tens of thousands of people with heat-related illness and, by some estimates, leaving more than 700 dead in the immediate aftermath. WHO predicts that by 2030 there will be almost 92,000 deaths per year from heat waves, with sub-Saharan Africa, Latin America, and South and Southeast Asia bearing the largest burdens (World Health Organization 2014). Extreme temperatures can contribute to deaths from cardiovascular and respiratory disease, both of which are among the leading causes of death in low- and middle-income countries — those least equipped to face the challenge (World Health Organization 2018).

Figure 1. The 10 most significant natural disasters worldwide by death toll from 1980 to 2017



Source: Statista 2018. Note: *In addition to Thailand, Sri Lanka, Indonesia, India, Bangladesh, Myanmar, Maldives and Malaysia were affected / ** In addition to Pakistan, India and Afghanistan were affected / *** Affected countries include France, Germany, Italy, Portugal, Romania, Spain and Great Britain

As climate change intensifies, heat waves will become more frequent, increasing risks to everyone, but especially the elderly, infants and young children, pregnant women, those with chronic health challenges or disabilities, and those who work outside without cover and face increased exposure to extreme temperatures.

Reducing the health impacts of heat waves requires addressing key questions, beginning with what constitutes a heat wave and how to assess the impacts of heat stress. While there are known absolute limits to human survivability under extreme temperatures, there is no consistent approach to measuring the combined effects of temperature, humidity and other meteorological factors on populations and systems. Rather, these effects are context specific and depend on the adaptive capacity of people, services that help to mediate the impacts of heat and the population's ability to implement actions that limit or reduce heat exposure. An important first step is understanding when and where heat waves can affect health.

DEFINITIONS

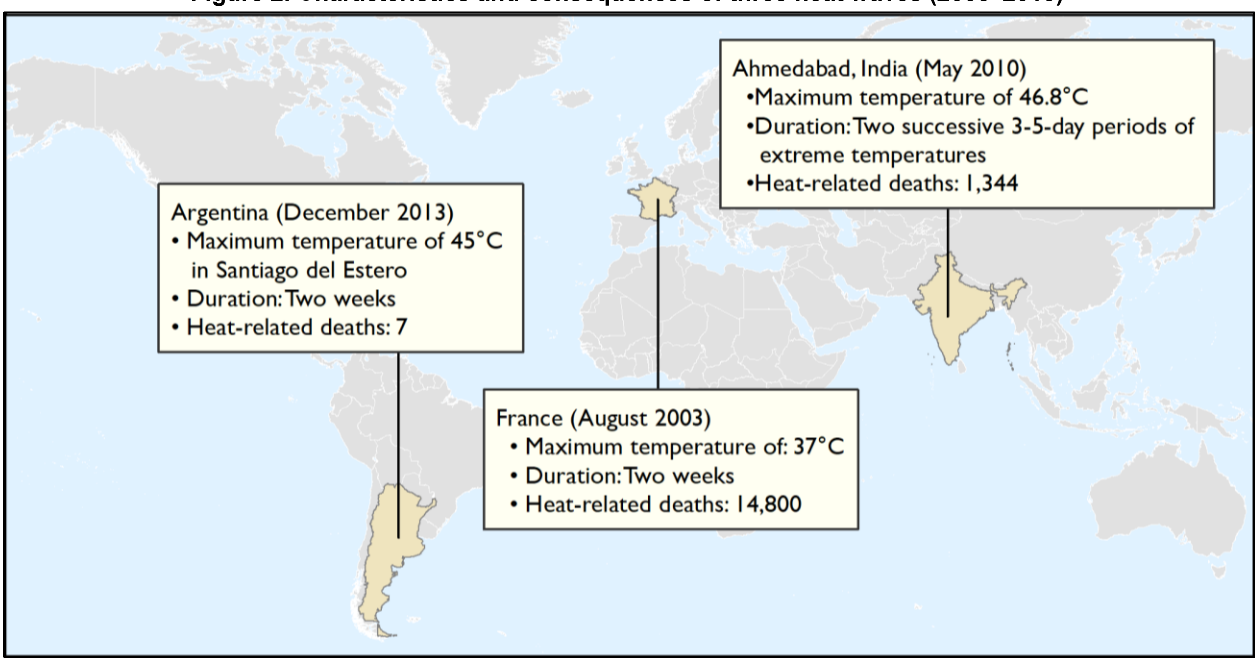
According to the WMO, a heat wave is a period of "marked unusual hot weather (Max, Min and daily average) over a region persisting at least two consecutive days during the hot period of the year based on local climatological conditions, with thermal conditions recorded above given thresholds." While extreme heat events occur worldwide (Figure 2), these events are episodic and context specific—geography, local weather conditions (e.g., temperature, humidity, cloud cover), duration and the time of year at which they occur all interact to influence the severity of their impacts. In addition, the services and resources to address the resulting risks of heat waves clearly play a role in how heat waves affect people, such that the same meteorological conditions can constitute a heat wave in one place but not in another. For example, the deadly heat wave in France in August 2003, with temperatures of 37°C (+15°C compared with historical averages for the months of July and August), occurred during an exceptionally warm and dry summer across Europe. These unprecedented temperatures—paired with a health system that was unprepared for such extremes—limited responses and left the most vulnerable, in this case the elderly, to suffer devastating consequences. Such an event could have had more tempered consequences in other regions of the world, such as India, where populations and systems are accustomed to high temperatures. Extreme heat events do not necessarily translate into extreme impacts if vulnerability is low.

KEY TERMS

Extreme heat, *or an* ***extreme heat event,*** refers to temperature and humidity conditions that are above average for a location at that time of year.

A ***heat wave*** broadens the meteorological definition of an extreme heat event to account for discernable impacts on human and natural systems.

Figure 2. Characteristics and consequences of three heat waves (2003–2013)



Source: NASA 2014; Chappell 2013; Dhainaut et al. 2003; Azhar et al. 2014

HOW IS EXTREME HEAT MEASURED?

As noted, air temperature alone is not an adequate indicator of heat waves, as other conditions affect the body's natural mechanisms for coping with heat (perspiring and breathing). For example, high humidity limits the cooling evaporation of perspiration. Most of the indices that define heat waves around the world highlight the important role of humidity in their calculations (Table 1).

Table 1. Common indices for measuring heat waves around the world

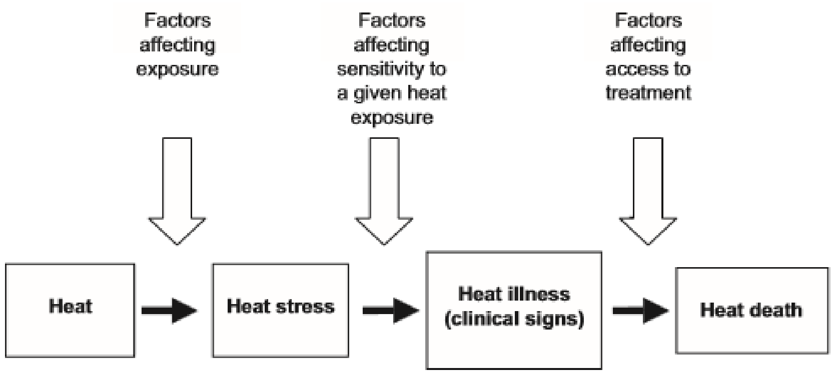
Index	Definition	Current use
Heat index (HI)	• Combines air temperature and relative humidity to determine an apparent temperature (how hot it feels)	• Widely used in the United States when temperatures are >26°C and relative humidity is ≥ 40 percent
Humidex	• Combines temperature and humidity into one number to reflect perceived temperature on the following scales of comfort related to the body's coping mechanisms: • Less than 29 – no discomfort • 30–39 – some discomfort • 40–45 – great discomfort • Above 45 – dangerous • Above 54 – heat stroke imminent	• Widely used in Canada • > 40 considered high Humidex during which all unnecessary activity should be curtailed
Apparent temperature (AT)	• An estimate of what the temperature "feels like" • Uses absolute humidity with a dewpoint of 14°C as a reference level from which air temperature is adjusted	• Widely used in Australia • AT is measurable over a range of temperatures above 20°C and considers the cooling effects of the wind at lower temperatures
Net effective temperature (NET)	• Considers the effect of air temperature, wind speed and relative humidity	• Monitored in Hong Kong, China and Portugal • Alerts for temperature extremes typically issued when NET is forecast to be lower or higher than the 2.5th percentile or 97.5th percentile, respectively
Wet-bulb globe temperature (WBGT)	• Combines temperature and humidity into a single number • Affected by wind and radiation • A measure of 35°C is thought to be the threshold for human survivability (Sherwood and Huber 2010)	• Monitored in Australia • Widely used among researchers as an easily measured heat-stress index in occupational medicine

Source: Adapted from **WMO & WHO** 2015

DIMENSIONS OF HEAT VULNERABILITY

The extent and severity of impacts from heat waves depend not only on the characteristics of heat waves themselves but also on the underlying vulnerability of the affected population (Figure 3).

Figure 3. Points along the causal chain from heat exposure to heat-related death



Source: Kovats & Hajat 2008

Epidemiology studies have identified a long list of populations particularly affected by extreme heat. In general, as noted above, the following groups are at particular risk during a heat wave (WMO & WHO 2015):

- Youth and elderly (adults over the age of 65 years)
- Individuals with chronic diseases (e.g., diabetes, heart disease) or who take medications to control them (e.g., beta-blockers), the disabled or the homebound
- Pregnant women (and fetuses)
- Outdoor workers and athletes
- Socially disadvantaged and marginalized groups, including migrants, refugees and the homeless
- Tourists lacking acclimatization and awareness of weather conditions when there are language barriers

Vulnerability has several dimensions, each with spatial and temporal variation. Heat vulnerability is influenced by complex physiological pathways, with impacts presenting differently in vulnerable groups depending on the intensity, duration and onset of heat stress. Some demographic and socioeconomic factors that strongly influence vulnerability, such as workplace conditions, are modifiable. Factors that interact to contribute to heat vulnerability include:

- ***Age and aging***—Body temperature regulation (thermoregulation) in elderly populations is less efficient compared with younger adults. The elderly sweat less, which limits the body's ability to cool (Murari et al. 2015). In July 2018, more than 30,000 people in Japan were hospitalized due to heat stroke, with 77 heat-related deaths registered in two weeks. The elderly were the hardest hit: more than half of hospital admissions and at least 80 percent of the deaths were people older than 65 (Tan 2018; Reuters 2018). Children and infants are also at risk of heat-related illness or death due to their developing thermoregulation mechanisms. An age group study in Durban, South Africa, reported that children under age four had the largest increase in natural deaths for each 1°C increase in apparent temperature above a 20°C threshold, followed by adults over the age of 60 (Wichmann

2017). In addition, children, unaware of the need to drink more water, risk dehydration. Parents of young children may not be aware of the need or may not have the means to ensure their children drink enough water.

- ***Clinical factors***—Several medical conditions, namely depression, diabetes and cardiovascular and cerebrovascular conditions, can exacerbate heat risks by 1) limiting mobility, awareness and behaviors such as staying hydrated, 2) increasing blood viscosity through dehydration and 3) compounding the dehydrating effects of medications. High heat wave thresholds have been associated with elevated risk for coronary heart disease (CHD) mortality in Beijing, China (Tian et al. 2013) and increased hospitalizations for CHD in Ontario, Canada (Bai et al. 2017). Between 2008 and 2012, the Hanoi Mental Hospital in Vietnam saw increased admissions for mental disorders during heat waves, in which the average temperature exceeded 35°C for three or more consecutive days (Trang 2017).

- ***Other physiological factors***—Pregnant women face differentiated sensitivity to extreme heat since their ability to thermoregulate is compromised, and emerging evidence indicates associations between extreme temperatures and stillbirth at term (Auger et al. 2017; Ha et al. 2017). Compared with non-stillbirths, stillbirths were linked to exposure to hot temperatures during the entire pregnancy.

- ***Socioeconomic factors***—Workers performing strenuous activities both outdoors and indoors—such as farming, construction and manufacturing in poorly ventilated buildings—are at greater risk from dehydration and heat stress when heat-related work practices are not in place (Lundgren et al. 2013). This problem is acute in tropical countries where these sectors employ a large proportion of the workforce. Chronic dehydration, for example, is mentioned repeatedly as a hypothesis linking heat exposure to recent epidemics of chronic kidney disease reported among farm workers around the world (García-Trabanino et al. 2005; Orantes et al. 2011; O'Donnell et al. 2010; Tawatsupa et al. 2012). Clothing and personal protective equipment can also be a factor when they restrict or prevent moisture from escaping, hindering the body's ability to cool itself through perspiration.

- ***Cultural factors***—Some cultural beliefs may act as barriers to heat-related illness prevention and produce differentiated impacts among various population segments. Men and women may have differentiated heat risks as a result of socioeconomic factors and cultural norms around division of labor (WMO & WHO 2015). For example, occupational heat stress is linked to increased risk of kidney disease in young males in Thailand (Tawatsupa et al. 2012). In May 2018, a heat wave in Pakistan coincided with Ramadan, during which able-bodied Muslims fast from sunrise to sunset. Many suffered from heat-related injuries linked to dehydration (Ahmad 2018).

- ***Housing characteristics and the availability of air conditioning*—** Modern building materials such as glass, asphalt and aluminum have different thermal properties (i.e., heat capacity and thermal conductivity) and radiative properties (i.e., reflectivity and emissivity) from traditional materials found in more rural areas. A rapidly changing profile for the built environment has led to increasing square footage at the expense of shade cover from trees and vegetation. The increasing number of skyscrapers and buildings with glazing that traps heat and limits air flows has significantly increased the need for air conditioning around the world. The deadly heat waves across Europe in 2003 showed that the lack of air conditioning in nursing homes increased exposure of elderly populations in France, with attendant impacts most pronounced in this age group. As a result, new regulations introduced in France in 2004 require institutions for the elderly to have at least one cooling center during periods of high heat. Nevertheless, many argue that increasing the use of air conditioning is neither practical nor sustainable in many parts of the world and point to the use of passive cooling approaches in green construction and design as a long-term, carbon-neutral solution (Kjellstrom et al. 2009). In many of the world's informal settlements, where metal roofs are common, residents are particularly prone to heat exposure. Efforts to address extreme heat for those living in informal settlements are already underway in India. The NGO Mahila Housing Sewa Trust, has installed waterproof modular roofs in slums in several cities, including Delhi. The roofs, which are made of paper waste and coconut husk, are low-cost and easily installed and have been shown to bring down indoor temperature by as much as 6°C (C40 Cities 2018).

Cool innovations in urban design

Urbanization and the built environment can have profound implications for heat exposure and vulnerability. For example, glass exteriors in high-rise buildings trap the sun's rays and heat. Roofs and pavements cover some 60 percent of city surfaces, and as such, the use of reflective materials can substantially reduce warming effects. Cool roofs—roofs that are prepared, covered or coated with materials that reflect sunlight and reduce heat-emitting solar radiation—have become an important adaptation measure across urban (and urbanizing) areas from Delhi, India, to !Kheis, South Africa. Cool roofs can reduce indoor temperatures by 20 percent (Sustainable Energy for All 2018).

In Morocco, architects of the Technology School of Guelmim are adapting "vernacular" architecture by combining concrete structures and large north-facing and small south-facing windows, striking a balance between reducing the amount of direct sunlight while still allowing sufficient natural light to permeate the building's interior. The design maximizes airflow through the complex, creating a natural cooling system (Holland 2017). Similarly, cities throughout the Middle East are turning to *mashrabiya,* a traditional latticed screen that controls air flow and reduces reflected heat and solar radiation, to build resilience into modern buildings.

- ***Urban heat islands***—Urban heat islands (UHIs) are areas within cities that are significantly warmer than surrounding rural areas due to human activities. Cities are mosaics of heterogeneous geophysical features that contribute to different microclimates at a granular scale. Pavement and buildings in urban environments trap and gradually release absorbed energy, raising air temperatures. This UHI effect suggests that people who reside in built-up urban areas are likely to be more exposed to higher temperatures than those living in rural areas (Heaviside et al. 2016). Heat islands appear and disappear over time and space, and are difficult to quantify spatially or temporally for individual heat wave events (Kovats & Hajat 2008). While a large proportion of the world's population lives in urban areas, urban areas themselves account for only a small percentage of the earth's land surface. Paradoxically, the UHI effect is not captured in larger-scale land surface temperature studies, meaning that a few degrees' increase in global mean temperature can translate into much higher temperatures within urban settings (Parker 2009; Fischer et al. 2012). Those lacking access to cooling technology, such as the homeless or those living in informal settlements in urban areas, face increased exposure to UHIs.

Heat stress in Nairobi's urban mosaic

The intensity of UHIs can vary greatly due to intra-urban variations in the built environment. Stone, concrete and asphalt tend to trap heat, while lighter colored surfaces, reflective materials and low-thermal conductive materials reduce the intensity of UHIs.

While the central business district of Nairobi is characterized by paved roads, high-rise buildings and pockets of low vegetation, large neighborhoods of informal settlements have dense metal housing with little to no vegetation. A recent study found that during the hottest summer on record in Nairobi, temperatures measured within three informal settlement neighborhoods (Kibera, Mathare and Mukuru) regularly exceeded temperatures at the central, nonslum monitoring station by several degrees or more. The temperatures in these neighborhoods were also within the range associated with negative health outcomes for children and the elderly.

Source: Scott et al. 2017

Challenges to keeping cool

Cooling is an integral response to extreme heat, but for many millions living in hot climates, the absence of modern cooling services has profound impacts on human health and well-being. While access to cooling technology remains a widespread problem across the developing world, a 2018 report by Sustainable Energy for All (SEforALL) notes that populations that are actually in a position to buy air conditioners may not buy the most energy-efficient machines, ironically accelerating the trend toward extreme temperatures. Inefficient cooling devices are likely to be the most affordable option for a growing lower-middle class. India—followed by Indonesia, Pakistan, Bangladesh, and Brazil—has the largest "carbon captive" population at risk of buying the least energy-efficient appliances.

Source: Sustainable Energy for All 2018

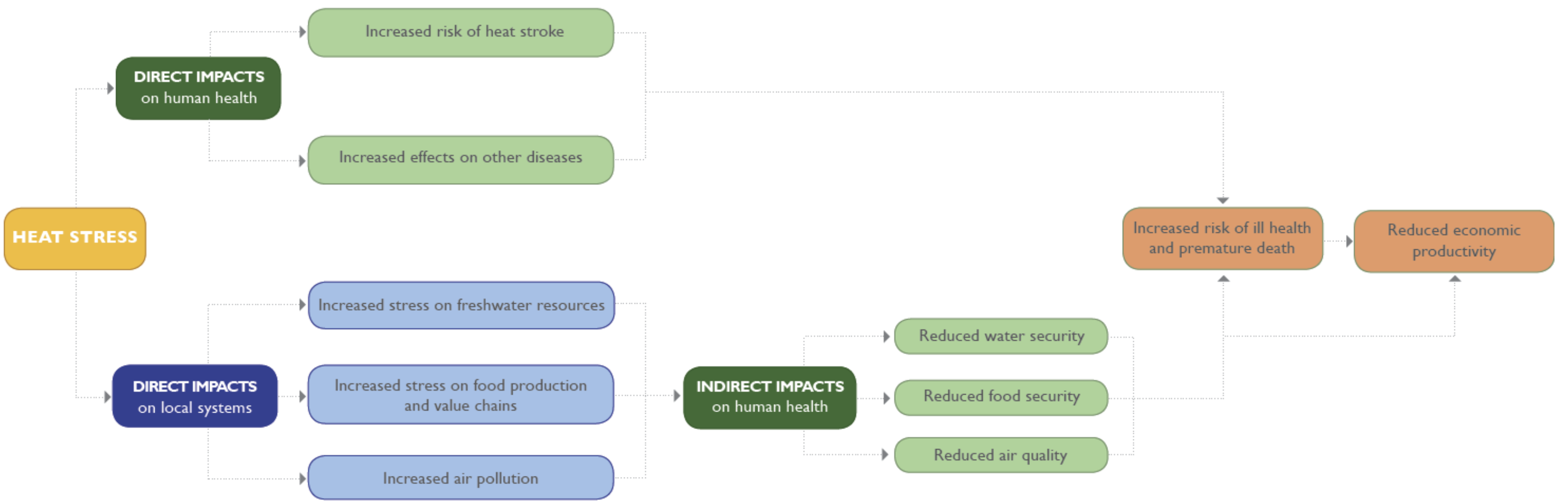
HOW DO HEAT WAVES IMPACT HEALTH?

HIGHLIGHTS

- The magnitude of an event—heat exposure and vulnerability together—creates risk.
- The impacts of excessive heat can be both direct, affecting the body's physiological responses and functions, as well as indirect, increasing challenges to food and water security.
- Direct impacts can range in severity, from mild skin irritation (heat rash), cramps, swelling and fatigue to heat exhaustion and heat stroke, which occurs when body temperature climbs above 40°C.
- Several factors can amplify the health risks of excessive heat, including air pollution and wildfires.
- The cumulative effects of low- and middle-intensity heat waves on total and cause-specific mortality may, in fact, be greater than for high-intensity heat waves.
- Future heat waves will place additional stress on staple crops and water resources, jeopardizing hard-fought development gains in health, nutrition, WASH and health systems strengthening more broadly.

Acute heat stress is already recognized as a growing cause of death in the developed world and is slowly garnering attention on national and global health and development agendas. For example, a 2018 report by Sustainable Energy for All asserts that expanding access to cooling technology to manage unprecedented levels of human exposure to extreme heat is essential for achieving many of the Sustainable Development Goals (SDGs). With rising temperatures due to a changing climate, the negative impacts of heat on societal health are likely to intensify and will manifest with direct and indirect effects on human health (Figure 4). For example, heat stress can directly affect human health by overwhelming people's physiological ability to manage heat, thus harming the basic functioning of the body. Human health can be indirectly affected when heat increases stress on critical food and water systems.

Figure 4. Direct and indirect effects of heat stress on health



Source: Adapted from Lucas et al. 2014

DIRECT IMPACTS: ACUTE HEAT-RELATED ILLNESSES AND DEATH

As described above, extreme heat affects the body's temperature-regulating mechanisms of sweating and breathing. As the body struggles to compensate for higher ambient temperature, it pushes the regulatory mechanisms, such as heart rate and function, harder to release internal heat. In highly humid environments, the body's excess temperatures can lead to dehydration and chemical imbalances that increase risk for heat-related illnesses.

Impacts include mild skin irritation (heat rash), cramps, swelling, fatigue, heat exhaustion and heat stroke, which occurs at body temperatures above 40°C. Heat stroke, an extreme case, results either from physical exertion (such as exercise or strenuous labor) or physiological inability to regulate body temperature, also called passive heat stroke. If not recognized early or treated correctly, either form of heat stroke can result in permanent physical and/or mental disability, and even death (Guerrero et al. 2013). When the body's cooling mechanisms fail, thermal stress intensifies, and rising core body temperature further compromises the central nervous and circulatory systems with broad and varied impacts on many organ systems. Caring for victims of heat stroke may strain medical services. For example, in places with prolonged heat exposure, a marked increase in emergency visits and hospital stays has been recorded, with medical issues associated with organ systems, such as kidney problems (Tan 2018; Bai et al. 2017; Dhainaut et al. 2003). Training health workers to recognize the basic sequence and range of physiological responses that present with thermal stress is critical to providing treatment that avoids sending the body's regulating and cooling mechanisms into overdrive (sometimes referred to as hypothermic overshoot). Equipping health facilities with appropriate resources to respond to surges in hospitalization rates is essential to building more resilient health systems.

The health impacts of extreme heat can be more pronounced depending on physical condition and age. Pregnant women's ability to thermoregulate is challenged, increasing their risk of heat-related illness and birth complications. People suffering from chronic respiratory or circulatory conditions are at greater risk from heat than the rest of the population. Likewise, elderly populations (65+ years of age), suffer a disproportionate burden from heat stress, with evidence pointing to increased cardiovascular complications and heart failure following a 1°C increase in temperature (Bunker et al. 2016).

In nearly all cities and regions worldwide, mortality increases, often abruptly, when the temperature drops below or rises above a certain range, or the "minimum mortality temperature" (Gasparrini et al. 2015). This minimum temperature varies, depending on historic weather, with warmer climates having a higher minimum mortality temperature than colder climates, as Figure 2 in the previous section illustrates. A recent study from Thailand found the cumulative effects of low- and middle-intensity heat waves on total and cause-specific mortality was greater than for high-intensity heat waves (Huang et al. 2018). The highest causes of death included infectious and parasitic diseases. The effects of heat waves on deaths from endocrine, nutritional and metabolic diseases were longer-lasting, and effects of heat waves on deaths from ischemic heart diseases and pneumonia occurred more rapidly.

Heat's toll on mental performance and productivity around the world

A study of school children in Cameroon showed a relationship between high indoor temperatures and dew points and headache and fatigue. Poor school performance was observed during the warmest period of the school day when temperatures exceeded 32°C in the classroom (Dapi Nzefa et al. 2010). In Southern India, steel workers reported not only a reduction in productivity and personal health, but also negative impacts on their social life resulting from heat stress (Krishnamurthy et al. 2017).

Heat-stress–induced mental and physical impairments can have broader implications for communities facing increasing temperature extremes. For example, studies in Australia, Spain and India indicate increases in both driving accidents and occupational injuries during periods of extreme heat (Rameezdeen & Elmualim 2017; Basagaña et al. 2015; Ramsey et al. 1983).

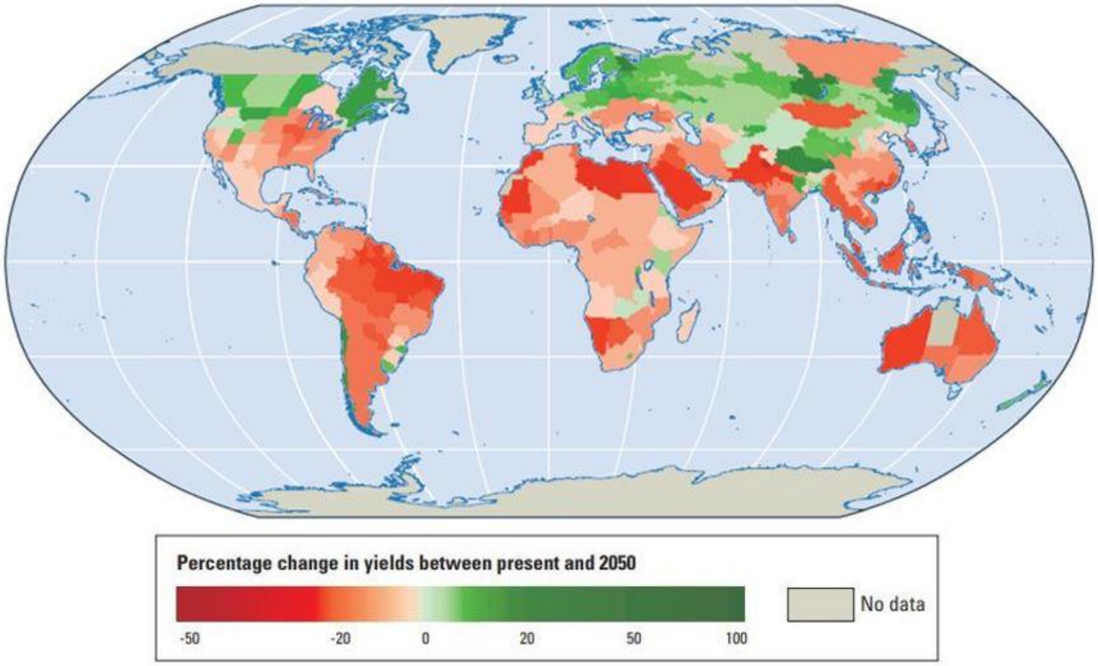
INDIRECT IMPACTS

In addition to the direct impacts of extreme heat on human health as outlined previously, potentially more consequential in terms of the number of people affected is the damage to the ecological systems and services on which society depend, which can alter the availability of critical resources, thus having indirect effects on human health. These include energy infrastructure and changes in the quality and availability of food and water resources:

- ***Energy***—Rolling electrical blackouts often accompany extended heat waves, which can further compromise health care delivery. For example, urban hospitals are large electricity consumers, and often they are asked to shift to emergency power generation to free grid resources during peak demand periods. However, many hospitals do not have their cooling systems on their emergency power generation systems. As a result, required basic ventilation systems may remain operational at the expense of portions of the space cooling systems that control indoor temperature. In general, hospitals are designed to be sealed buildings that do not incorporate operable windows due to infection control and pressurization requirements (Balbus et al. 2016). Without a functional cooling system, a hospital would become uncomfortably—if not dangerously—warm, especially during a heat wave. Power outages may also constrain household cooling capacity and expose more people to deadly temperatures, which underscores the need for community and municipal contingency measures.

- ***Agricultural production***—Heat extremes directly affect crop productivity, thus indirectly affecting livelihoods, well-being and human dietary and health patterns and potentially exacerbating or creating food security problems. Many of the world's staple food crops are already grown at their thermal tolerance, where even minimal increases in temperatures can significantly reduce yields. These impacts vary from region to region (Figure 5). For example, models point to declines in maize and wheat yields with 1°C to 2°C of local warming in the tropics. In the absence of climate change adaptation, South Asia and southern Africa—both of which have large populations facing challenges of food security—could suffer the most negative impacts on several important crops (Porter et al. 2014). In addition to the implications on food security and nutrition, the impacts of heat waves on agricultural output may have devastating consequences on human well-being. For example, heat waves in India have been associated with an uptick in suicide among poor farmers (Carleton 2017).

Figure 5. Projected impact on global crop yields



Source: Müller et al. 2009. Note: Projected percentage change in yields of 11 major crops (wheat, rice, maize, millet, field pea, sugar beet, sweet potato, soy, groundnut, sunflower and rapeseed). The yield-change values are derived from an average of three emission scenarios across five global climate models, equivalent to approximately a 3°C increase by 2050.

- ***Water resources***— As air temperatures continue to rise, so do the temperatures of the world's oceans, lakes and rivers. Open water sources, which are exposed to sunlight, will decrease because of increased evaporation. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5), climate change is likely to increase the frequency of droughts in areas that are already dry, potentially decreasing available surface and groundwater. With warming, the dissolved oxygen concentration in water declines, potentially leading to toxic algal blooms and other contaminants, which can reduce water quality and make people ill. Coral bleaching and degradation of fish habitat associated with warming will have important implications for livelihoods and local economies that depend on these natural resources for tourism revenue. The relationship between warming temperatures and water resources will also affect hydropower production, a critical source for cooling infrastructure throughout

When extreme heat compounds health risks: Water shortages in Swaziland

Elevated temperatures increase evaporation and raise demand for water, amplifying water stress and posing challenges to water resource management. During heat waves, some communities may ration water, which can have important economic and public health repercussions. In 2016 Mbabane, the capital of Swaziland, rationed water in response to successive heat waves compounded by drought conditions, affecting some 40 percent of primary and secondary schools and exacerbating WASH challenges.

Sources: Funari et al. 2012; Lama et al. 2004; Singh et al. 2001 the world, placing greater strain on strategies to address heat stress.

CONFOUNDING FACTORS

The interaction of extreme temperatures and other hazards such as wildfires and air pollution can multiply threats and amplify the impacts on human health.

- ***Wildfires***—Heat waves can stoke wildfires, as was the case in July 2018 when record-setting temperatures and moderate winds sparked nearly a dozen brush fires across southern California (Reyes-Velarde et al. 2018). Rising temperatures accelerate the dissipation of clouds, increasing solar radiation and moisture loss from vegetation and creating the hot and dry conditions for wildfires to occur (Williams et al. 2018). The interaction between extreme heat and air pollution from fires in forests and peat bogs around Moscow during the 2010 heat wave contributed to a number of deaths in working-age adults and the elderly (Shaposhnikov et al. 2014).

- ***Air quality*****—**Air pollution is often amplified by heat waves. Extreme heat intensifies ground-level ozone, which combines with fine particulate pollution (soot and dirt from coal combustion, diesel engines or fires) and chemicals like carbon monoxide or sulfur dioxide (i.e., smog) to reduce air quality, especially in urban areas. High concentrations of ozone near ground level can be harmful, and children, the elderly and those with respiratory problems such as asthma can be particularly sensitive. Of 1,000–1,400 heat-related deaths estimated in the Netherlands during the 2003 European heat wave, 400–600 were linked to increased air pollution (Fischer et al. 2004). In England and Wales an estimated 21–38 percent of total excess deaths were associated with the elevated ambient ozone concentrations during the 2003 European heat wave (Stedman 2004). While much of the literature confirms an increase in mortality when both temperature and air pollution levels are high, studies tend to emphasize either air pollutants or temperature in the air pollution–heat–mortality relationship, and findings appear to differ across geographies (see Shaposhnikov et al. 2014; Rainham & Smoyer-Tomic 2003; O'Neill et al. 2003; Stafoggia et al. 2008; Bell et al. 2008; Vaneckova et al. 2008; Zanobetti & Schwartz 2008). Therefore, more research is needed to understand the synergistic effects of air pollution and temperature on mortality.

HEAT WAVES UNDER A CHANGING CLIMATE

HIGHLIGHTS

- Heat extremes are already taking place and impact human health.
- Rising temperatures and changes in relative humidity have increased the risk of heat-related death and illness and will continue to directly and indirectly impact human health.
- Heat extremes will increase in frequency and intensity.

The Fifth Assessment Report of the IPCC confirms that heat extremes are already taking place and assesses the evidence used to project the effects of future changes in heat extremes on populations and individuals. These are summarized below.

1) Heat extremes are already taking place and impact human health.

- Heat risk is a function of the magnitude of an event, the level of exposure and the vulnerability of a population.
- Each of the last three decades has been successively warmer than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was *likely* the warmest 30-year period of the last 1,400 years.
- Rising temperatures have *likely* increased the risk of heat-related death and illness by altering distribution of some waterborne illnesses and disease vectors and reducing food production for some vulnerable populations.
- Some parts of the world already exceed the international standard for safe work activity during the hottest months of the year.
- The capacity of the human body to thermoregulate may be exceeded on a regular basis, particularly during manual labor, in parts of the world during this century. In the worst-case scenarios of climate projections, by 2100 some of the world's land area will be experiencing 4°C-to-7°C higher temperatures. If this occurs, the combination of high temperatures and high humidity will compromise normal human activities, including growing food or working outdoors in some areas for parts of the year.

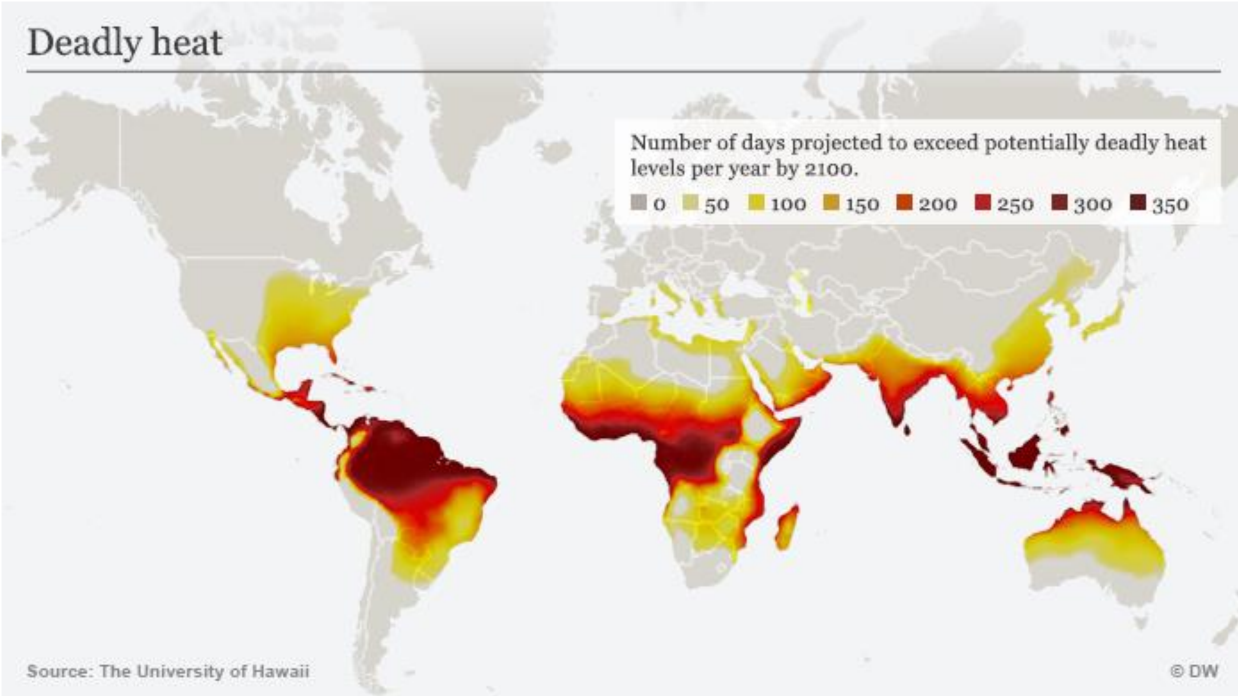
2) Heat extremes will increase both in frequency and intensity.

- It is *virtually certain* that there will be more frequent hot temperature extremes and fewer cold temperature extremes over most of the world on daily and seasonal timescales as global mean temperatures increase.

- Heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur.
- The magnitude of the challenges with heat-related mortality will increase in a warming climate. This elevates the importance of investing in heat wave early warning and response systems and in other interventions (e.g., green space to reduce UHIs) to protect human health.
- Several climate models project that warming is *likely* to exceed 1.5°C –2°C by the end of the 21st century relative to the average from 1850 to 1900.

3) **Heat extremes will continue to pose risks to human health.**
If climate change and its concomitant risks of extreme heat continue as projected, the major changes in ill health compared with no climate change will occur directly and indirectly through:
- Greater risk of injury, disease and death due to more intense heat waves as well as coupled threats such as air pollution and increased risk of fires. As the number of deadly heat days increases (Figure 6), populations in the tropics and subtropics will be confronted with higher rates of heat-related mortality. Observed temperature–mortality data from Southeast Asia suggest that the region is particularly vulnerable and could face large increases in heat-mortality impacts. Impacts for other warm regions, including Africa and the Arabian Peninsula, require further study and examination of temperature-mortality data (Vicedo-Cabrera et al. 2018).
- Increased risk of undernutrition resulting from diminished food production in poor regions.
- Increased risks to livelihoods, human well-being and economic growth, for example, lost work capacity and reduced labor productivity in vulnerable populations.

Figure 6. Number of deadly heat days in 2100



Note: The [Heat waves: Number of deadly heat days application]developed by Mora et al. 2017 with Esri counts the number of days in a year when conditions of temperature and humidity surpass a given threshold and thus pose a risk of death (i.e., the number of deadly days). This map is based on a business-as-usual scenario (RCP 8.5).

In short, the extreme heat events of 2003, 2010 and 2018 paint a picture of what the not-so-distant future holds. Heat waves will be common occurrences affecting growing populations around the world. Today, nearly one-third of the global population covering just 13 percent of the Earth's land area experience at least 20 extreme heat days per year. If emissions continue unchecked and heat interventions are not implemented, this risk expands to 47 percent of the land area, affecting 74 percent of the world's population by 2100 (Mora et al. 2017).

UNDERSTANDING THE BASICS:
WHAT DOES THE IPCC TELL US ABOUT CLIMATE PROJECTIONS?

Climate scientists draw upon a suite of models to describe future climate changes. The primary sources of information are Global Climate Models (GCMs), Regional Climate Models (RCMs) and downscaling techniques, both empirical and statistical. The models comprise simplified but systematically rigorous mathematical descriptions of physical and chemical interactions governing climate, including the role of the atmosphere, land, oceans and biological processes.

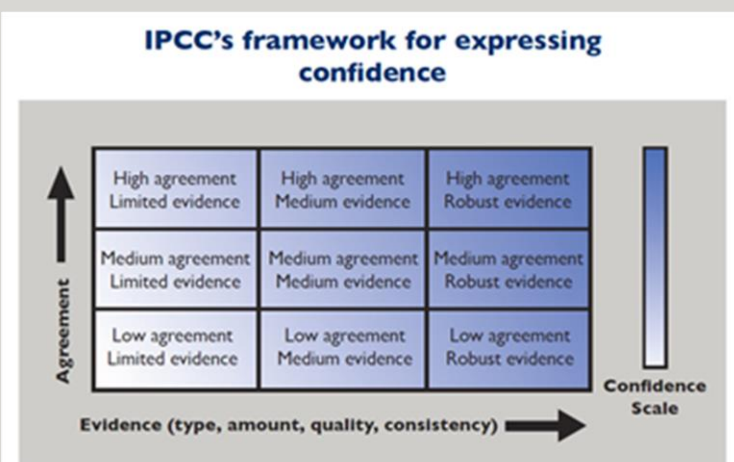
The IPCC scenarios offer valuable insights into the future of the climate system. These scenarios, termed Representative Concentration Pathways (RCPs), describe four scenarios of global change, considering emissions, climate, environmental change and vulnerability. These include: RCP8.5, RCP6, RCP4.5, and RCP2.6. The numbers refer to radiative forcing, a measure of how greenhouse gases in the atmosphere change the Earth's normal energy balance. The timescale is by the year 2100. This information is translated through models of climate dynamics and used to make projections of how much the Earth will heat as a result of increased greenhouse gases.

The projections, models and scenarios used to forecast the impacts of climate change carry some level of uncertainty. The particular uncertainty associated with climate change and health relates to a combination of factors linked to the clarity of the climate models as well as the unpredictability of natural events and human decision- making. Some of these factors include: natural variability, human impacts such as future emissions and land use, imperfect scientific knowledge, and the reliability of modeling tools. The uncertainty of the science has multiple dimensions tied to the lack of historical and current data, a limited understanding of regional climate dynamics and challenges in scaling down global models into regional models.

To manage this uncertainty, IPCC AR5 devised a standardized approach to analyzing evidence and communicating its findings. This standardization brings rigor and consistency to the process, enabling the comparison of a wide diversity of research, data and other information. To support decision-making, IPCC describes its findings with a common language. In particular, AR5 relies on two metrics to express certainty:

- Confidence in a finding is based on the type, amount, quality and consistency of evidence, together with the degree of agreement. Confidence is expressed qualitatively.
- Uncertainty is quantified and expressed as a probability.

This terminology is important in understanding AR5's use of scenarios on possible future events. Each of these scenarios is discussed with a confidence rating.



IPCC's framework for expressing certainty

Likelihood Terminology	Likelihood of the occurrence/outcome
Virtually certain	> 99% probability
Extremely likely	> 95% probability
Very likely	> 90% probability
Likely	> 66% probability
More likely than not	> 50% probability
About as likely as not	33 to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Extremely unlikely	< 5% probability
Exceptionally unlikely	< 1% probability

Source: Adapted from USAID 2017.

WHAT IS BEING DONE TO MANAGE HEAT RISK?

HIGHLIGHTS

- A diversity of efforts to better understand and manage the risks of extreme heat have emerged in the wake of recent and deadly heat waves around the world.
- The ability to forecast extreme heat has improved substantially in recent years, allowing for advanced preparedness through the development of heat early warning systems (HEWSs).
- Heat-health action plans (HHAPs) are useful frameworks that have mitigated the negative impacts of heat waves in many parts of the world by communicating the dangers of extreme heat and recommending risk-reduction and adaptation activities.

Many countries, cities and communities are taking steps to manage and prevent the impacts of extreme heat. As of August 2017, the Global Heat Health Information Network (GHHIN) identified 47 countries with national or subnational heat action plans that, to varying levels of detail, lay out a framework for mitigating the negative impacts of heat waves on human health (see Annex A). The majority of experience in addressing heat waves is from the global north, but nascent and important interventions in the Southern Hemisphere and developing world are increasing. These responses can be categorized as:

- **Advancing preparedness,** both in improving the science of forecasting extreme heat and in developing heat-health action plans (HHAPs) with early warning systems. Advancing preparedness also means investing in vulnerability assessments and research to inform risk management and improve local responses to heat waves.
- **Improving heat interventions** by prioritizing cross-sectoral collaboration and investing in training and capacity building for health officials and health workers, ranging from national health ministry officials to hospital staff, ambulance providers, health clinic staff and emergency management authorities.

This section highlights some of the recent efforts to improve local heat interventions through coordinated institutional activities with special emphasis placed on experiences in the developing world.

ADVANCING PREPAREDNESS

FORECASTING EXTREME HEAT

Forecasting extreme heat with high skill would inform health services when and where to establish cooling centers for the most vulnerable, and utilities could plan for increased electricity demand. Fortunately, forecast methods can predict temperature extremes in the short-term weather (i.e., 3 to 10 days) across many regions of the world, based on atmospheric processes (namely, a high-pressure system), sea surface temperatures, soil moisture, and, most importantly, a historical record (derived from station-level data) from which to infer the influence of these factors on extreme heat. For example, a retrospective analysis of the 2015 heat wave in Karachi, Pakistan, killing 1,200 people and leaving 40,000 suffering from heat stroke and heat exhaustion, showed that high humidity levels combined with vortex (low pressure) areas developing over the North Arabian Sea were drivers of the crisis (Singh Khadka 2015).

Nevertheless, many challenges remain in the science of forecasting heat waves. This is due to:

- **Limitations in the available observational record**. Without reliable, long-term observational data, forecasts are unable to draw on a historical record to evaluate the interaction between extreme events and factors such as those mentioned above. Forecast accuracy across regions and localities will be limited where *in situ* observations (temperature stations) are themselves limited or where remotely sensed data cannot capture the requisite resolution of an area or region. For example, many islands are too small to be accurately represented at the resolution of global models, and heat waves can be extremely localized (de Perez et al. 2018).
- **Lack of contextual information**. Differences in land cover type and architecture affect local temperature and how hot it feels even within a small area, but many countries lack extensive networks of weather observation stations that can provide this level of detail about temperature. Temperature monitoring sites are often located outside of city centers, meaning that point measurements do not necessarily reflect the true air temperature of urban areas. Estimates of health impacts based on such data may underestimate the impact of heat on public health (Heaviside et al. 2016).
- **Poorly resolved or understood local and regional feedback processes driving extreme events.** Understanding these processes is necessary to improve forecasts. For example, increased surface evaporation from water bodies could amplify heat waves, and these dynamics are poorly studied at the local level due in part to a paucity of data at various spatial resolutions. Nevertheless, remote-sensing technologies have improved significantly in recent years and are now sufficiently fine-grained to map local vulnerability. These technologies can map surface temperatures and UHI effects for neighborhoods, indicating where city greening and other urban cooling measures could be most effective, and alerting public health authorities to populations that may be at greatest risk of heat waves (Luber & McGeehin 2008).

WARNING SYSTEMS

According to the WMO/WHO's Guidance on Warning Systems Development (2015), "The primary objective of a warning system is to empower individuals and communities to respond timely and appropriately to the hazards in order to reduce the risk of death, injury, property loss and damage." Heat wave early warning systems (HEWSs) include core components of weather forecasting, alerts triggered by threshold temperatures and warning messages to the public. HEWSs are built on historical relationships between health impacts and the thermal environment and generally designed for a broad population. HEWSs commonly use forecasts of weather parameters, namely temperature, humidity and wind speed, with a timespan that provides advance warning. HEWSs require:

- **Risk knowledge** that is based on an understanding of the physical factors that lead to heat waves and that takes into account people's exposure to risk through natural hazards and social vulnerabilities.
- **A monitoring and alert system** to inform stakeholders and actors who will make sure people know what to do when a heat wave hits.

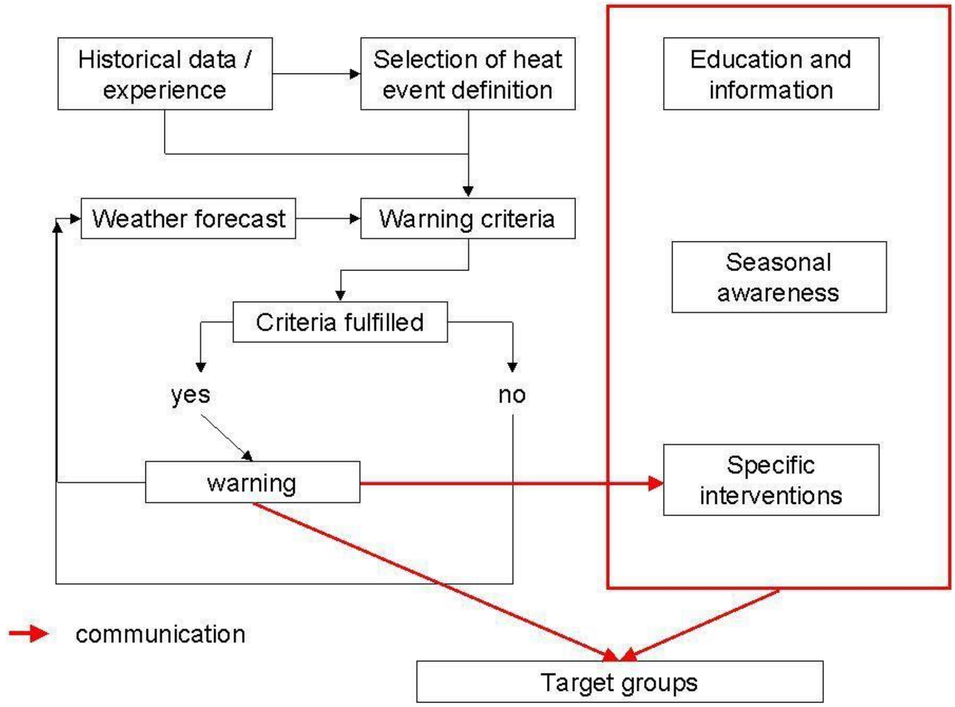
What constitutes a heat wave alert?

A review of operational and experimental HEWSs reveals that they range in complexity (see Annex A). Threshold indicators to determine the intensity of the hazard and potential impacts may be absolute (e.g., a maximum temperature) or relative (e.g., a percentile of the temperature distribution), and may use simple (e.g., maximum temperature) or more complex metrics, such as synoptic air masses.

In some cases, HEWSs employ metrics in addition to temperature thresholds to determine the severity of a heat wave. Measures that include humidity, such as apparent temperature (AT), are often used in areas with highly variable atmospheric moisture, where temperature alone may not accurately represent how weather conditions feel (WMO & WHO 2015).

The most common threshold is temperature exceeding a maximum on a given day or for a number of days. For example, Portugal's Watch Warning System for Heatwaves issues warnings after two consecutive days of 32°C. As with most weather and climate hazards, communication of the risks of extreme heat and how to prepare for it is an essential element of any HEWS. Decision-makers and the general public rely on not only the timing, accessibility and clarity of a HEWS alert, but also guidance on actions they need to take depending on the type and severity of the alert. The red lines in Figure 7 illustrate how information moves through a HEWS to inform target groups.

Figure 7. HEWS information flows



Source: WMO & WHO 2015

While specific thresholds vary across HEWSs, most employ a three-tier alert system based on threshold severity:

Advisory or notification (Severe)	● Signal of warmer-than-average weather expected, potentially problematic for some groups (e.g., elderly, outdoor workers) ● Notification to health care providers to anticipate potential increase in admissions and larger caseload
Alert (Very Severe)	● Cue to mobilize human and financial resources to initiate heat response interventions (e.g., open cooling centers, communicate best practices for staying cool through information and education campaigns)
Warning (Extreme)	● Cue to prioritize critical services (e.g., power supply at hospitals, water provision in vulnerable neighborhoods)

When issuing alerts, it is essential to pair them with tailored information so that vulnerable groups like the elderly, the chronically ill or outdoor workers can implement recommended coping actions. The warnings should consider specific physical and social vulnerabilities of target groups in order to convey appropriate and feasible actions. In a warming climate, where vulnerability patterns shift over time, HEWSs will also need to adapt to changing conditions to manage and reduce risk for the public as a whole and vulnerable groups.

How are HEWSs being developed around the world?

Coordinating and forecasting capacities often influence how these systems are designed and operated. In many cases, HEWSs are developed and relevant actions are taken at a municipal scale, but these systems rely on national-level meteorological data. Multicountry systems are also being developed, either in tandem with national systems or as regional initiatives. In West Africa, the ACASIS project has worked with health and hydrometeorological institutions in Burkina Faso and Senegal to establish an early warning system for Sahelian heat waves with a view to strengthen capacity for heat-health responses. Recognizing the cross-border dimensions of hazards like heat waves, the South-East European Multi-Hazard Early Warning Advisory System, which brings together more than a dozen countries across southeastern Europe and parts of the Middle East, will provide a regional platform for cooperation and capacity building in climate services for risk management.

What is the role of HEWSs within broader risk management and planning?

A HEWS is just one component, sometimes nested within an HHAP, under the broader umbrella of disaster risk management. An HHAP includes a host of actions that are taken by different stakeholders to anticipate and manage risks of extreme heat over time. In addition to incorporating a HEWS, an HHAP requires:

- A lead body that oversees implementation and coordination across sectors;
- A communication plan that includes strategies for preparing local operators, health systems and social services as well as strategies to raise public awareness of the dangers of extreme heat and ways appropriate actions to take to stay cool;
- Specific actions to support vulnerable individuals and communities, such as hotspot mapping to identify populations living in UHIs and expanding access to cooling technology and water;
- Steps for real-time surveillance, evaluation and feedback; and
- Considerations of long-term urban design and planning to reduce exposure (WMO & WHO 2015).

Most HEWSs are active for only a portion of the year, typically during summer months when temperatures are warmest. For example, Ahmedabad’s heat alert system is activated at the start of March and operates through July. A large body of research has shown that heat vulnerability varies throughout the season, with higher vulnerability earlier in the warm season (WMO & WHO 2015). As such, an HHAP may prescribe actions for different stages of the season (described in further detail in the next section). However, with increasing climate variability, the period during which the HEWS is active may need to be reassessed to consider less predictable seasonal effects (Lowe et al. 2011). Research to inform upgrades to a HEWS, and necessary investments to adapt HEWSs, are therefore important considerations within an HHAP.

IMPROVING RESPONSES

HEAT-HEALTH ACTION PLANS

Heat alerts disseminated via HEWSs are important for mitigating the negative impacts of heat waves, but insufficient on their own. Actions to prepare for and respond to a heat wave take place at multiple scales, including:

- **Individual**: Wear appropriate clothes, seek cooler environments, drink adequate quantities of nonalcoholic fluids, stay informed about the weather conditions, and check on vulnerable people, such as older adults, the disabled or the homebound.
- **Communities**: Provide community service announcements and solutions in anticipation of increased cooling needs. In resource-constrained settings, ecosystem approaches, such as introducing trees for shade, are lower-cost solutions to help anticipate increasing cooling needs.
- **Organizations and institutions** (such as hydrometeorological services and departments and ministries of health): Set thresholds for heat waves and implement early warning and response centers. Electrical utility companies can ensure power is maintained to critical facilities, such as care homes, and to vulnerable individuals.
- **Local and national policy:** Create a supportive policy environment for an effective warning and response system. In the longer term, policies will be needed for changes in requirements for housing and the built environment (e.g., increasing green spaces) to facilitate adjustment to higher temperatures with climate change.

Planning for heat waves is not limited to a defined heat season, but is rather a comprehensive, year-round approach to risk management. Planning requires, first and foremost, strengthening coordination among health agencies, social services, emergency management authorities, and hydrometeorological services (see Table 2). It also includes raising awareness of the dangers of extreme heat, improving health surveillance systems, conducting vulnerability assessments to inform heat interventions, and developing longer-term strategies for reducing heat risk.

Table 2. Institutional arrangements to support effective planning for heat waves

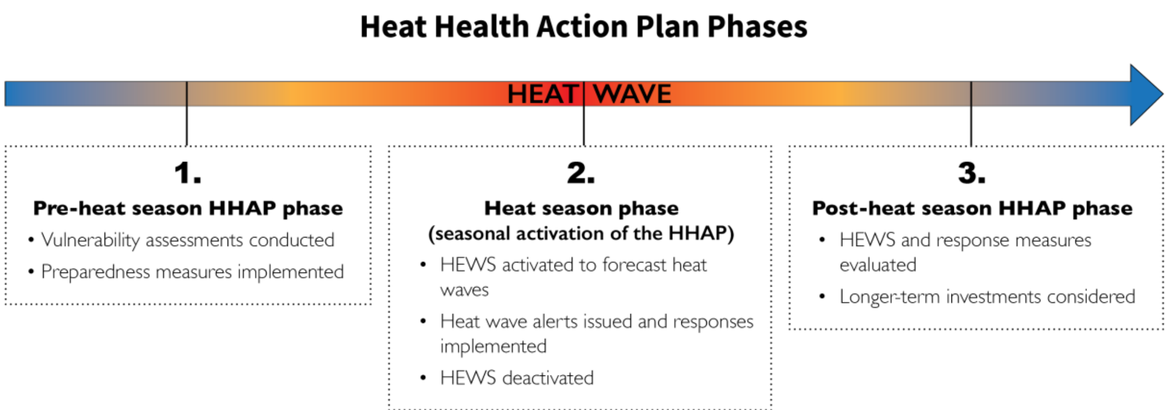
Sector	Example lead institution (national level)	Roles and responsibility
Transport & Infrastructure	• National Hydrometeorological Service	• Provides and disseminates forecast information • Transport and infrastructure agencies ensure access points remain passable to facilitate efficiency of first responders
Health	• Ministry of Health and Family Welfare	• Ensures care of heat illness and supports preparedness, monitoring and surveillance
Environment	• Ministry of Environment and Forest	• Helps reduce climate risk in alignment with heat reduction
	• Ministry of Earth Sciences	• Coordinates with disaster management authorities to ensure integration of heat data within larger preparedness and contingency systems
Water	• Ministry of Water Resources	• Helps manage water resources in alignment with heat risks
Disaster Management	• National Disaster Management Authority	• Responds to and coordinates efforts during heat waves

Urban	• Ministry of Urban Development	• Addresses heat-sensitive urban planning, infrastructure, services and management

Source: Adapted from Roadmap for Planning Heatwave Management in India (TARU 2016)

HHAPs, which have been developed in many parts of the world, are useful frameworks to institutionalize and operationalize heat risk management. HHAPs typically include three phases—pre-heat season, heat season and post-heat season—each with its own set of risk-reducing actions (Figure 8).

Figure 8. HHAP Phases



The **pre-heat season** phase of an HHAP informs the public and medical staff and pre-positions resources before the hottest temperatures are expected. In Ahmedabad this includes public awareness campaigns and training programs for medical staff at hospitals and urban health centers (see box below on Ahmedabad's heat action plan). In neighboring Pakistan, Karachi uses geographic information system (GIS) maps to identify hotspots where first-response centers can be set up to provide immediate first aid to the most vulnerable residents at their doorstep, which reduces intake flows at hospitals. Cities may advise residents to "heat-proof" their homes by hanging shades or draperies and/or installing awnings on windows that receive sunlight, purchasing an air conditioner (electric fans where appropriate), or painting their roofs white. Also, during the pre-heat season phase, cities may consider precautionary adjustments to business hours, work schedules or expected "heat curfews" and ensure that contingency measures (e.g., coordinated responses of ambulance and emergency services, hospitals and other organizations providing care) are clear and well-established.

During the **heat season** phase of an HHAP, the HEWS becomes critical to guide individual and community heat interventions. Governments typically disseminate messages and guidance to the public about keeping cool and seeking medical care if they show signs of heat illness. Concurrently, heat wave warnings are issued via radio, television, SMS, pamphlets, posters and billboards. During high-alert periods, local authorities set up cooling centers in, for example, public buildings, malls, places of worship or temporary shelters. Local authorities may also expand access to cool drinking water through neighborhood or city distribution networks and reduce nonessential water use (i.e., other than for drinking and keeping cool).

The **post-heat** season phase allows for evaluation of systems and institutional effectiveness to identify gaps in preparing for and responding to heat waves. The HEWS should be examined at all stages—from the forecast to the alerts to the heat interventions. During the post-heat season phase, stakeholders also consider medium- and longer-term initiatives and investments to reduce heat risk, such as adjustments to urban planning and green infrastructure.

Table 3 summarizes types of heat interventions implemented across different HHAPs.

Table 3. Types of heat interventions

Reducing vulnerability (Implementing actions to reduce heat exposure and care for heat-related illness)	**Developing Early Warning Systems**	**Addressing future risks**
China: Local centers for disease control roll out health education on how to read early warning information and how to protect health during heat waves through posters, fliers, internet, newspapers, etc. (Harbin, Nanjing, Shenzhen and Chongqing pilot HEWSs)	***Southern Africa Development Community (SADC)***: Publish regional heat season outlook to provide notice of potential heat waves to national health departments and disaster management authorities (SADC Climate Services Centre)	***England*** and ***Pakistan***: Conduct hotspot mapping to identify spatial dimension of vulnerability patterns and at-risk populations (Heatwave Plan for England/Karachi Heatwave Management Plan)
India: Train medical professionals to offer heat-specific advice on display of symptoms, diagnosis and treatment, and reduce mortality/morbidity through standard surveillance protocols (Ahmedabad Heat Action Plan)	***China***: Activate synoptic, four-tier warning system for heat during the summer season (Shanghai Heat/Health Warning System)	***India*** and ***United States***: Expand "cool roofs" program by painting roofs white or retrofitting roofs with more reflective materials (Ahmedabad Heat Action Plan/Berkeley, California Climate Action Plan)
Pakistan (Karachi): Update registry of volunteers who can be mobilized quickly, as well as designated charities, NGOs and hospitals to supply the city with ambulances, paramedics and supplies (Karachi Heatwave Management Plan)	***Spain*** and ***United States***: Activate a heat hotline for people to call; collaborate with pharmacies and clinics to share advice and information (Catalonia Action Plan to Prevent the Effects of a Heat Wave on Health/Philadelphia Excessive Heat Public Safety Plan)	***United States***: Maintain tree cover (500,000 trees) and incentivize green roofs through grants (Chicago Climate Action Plan)
Belgium and ***Hungary***: Communicate compound risks from high ozone levels and/or fires with heat wave alerts (Heat Wave and Peak Ozone Plan/Tatabánya Heat and UV-Alert System)		
France: Require institutions for the elderly to have at least one cooling center during periods of high heat (National Heat Wave Plan)		

AHMEDABAD'S HEAT WAVE ACTION PLAN: A MODEL FOR CITIES IN INDIA AND BEYOND

In May 2010, temperatures in Ahmedabad, India, soared to 46.8°C, causing a startling spike in heat-related illnesses and deaths. This catastrophic episode of extreme heat, which claimed 1,344 lives, marked a turning point for the city, leading the Ahmedabad Municipal Corporation (AMC) to partner with health, environment and academic stakeholders to develop a comprehensive preparedness and response strategy. Now in place, Ahmedabad's heat wave action plan defines critical heat periods and provides a framework for mobilizing resources and a protocol which assigns responsibility for priority actions at specified heat thresholds.

To develop its plan, AMC and its partners:

- Conducted epidemiological analysis of the health effects of heat exposure among Ahmedabad's residents
- Examined specific vulnerability factors among slum dwellers and highly exposed occupational workers
- Explored longer-term forecasting options to allow for earlier warnings
- Developed heat illness management training for health professionals
- Reviewed heat action plans from around the world

The HEWS component of the plan is activated at the start of the hot season in March and operates through July. The Ahmedabad office of the India Meteorological Department provides real-time weather data and a seven-day probabilistic forecast of maximum temperature, while a designated AMC Nodal Officer is responsible for activating alerts and managing responses when temperatures exceed the thresholds (see table below). This includes activating cooling centers (temples, public buildings, malls) or setting up temporary night shelters for those without access to water and/or electricity, keeping night shelters open for migratory populations, and imposing a ban on nonessential water use in accordance with the city's protocol during any water shortage.

Alert Category	Alert Name	Temperature Threshold (°C)
RED ALERT	Extreme Heat Alert Day	≥ 45°C
ORANGE ALERT	Heat Alert Day	43.1°C – 44.9°C
YELLOW ALERT	Hot Day Advisory	41.1°C- 43°C
WHITE	No Alert	≤41°C

During a heat alert, the AMC press officer issues warnings via radio broadcasts and via text or WhatsApp messages in collaboration with telecom carriers. Temperature forecasts and Orange and Red alerts are displayed on LED boards around the city. AMC health department workers monitor hospital admissions and emergency case records to track heat-related morbidity and mortality. They also ensure that stocks of rehydration solution and other supplies are available to treat patients suffering from heat stroke.

Municipalities across India, such as Nagpur, Surat and Bhubaneswar, took note of Ahmedabad's success in minimizing heat-related deaths, and plans to expand the model to regional and the national level have already shown encouraging results. India's National Disaster Management Authority reported just 13 heat-related deaths for the 2018 heat season (March–July), compared with 2,422 in 2015 and 250 in 2017 (Dewan 2018).

In Pakistan, Karachi has modeled elements of its own heat action plan on Ahmedabad's. It has established a registry of volunteers who can be mobilized quickly, as well as designated charities, NGOs and hospitals to supply the city with ambulances, paramedics and supplies.

Sources: Knowlton et al. 2014, Ebrahim 2018

MOVING FORWARD

HIGHLIGHTS

- The last decade of investments, which focused on identifying thresholds for adverse health outcomes, vulnerable groups, and effective heat interventions, has produced valuable information for risk management, but the research investment has been uneven, with the most emphasis on specifying thresholds.
- Relatively little emphasis has been placed on assessing the effectiveness of HEWSs at the local level.
- To confront the increasing number and intensity of heat waves, countries will need to work across sectors to advance preparedness and improve heat interventions by adopting iterative approaches to risk management informed by more systematic evaluation.

Much has been done to begin to understand the relationship between a warming climate, heat waves and their impact on human health. Increases in injuries, illnesses and deaths from high temperatures resulted in increased research investments focused on identifying 1) thresholds for adverse health outcomes; 2) populations particularly vulnerable to heat exposures; and 3) effective interventions to prevent adverse health outcomes. The definition and communication of thresholds is just one aspect of improving heat risk management, and there is an opportunity now to continue identifying, piloting and evaluating appropriate interventions and response mechanisms. Several networks and communities of practice have begun to coalesce around risk management practices for addressing extreme heat. Networks like the Global Cool Cities Alliance, Cool Cities Network and the GHHIN provide opportunities for knowledge exchange that can lead to broader learning and identification of longer-term interventions and investments that can be brought to scale. Advancing preparedness, improving heat interventions and ultimately encouraging adaptation must build on the research reported here and elsewhere.

ADVANCING PREPAREDNESS

To date, significant effort has been dedicated to understanding, monitoring and adjusting the precision of local heat thresholds in order to establish HEWSs and HHAPs. One study showed that although awareness of heat warnings in the United States was almost universal, only about half of survey respondents made any changes in their behavior; the main response was avoiding the outdoors (Sheridan 2007). Access to air conditioning was nearly universal, yet over one-third of respondents stated that the costs of energy were considered in terms of how long or whether the air conditioner was turned on. These results are underscored by the description of the 2018 Japanese heat wave; the deaths and hospitalizations occurred even though the Japan Meteorological Agency issues extreme high-temperature forecasts. Furthermore, of the more than 160 heat stress indices proposed for various thermal environments since 1905, no single index has gained universal acceptance, despite evidence pointing to a high correlation among the most widely used thermal indicators (de Freitas & Griorgrieva 2015; Barnett et al. 2010; Urban and Kysely 2014). This suggests that their predictive ability is the same. In New York City, for example, the maximum heat index performed similarly to alternative and more complex metrics in estimating mortality risk during hot weather (Metzger et al. 2010).

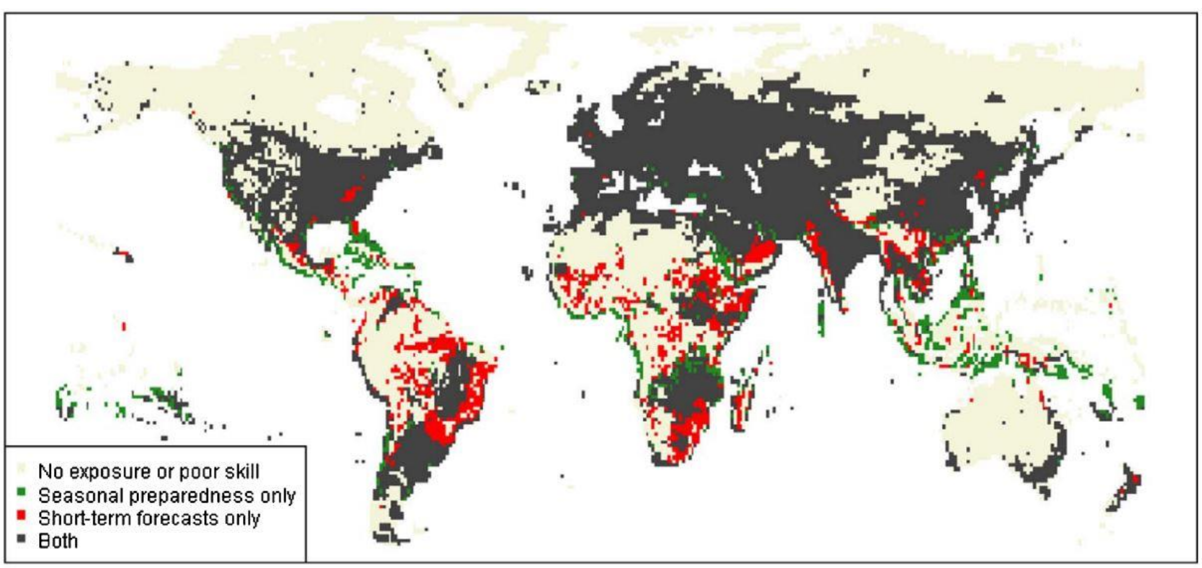
Surveillance and, increasingly, evaluation and iterative management of HEWSs and context-specific heat interventions are vital to early warning and risk management. In particular, as climate variability and change increase, health and hydrometeorological stakeholders will need to:

- Clearly define factors contributing to vulnerability and risk from heat
- Understand changes in the distribution of extreme heat over a specific region
- Develop baselines and collect and monitor mortality and morbidity data
- Periodically assess local vulnerabilities to identify populations that might be at increased risk and understand where they are located
- Develop context-specific interventions
- Measure and evaluate progress
- Scaling up investments and building awareness of the issue in regions, such as West, East and Southern Africa, where HEWs are sparse, and where awareness is limited.

UNDERSTANDING CHANGES IN THE DISTRIBUTION OF EXTREME HEAT

As temperatures rise, improved forecasting skill is needed, along with a better understanding of changes in the distribution of extreme heat over different regions and seasonal risk patterns (WMO & WHO 2015; Hess & Ebi 2016). Emerging studies of areas where seasonal

Figure 9. Forecast potential to improve global heat wave preparedness



preparedness and/or HEWSs could be beneficial (Figure 9) should be informed by locally calibrated weather observations and local morbidity and mortality data.

Source: de Perez et al. 2018

Note: This image shows what type of preparation might be possible for heat waves based on current forecast skill. Black areas offer both skillful short-term forecasts and seasonality of heat waves in either the NOAA or European Centre for Medium-Range Weather Forecast (ECMWF) models. Green areas are regions where only seasonality could be used for preparation. Red areas are regions where only skillful short-term forecasts can be used for preparation. Cream-colored areas have no exposure or have neither distinct climatology nor forecast skill.

DEVELOPING MORTALITY AND MORBIDITY BASELINES TO IMPROVE WARNING THRESHOLDS AND RESPONSES

More concerted efforts to collect metrics on specific health indicators should be a priority for establishing an adequate baseline on which to build, monitor, evaluate and modify alerts and interventions as changes in climate influence health impacts. The most widely used indicator, excess mortality, compares the observed mortality during and following a heat wave with historical mortality rates. Table 4 summarizes other common indicators and operational considerations for data collection.

Table 4. Common surveillance indicators for heat-related mortality

Indicators	Definitions	Data collection timeframe	Operational considerations
Excess mortality	• Number of excess deaths per 1,000 deaths, attributable to each 0.3°C increase in the same day's summer temperature (Bobb et al. 2014)	• Requires monitoring during a heat wave, and analysis following a heat wave	• Requires a daily baseline for mortality • Compares daily baseline to number of deaths during and after a heat wave • Captures expected decrease in deaths post-heat wave
Heat mortality (also referred to as "heat-related deaths")	• Annual rate for deaths classified by medical professionals as "heat-related" based on death certificate records (US Environmental Protection Agency)	• Following a heat wave	• Requires a clear definition of heat-related death that includes deaths caused by heat or cases in which heat significantly contributed (Donoghue et al. 1997) • Underestimates true mortality • Often quicker to ascertain than excess mortality
Excess hospital visits	• Proxy indicator to assess morbidity and mortality and the overall burden on the health system	• Requires monitoring during a heat wave, and analysis following a heat wave	• Requires sufficient data (e.g., 30 years) on daily visits to the hospital to create an average daily baseline • Requires infrastructure and personnel to document number and nature of hospital visits during a heat wave • Compares the baseline to the number of hospital visits during a heat wave
Excess emergency calls	• Proxy indicator to assess morbidity and mortality and the overall burden on the health system	• Requires monitoring during a heat wave, and analysis following a heat wave	• Requires sufficient data on emergency calls to create a daily baseline • Requires infrastructure and personnel to document number and nature of emergency calls during a heat wave • Compares the number of calls during a heat wave with the daily baseline for that time of year

IMPROVING HEAT INTERVENTIONS AND BUILDING RESILIENCE

Once the definition of a heat wave is defined for a city or region, warning and response systems need to identify the particularly susceptible groups, including their location; combine warnings with an effective notification and response program; and specify evaluation criteria, such as acceptability, timeliness and sensitivity and specificity (WMO & WHO 2015).

ASSESSING LOCAL VULNERABILITIES TO IDENTIFY AT-RISK POPULATIONS

HHAPs must be adaptive and address a variety of factors: heat risk characterization and communication, evolving profiles of exposure to extreme heat, changing vulnerability that will affect response plans, and changing communications about extreme heat events and appropriate public health responses (Hess & Ebi 2016). Because needs and capacities are dependent on the local context, carrying out comprehensive vulnerability and adaptation assessments that incorporate local practitioner, community member, decision-maker, and researcher opinions is vital to the development of a locally suited HHAP. When assessing vulnerability, it is important to also take into account the different roles and responsibilities of women, men, girls, and boys, and members of other vulnerable communities.

DEVELOPING CONTEXT-SPECIFIC INTERVENTIONS

Health communication strategies are an important consideration because HEWSs typically include general public education and awareness, such as guidance on actions to reduce personal health risks, and sometimes targeted risk communication and other activities aimed at high-risk populations (Hess & Ebi 2016). Additionally, an understanding of local characteristics can help HHAP actors identify entry points to communicate and implement context-specific heat interventions. Table 5 highlights some of the constraints and opportunities of rolling out heat interventions in urban and rural settings.

Identifying who is vulnerable and where they are located

A workshop in India following Ahmedabad's 2010 heat wave highlighted the potential high burden of heat-related morbidity and mortality of infants in non-climate-controlled buildings, such as hospitals. An analysis in a non-air-conditioned hospital for the months of April–June 2010 found there were 24 neonatal intensive care unit (NICU) heat-related admissions, compared with eight and four in 2009 and 2011, respectively. Above 42°C, each one degree increase in daily maximum temperature was associated with a 43-percent increase in heat-related admissions. Moving the maternity ward from the top floor to a lower floor in the hospital after the 2010 heat wave led to a decrease in the number of NICU admissions.

Sources: Kakkad et al. 2014

Table 5. Challenges and opportunities for introducing context-specific heat interventions

Context	Challenges	Opportunities
Rural	• Limited access to basic services • Limited access to basic infrastructure such as electricity for cooling technology • Lower socioeconomic status, reduced ability for adaptive actions • Greater distance from emergency and health services • Limited access to communication platforms (TV, computer, etc.) through which warnings might be issued	• Greater access to green space • Greater knowledge of traditional cooling methods • Greater social cohesion
Urban	• UHI and higher nighttime temperatures • Less access or inequitable access to green space • Reduced social cohesion • Overburdened infrastructure • Poor air quality • Limited access to infrastructure and services for people living in informal settlements	• Greater accessibility to adaptive services/ cooling centers • Greater access to health services • Greater human and financial capacity to implement preparedness and management programs • Greater access to communication platforms

Expanding access to cooling infrastructure must be addressed within HHAPs in the near term to manage increasing heat risks. There is an opportunity now to build more resilient urban spaces. For example, 75 percent of the buildings required for India's population in 2030 have not yet been built, which is an opportunity to incorporate passive cooling and lay out urban developments to use district cooling. Many cities across the world have begun cool roof programs, which, as noted above, can reduce indoor temperatures by 20 percent. In resource-constrained and rural areas, low-cost innovations (some of which borrow from traditional practices) can meet cooling needs. For example, simple evaporative coolers using wet sand between two clay containers can be constructed for less than US$2 and are able to prolong the shelf life of fruits and vegetables from as little as two days to as much as 20 days (Sustainable Energy for All 2018). Such opportunities hinge on planning and investment underpinned by community and stakeholder engagement, economic development, disaster risk management and service provision.

MEASURING AND EVALUATING PROGRESS

In places where they are implemented, HEWSs and HHAPs have mitigated the negative impacts of heat waves by facilitating adaptation, but more systematic and robust evaluation of specific interventions is needed. In addition, increasing climate variability poses challenges infrequently addressed in HHAPs. These challenges include changes in the onset, duration and intensity of extreme temperatures, and changes over time in the relationships between temperature and health outcomes. Iterative management should be routine for a HEWS, and while many HHAPs undergo annual updates, more thorough revision of HEWSs and HHAPs should occur with greater frequency.

While there is a wide range of interventions undertaken as part of heat wave response plans, there is limited evidence of the effectiveness of individual interventions. Until research identifies which interventions are effective under which circumstances, heat wave responses can build on measures to manage hot days in the region of interest. As emphasized above, local authorities must identify the population groups most at risk and be mindful of the social and cultural appropriateness of interventions.

CONCLUSION

The consequences of the heat waves around the world today are a warning of what is to come. Investment in research and proactive, climate-sensitive measures can help mitigate damage and prevent loss of life. As evidenced by the limited but growing data on HEWS and HHAP effectiveness, heat-related deaths and illnesses are largely preventable. The effectiveness of HHAPs also hinges on a sound institutional foundation that enables multisectoral collaboration. To support HHAPs, opportunities for capacity development should be identified, created and reinforced for a range of actors, including public health and health care professionals, the general public and decision-makers and policymakers within the health sector and across relevant agencies, such as national hydrometeorological services and disaster management agencies. This report summarizes the global experience managing extreme heat. More concerted effort is needed to develop tools and climate- resilient systems to ensure the health of people in the face of a rapidly warming world.

ANNEX A: RAPID INVENTORY OF GLOBAL HEWSs/HHAPs

Below is an abbreviated inventory of operational HEWSs and HHAPs around the world. A more detailed and exhaustive inventory of global HEWSs and HHAPs compiled by the GHHIN can be found on http://ghhin.org/.

HEWS/HHAP	Country	Level	Year developed	Heat wave alert coordinating body	Trigger indicator	Threshold trigger	Lead time	Indicator monitoring/ forecasting body
Asia								
Ahmedabad Heat Action Plan	India	Municipal	2013	Ahmedabad Municipal Corporation	Tmax	1 day ≥ 41.1° C	5–7 days	Indian Meteorological Centre (Ahmedabad)
Heat Wave Action Plan for Odisha	India	State/Regional	2016	Odisha State Disaster Management Authority	Tmax	2 days ≥ 40° C	5 days	Indian Meteorological Department
Shanghai Heat/Health Warning System	China	Municipal	2001	Shanghai Municipal Civil Defense Office	Tmax, airmass	3 consecutive days ≥ 35°C	3 days	Shanghai Meteorological Bureau
Europe								
Heat Wave and Peak Ozone Plan	Belgium	National	2003	Crisis Center of the Federal Public Service	Tmin, Tmax; ozone	3-day average ≥ 18°C low; ≥ 30°C high; average hourly concentration > 240 µg/m3 ozone	5 days (temperature); 2 days (ozone)	Royal Meteorological Institute
Tatabánya Heat and UV-Alert System	Hungary	Municipal	2008	Office of the Mayor, Tatabánya	Tmean	Daily average ≥ 25 °C	3 days	Hungarian Meteorological Service

Heatwave Plan for England	England	National	2004	National Severe Weather Warning Service	Tmin, Tmax	2 consecutive days daytime ≥ 30°C; nighttime ≥ 15°C (regional average)	2–3 days	UK Met Office
North and South America								
Surveillance System for the Prevention of Health Impacts from Extreme Weather Events (SUPREME)	Canada	State/Regional	2010	National Institute for Public Health –Quebec	Tmin, Tmax	3-day average ≥ 16–20°C low ≥ 31–33°C high	2–3 days	Environment Canada (Weather Service)
Napa County Excessive Heat Emergency Response Plan	United States	State	2008	Napa County Health and Human Services Agency	Heat index, airmass	3 consecutive days ≥ 40.5–43.3 °C (105–110°F heat index)	5–7 days	National Weather Service
Philadelphia Excessive Heat Public Safety Plan	United States	Municipal	1995	Philadelphia Department of Public Health	Heat index, airmass	3 consecutive days ≥ 95th percentile	3–7 days	National Weather Service
Sub-Saharan Africa								
Heatwave and Heat Spells Alert System (HSAS)	Southern African countries	Regional	Unknown	National health departments and disaster risk reduction agencies in affected countries	Tmax	≥ 2°C anomalies over long-term average temperatures	7 days	Southern African Development Community Climate Services Centre

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