Climate Change Adaptations to Safeguard Aluminium Industry Workers and their Communities

Evidence Review and Path Forward

CLIMATE RISK INSTITUTE

RSI

INTERNATIONAL ALUMINIUM

Climate change and human health risks are ubiquitous across the aluminium sector and related communities. Since a reliable labour force is essential for the operation and profitability of the industry, these risks need to be properly managed.

Executive Summary

- Climate change brings **generally warmer temperatures**, meaning that health and safety challenges typically associated with the tropics and sub-tropics such as **heat-related illnesses, vector-borne diseases, and drought-related impacts** will increasingly become issues for operations in other latitudes;
- Climate change also manifests as an **increased frequency of extreme weather events**, which can damage infrastructure and cause **serious injuries, deaths, and long-term mental health effects to the workforce and communities;**
- The increasing frequency likewise makes compound extreme events more likely, which may produce damage to such a degree that adaptation is not feasible, and an affected community may need to relocate permanently;
- Even gradual changes such as sea level rise, or long-standing drought, can **impact water supplies and food production** to the extent that a community can no longer be supported, leading to migration and potential conflict;
- **Adaptation options** include work practice measures that address health and safety impacts directly, such as providing shade or cooling for workers engaged in strenuous labour in high temperatures, or rest and rehydration breaks as needed;
- Other adaptation options include **hardening infrastructure or ensuring redundancy** so that some potential impacts of extreme events, for example, are averted. Ecosystem-based Adaptation, which passively protects the facility and people in the community and workplace, may be preferred to engineered or energy-intensive measures that may not be sustainable over years. This may include the use of shade trees or slope-stabilizing groundcover.

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Figures and Tables

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The Climate Change and Health Imperative

The aluminium sector is already feeling the effects of climate change and these effects are expected to increase in both scope and magnitude in the future. One of the most consequential effects will be the impact of climate change on the health of aluminium sector workers and their communities. Climate change is already affecting human health and is likely to take an especially large health-related toll in decades to come. Notably, the human health impacts of climate change will be most severe in many of the same regions, and specific locations, where the aluminium industry is most active – developing countries and equatorial regions – as well as among many of the populations most relied upon for labour – people of lower socioeconomic means and people living in small and remote communities.

Of all aluminium sector operations, surface mining is particularly sensitive to high precipitation events and temperature extremes – both of which are generally intensifying under climate change – while facilities reliant on ports can expect challenges related to rising sea levels. Current impacts include damage to infrastructure which affects supply chains, and reduced availability of water. These impacts make it challenging to continue operating while at the same time meeting strict sustainability requirements and a growing demand for product. Impacts to mines, infrastructure, and supply chains can affect worker and community health in many different ways, ranging from direct physical injury to mosquito and waterborne disease, psychological stress, and mental illness.

The refining and smelting operations of the primary aluminium industry also have climate sensitivities. These facilities and their associated communities can therefore expect impacts under climate change. Implications for worker and community health may include heat-related illnesses (including heat stroke), increased vector-borne disease, airborne and waterborne hazards, and extreme weather events, to name a few.

Climate change and human health risks are ubiquitous across the aluminium sector and related communities. Since a reliable labour force is essential for the operation and profitability of the industry, these risks need to be properly managed.

This document describes some of the health effects anticipated under climate change, as well as some adaptation measures that can be implemented by the private and/or public sector, to reduce impacts on workers, communities, and business. It begins with a brief overview of the problematic pace and magnitude of climate change and some of the characteristics that make it so potentially impactful for human health.

This document describes some of the health effects anticipated under climate change, as well as some adaptation measures that can be implemented by the private and/or public sector, to reduce impacts on workers, communities, and business.

The Earth under Climate Change

What is climate change? Climate change refers to a change in the properties of climate, for example temperature and precipitation, on the scale of decades or longer (IPCC, 2019). As climate can be considered an aggregate of weather (Fouque and Reeder, 2019), climate change can be experienced as an increase in the frequency of weather events that are outside the norm.

Warming trend. For example, taking the average global surface temperature over the 20th century as a baseline from which to measure anomalies, the years 1880 to 1940 were all colder-than-average, while the past 40 years have all been warmer-than-average, and this warmer-than-average trend is increasing as seen in Figure 1 below.

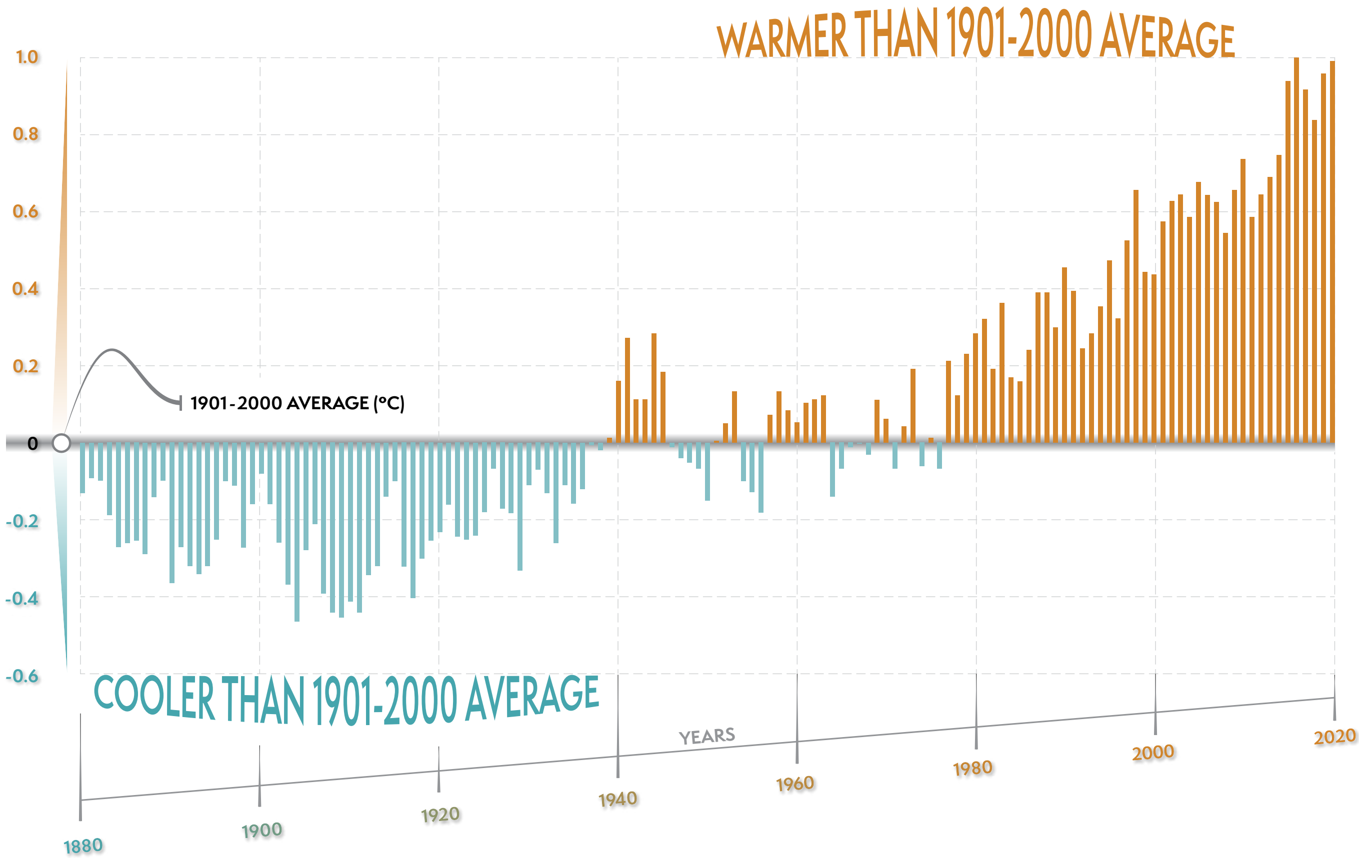


Figure 1. Anomalies in global average surface temperature as compared to the 20th century average. Source: NOAA (2021).

Photo by Dziana Hasanbekava from Pexels

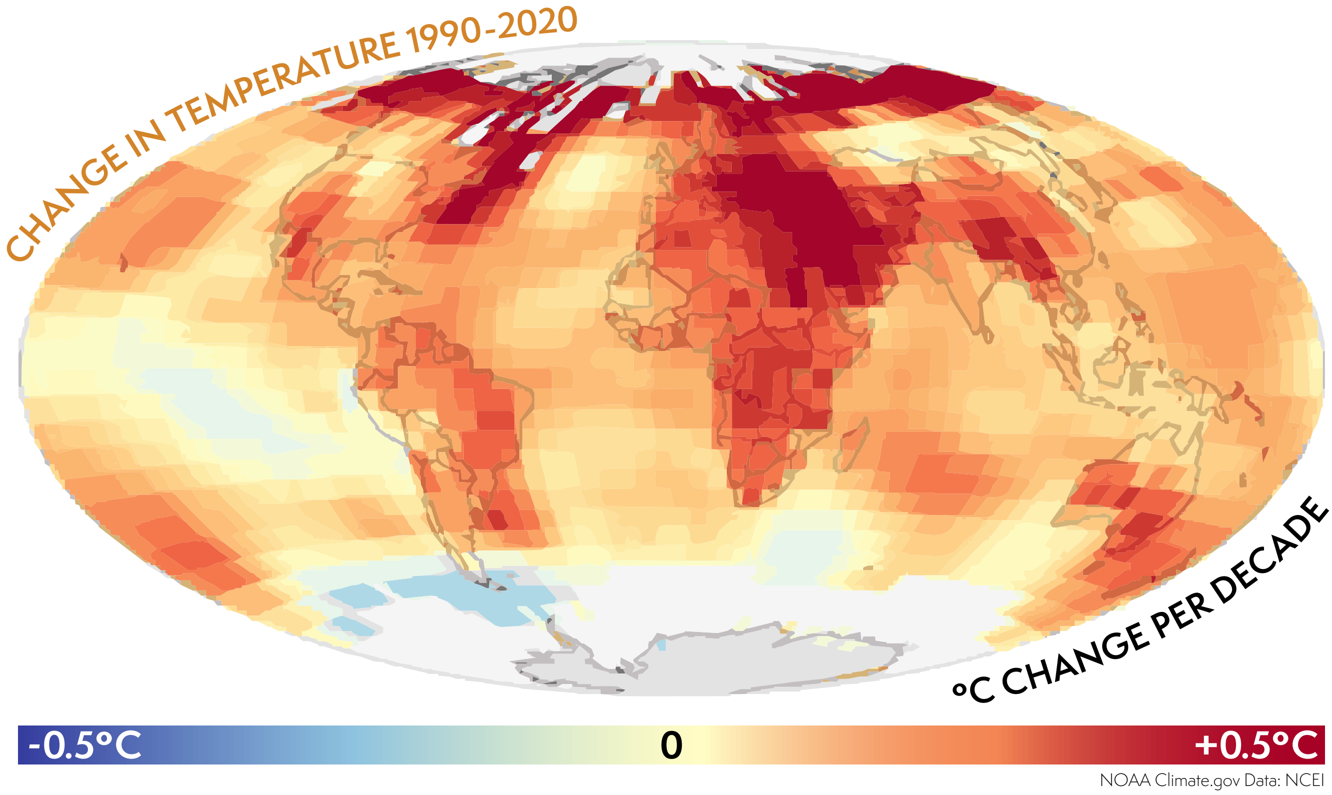


Figure 2. Global average surface temperature anomalies between 1990 and 2020, compared to the 20th century average. Source: NOAA (2021).

The warming trend over the past 30 years is most pronounced in certain regions of the world, such as the Arctic and the Middle East (Figure 2 above), and has produced an increase in the global average temperature of 1.1 to 1.2°C above the pre-industrial period. In general, land temperature will increase sooner and faster than water temperature since water can absorb more energy than land before showing temperature changes.

In fact, the ocean has absorbed more than 90% of the excess heat gained by the earth from 1971 to 2010; air temperatures would be much higher if this were not the case. This warming of the oceans, however, will lead to more frequent extreme weather events such as hurricanes/cyclones/typhoons.

In mid-June of 2021, 7 states in the western U.S. broke all-time maximum temperature records, with Death Valley, California reporting 53.3°C. That same month Lytton, B.C. set an all-time Canadian record with 46.1°C on June 27, then 47.5°C on June 28 followed by 49.5°C on June 29, and burned to the ground the following day (De Liberto, 2021; Lindsay and Dickson, 2021).

Increasing variability. Figure 2 above illustrates the change in global average temperature, but more damaging than this is the increased variability of weather and severity of extreme conditions.

Figure 3 on page 5 demonstrates this increased variability and severity of extremes. If climate change involved only a consistent 2°C increase in daily temperature, then the dotted curve representing our previous climate would shift to the right (for example, a current temperature range of between -30° to +30°C could become -28° to +32°C). Instead, extreme high temperatures are becoming more frequent (solid curve), while moderate temperatures become less frequent; the effect is an increase in the average temperature.

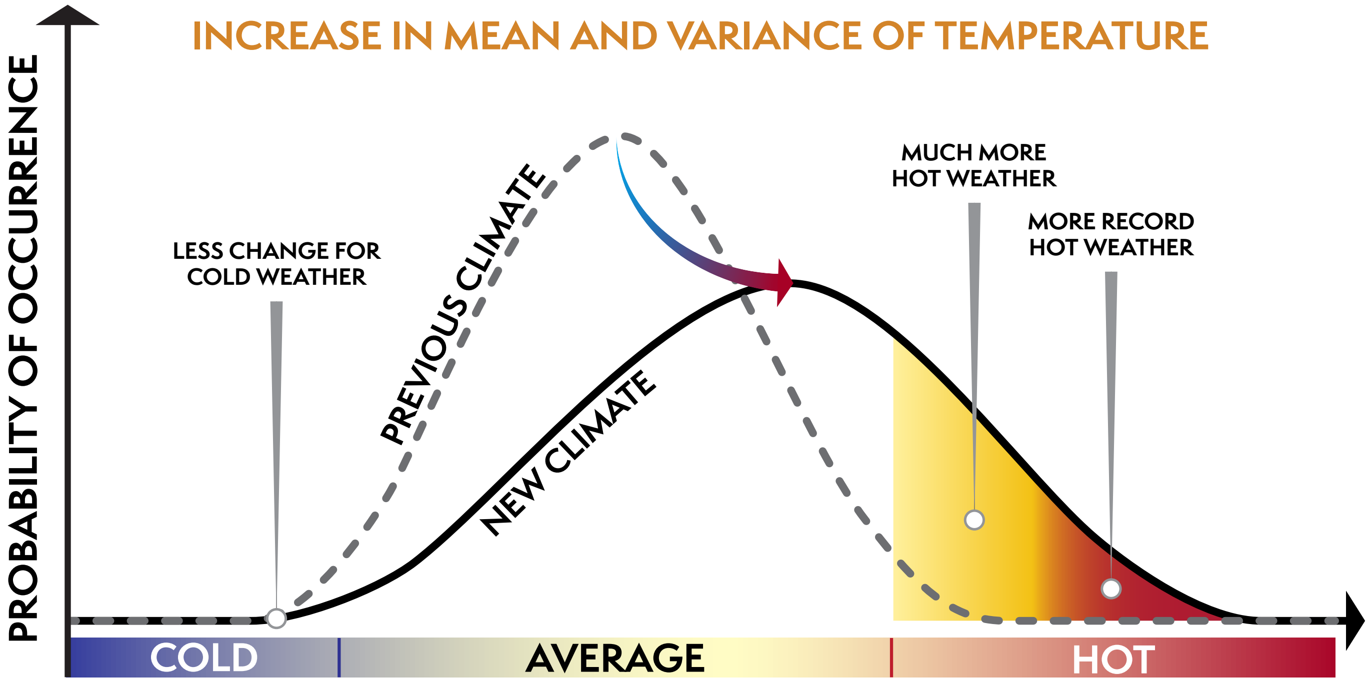
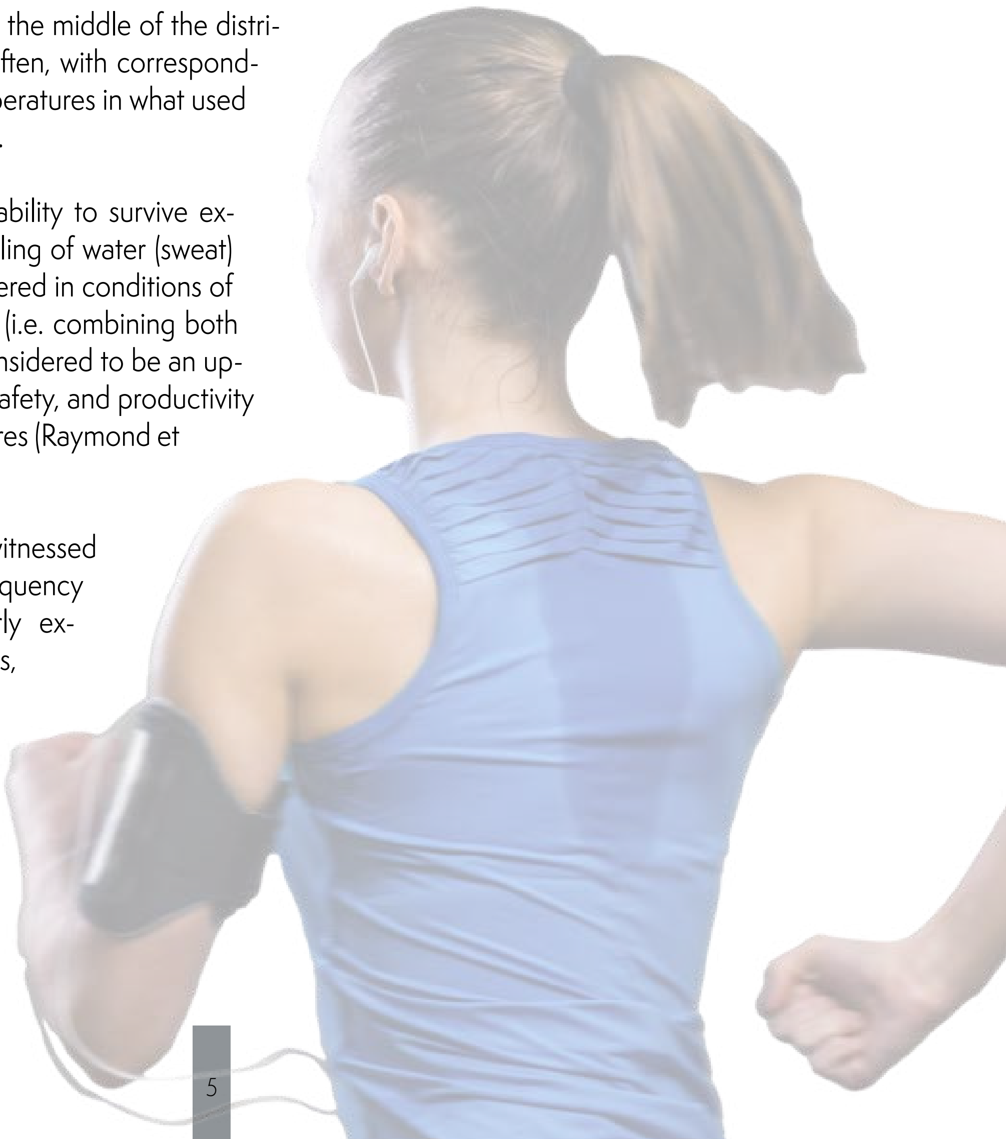


Figure 3. Schematic diagram showing the increase in the probability of extreme high temperatures associated with climate change. Source: IPCC (2001).

No more 'normal'. Figure 3 above demonstrates why the term "the new normal" may not be appropriate. While the dotted curve representing our previous climate has a strong "normal" temperature (labelled 'Average'), as the curve flattens under the influence of climate change, temperatures in the middle of the distribution (the "normal" range) occur less often, with correspondingly more frequent occurrences of temperatures in what used to be considered the 'extreme hot' range.



Limits of human tolerance. Humans' ability to survive extreme heat depends on evaporative cooling of water (sweat) from the skin, a mechanism that is hampered in conditions of high humidity. A 'wet-bulb' temperature (i.e. combining both temperature and humidity) of 35°C is considered to be an upper physiological limit, however health, safety, and productivity can be affected even at lower temperatures (Raymond et al., 2020).

Extreme Events. Meanwhile we have witnessed a generally increasing trend in the frequency of weather-related disasters, particularly extreme temperatures, floods and storms, over the past 50 years (Figure 4 on page 6).

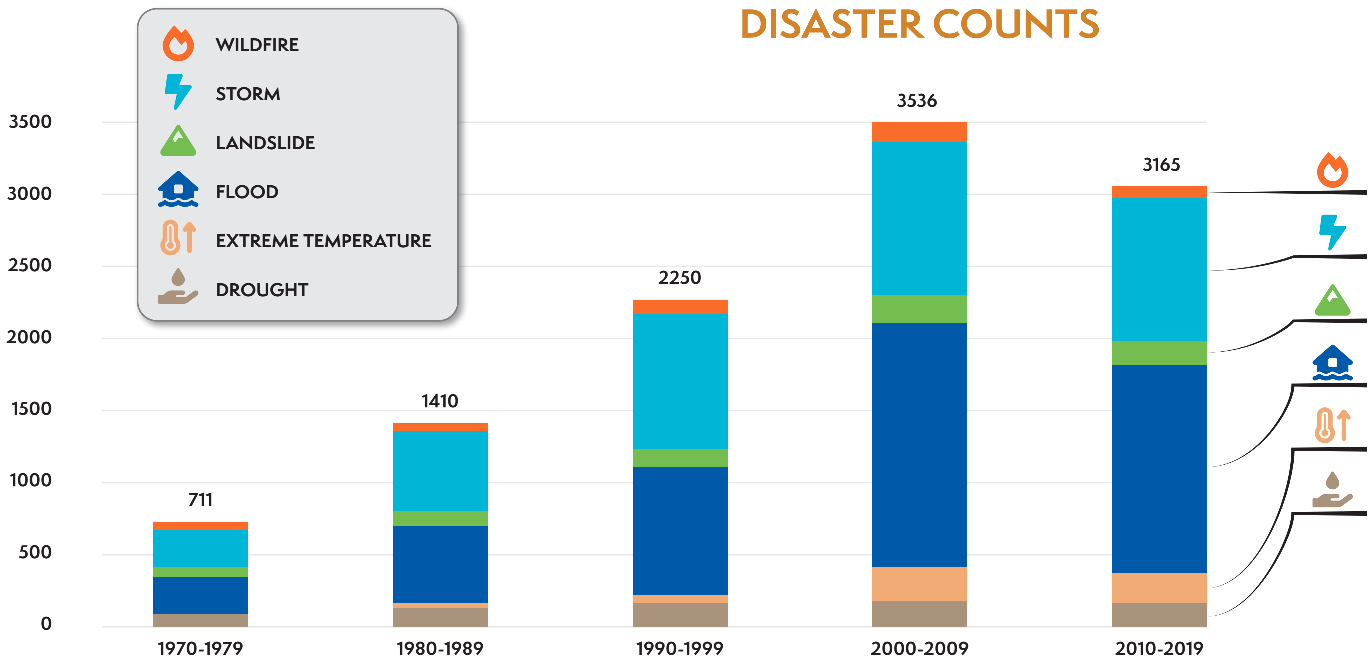


Figure 4. Disaster counts from weather, climate and water extremes, globally by decade. Source: WMO (2021).

As urbanization and development progress, more assets are in a position to be damaged in each event. In the period 2010-2019, total global economic losses from weather-related disasters exceeded USD 1 trillion (Figure 5 below), of which approximately USD 600 billion were insured. The insurability of assets in the future requires consideration of both the increasing value of exposed assets, and the changing climate which has rendered historical data irrelevant (Bevere and Bertogg, 2020).

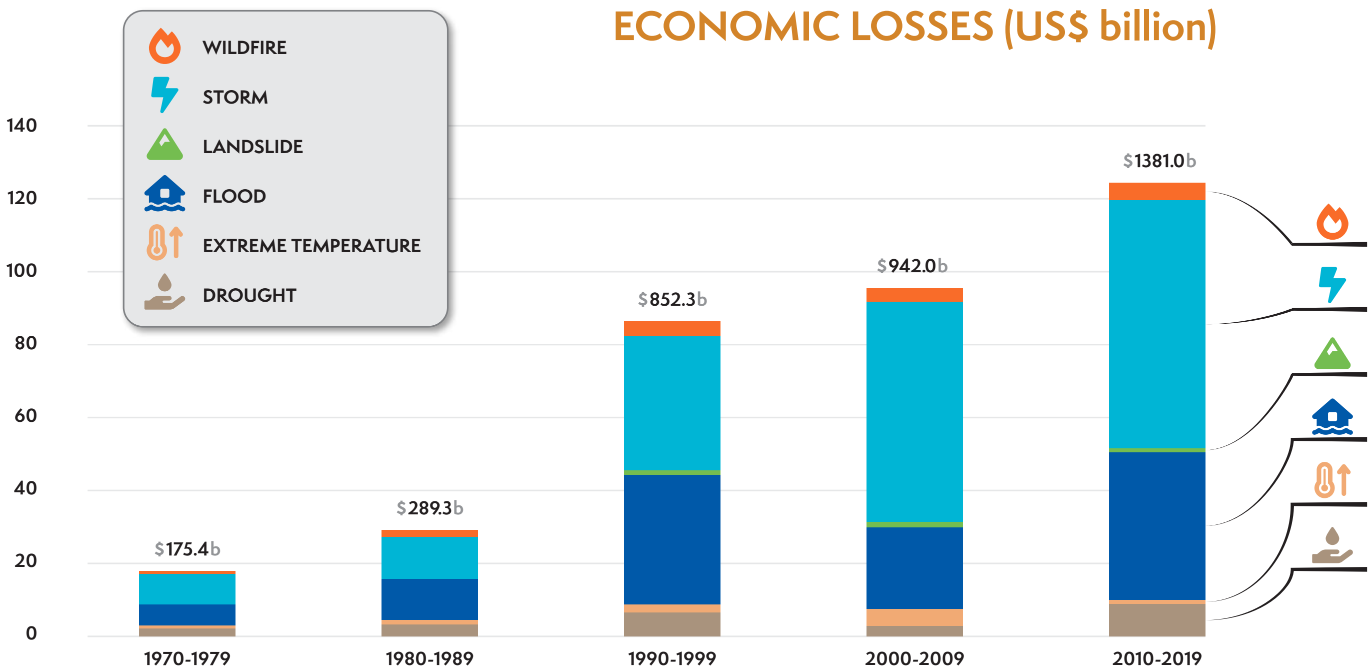


Figure 5. Reported economic losses in US$ billion from weather, climate and water extremes, globally by decade. Source: WMO (2021).

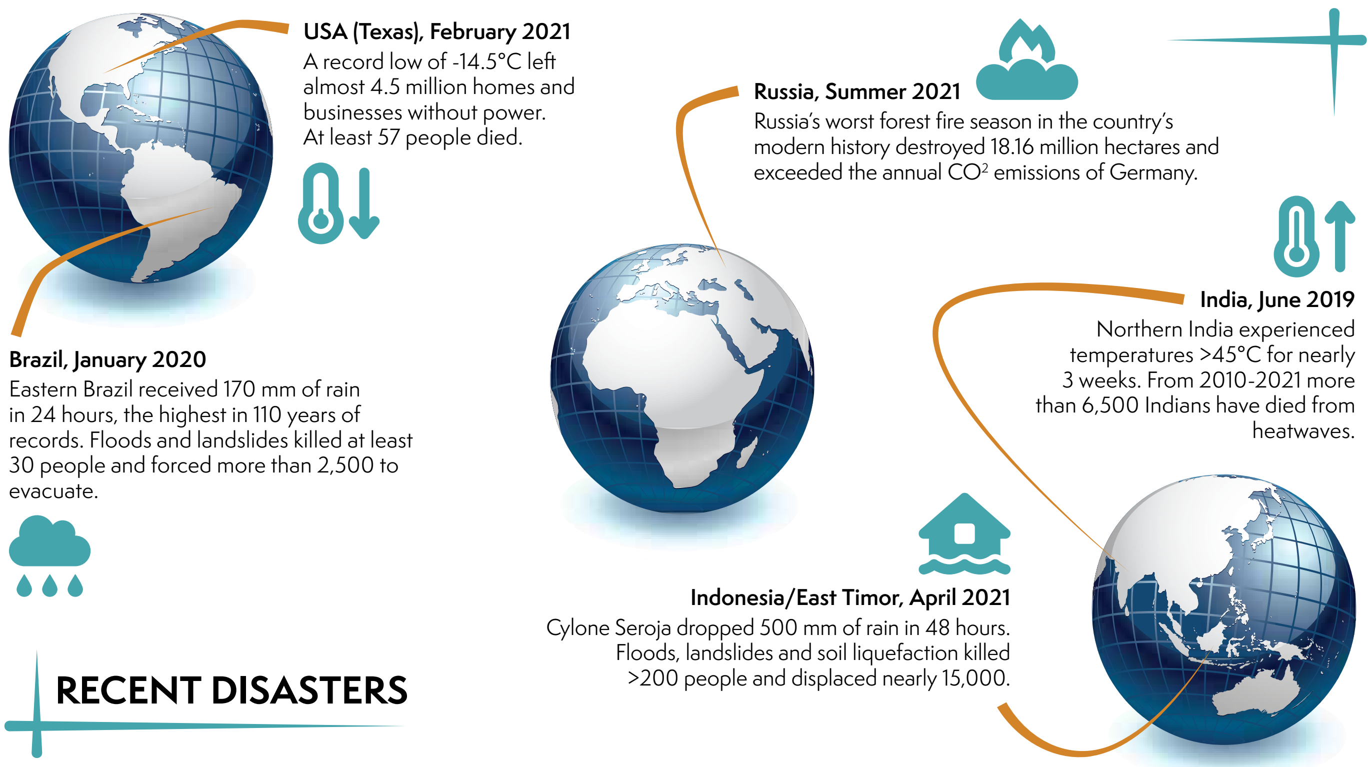


Figure 6. Recent disasters representing extreme events globally.

Future Scenarios. Projections of what the climate will look like in the next few decades are based on assumptions about how successful we will be in limiting the level of greenhouse gases, such as carbon dioxide, in our atmosphere. Different Representative Concentration Pathways (RCPs) represent a spectrum of assumptions from optimistic to pessimistic. The most pessimistic of the modelled scenarios, RCP8.5, is associated with a projected global mean temperature increase of between 3 and 5°C by 2100, assuming continued fossil-fuel based development (SSP5; see Figure 7 below).

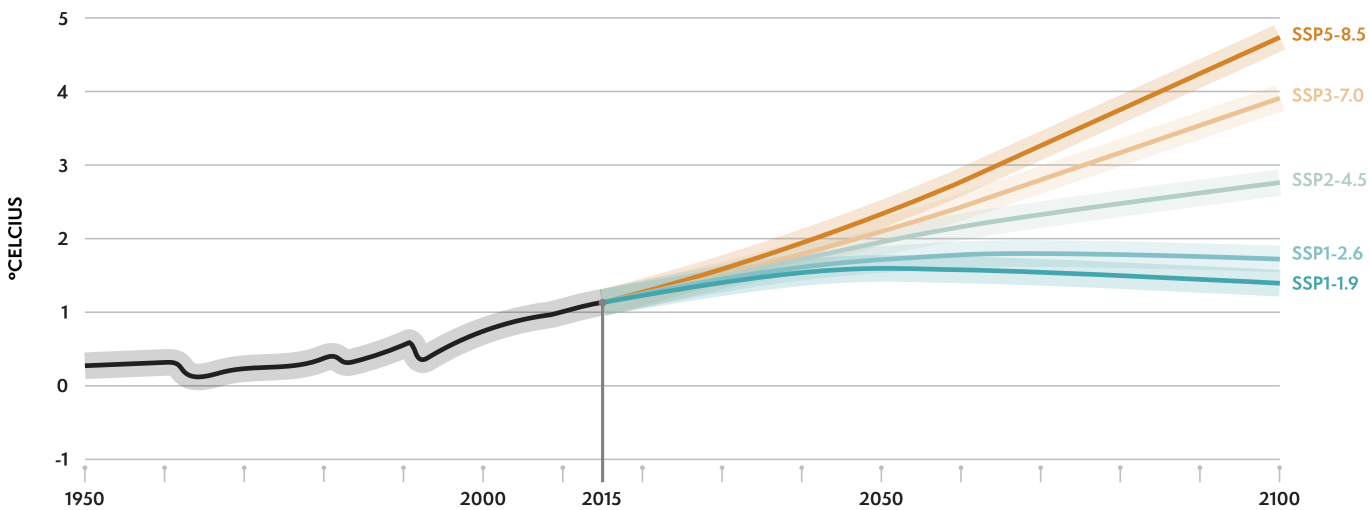


Figure 7. Global surface temperature change relative to 1850-1900: historical and under 5 different scenarios combining assumptions of Shared Socioeconomic Pathways (SSPs) and emissions. Source: IPCC. (2021).

Impacts on Human Health and Well-Being, and Public Health Based Adaptations

Climate adaptations can reduce the vulnerability of humans and communities to climate hazards by reducing exposure to the hazard or by reducing the sensitivity of the exposed entity to the impact. Some adaptation measures, described below, can be implemented in workplaces and communities by occupational health and public health groups. Other measures are more broadly based, involving upgrades to infrastructure or land use planning, and will be described in a subsequent section.

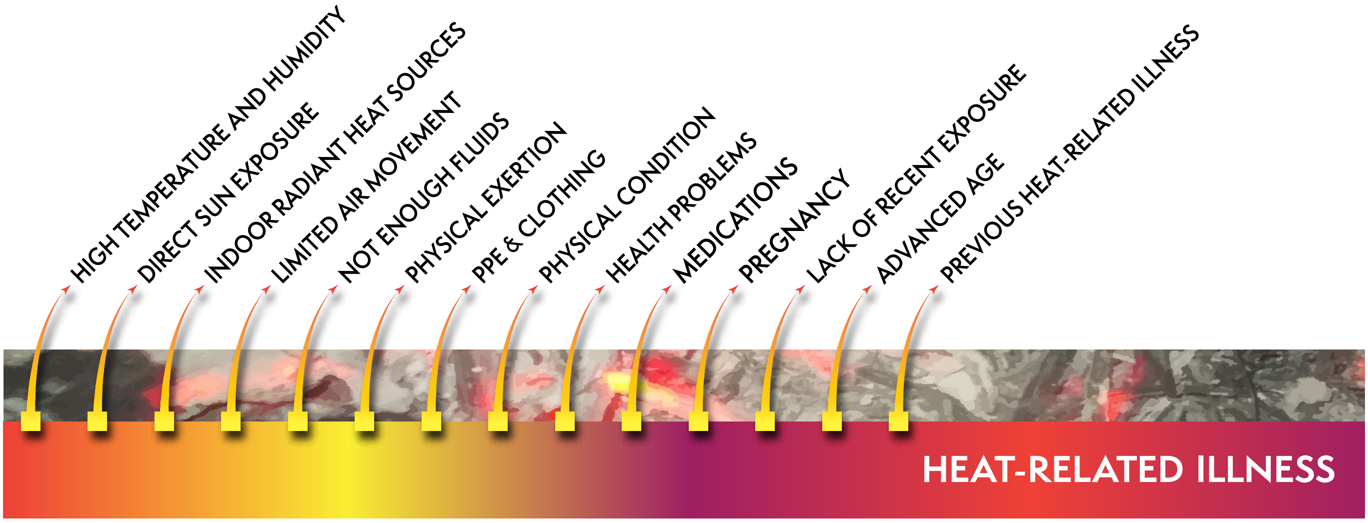
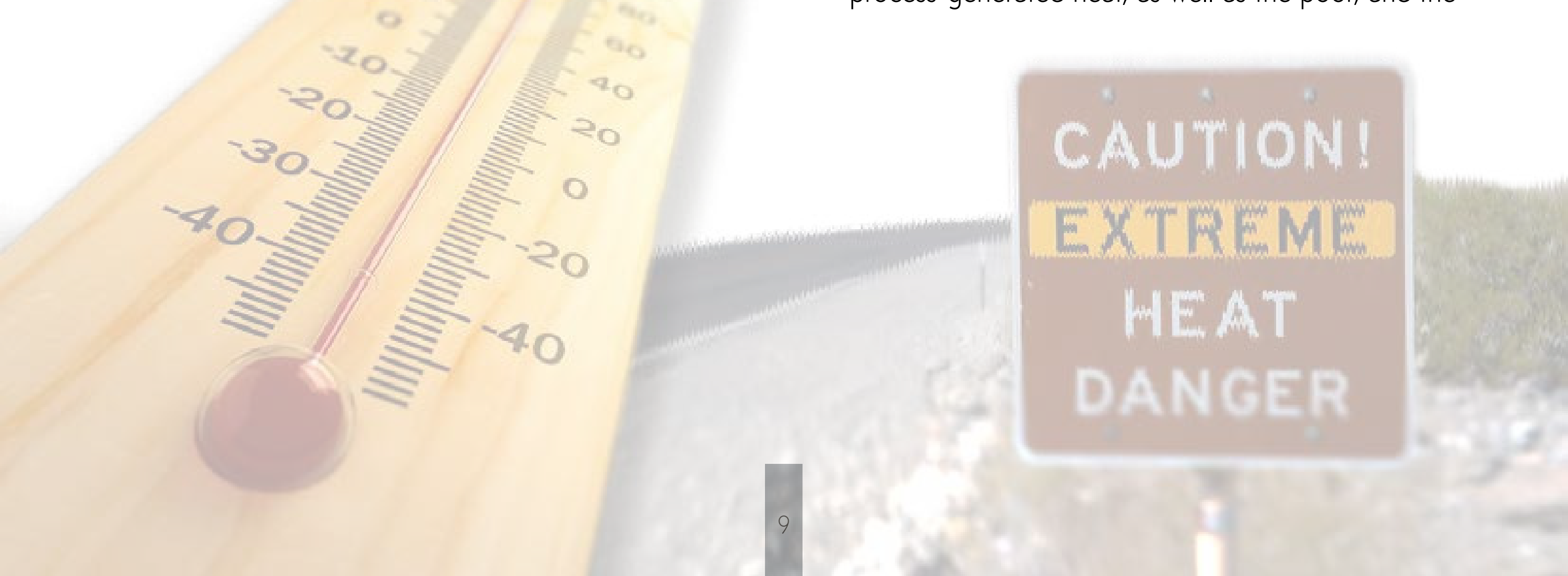


Figure 8. Several factors affecting the risk of heat-related illness (adapted from Jacklitsch et al., 2016).

HIGH TEMPERATURE

The direct effect of high temperature on the body is felt when the body is no longer able to regulate its internal temperature. The net heat load on the body (heat stress) induces a physiological response (heat strain) as the body attempts to compensate. Failure to compensate can result in heat cramps, fainting, heat exhaustion, or, at the extreme end, potentially fatal heat stroke which is a medical emergency. Over-exertion in hot surroundings can lead to a condition called rhabdomyolysis, in which muscle tissue breaks down and leaks into the bloodstream, causing heart abnormalities and kidney damage.

Those most likely to be exposed include people working outdoors, those working indoors in high ambient temperatures, those working indoors where there is heat stress created by process-generated heat, as well as the poor, and the



socially-isolated. Urban populations tend to have higher exposure to extremely high temperatures during heat waves due to the heat island effect. Young infants and the elderly are particularly sensitive to high temperature, and died at a higher rate during the 2019 heat wave in France during which the temperature reached 46°C.

Exposure to high temperatures can be reduced by providing cooling centres open to the public; ensuring accessibility of these centres for all is a key consideration.

Risk to Workers. Workers who work outdoors, in uncontrolled settings, or indoors in high-temperature operations are at risk of heat stress and heat-related illness, including potentially fatal heat stroke. These groups include industrial workers, as well as public safety personnel, construction workers, delivery and mail carriers, and agricultural workers. Smelters generate intense heat and so are a high-risk work environment.

The risk of injury also increases with heat because of passing out (usually from a drop in blood pressure due to heat), light-headedness, and confusion, disordered thinking, and inability to concentrate. Heat cramps and other heat-related illness complicate the situation, especially in the presence of humidity. Safety equipment becomes much harder for workers to use.

Temperatures of 40°C at 100% relative humidity are normal for aluminium plants in hot, humid regions, and measures to address this challenge can involve engineering the physical work environment or implementing work practice controls to reduce exposure or sensitivity to heat. For example providing shade, furnace wall insulation, or heat-reflective clothing can reduce radiant heat gain, and providing water- or air-cooled clothing can reduce heat stress on the worker. The efficiency of sweating to shed heat can be improved by reducing sources of humidity and increasing ventilation, however at air temperature >35°C, ventilation without cooling can be detrimental, resulting in increased body temperature. Hourly or more-frequent monitoring of the environment during high heat periods is required to evaluate the measures required.

Work practice controls are complementary to engineering controls, and include providing power tools to reduce exertion, providing cooling rooms for recovery breaks, increasing the ratio of recovery time to work time, encouraging hydration, shifting work hours to morning or evening, and ensuring an acclimatization period for new or returning workers.

Training of both supervisors and workers to recognize the early signs of heat illness is recommended, and a buddy system can be implemented for close monitoring. Physiological monitoring (e.g., skin or core temperature, urine colour or density) can also indicate when an individual's tolerance is being exceeded. When warning signs are recognized, appropriate first aid can include re-hydration, electrolyte replacement, and if necessary, medical evaluation or urgent transport to a healthcare facility.

Reduced heat tolerance is associated with increasing age, increasing body mass index, and use of certain medications, illicit drugs, and alcohol. Workers with chronic health conditions such as cardiovascular disease or diabetes are also more susceptible to serious health problems from heat.

Figure 9 and Figure 10 on page 11 show the projected global occurrence of days above 35°C in the near future, both in terms of absolute number and in terms of change from historical values. Many of the countries with significant bauxite reserves will be affected.

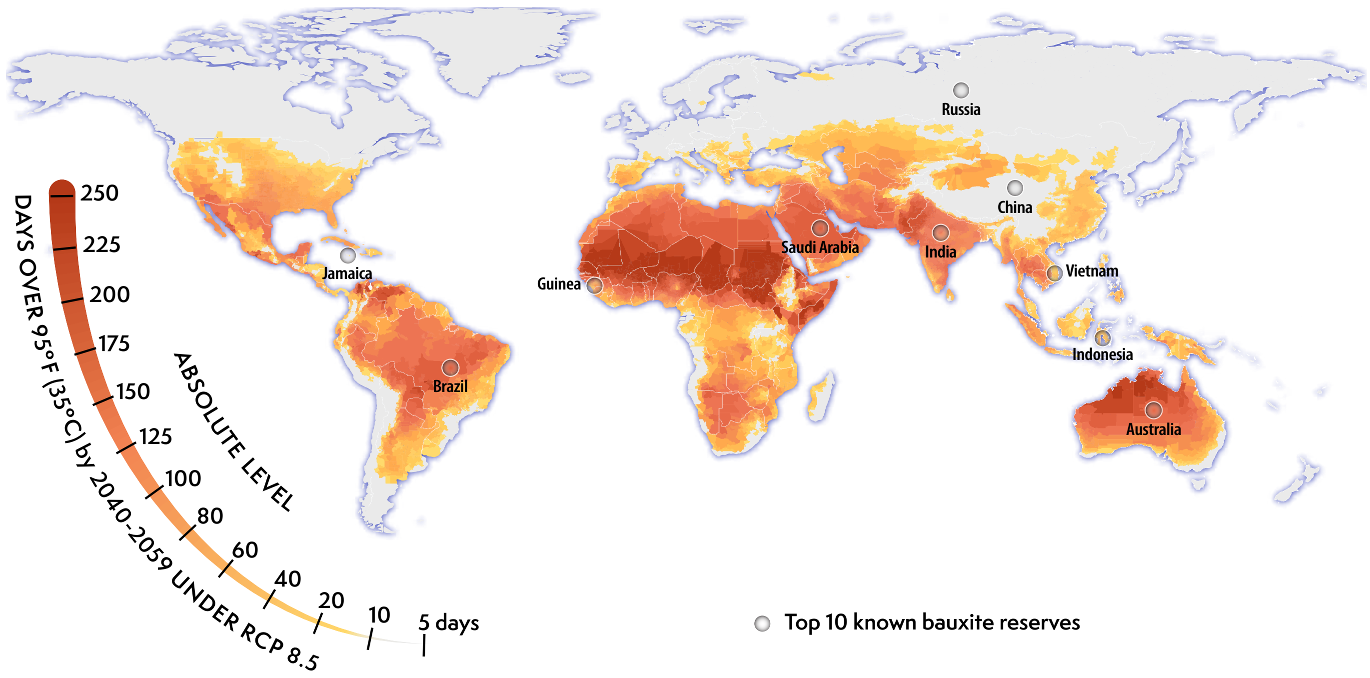


Figure 9. Top 10 known bauxite reserves by country, against the predicted number of days over 95°F (35°C) by 2040-2059, under RCP8.5. Sources: USGS (2020), Climate Impact Lab (no date).

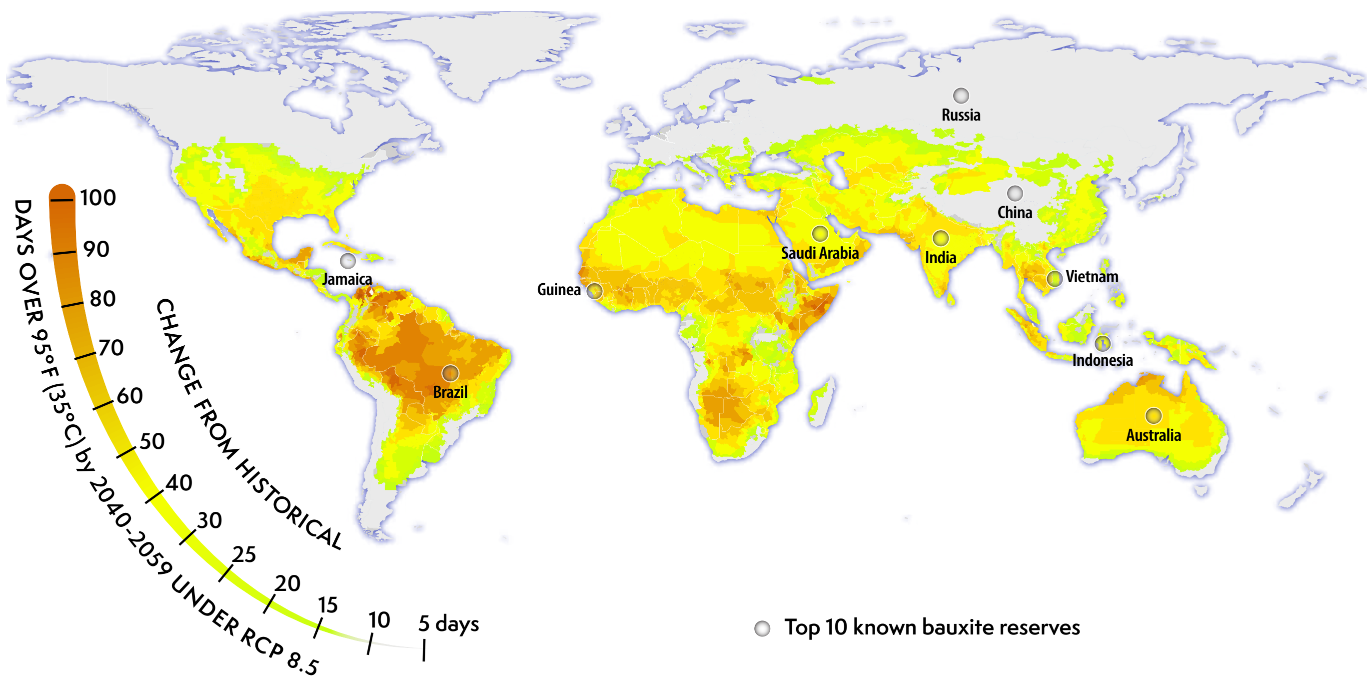
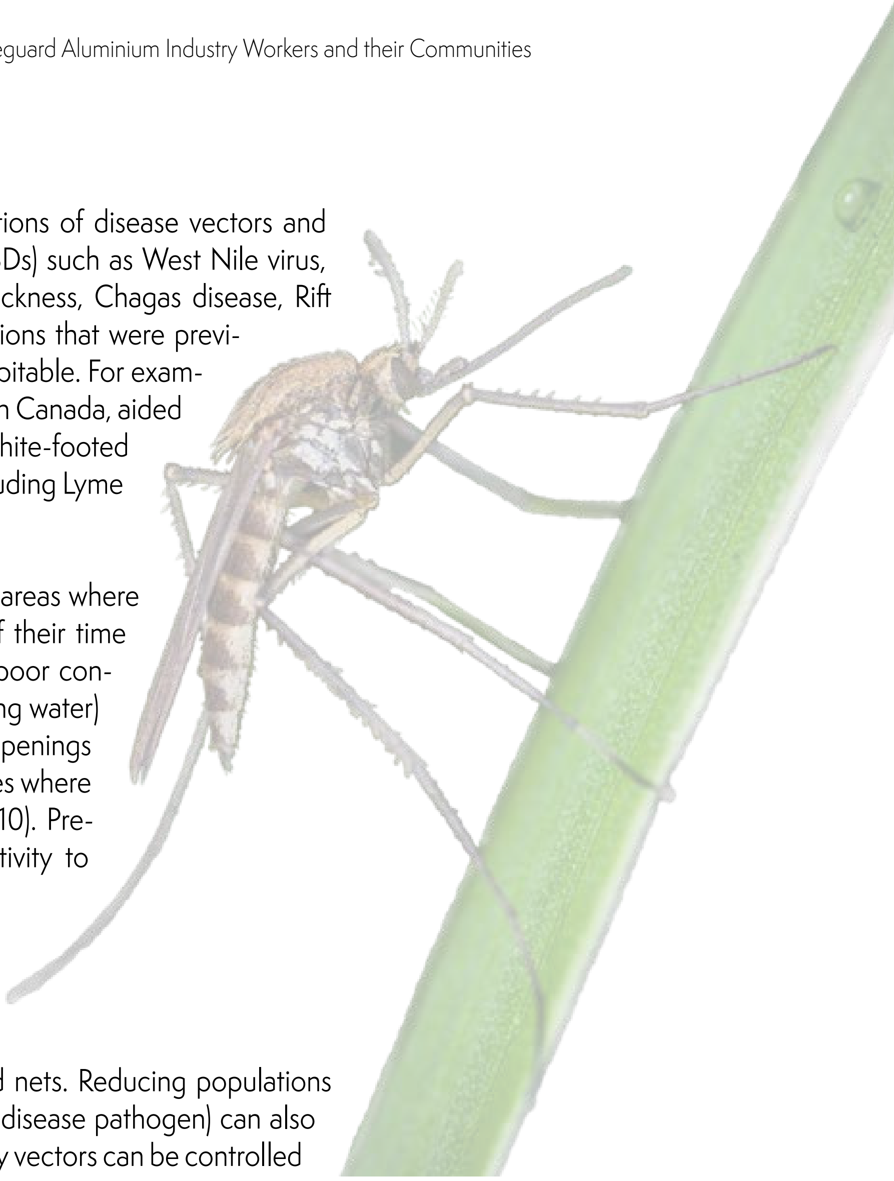


Figure 10. Top 10 known bauxite reserves by country, against the predicted change in the number of days over 95°F (35°C) by 2040-2059 (compared to 1986-2005), under RCP8.5. Sources: USGS (2020), Climate Impact Lab (no date).

VECTOR-BORNE DISEASE



High temperatures can lead to increased populations of disease vectors and incidence of traditional vector-borne diseases (VBDs) such as West Nile virus, malaria, schistosomiasis, leishmaniasis, sleeping sickness, Chagas disease, Rift Valley fever, Zika, Chikungunya, and dengue. Regions that were previously too cold for these vectors become more hospitable. For example, the deer tick has expanded its range in southern Canada, aided by the northern spread of one of its hosts, the white-footed mouse. This tick is a vector for several diseases including Lyme disease.

People most vulnerable to VBD are those living in areas where there is endemic disease and who spend most of their time outdoors, particularly if public infrastructure is in poor condition (e.g., rutted roads or other sources of standing water) or who live in poor-quality housing offering many openings for vectors to enter. Transmission is increased in sites where biodiversity has been reduced (Keesing et al., 2010). Pre-existing chronic health conditions increase sensitivity to some VBDs.

Control of exposure to VBD traditionally relies on removal of potential mosquito breeding sites (open standing water), spraying sites with insecticides, and use of window/door screens and bed nets. Reducing populations of wildlife reservoirs (e.g., mice carrying the Lyme disease pathogen) can also reduce exposure. As a second line of defence, many vectors can be controlled with permethrin-treated clothing.

Risk to Workers. Exposure to VBD is higher in outdoor workers and healthcare workers involved in treating infected patients, depending on possible transmission routes. The labour requirements of mining operations can induce the creation of informal settlements: a pattern of makeshift housing and absence of public health infrastructure that is conducive to the transmission of VBD. Workforce availability can thus be negatively impacted under these conditions.

Clothing that covers as much exposed skin as possible, including hats with netting covering the face and neck, should be worn and can be permethrin-impregnated for added protection. When clothing is impractical, an approved insecticide should be applied on top of sunscreen. The risk from some VBDs and other infectious diseases, e.g. Malaria, Hepatitis, and Yellow Fever can also be managed through medical prophylaxis. Education to enhance awareness about VBDs is important in ensuring that affected workers seek medical attention promptly.

AIRBORNE HAZARDS

Increased temperature can contribute to respiratory illness in at least three ways.

- Heat and sunlight increase the rate of chemical reactions by which ground-level ozone is created from air pollutants, and this increase in ozone can worsen conditions such as asthma, emphysema, and chronic bronchitis. People with poor nutritional status are particularly sensitive to the effects of ozone.

- High temperature (and longer growing season) promotes the growth of plants and fungi leading to an increase in airborne pollen and mould spores. Mould spores are a common problem following flooding events, when organic building materials such as plywood and insulation remain damp long enough for fungus to infest the material and sporulate. People lacking the ability or means to replace damaged housing components promptly are most at-risk of exposure to airborne spores, and those with environmental allergies are especially sensitive.

Weed control including herbicide treatment and mowing can lower the level of some airborne pollens, and prompt remediation following water damage to buildings will discourage the growth of fungi and production of spores.

- When high temperature is combined with low precipitation, bare soil becomes dry and more likely to be lost to wind erosion – this results in an increased load of particulate matter in the air. High particulate matter is especially hazardous to those with chronic and acute cardiovascular and respiratory health conditions and increases the risk of premature death. Hot, dry conditions are also associated with an increased risk of wildfires, which lower air quality. This may be mediated through insect pests that attack monocultures of drought-stressed trees, leaving many dead and more likely to ignite. Wildfire smoke can be carried long distances in the wind, leading to wide exposure.

  The level of airborne particulate matter from wildfires or soil erosion, as well as pollen and spores, can be temporarily reduced by spraying water to suppress dust. Exposure can be reduced by avoiding the outdoors as much as possible and sealing openings in homes and buildings or by using Personal Protective Equipment (PPE) such as a face mask or respirator.

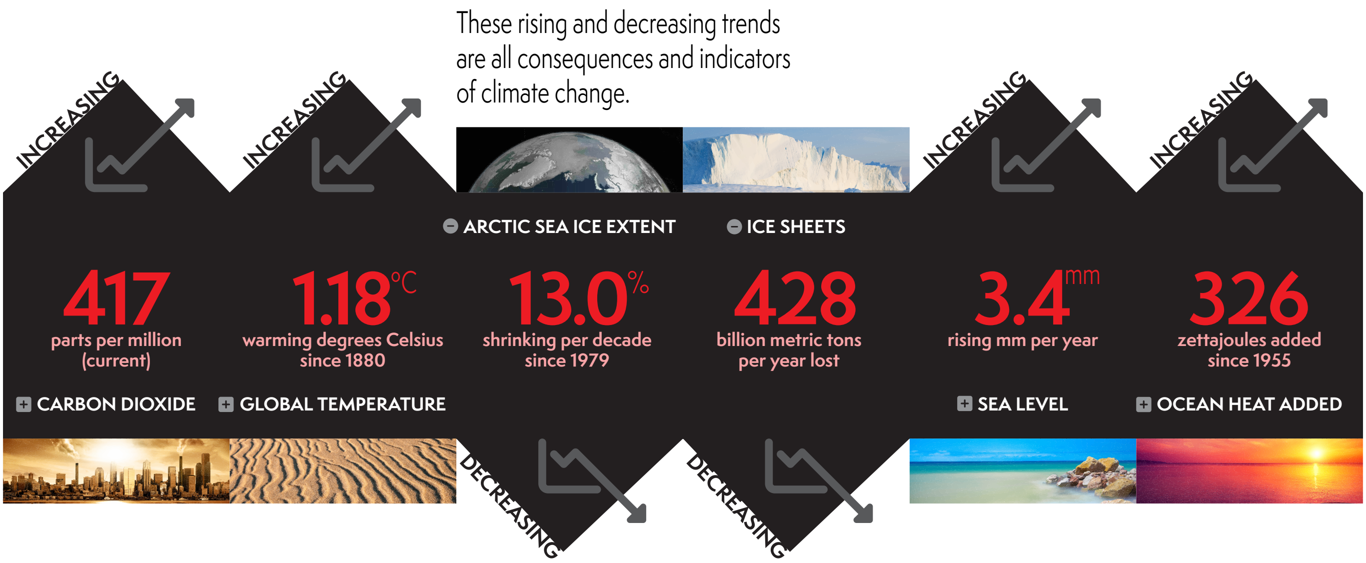


Figure 11. Six vital signs that the planet is undergoing climate change.

Risk to Workers. Outdoor workers are particularly exposed to airborne irritants such as particulate matter, pollen and ground-level ozone. In contrast, indoor workers can be exposed to fungal spores and pathogens that are associated with high humidity, and particularly with damp building materials following flooding, or even following rain events in poor-quality buildings.

Indoor spaces can be improved by ventilation and air purification systems, and PPE can reduce exposure of both indoor and outdoor workers.

SEA LEVEL RISE AND COASTAL FLOODING

Coastal cities tend to enjoy more moderate temperatures than inland cities. This is due to the ability of water to absorb heat without much change in temperature. The earth's oceans absorb most of the excess heat associated with green-house gases (GHGs). This heat has had two effects: melting of the polar ice sheets, and an increase in the volume of the ocean. The resulting sea level rise is one of 6 "vital signs of the planet" as shown in Figure 11 above.

While the current rate of sea level rise of 3.4 mm/yr may seem trivial, this is the average value and does not convey the risk accurately. Storm surges can force water higher along coasts, and this is forecast to happen more frequently under

climate change. Under the RCP8.5 scenario, sea level rise is likely to displace 150 million people globally from their homes due to permanent inundation by 2050. By 2100, this estimate grows to 230 million, with a further 390 million subjected to annual flooding (Kulp and Strauss, 2019).

Currently sea level rise produces 'nuisance flooding' in low-lying coastal cities during high tides. Underground, sea level rise can cause salt-water intrusion, which can contaminate aquifers that supply drinking water. This can mean water scarcity not only for drinking but also for irrigation, and farms may be abandoned.

Risk to Workers. Sea level rise will affect workers and facilities in entire sectors, including those that are located in coastal areas for transport reasons, those serving coastal populations, and those using coastal resources. These sectors include iron and steel works, oil refineries, alumina refineries, cement works, chemical plants, meat and fish processing plants, power stations, smelters, pulp and paper mills, supporting port facilities, and other manufacturing plants. In addition to potential water scarcity, health impacts will include those associated with storm surges and flooding more generally as described below.

HIGH PRECIPITATION AND FLOODING

For each 1.0°C (1.8°F) increase in temperature, saturated air can hold 7% more moisture. The result is that more precipitation falls to earth during rain or snow events, and this can cause flooding.

Flash flooding and storm surges can involve fast flowing water causing pedestrians to lose their footing and vehicles to be carried away, even at relatively small depths, and injuries or drownings can result. Other drownings occur when individuals are trapped by the rising water, such as in underground parking facilities or basement apartments. People trapped in attics or on roofs can succumb to hypothermia if not rescued in time. Shock, cardiac arrest and respiratory diseases can be caused by contact with water during flood events. Exposure to polluted flood water can lead to wound infections, dermatitis, conjunctivitis, and infections of the gastrointestinal system, ear, nose or throat (WHO, 2002).

Indirect impacts of flooding may develop in the aftermath of the event. Chemical contaminants can be washed into floodwaters from soil, storm sewers, sanitary sewer overflow, holding ponds, tanks,or other storage sites, and cause acute or chronic toxicity in those who contact these floodwaters. Disruption of habitat can cause pests such as rats or snakes to seek other shelter, leading to an increase in interactions with humans and potential disease or injury. Overland flooding crossing agricultural areas can wash fertilizers into water bodies, leading to excess nutrient content which can promote harmful algal blooms (see 'Waterborne hazards').

People most vulnerable to flooding are those with difficulty in limiting their exposure, including those living in basement accommodations, those needing to work (e.g. delivery workers) in inclement weather, and those with disabilities that limit movement or understanding of the danger.

Photo by Rok Rie from Pexels

Public health measures for reducing the exposure of populations to flooding involve monitoring weather forecasts and issuing warnings when required, to encourage people to take shelter, or evacuate, if able. An effective warning system uses as many types of communication as possible, to reach individuals using a variety of news sources, and health teams can be trained to reach and assist the most vulnerable. Planning for these measures can be conducted between events, including vulnerability assessments as well as ongoing educational programs to strengthen awareness of shelter-in-place guidance, or evacuation procedures and routes.

Risk to Workers. Flooding itself is a broadly-applicable impact of climate change that directly affects the health and safety of rescue and public safety personnel and presents site-specific hazards. Potential risks of contact with water include electrocution, release of toxic chemicals, or, in molten metal operations, explosion. Operating a vehicle during a flood is particularly risky, and nearly half of workers who died due to flooding in one survey were operating or riding in a motor vehicle at the time (Schulte et al., 2016).

See "Waterborne Hazards" for non-drowning impacts of flooding, and see "Extreme Events" for impacts of flooding that are mediated by damage to infrastructure.

WATERBORNE HAZARDS

As water absorbs some of the heat from the atmosphere, the conditions at the surface become more favourable for growth of algae, including toxin-producing species that can produce a Harmful Algal Bloom (HAB) or overgrowth. The toxins released into the water can affect seafood, marine mammals, birds, and humans. Ingestion of the toxins, which can bioaccumulate in seafood, can cause neurotoxicity as well as respiratory, hepatic, dermatological or cardiac symptoms.

Managing the human impact of HAB requires monitoring the algal populations, particularly during favourable weather conditions, restricting recreational use of the shoreline, and suspending seafood harvesting while the situation persists.

High precipitation and flood events overwhelm watersheds with higher than normal volumes of water draining into surface water bodies. The flow of water can both mobilize micro-organisms and chemicals from soils and other surfaces, and disrupt river and lake sediments, causing increased turbidity. This results in contamination of potential water sources including wells, and has been linked to increased gastrointestinal illness in the weeks following the event. Boil-water advisories are called for if water sources are contaminated with microbial pathogens following flooding, but if chemical contamination is present, or if boiling cannot be undertaken safely, the community will need to rely on bottled water or trucked-in water until the system is flushed.

Some of the micro-organisms mobilized in floodwater may be the protozoan hosts of Legionella bacteria. These bacteria can become airborne when water is aerosolized, and if inhaled can cause Legionellosis ("Legionnaire's Disease"). Legionella bacteria can persist in biofilms lining the inside of water systems such as water supply lines, cooling towers, whirlpool spas, and especially pipes carrying recycled water. Their proliferation is favoured if the water is allowed to become warm and stagnant, so disinfection and frequent flushing are recommended.

Until it recedes, ponding of floodwater provides a site for mosquitoes to hatch and develop, a process that can take as little as 8-10 days. Flooding is therefore an indication that control programs against VBD should be implemented.

Risk to Workers. In areas affected by previous mine workings, flood-mobilized chemicals can contaminate agricultural fields, leading to losses of crops and/or livestock (Foulds et al., 2014). Impacts to individual workers such as gastrointestinal complaints can affect workforce availability in the short-term, while impacts to the food or water supply can reduce availability more broadly.

Other waterborne hazards expected to increase under climate change are those mediated by infrastructure damage, and these are described below, under Extreme Events..

LOW PRECIPITATION AND DROUGHT

Persistent droughts kill vegetation, leaving the soil bare and more susceptible to wind erosion. Soil and dust particles contribute to poor air quality and an increase in respiratory conditions. If the affected vegetation is a crop for food or feed, the food supply might be threatened. As droughts reduce the supply of water, the population may resort to using non-potable water for washing, cooking, and drinking, and this can cause an increase in waterborne diseases and exposure to potential chemical contaminants. If drought conditions persist long enough, famine, civil conflict, and migration can result as communities struggle to secure adequate water access. Impacts on labour availability can occur sporadically in the first instance, as individual workers are affected by diarrheal illness or potentially, chemical toxicity. In the second case the impact will be much more significant, with the possibility that the community from which the workforce is drawn leaves the area entirely.

EXTREME EVENTS

The heat exchange between the atmosphere and the oceans produces a rise in Sea Surface Temperature (SST). High SSTs provide fuel for tropical cyclones (or equivalents, i.e., hurricanes, typhoons) that can do tremendous damage if they interact with land. These storms and other extreme events such as wildfires and floods often disrupt power, communication, transportation, and water infrastructure, and cause destruction of human habitats and other critical infrastructure such as hospitals. These disruptions in turn produce harmful effects on human health and well being.

For example, when communication, transportation, and power infrastructure are damaged, emergency responders have trouble finding and treating people who need health care. Hospitals can experience damage to power supply or heating/cooling ability. As a result individuals injured by the event and those with chronic conditions needing care may go untreated.

Extreme events that affect water and wastewater infrastructure can result in an inadequate supply of clean water, or in chemical and biological contamination of ecosystems, water bodies, and/or soil. This can result exposure to water-related pathogens, chemicals, and algal toxins leading to more cases of waterborne infection, or acute or chronic effects of chemical hazards. Loss of access to the water supply may lead to dehydration-related health impacts.

The bowtie diagrams in Figure 12 and Figure 13 on page 17 illustrate some potential follow-on effects of extreme events. Bowtie diagrams are a way to visually analyse a risk given an adverse event or condition. A bowtie diagram illustrates the causes or precedents of the event, and the different effects that result. Control measures with the potential to prevent the adverse event, or with the potential to minimize the effect, are also included. The causes shown in Figure 12 and Figure 13 on page 17 are themselves the result of extreme events.

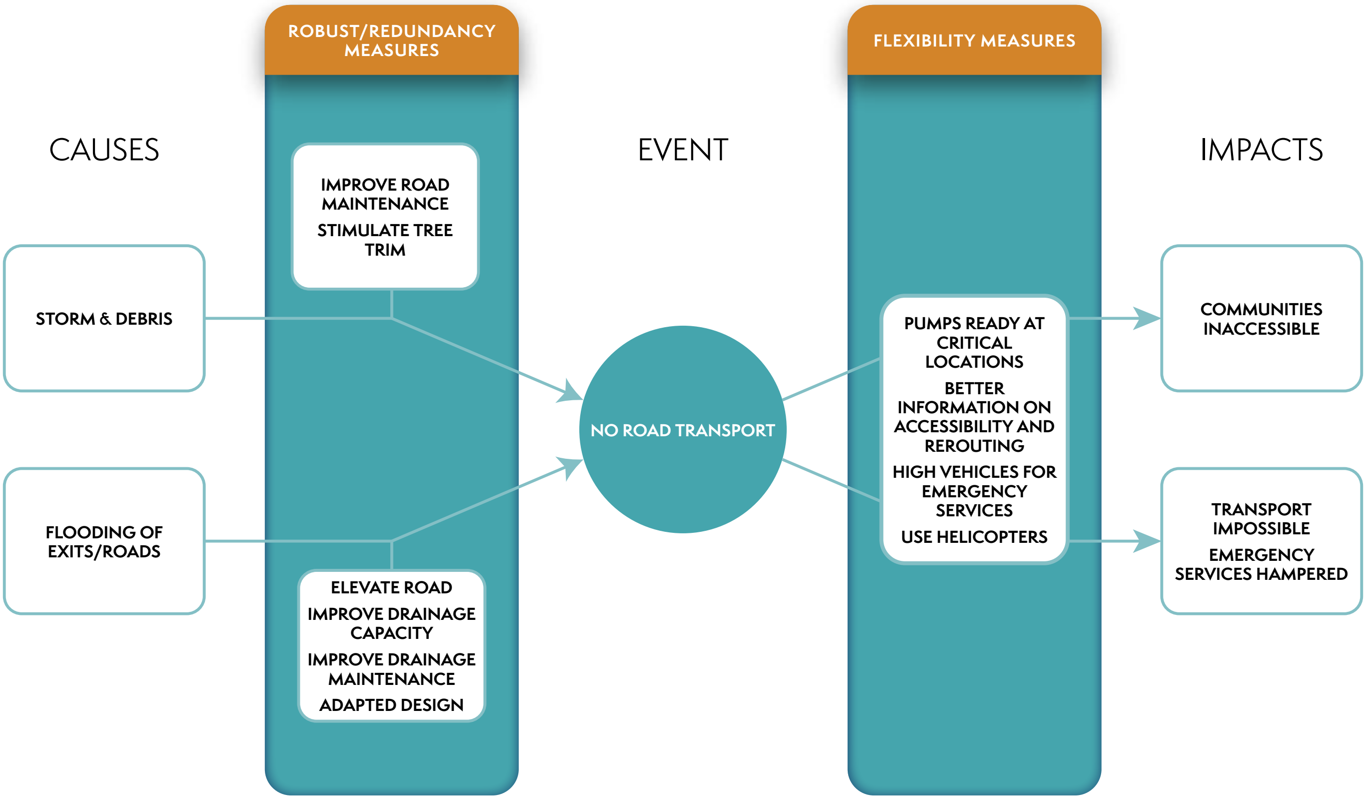


Figure 12. Road transport: causes, impacts, and potential measures which prevent disruption of road transport (on the left side) or mitigate impacts (on the right side). Adapted from de Bruijn et al., (2019).

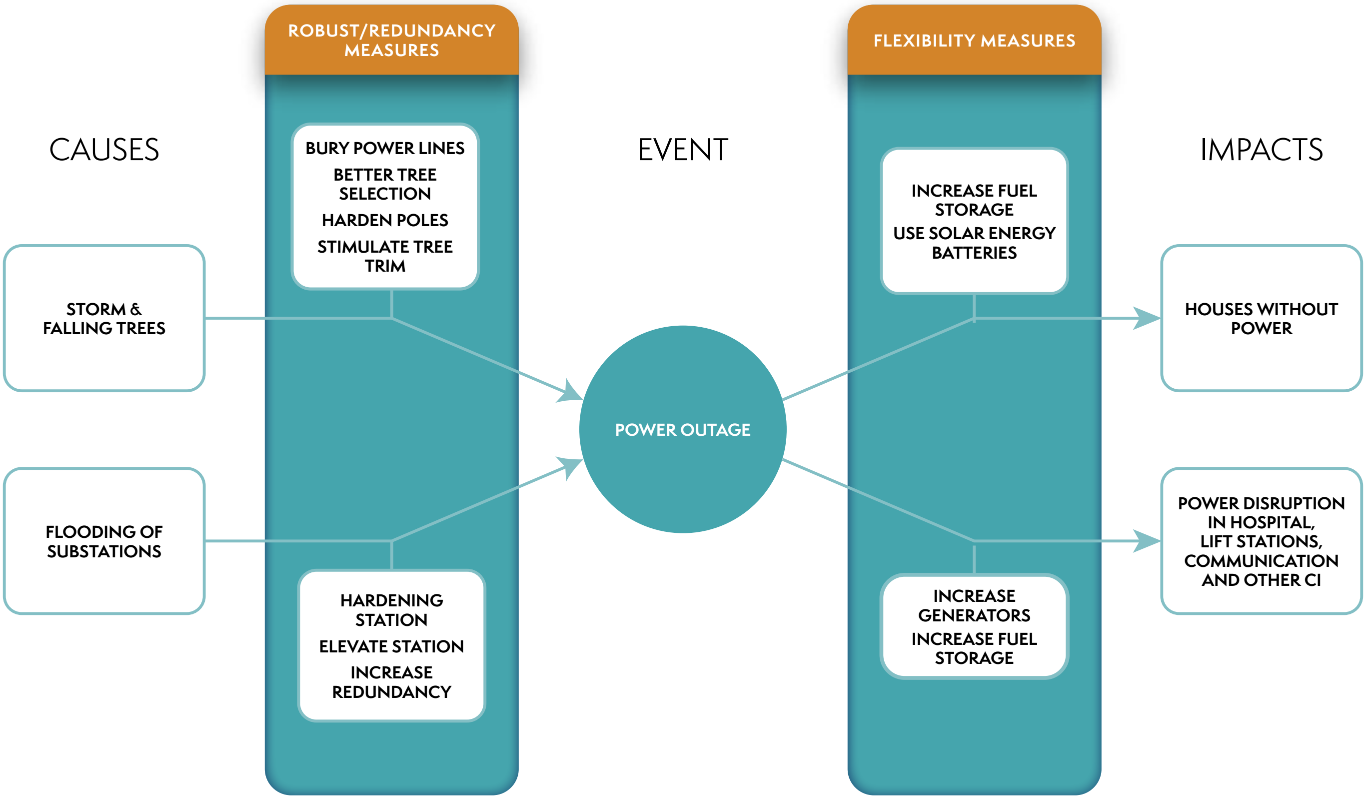


Figure 13. Electricity: causes, impacts, and potential measures which prevent power outages (on the left side) or mitigate impacts (on the right side). 'CI' is critical infrastructure. Adapted from de Bruijn et al., (2019).

Extreme events threaten the food supply. They can cause damage to crops, livestock, or stored food, or damage the infrastructure needed to safely transport the food to market. Disruptions to the cold chain (that ensures adequate refrigeration of food when necessary) from power outages can also result in spoiled food and can increase the levels of food-borne pathogens and other food contaminants (for example fungal toxins in stored cereals).

Populations lacking the means or ability to effectively shelter-in-place or evacuate ahead of an extreme event are particularly vulnerable to adverse health effects. Individuals with chronic health conditions especially those requiring medicine, or who rely on electrical power for medical equipment can also be disproportionately affected by extreme events.

During the aftermath of the event, as the ripple effects caused by supply chain issues or water treatment failure increase, the portion of the population affected also expands.

Adaptation approaches such as early detection and warning systems will help as many people as possible avoid exposure to the event, especially if options such as community shelters have been well-publicized in advance. Transmitting warnings and information in as many ways as possible is helpful. In the immediate aftermath of the event, public health authorities can issue boil-water advisories if the water supply is unsafe. The common recommendation to have 3-5 days worth of food and water on hand is intended for these situations, so that public health resources can be spent on the most vulnerable when demand is high. Cash cards can be distributed following an extreme event, to target aid as quickly as possible.

Impacts of extreme events are particularly acute in remote communities, which are more likely than those in more-populated areas to lack secondary providers of electricity or communication infrastructure, and which often have few means of transportation to and from cities from which additional essential supplies might be obtained. Social services such as education and public health can be limited by challenges in attracting competent personnel in sufficient numbers. The development of a mine or similar employer in remote communities can exacerbate this effect, as in-migration results in a larger population competing for the same services. One approach for handling emergency response needs in a remote community is to capitalize on existing local capacity, using fit-for-purpose training to develop a 'community-based emergency care' model (Orkin et al., 2016).

Risk to Workers. Extreme events can cause disruptions to businesses whose employees cannot get to the workplace due to damage to the transportation infrastructure, or who are injured as a result of the event. Employees tasked with remediation after an event need appropriate protective equipment, potentially including breathing equipment, to reduce exposure to waterborne and airborne hazards.

Compound extreme events, or even single extreme events affecting low-income communities, can exhaust the resources available to rebuild or remediate, and so can ultimately lead to reduction or loss of the available workforce.

Mental health & well-being. Employees as well as the general population are at risk of mental-health problems after surviving an extreme event. The stress of living through an extreme event can cause a multitude of mental health effects including post-traumatic stress disorder (PTSD), depression, and general anxiety, which may become chronic. The ability to cope is compromised by feelings of fatigue or exhaustion stemming from relocation or living in damaged housing, bureaucratic obstacles to accessing financial aid, money stress, sleep disruption, family pressures, and lack of recreational opportunities. For workers, an obligation to work overtime to restore function to the operation adds to these factors. New or increased substance abuse can worsen social and family relationships already strained from the initial after-effects of the event.

Collectively, the effects on mental health can produce an increase in interpersonal aggression, violence and crime, and social instability. These effects tend to become apparent weeks or months after the event, when the sense of optimism instilled by media attention and government aid during the initial aftermath begins to fade in the face of the challenges involved in recovery and rebuilding (Morganstein and Ursano, 2020).

Children, the elderly, women (especially pregnant or with young infants), people with pre-existing mental illness, the poor, the homeless, and first responders are groups identified as being at higher risk for adverse mental health effects from weather-related disasters.

Following a disaster, the community health services may need to be expanded. Frequent communication of recovery and reconstruction status, and opportunities for citizens to participate in meaningful action can be helpful. A close-knit community will help ensure that the more vulnerable receive at least some support, thus sparing public health capacity. Initiatives to promote the discovery and fulfilment of needs on a local basis should encourage individuals to reach out to others in their community.

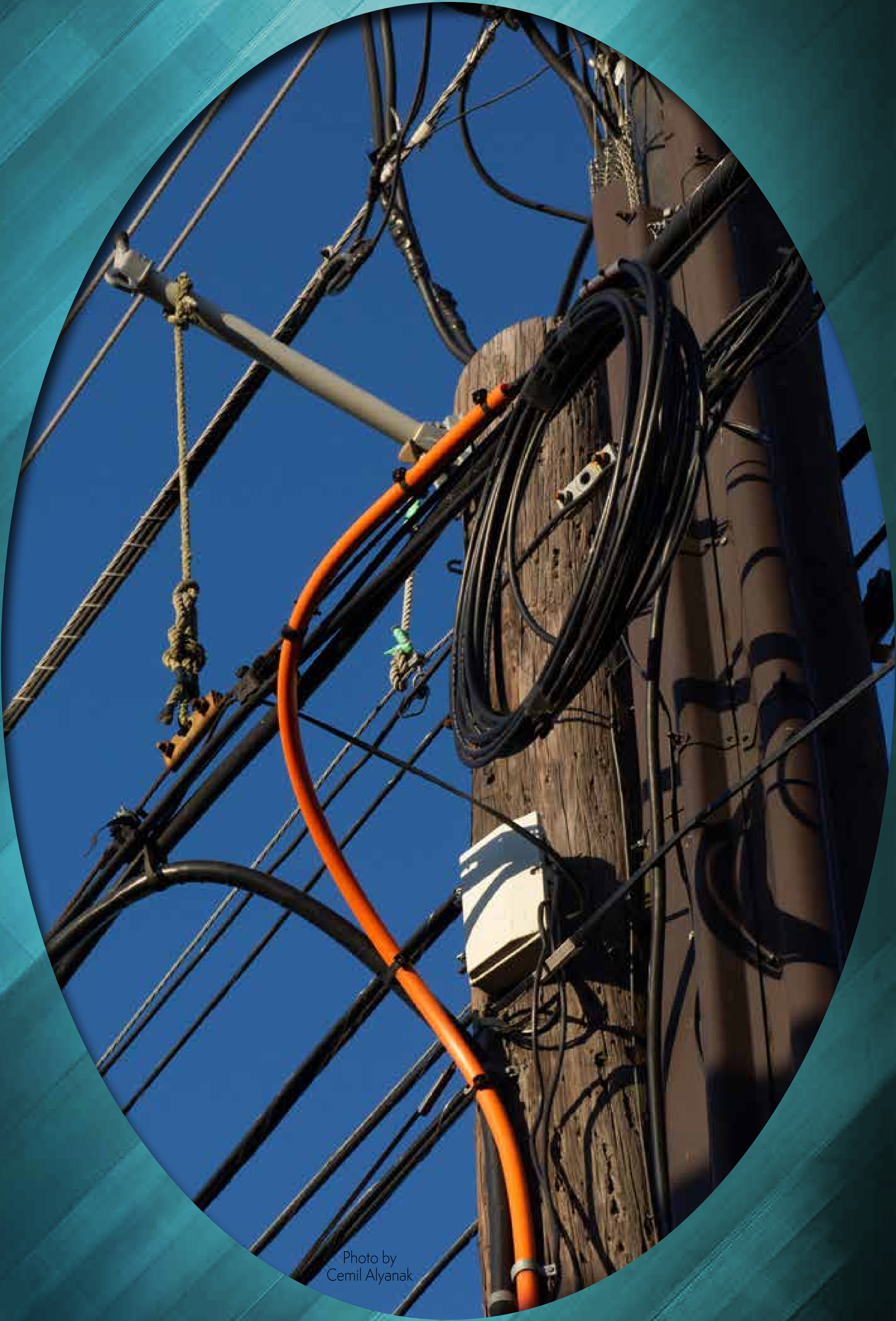


Photo by
Cemil Alyanak

Infrastructure/Ecosystem Based Adaptation

Challenges of Climate Adaptation. While there have been many weather disasters through history, more and more these events are occurring either simultaneously or in quick succession, with the impact of the first severely handicapping effective response to subsequent events. For example, a heat wave in British Columbia in June 2021 resulted in over 500 deaths. This event was accompanied by a drought that prompted a series of forest fires in the following months, then November brought excessive rain washing out roads and rail lines, flooding cities and farms, and causing severe hardship for the inhabitants.

The frequency of simultaneous heat waves is estimated to have increased 6-fold from 1979 to 2019 (Rogers et al., 2021).

Compound events increase the costs associated with climate disasters, and increase the pressure to implement effective adaptation.

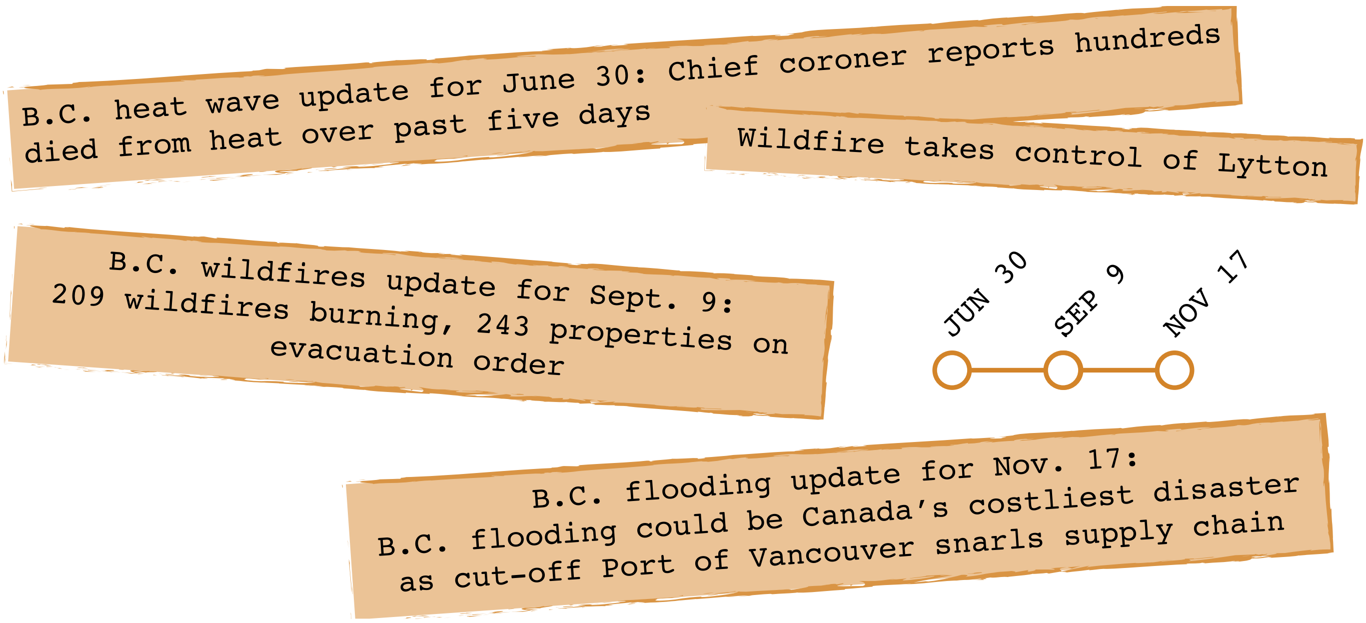


Figure 14. Headlines from the Vancouver Sun on June 30, September 9, and November 17, 2021, demonstrating compound events.

To adapt to climate change, we need to improve our resilience to its effects. The sheer diversity of climate change effects complicates adaptation plans: measures designed to minimize the impact of flooding (for example installation of basement backflow valves) may be useless if your community is instead afflicted with a drought. The best course of action is to address community needs on a fundamental level so as to be 'ready for anything' and recover quickly. This is resilience.

Adaptation planning for infrastructure resilience. Infrastructure resilience is improved by finding an effective balance between a centralized system of organization depending on strict division of function, and a system with built-in redundancy.

When electrical power lines are down, gas-powered generators are frequently used to provide emergency power , but may present a serious, potentially lethal carbon monoxide hazard if used indoors. Having both types of power available represents a redundancy in the system that can be very beneficial during a disaster. Land-line phones are redundant to cell phones most of the time, but can become crucial if the cell phone towers are damaged. Similarly, redundant transportation modes and routes are desirable to avoid being cut-off from supplies or help during an extreme event. When redundancy is impractical, the existing infrastructure should be better-protected against failure, for example power lines can be buried.

Central warehousing and 'just in time' delivery fails when extreme events disrupt transportation, as certain locations will be unable to receive goods depending on which routes are affected (Figure 12 on page 17).

It can be helpful to maintain a reasonable stockpile of goods where they will ultimately be required. The same logic can be applied to the provision of emergency shelters. A greater number of well-distributed sites will make it easier for vulnerable citizens to reach shelter when travel is difficult. The balance between centralization and distribution should take into account information needs; for example, a centralized database of hospitals accepting patients is useful to ambulance drivers if communication is still possible.

These infrastructure-based adaptation methods are particularly useful after extreme events that would otherwise cause wide-spread disruption in the community.

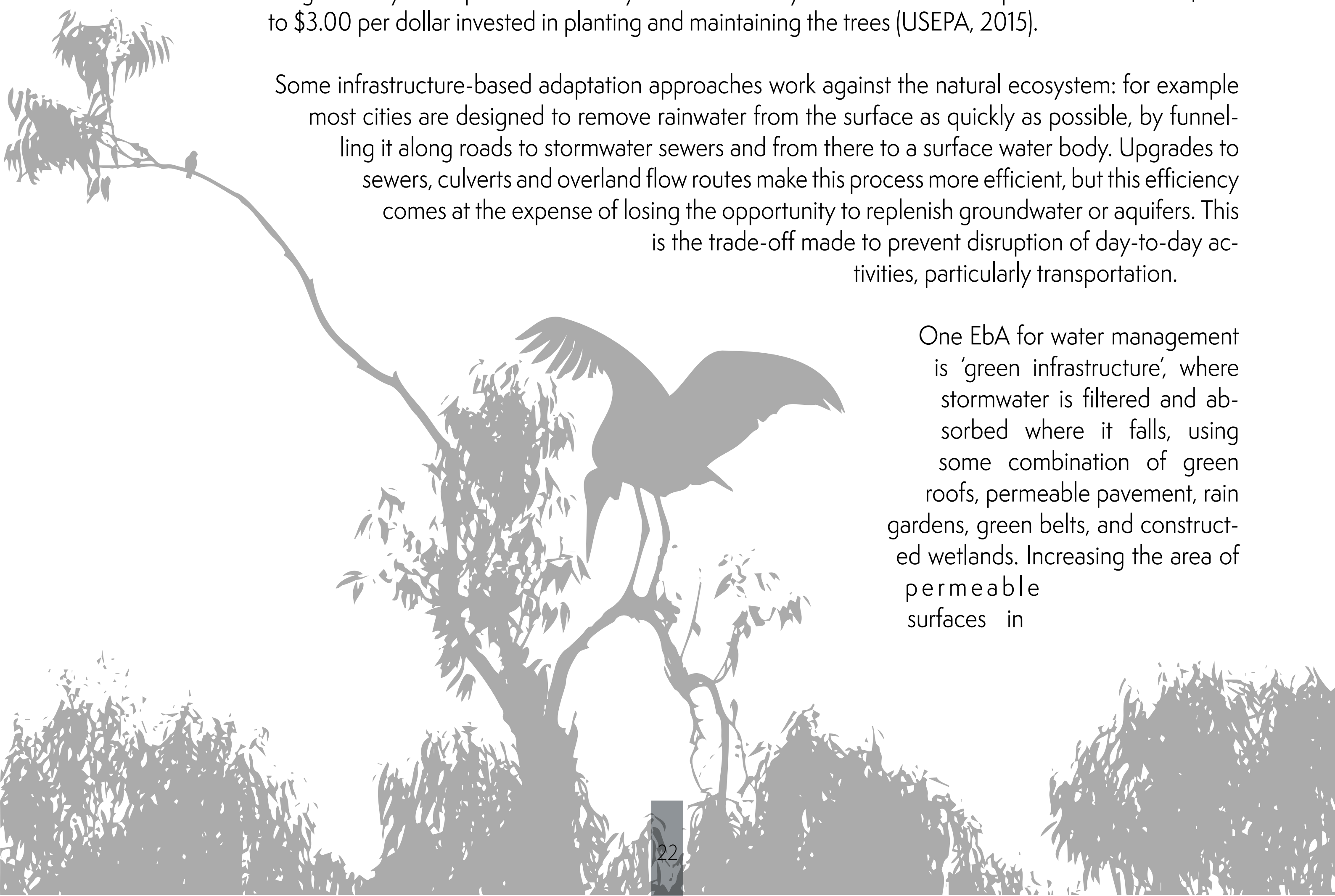
Adaptation planning for ecosystem resilience. Just as human-built infrastructure provides essential services such as communication and transportation, ecosystems provide a variety of other essentials such as food and water resources, recreational opportunities, and building materials.

Natural ecosystems consist of a network of species acting as checks and balances on each other. It follows that by maintaining ecosystems in as natural a state as possible we can ensure their ability to continue to provide ecosystem services.

Ecosystem-based adaptation. Adaptation strategies that leverage natural ecosystem services such as erosion control and water retention are referred to as Ecosystem-based Adaptations (EbAs). The fundamental benefits of encouraging natural vegetation are numerous. Tree canopies and groundcovers absorb both solar energy and carbon, storing them as food. They reduce evaporation from the soil, and generally moderate the temperature and humidity for the trees and shrubs growing below the canopy, including at soil level. They provide these services for free, being naturally 'solar-powered'. A study of urban forestry over five US cities reported a benefit of \$1.50 to \$3.00 per dollar invested in planting and maintaining the trees (USEPA, 2015).

Some infrastructure-based adaptation approaches work against the natural ecosystem: for example most cities are designed to remove rainwater from the surface as quickly as possible, by funnelling it along roads to stormwater sewers and from there to a surface water body. Upgrades to sewers, culverts and overland flow routes make this process more efficient, but this efficiency comes at the expense of losing the opportunity to replenish groundwater or aquifers. This is the trade-off made to prevent disruption of day-to-day activities, particularly transportation.

One EbA for water management is 'green infrastructure', where stormwater is filtered and absorbed where it falls, using some combination of green roofs, permeable pavement, rain gardens, green belts, and constructed wetlands. Increasing the area of permeable surfaces in



a community can recharge the water table to guard against the effects of drought, reduce the risk of overland flooding, reduce the urban heat island effect and can potentially increase biodiversity (for example through use of bioswales). Increased biodiversity can reduce the risk of VBD, since vector reproduction is increased in degraded landscapes. These types of adaptation strategies maximize co-benefits and are more beneficial than strategies that involve trade-offs, such as encouraging the uptake of air-conditioners (which increase emissions) to handle a heat wave (by reducing heat exposure).

An example of a large-scale EbA project is the 18 km 'triple dike' being developed in the Dapeng peninsula northeast of Hong Kong (Felixx, 2021). The first (outer) dike attenuates waves to reduce erosion and enhance sedimentation, to preserve the shoreline, and the middle dike is a multi-purpose elevated embankment forming a barrier against storm surges. The 3rd dike handles excess rainwater flowing down from the inland hills using a 'sponge city' (Figure 15 below). This approach consists of planting vegetation on slopes to slow the course of the rain as it runs downhill, and temporarily storing any excess water that does collect in rain-parks, raingardens, wet forests, wetlands and green streets.

Similar restoration of vegetation along freshwater shores can reduce erosion and absorb soil and nutrients that might otherwise be washed into lakes or streams; this reduces the risk of algal blooms as well as helping to stabilize the shoreline.

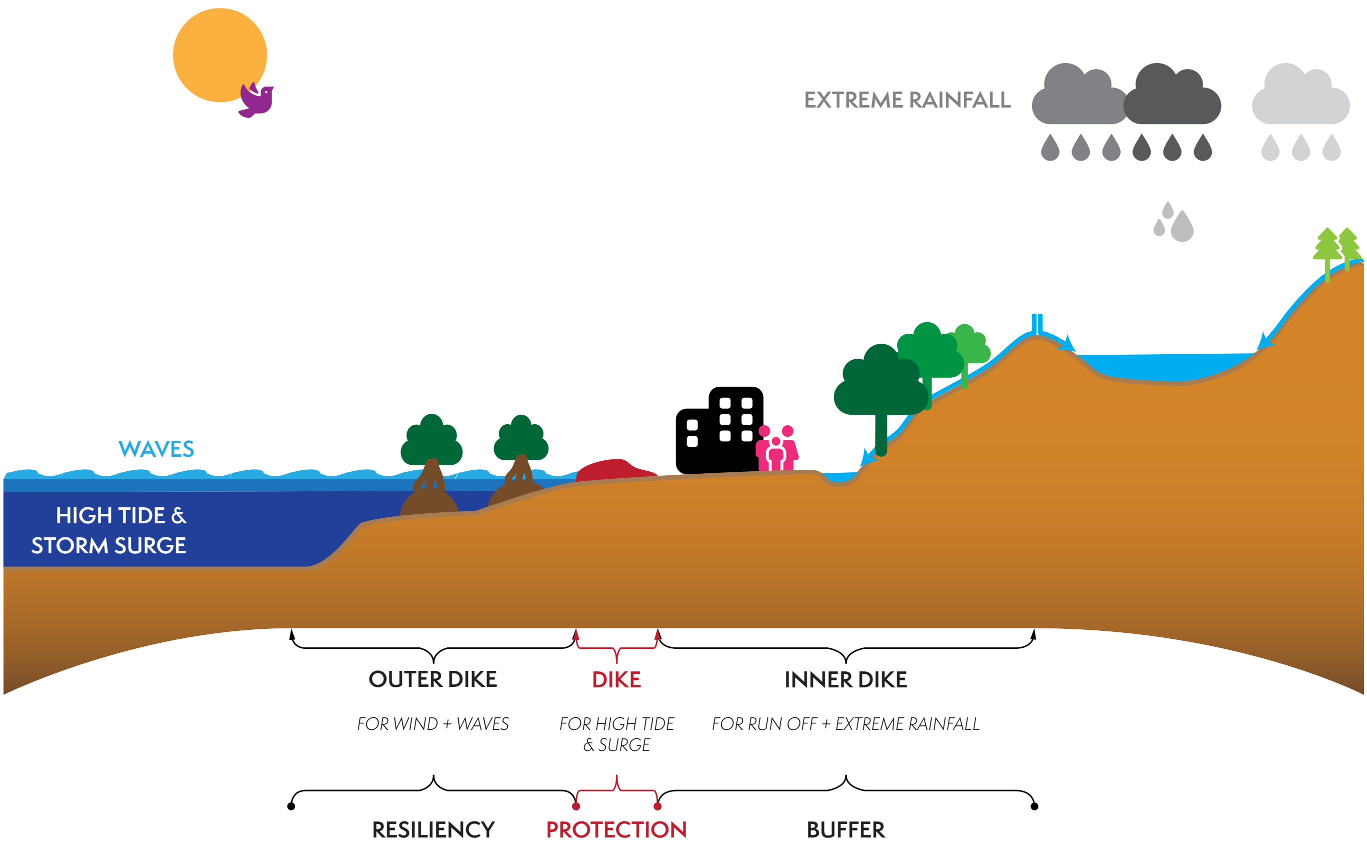


Figure 15. Cross-section of the triple dike project in the Dapeng peninsula, Shenzhen, China. Adapted from: Felixx (2021).

Conclusion: The Path Forward

To tackle the adaptation challenge, communities and asset-owners need to engage in a structured, evidence-based process to identify, prioritise, and analyse health risks and the associated adaptation options. In anticipation of this challenge and process, an IAI-funded project has developed a detailed, highly-structured catalogue of cause-and-effect relationships (similar in nature to the pathways within a bowtie diagram). These range from the most direct, such as the impacts of heat, through to complex and indirect, such as mosquito-borne disease. They also vary from the immediately possible, such as extreme weather events, to longer-term consequences of gradual but eventually harmful impacts, such as food insecurity and civil unrest.

In addition to describing the cause-and-effect relationships, the catalogue includes specific vulnerabilities that make the associated impacts more likely or more severe. Adaptation options that address these vulnerabilities can reduce or eliminate the risk.

Communities and asset-owners can carry out the following steps to identify, prioritise, and analyse health impacts and possible adaptations:

- Collect historical data and climate model projections for the site and community
- Develop and implement a worker and community engagement process intended to inform the identification and prioritization of health impacts and adaptations
- Within this engagement process, filter the catalogue of cause-and-effect relationships by identifying relevant site- and community-level characteristics that make each relationship applicable or non-applicable
- Select and prioritise health risks with immediate potential impact, and associated adaptation options, for in-depth analysis
- Select and prioritise health risks with a longer-term horizon, and associated adaptation options, for in-depth analysis
- Consider formal Cost-Benefit Analysis of adaptation options, with consideration of community co-benefits of the adaptation options.

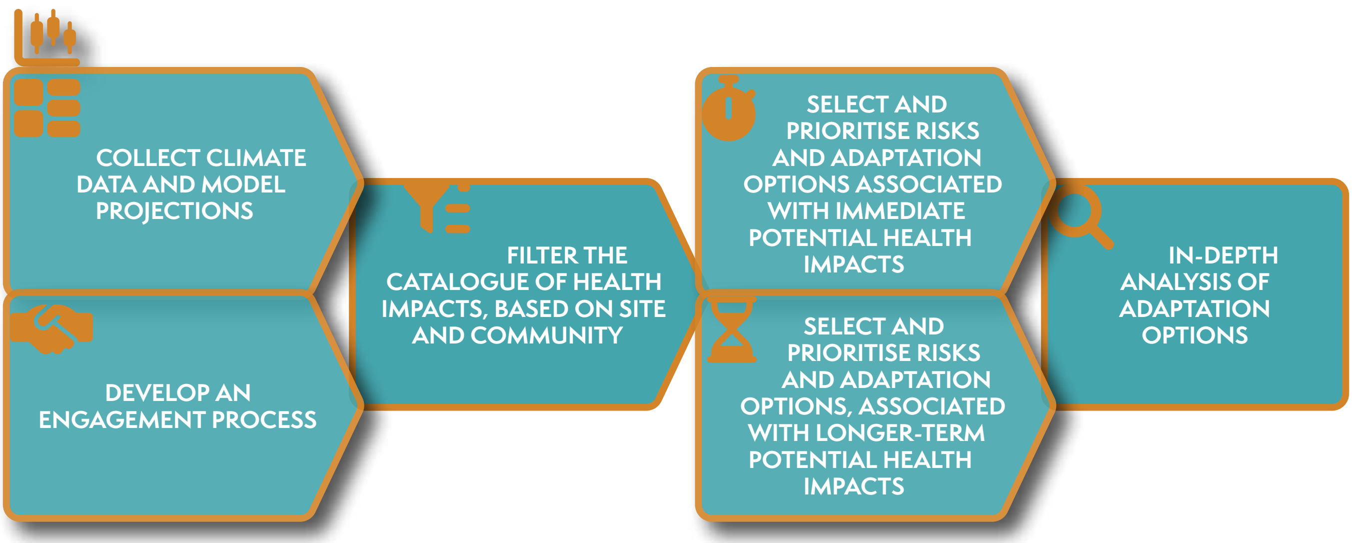


Figure 16. Recommended steps to identify, prioritise, and analyse health risks and adaptation options.

Climate change represents an existing and future challenge. There are examples of successful and diverse adaptations to climate change around the world. The path forward presents a concrete set of next steps leading to the prevention of health impacts in workers and communities, and to a more sustainable and resilient aluminium industry.

Photo by Laura Tancredi from Pexels

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Inaction is not an option. What we need is a structured, evidence-based process to identify, prioritise, and analyse health risks and the associated adaptation options.

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