Chapter 7: Health, Wellbeing, and the Changing Structure of Communities

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Date of Draft: 1 October 2021

Notes: TSU Compiled Version

Table of Contents

Executive Summary

Climate-related illnesses, premature deaths, malnutrition in all its forms, and threats to mental health and wellbeing are increasing *(very high confidence*[1]*)*. Climate hazards are a growing driver of involuntary migration and displacement (*high confidence*) and are a contributing factor to violent conflict *(high confidence)*. These impacts are often interconnected, are unevenly distributed across and within societies, and will continue to be experienced inequitably (*very high confidence*). Cascading and compounding risks affecting health due to extreme weather events have been observed in all inhabited regions, and risks are expected to increase with further warming (*very high confidence*). [7.1.3, 7.1.4, Cross-Chapter Box COVID in Chapter 7, 7.2.1, 7.2.2, 7.2.3, 7.2.4, 7.3.1, 7.3.2, 7.3.3, 7.4.1, 7.4.4, Cross-Chapter Box HEALTH in Chapter 7, Cross-Capter Box ILLNESS in Chapter 2]

Since AR5, new evidence and awareness of current impacts and projected risk of climate change on health, wellbeing, migration, and conflict emerged, including greater evidence of the detrimental impacts of climate change on mental health (*very high confidence*). New international agreements were reached on climate change (Paris Agreement), disaster risk reduction (Sendai Agreement), sustainable development (the SDGs), urbanisation (The New Urban Agenda), migration (Global Compact for Safe, Orderly and Regular Migration), and refugees (Global Compact on Refugees) that, if achieved, would reduce the impacts of climate change on health, wellbeing, migration, and conflict (*very high confidence*). However, the challenges with implementing these agreements are highlighted by the COVID-19 pandemic, which exposed systemic weaknesses, at community, national, and international levels in the ability of societies to anticipate and respond to global risks *(high confidence)*. Incremental changes in policies and strategies have proven insufficient to reduce climate-related risks to health, wellbeing, migration, and conflict, highlighting the value of more integrated approaches and frameworks for solutions across systems and sectors that are embodied in these new international agreements *(high confidence)* [7.1.3, 7.2.1, 7.4.1, 7.4.2, 7.4.3, 7.4.6, Cross-Chapter Box COVID in Chapter 7]

With proactive, timely, and effective adaptation, many risks for human health and wellbeing could be reduced and some potentially avoided (*very high confidence*). A significant adaptation gap exists for human health and well-being and for responses to disaster risks (*very high confidence*). Most Nationally Determined Contributions to the Paris Agreement from low- and middle-income countries identify health as a priority concern. National planning on health and climate change is advancing, but the comprehensiveness of strategies and plans need to be strengthened and implementing action on key health and climate change priorities remains challenging *(high confidence)*. Multisectoral collaboration on health and climate change policy is evident, with uneven progress, and financial support for health adaptation is only 0.5% of dispersed multilateral climate finance projects *(high confidence)*. This level of investment is insufficient to protect population health and health systems from most climate-sensitive health risks (*very high confidence*) [7.4.1, 7.4.2, 7.4.3].

Climate resilient development has a strong potential to generate substantial co-benefits for health and wellbeing, and to reduce risks of involuntary displacement and conflict (*very high confidence*). Sustainable and climate-resilient development that decreases exposure, vulnerability, and societal inequity, and that increases timely and effective adaptation and mitigation more broadly, has the potential to reduce but not necessarily eliminate climate change impacts on health, wellbeing, involuntary migration, and conflict *(high confidence)*. This development includes, but is not limited to, greenhouse gas emissions reductions through: clean energy and transport; climate resilient urban planning; sustainable food systems that lead to healthier diets; universal access to health care and social protection systems; wide-scale, proactive adaptive capacity building for climate change; and, achievement of the Sustainable Development Goals *(very high confidence)*. Meeting the objectives of the Global Compact for Safe, Orderly, and Regular Migration, and building inclusive and integrative approaches to climate resilient peace would help prevent health risks related to migration and conflict (*high agreement, medium evidence*)**.** The net global financial gains from these co-benefits to health and well-being, including avoided hospitalizations, morbidity, and

[1] In this Report, the following summary terms are used to describe the available evidence: limited, medium, or robust; and for the degree of agreement: low, medium, or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high, and very high, and typeset in italics, e.g., *medium confidence*. For a given evidence and agreement statement, different confidence levels can be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence.

premature deaths, exceed the financial costs of mitigation (*high confidence*) As an example of co-benefits, the financial value of health benefits from improved air quality alone is projected to be greater than the costs of meeting the goals of the Paris Agreement *(high confidence)*. All pathways to climate resilient development, including those for the health and healthcare systems, involve balancing complex synergies and trade-offs between development pathways and the options that underpin climate mitigation and adaptation pathways (*very high confidence*). [7.4.6, Cross-Capter Box HEALTH in Chapter 7, Cross-Chapter Box MIGRATE in Chapter 7].

Key transformations are needed to facilitate climate resilient development pathways for health, well-being, migration and conflict avoidance *(high confidence)*. The transformational changes will be more effective if they are responsive to regional, local, and Indigenous Knowledge, and consider the many dimensions of vulnerability, including those that are gender- and age-specific *(high confidence)*. A key pathway toward climate resilience in the health sector is universal access to primary health care, including mental health care (*high confidence*). Investments in other sectors and systems that improve upon the social determinants of health have the potential to reduce vulnerability to climate-related health risks (*high confidence*). Links between climate risks, adaptation, migration, and labour markets highlight the value of providing better mobility options as part of transformative change *(medium confidence)*. Strong governance and gender-sensitive approaches to natural resource management reduce the risk of intergroup conflict in climate-disrupted areas *(medium confidence).* [7.4.6, Cross-Chapter Box COVID in Chapter 7, Cross-Chapter Box HEALTH in Chapter 7, Cross-Chapter Box GENDER in Chapter 18, Cross-Chapter Box INDIG in Chapter 18, Cross-Capter Box MIGRATE in Chapter 7]

Observed Impacts

Climate hazards are increasingly contributing to a growing number of adverse health outcomes (including communicable and non-communicable diseases) in multiple geographical areas *(very high confidence)*. The net impacts are largely negative at all scales *(very high confidence),* and there are very few examples of beneficial outcomes from climate change at any scale *(high confidence)*. While malaria incidence has declined globally due to non-climatic socio-economic factors and health system responses, a shift to higher altitudes has been observed as the climate warms *(very high confidence)*. Climate variability and change (including temperature, relative humidity, and rainfall) and population mobility are significantly and positively associated with observed increases in dengue globally, chikungunya virus in Asia, Latin America, North America, and Europe *(high confidence)*, Lyme disease vector *Ixodes scapularis* in North America *(high confidence)*, and Lyme disease and Tick-Borne Encephalitis vector *Ixodes ricinus* in Europe *(medium confidence)*. Higher temperatures (*very high confidence*), heavy rainfall events *(high confidence),* and flooding *(medium confidence)* are associated with an increase of diarrheal diseases in affected regions, including cholera *(very high confidence)*, other gastro-intestinal infections *(high confidence)*, and foodborne diseases due to Salmonella and Campylobacter *(medium confidence).* Floods have led to increases in vector-borne and water-borne diseases and to disturbances of public health services *(high confidence)*. Climate extremes increase the risks of several types of respiratory tract infections *(high confidence)*. Climate-related extreme events such as wildfires, storms, and floods are followed by increased rates of mental illness in exposed populations (*very high confidence*). [7.2.1, 7.2.2, 7.2.3, 7.2.4, 7.2.5]

Several chronic, non-communicable respiratory diseases are climate-sensitive based on their exposure pathways (e.g., heat, cold, dust, small particulates, ozone, fire smoke, and allergens) *(high confidence),* although climate change is not the dominant driver in all cases. Worldwide, rates of adverse health impacts associated with small particulate matter exposure have decreased steadily due to decreasing primary emissions *(very high confidence)*, while rates of adverse health impacts from ozone air pollution exposure have increased *(very high confidence)***.** Exposure to wildland fires and associated smoke has increased in several regions (*very high confidence*). Spring pollen season start dates in northern mid-latitudes are occurring earlier due to climate change, increasing the risks of allergic respiratory diseases *(high confidence)*. [7.2.3.2.]

Heat is a growing health risk due to burgeoning urbanization, an increase in high temperature extremes, and demographic changes in countries with aging populations *(very high confidence)*. Potential hours of work lost due to heat has increased significantly over the past two decades (*high confidence*). Some regions are already experiencing heat stress conditions at or approaching the upper limits of labour productivity *(high confidence).* A significant proportion of warm season heat-related mortality in temperate regions is linked to observed anthropogenic climate change, (*medium confidence*) but greater evidence is required for tropical regions. For some heatwave events over the last two decades, associated health impacts can be at least partially attributed to observed climate change (*high confidence*). Extreme heat has negative impacts on mental health, wellbeing, life satisfaction, happiness, cognitive performance, and aggression (*medium confidence*). [7.2.4.1, 7.2.4.5]

Climate variability and change contribute to food insecurity, which can lead to malnutrition, including undernutrition, overweight, obesity; and to disease susceptibility in low- and middle-income countries (*high confidence*). Populations exposed to extreme weather and climate events may consume inadequate or insufficient food, leading to malnutrition and increasing the risk of disease (*high confidence*). Children and pregnant women experience disproportionately greater adverse nutrition and health impacts *(high confidence)*. Climatic influences on nutrition are strongly mediated by socio-economic factors (*very high confidence*). [7.2.4.4, 7.3.1]

Extreme climate events act as both direct drivers (e.g., destruction of homes by tropical cyclones) and as indirect drivers (e.g., rural income losses during prolonged droughts) of involuntary migration and displacement *(very high confidence).* Most documented examples of climate-related displacement occur within national boundaries, with international movements occurring primarily within regions, particularly between countries with contiguous borders *(high confidence)*. Global statistics collected since 2008 by the Internal Displacement Monitoring Centre show an annual average of over 20 million people internally displaced by weather-related extreme events, with storms and floods the most common drivers *(high confidence).* The largest absolute number of people displaced by extreme weather each year occurs in Asia (South, Southeast and East), followed by sub-Saharan Africa, but small island states in the Caribbean and South Pacific are disproportionately affected relative to their small population size (*high confidence*). Immobility in the context of climate risks can reflect vulnerability and lack of agency but can also be a deliberate choice of people to maintain livelihoods, economic considerations and social and cultural attachments to place (*high confidence*). [7.2.6, Cross-Chapter Box MIGRATE in Chapter 7].

Climate hazards have affected armed conflict within countries (medium confidence), but the influence of climate is small compared to socio-economic, political, and cultural factors *(high confidence).* Climate increases conflict risk by undermining food and water security, income and livelihoods, in situations where there are large populations, weather-sensitive economic activities, weak institutions and high levels of poverty and inequality *(high confidence).* In urban areas, food and water insecurity and inequitable access to services has been associated with civil unrest where there are weak institutions *(medium confidence)*. Climate hazards are associated with increased violence against women, girls and vulnerable groups and the experience of armed conflict is gendered *(medium confidence)*. Adaptation and mitigation projects implemented without consideration of local social dynamics have exacerbated non-violent conflict *(medium confidence)*. [7.2.7]

Projected Risks and Vulnerabilities

A significant increase in ill health and premature deaths from climate-sensitive diseases and conditions is projected due to climate change *(high confidence)*. An excess of 250,000 deaths per year by 2050 attributable to climate change are projected just due to heat, undernutrition, malaria, and diarrheal disease, with more than half of this excess mortality projected for Africa (compared to a 1961-1991 baseline period, for a mid-range emissions scenario) *(high confidence)*. Risks for heat-related morbidity and mortality, ozone-related mortality, malaria, diseases carried by Aedes sp. mosquitoes, Lyme disease, and West Nile fever, with the temperature at which risk transitions occur, from moderate to high to very high, contingent on future development pathways *(high confidence)*. [7.3.1]

Climate change is projected to significantly increase population exposure to heat waves (*very high confidence*). Models suggest exposure increases 16 times under RCP4.5/SSP3 and 36 times under RCP8.5/SSP3, with the impact of warming amplified under development pathways that do not foster sustainable development. Globally, the impact of projected climate change on temperature-related mortality is expected to be a net increase under RCP4.5 to RCP8.5, even with adaptation (*high confidence).* Strong geographical differences in heat-related mortality are projected to emerge later this century, mainly driven by growth in regions with tropical and subtropical climates *(very high confidence).* [7.3.1]

The burdens of several climate-sensitive food-borne, water-borne, and vector-borne diseases are projected to increase under climate change, assuming no additional adaptation *(very high confidence)*. The distribution and intensity of transmission of malaria is expected to decrease in some areas and increase in others, with increases projected mainly along the current edges of its geographic distribution in endemic areas of Sub-Saharan Africa, Asia, and South America *(high confidence)*. Dengue risk will increase, with a larger spatio-temporal distribution in Asia, Europe, and sub-Saharan Africa under RCPs 6.0 and 8.5, potentially putting another 2.25 billion people at risk *(high confidence).* Higher incidence rates are projected for Lyme disease in the northern hemisphere *(high confidence)* and for transmission of *Schistosoma mansoni* in eastern Africa *(high confidence)*. [7.3.1, Cross-Chapter Box ILLNESS in Chapter 2]

Increasing atmospheric concentrations of carbon dioxide and climate change are projected to increase diet-related risk factors and related non-communicable diseases globally, and increase undernutrition, stunting, and related childhood mortality particularly in Africa and Asia, with outcomes depending on the extent of mitigation and adaptation *(high confidence)*. These projected changes are expected to slow progress towards eradication of child undernutrition and malnutrition *(high confidence)*. Higher atmospheric concentrations of carbon dioxide reduce the nutritional quality of wheat, rice, and other major crops, potentially affecting millions of people at a doubling of carbon dioxide *(very high confidence)* [7.3.1].

Climate change is expected to have adverse impacts on wellbeing and to further threaten mental health (*very high confidence*). Children and adolescents, particularly girls, as well as people with existing mental, physical, and medical challenges and elderly people, are particularly at risk. Mental health impacts are expected to arise from exposure to high temperatures, extreme weather events, displacement, malnutrition, conflict, climate-related economic and social losses, and anxiety and distress associated with worry about climate change (*very high confidence*) [7.3.1.11]

Future climate-related migration is expected to vary by region and over time, according to future climatic drivers, patterns of population growth, adaptive capacity of exposed populations, and international development and migration policies (*high confidence*). The wide range of potential outcomes is reflected in model projections of population displacements by 2050 in Latin America, Sub-Saharan Africa and South Asia due to climate change, which vary from 31 million to 143 million people, depending on assumptions made about future emissions and socio-economic development trajectories *(high confidence)*. With every additional one degree Celsius of warming, the global risks of involuntary displacement due to flood events have been projected to rise by approximately 50% *(high confidence)*. High emissions/low development scenarios raise the potential for higher levels of migration and involuntary displacement *(high confidence)* and increase the need for planned relocations and support for people exposed to climate extremes but lacking the means to move (*high confidence*) [7.3.2, Cross-Chapter Box MIGRATE in Chapter 7].

Climate change may increase susceptibility to violent conflict, primarily intrastate conflicts, by strengthening climate-sensitive drivers of conflict *(medium confidence)*. Future violent conflict risk is highly mediated by socio-economic development trajectories (high confidence) and so trajectories that prioritise economic growth, political rights and sustainability are associated with lower conflict risk *(medium confidence)*. Future climate change may exceed adaptation limits and generate new causal pathways not observed under current climate variability *(medium confidence).* Economic shocks are currently not included in the models used and some projections do not incorporate known socio-economic predictors of conflict *(medium confidence)*. As such, future increases in conflict-related deaths with climate change have been estimated, but results are inconclusive *(medium confidence)*.

Solutions

Since AR5, the value of cross-sectoral collaboration to advance sustainable development has been more widely recognized, but despite acknowledgement of the importance of health adaptation as a key component, action has been slow *(high confidence)*. Building climate resilient health systems will require multi-sectoral and multisystem and collaborative efforts at all governance scales (*very high confidence*)

[7.4.1, 7.4.2]. Globally, health systems are poorly resourced in general, and their capacity to respond to climate change is weak, with mental health support being particularly inadequate (*very high confidence*). The health sectors of some countries have focused on implementing incremental changes to policies and measures to fill the adaptation gap (*very high confidence*). As the likelihood of dangerous risks to human health continue to increase, there is greater need for transformational changes to health and other systems (*very high confidence*). This highlights an urgent and immediate need to address the wider interactions between environmental change, socioeconomic development, and human health and wellbeing *(high confidence)*. [7.4.1, 7.4.2, 7.4.3]

Targeted investments in health and other systems, including multi-sectoral, integrated approaches, to protect against key health risks can effectively increase resilience (*high confidence*). Increased investment in strengthening general health systems, along with targeted investments to enhance protection against specific climate-sensitive exposures (e.g., hazard early warning and response systems, and integrated vector control programs for vector-borne diseases) will increase resilience, if implemented to at least keep pace with climate change *(high confidence).*

- The future effects of climate change on vector borne diseases can be significantly offset through enhanced commitment to and implementation of integrated vector control management approaches, disease surveillance, early warning systems, and vaccine development *(very high confidence).* [7.4.1, 7.4.2]
- Adaptation options for future climate risks associated with water-borne and food-borne diseases include improving access to potable water, reducing exposure of water and sanitation systems to flooding and extreme weather events, and improved (including expanded) early warning systems *(very high confidence).* [7.4.1, 7.4.2]
- Adaptation options for future extreme heat risks include heat action plans that incorporate early warning and response systems for urban and non-urban settings; tried, tested, and iteratively updated response strategies targeting both the general population and vulnerable groups such as older adults or outside workers; and effective stakeholder communication plans (*high confidence*). These short-term responses can be complemented by longer term urban planning and design, including Nature-based Solutions that mitigate urban heat island effects *(high confidence)* [7.4.1, 7.4.2, 7.4.3]
- Adaptation options to reduce the future risks of malnutrition include access to healthy, affordable diverse diets from sustainable food systems *(high confidence)*; health services including maternal, child and reproductive health (*high confidence*); nutrition services, nutrition and shock sensitive social protection, water and sanitation and early warning systems *(high confidence)*; and risk reduction schemes such as insurance *(medium confidence)*. [7.4.2.1.3]

The COVID-19 pandemic has demonstrated the value of coordinated and multi-sectoral planning, social protection systems, safety nets, and other capacities in societies to cope with a range of shocks and stresses *(high confidence)*. The pandemic posed a severe shock to many socio-economic systems, resulting in substantial changes in vulnerability and exposure of people to climate risks (*high confidence*). The pandemic underscores the interconnected and compound nature of risks, vulnerabilities, and responses to emergencies that are simultaneously local and global *(high confidence).* Pathways to climate resilient development can be pursued simultaneously with recovering from the COVID-19 pandemic *(high confidence).* The COVID-19 pandemic has aggravated climate risks, demonstrated the global and local vulnerability to cascading shocks, and illustrated the importance of integrated solutions that tackle ecosystem degradation and structural vulnerabilities in human societies *(high confidence)*. [Cross-Chapter Box COVID in Chapter 7]

Transitioning toward equitable, low-carbon societies has multiple benefits for health and wellbeing *(very high confidence)*. Benefits for health and wellbeing can be gained from wide-spread, equitable access to affordable renewable energy (*high confidence*); active transport (e.g., walking and cycling) (*high confidence*); green buildings and nature-based solutions, such as green and blue urban infrastructure (*high confidence*)*,* and by transitioning to a low-carbon, wellbeing-oriented and equity-oriented economy consistent with the aims of the Sustainable Development Goals *(high confidence)*. Plant-rich diets consistent with international recommendations for healthy diets, could contribute to lower greenhouse gas emissions while also generating health co-benefits, such as reducing ill health related to over-consumption of animal-based products *(high confidence)* [7.4.2*,* Cross-Chapter Box HEALTH in Chapter 7, 7.4.4]

Reducing future risks of involuntary migration and displacement due to climate change is possible through cooperative international efforts to enhance institutional adaptive capacity and sustainable development *(high confidence).* Institutional and cross-sectoral efforts to build adaptive capacity, coupled with policies aimed at ensuring safe and orderly movements of people within and between states, can form part of climate-resilient development pathways that reduce future risks of climate-related involuntary migration, displacement, and immobility *(medium confidence)*. In locations where permanent, government-assisted relocation becomes unavoidable, active involvement of local populations in planning and decision-making increases the likelihood of successful outcomes *(medium confidence)*. People who live on small island states do not view relocation as an appropriate or desirable means of adapting to the impacts of climate change *(high confidence)* [7.4.3, Cross-Chapter Box MIGRATE in Chapter 7]

Adaptation and development build peace in conflict-prone regions by addressing both the drivers of grievances that lead to conflict and vulnerability to climate change *(high confidence).* Environmental peacebuilding through natural resource sharing, conflict-sensitive adaptation, and climate-resilient peacebuilding offer promising avenues to addressing conflict risk but their efficacy is still to be demonstrated through effective monitoring and evaluation *(high confidence)*. However, formal institutional arrangements for natural resource management have been shown to contribute to wider cooperation and peacebuilding *(high confidence)* and gender-based approaches provide underutilised pathways to achieving sustainable peace *(medium confidence)*. Inclusion, cross-issue and cross-sectoral integration in policy and programming, and approaches that incorporate different geographical scales and work across national boundaries, can support climate resilient peace *(high confidence)* [7.4.5; 7.4.6].

7.1 Introduction

This chapter assesses peer-reviewed and selected grey literature published since the IPCC's Fifth Assessment Report (AR5) on the impacts and projected future risks of climate change for health, wellbeing, migration and conflict, taking into consideration determinants of vulnerability and the dynamic structure of human populations and communities. Particular attention is given to potential adaptation challenges and actions, as well as the potential of co-benefits for health associated with mitigation actions. AR5 presented strong evidence-based statements regarding the *likely*[2] impacts of climate change on health, migration, and conflict in two separate chapters on Human Health (Chapter 11) and Human Security (Chapter 12). The present chapter covers all topics found in AR5 Chapter 11 and sections 12.4 (Migration and Mobility Dimensions of Human Security), 12.5 (Climate Change and Armed Conflict), and 12.6 (State Integrity and Geopolitical Rivalry), and provides additional, expanded assessment of mental health impacts, gender dimensions of climate risks, and solution pathways.

7.1.1 Major Health-related Statements in AR5

AR5 stated with very high confidence that the health of human populations is sensitive to climate change (Smith et al., 2014). Specific observations of current impacts included the expansion of the geographical ranges of some diseases into previously unaffected areas and changes in the distributions of some food-, water- and vector-borne diseases *(high confidence)*. Increasing future health risks were projected from injury, disease, and death due to more intense heat waves and fires *(very high confidence)*, undernutrition in poor regions *(high confidence)*, food- and water-borne diseases *(very high confidence),* and vector-borne diseases *(medium confidence)*. AR5 found that climate change is a multiplier of existing health vulnerabilities, including insufficient access to safe water and improved sanitation, food insecurity, and limited access to health care and education, and that the most effective measures to reduce vulnerability in the near term are programmes that implement and improve basic public health *(very high confidence)*. Opportunities for co-benefits from mitigation actions were identified, through such actions as reducing local emission of short-lived climate pollutants from energy systems *(very high confidence)* and transport systems that promote active travel *(high confidence)*. The significant growth in peer-reviewed publications on links between climate change and human health and wellbeing since AR5 allowed for a more detailed and wider reaching assessment in the present chapter and stronger confidence statements for many climate-sensitive health outcomes.

7.1.2 Major Statements About Migration and Conflict in AR5

Key statements made in AR5 Chapter 12 (Human Security) about the impacts of climate change on migration were that climate change will have significant impacts on forms of migration that compromise human security, and that mobility is a widely used strategy to maintain livelihoods in response to social and environmental changes (*high agreement, medium evidence*). Research on the influence of climate change and climate extremes on multiple forms of migration (including voluntary migration, involuntary displacement, and immobility) has expanded significantly since AR5, which has allowed for a more robust assessment in this chapter, with migration also featuring in most other sectoral and regional chapters of this report as well. With respect to violent conflict, AR5 Chapter 12 found that people living in places affected by violent conflict are particularly vulnerable to climate change (*medium evidence, high agreement*), that some of the factors that increase the risk of violent conflict within states are sensitive to climate change (*medium evidence, medium agreement*). and that climate change will lead to new challenges to states and will increasingly shape both conditions of security and national security policies (*medium evidence, medium agreement*). As with other subjects assessed in this chapter, there has been significant growth in the number of assessable studies, but there remain shortcomings with respect to the availability of evidence regarding the specific nature of causal linkages and the attributability of particular outcomes to climate events or conditions.

[2] In this Report, the following terms have been used to indicate the assessed likelihood of an outcome or a result: Virtually certain 99–100% probability, Very likely 90–100%, Likely 66–100%, About as likely as not 33–66%, Unlikely 0–33%, Very unlikely 0–10%, and Exceptionally unlikely 0–1%. Additional terms (Extremely likely: 95–100%, More likely than not >50–100%, and Extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*). This Report also uses the term '*likely* range' to indicate that the assessed likelihood of an outcome lies within the 17-83% probability range.

7.1.3 Important Developments Since AR5

7.1.3.1 International Agreements

Since AR5, several new international agreements came into effect that have implications for international responses to climate risks assessed in this chapter. The 2015 Paris Agreement, which explicitly mentions health in three separate sections, set new goals for adaptation, and established a working group to study the effects of climate change on population displacement. The seventeen United Nations (UN) Sustainable Development Goals (SDGs) for 2030, adopted in 2015, are all important for building adaptive capacity in general, with goals 13 ("Climate Action") and 3 ("Good Health and Wellbeing") being directly relevant for this chapter. Other SDG goals contain specific targets that are also relevant for this chapter, including Target 10.7 ("Well-managed migration policies"), Target 8.3 ("Decent work for all") and Target 5.4 ("Promotion of peaceful and inclusive societies") (Piper, 2017). The 2015 Sendai Framework for Disaster Risk Reduction, puts an emphasis on health and wellbeing (Aitsi-Selmi and Murray, 2016) In 2018, UN members states negotiated Global Compacts for Safe, Orderly and Regular Migration and on Refugees that, taken together with the Paris Agreement, provide pathways for coordinated international responses to climate-related migration and displacement (Warner, 2018). Since AR5, the UN system has been reforming its Peace and Security agenda, as part of a larger series of reforms initiated by the Secretary-General in 2017, and under the 2018 Climate Security Mechanism.

7.1.3.2 IPCC Special Reports

All three post-AR5 IPCC Special Reports considered some of the research that is assessed here in greater detail. The 2018 report on 1.5° C (SR1.5) included a review of climate change and health literature published since AR5 and called for further efforts for protecting health and wellbeing of vulnerable people and regions (Ebi et al., 2018b), and highlighted links between climate change hazards, poverty, food security, migration, and conflict. The 2019 Special Report on Climate Change and Land (SRCCL) (SRCCL, 2019) emphasized the impacts of climate change on food security; highlighted links between reduced resilience of dryland populations, land degradation migration, and conflict; and raised concerns about the impacts of climate extremes. The 2019 Special Report on the Ocean and Cryosphere in a Changing Climate (Pörtner et al., 2019) detailed how changes in the cryosphere and ocean systems have impacted people and ecosystem services, particularly food security, water resources, water quality, livelihoods, health and wellbeing, infrastructure, transportation, tourism, and recreation, as well as the culture of human societies, particularly for Indigenous peoples. It also noted the risks of future displacements due to rising sea levels and associated coastal hazards.

7.1.4 Interpretation of "Health and Wellbeing" Used in This Chapter

Assessing the links between human health, wellbeing, and climate change is a new task for AR6, reflecting a broad perspective on health that increasingly acknowledges the importance of wellbeing and its interactions with individual and population health. The World Health Organization (WHO) defines health as "a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity" (Organization, 1946). Although this chapter assesses physical health, mental health, and general wellbeing separately, they are interconnected; any type of health problem can reduce overall wellbeing, and vice versa. For example, a child receiving inadequate nutrition may not be sick, but is experiencing a clear threat to wellbeing that has implications for future physical and mental health.

There is no consensus definition of wellbeing, but it is generally agreed that it includes a predominance of positive emotions and moods (e.g. happiness) compared with extreme negative emotions (e.g. anxiety), satisfaction with life, a sense of meaning, and positive functioning, including the capacity for unimpaired cognitive functioning and economic productivity (Diener and Tay, 2015) (Piekałkiewicz, 2017). A capabilities approach (Sen, 2001) focuses on the opportunity for people to achieve their goals in life (Vik and Carlquist, 2018) or the ability to take part in society in a meaningful way: the result of personal freedoms, human agency, self-efficacy, an ability to self-actualize, dignity and relatedness to others (Markussen et al., 2018). An Indigenous perspective on wellbeing is broad and typically incorporates a healthy relationship with the natural world (Sangha et al., 2018); emotional and mental health have also been linked to a strong cultural identity (Butler et al., 2019);(Dockery, 2020). “Health” itself is sometimes described as including relationships between humans and nature as well as links to community and culture (Donatuto et al., 2020);(Dudgeon et al., 2017)

Subjective wellbeing is consistently associated with personal indicators such as higher income, greater economic productivity, better physical health (Diener and Tay, 2015);(Delhey and Dragolov, 2016);(De Neve et al., 2013), and environmental health; and associated with societal indicators such as social cohesion and equality (Delhey and Dragolov, 2016). In a global sample of over 1 million people obtained between 2004-2008 via the Gallup World Poll, annual income and access to food were strong predictors of subjective wellbeing, and a healthy environment, particularly access to clean water, was also associated even when household income was controlled (Diener and Tay, 2015). Access to green spaces is also associated with wellbeing (high confidence) (Lovell et al., 2018);(Yuan et al., 2018).

7.1.5 Toward Socio-Ecological Perspectives on Health, Wellbeing, and Loss and Damage

Since the AR5, more comprehensive frameworks for framing and studying global health issues, including planetary health, ‘one health’, and eco-health, have gained traction. These frameworks share an ecological perspective, emphasize the role of complex systems, and highlight the need for interdisciplinary approaches related to human health research and practice (Lerner and Berg, 2015);(Zinsstag et al., 2018);(Whitmee et al., 2015);(Steffen et al., 2015). These frameworks increasingly shape the evidence related to climate change health impacts and response options, highlight the dynamics of complex systems in risk management, and direct risk management efforts in new directions.

Building on these frameworks and perspectives, there is increasing overlap in literature on global health, climate change impacts, and estimates of loss and damage. The Global Burden of Disease study for 2019 now includes non-optimal temperature as a risk factor (Murray et al., 2020). Work by social scientists continues to explore how climate change indirectly affects resource availability, productivity, migration, and conflict (Burke et al., 2015a);(Carleton and Hsiang, 2016);(Hsiang et al., 2017), bringing multiple lines of inquiry together to study the associations between global environmental changes, socio-economic dynamics, and impacts on health and wellbeing. Morbidity associated with migration and displacement, especially in the context of small island states, has been called out as a non-material form of loss and damage (Thomas and Benjamin, 2020);(McNamara et al., 2021). Social costs of carbon estimates have been updated to include excess mortality associated with climate change, increasing estimates substantially (Dressler, 2021).

7.1.6 Developments Relevant to Tracking and Assessing Climate Change Impacts on Health

Since AR5 there has been a steady increase in standardized, globally scoped, data-driven health impact assessments, signified by the ongoing Global Burden of Disease study (James et al., 2018) that now includes scenario-based projections (Foreman et al., 2018) and its linkages with other global priorities, including the SDGs (Fullman et al., 2017). Attention has turned from prioritizing specific diseases like HIV/AIDS, malaria, and tuberculosis, to strengthening health systems and providing universal health coverage (Chang et al., 2019), accompanying an ongoing emphasis on the social determinants of health. Several climate-sensitive health outcomes are now tracked in the annual Lancet Countdown reports (Watts et al., 2015);(Watts et al., 2017);(Watts et al., 2018b);(Watts et al., 2019);(Watts et al., 2021). The Global Burden of Disease study is beginning to examine climate sensitive disease burdens, incorporate temperature as a risk factor(Murray et al., 2020), and project future cause-specific disease burdens in a warming world (Burkart et al., 2021). Although not assessed in this chapter, there are numerous ongoing assessments of climate change impacts on health and wellbeing being undertaken by national and local health authorities that continue to generate insights into climate-related health impacts and suggest response options relevant for decision makers.

While the knowledge base regarding global health has increased, a comprehensive framework is not in place that fully integrates health, wellbeing, and environmental impacts from climate change allowing for the cumulative assessment of their impact. Moreover, significant cracks in the foundation of global health governance that affect preparedness and adaptive capacity for climate change, among other threats, have been laid bare (Phelan et al., 2020); (Defor and Oheneba-Dornyo, 2020); (Ostergard et al., 2020); (A, 2021). While attention to climate change and health has increased (Watts et al., 2019) and there is evidence of increasing adaptation activity in the health sector (Watts et al., 2019), there is also continued evidence of substantial adaptation gaps (UNEP, 2018);(UNEP, 2021) including gaps in humanitarian response capacity for climate-related disasters (Watts et al., 2021), that appear to be widening as adverse climate change impacts on health and wellbeing accrue.

7.1.7 Hazards, Exposure and Vulnerability in the Context of Human Health, Wellbeing and Changing Structure of Communities

7.1.7.1 Possible Climate Futures and Hazards from AR6 WGI

This chapter uses the conceptual framing described in Chapter 1, in which risks emerging from climate change are described in terms of hazard, exposure, and vulnerability, with adaptation and climate-resilient development being responses that have the potential to reduce or modify risk. The observed and projected future risks to health, wellbeing, involuntary population displacements, and conflict identified in this chapter are associated with a range of hazards that are manifested at a variety of geographical and temporal scales. These include observed and projected changes in climate normals, changes in the frequency, duration, and or severity of extreme events, and hazards such as rising sea levels and extreme temperatures where the impacts have only begun to be widely experienced. The 2021 report of IPCC Working Group I provides an assessment of observed and projected changes in these hazards and is the backdrop against which assessments of future risks and adaptation options identified in the present chapter should be considered. The exposure to such hazards of populations, infrastructure, ecosystem capital, socio-economic systems, and cultural assets critical to health and wellbeing varies considerably across and within regions. Exposure is also projected to vary across and within regions over time, depending on future greenhouse gas (GHG) emissions pathways and development trajectories (Figures 7.1 a and b). For this reason, region-specific assessments of climate-related risks for health, displacement and conflict are found in each of the regional chapters of this report in addition to the general assessment that appears in this chapter.

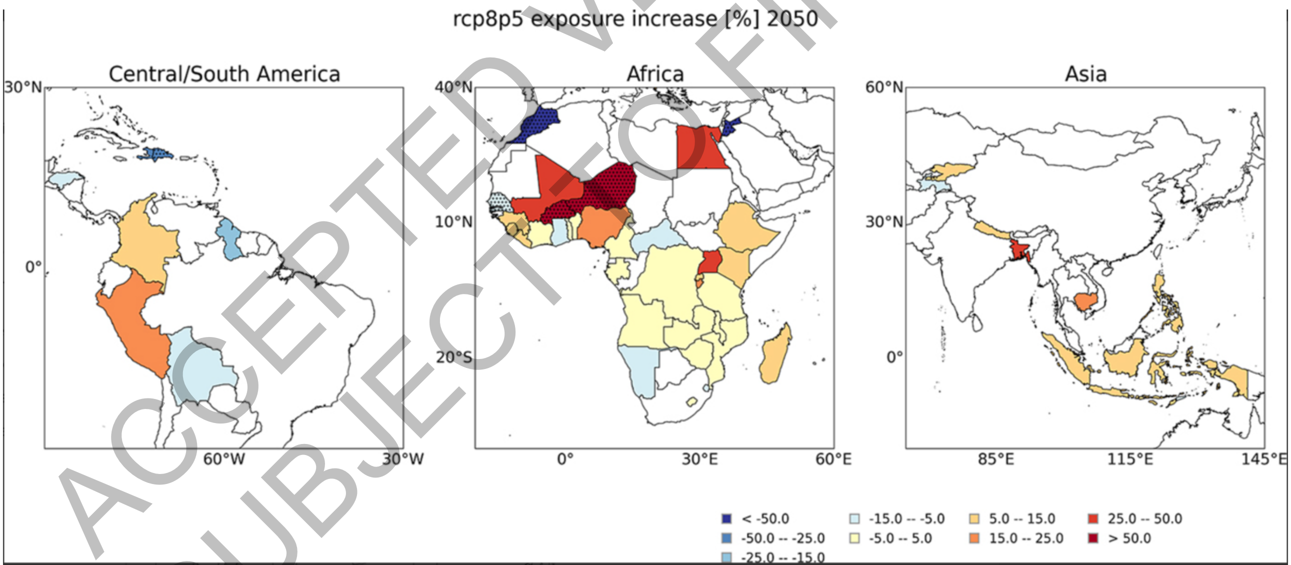

Figure 7.1a: Projected exposure of poor people to floods in selected regions by 2050 under a high emissions scenario (RCP 8.5) (Winsemius et al., 2018)

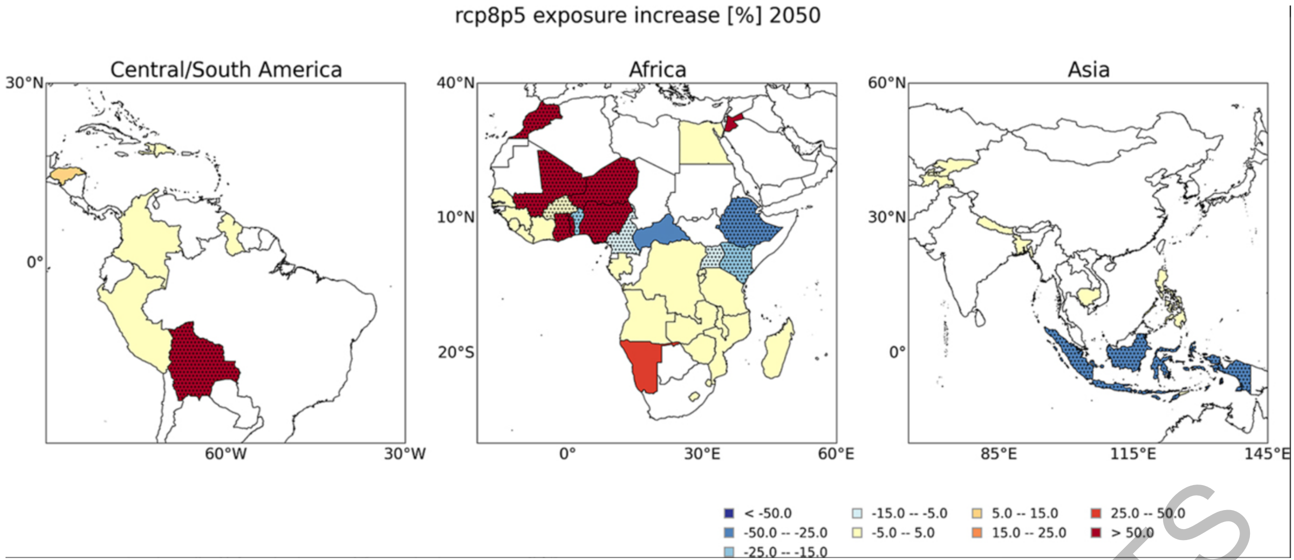

Figure 7.1b: Projected exposure of poor people to droughts in selected regions by 2050 under a high emissions scenario (RCP 8.5) (Winsemius et al., 2018)

7.1.7.2 Differential Vulnerability and Cascading Effects

Vulnerability to climate change varies across time and location, across communities, and among individuals within communities, and reflects variations and changes in macro-scale non-climatic factors (such as changes in population, economic development, education, infrastructure, behaviour, technology, and ecosystems) and individual- or household-specific characteristics, such as age, socioeconomic status, access to livelihood assets, pre-existing health conditions and ability, among others (Program, 2016); Chapter 1).

Many direct and indirect effects of climate change pose multiple threats to human health and wellbeing, and can occur simultaneously, resulting in compounding or cascading impacts for vulnerable populations. For example, many of the long-term impacts of climate change on non-communicable diseases and injury described in sections 7.2 and 7.3 are associated with future increases in air temperatures and levels of air pollution; in many regions, and especially in large urban centres in Asia and Africa, these particular hazards are already causing substantial increases in morbidity and mortality due to respiratory illnesses (Tong et al., 2016). Climate change can therefore be expected to magnify such health risks over the long term.

At the same time, urban populations will also be experiencing indirect risks through climate change impacts on food and potable water systems, variations in the distribution and seasonality of infectious diseases, and growing demand for shelter due to increased in-migration. The accumulation of these risks over time can be expected to generate accelerating declines in community resilience and health, with future vulnerability potentially expanding in a non-linear fashion (Dilling et al., 2017);(Liang and Gong, 2017);(El-Zein and Tonmoy, 2017);see also Chapter 6). Further, although each individual risk in isolation may be transitory or temporary for the individuals or groups exposed, taken cumulatively the impacts could create conditions of chronic lack of wellbeing, and early-life experiences with specific illnesses and conditions could have lifelong consequences (Watts et al., 2015);(Otto et al., 2017);(Organization, 2018a). In this context, there is a distinct need for greater longitudinal research on vulnerability to multiple climatic and non-climatic health and wellbeing hazards over time (Fawcett et al., 2017). There is also need for more research to identify critical thresholds in social vulnerability to climate change (Otto et al., 2017); these include rapid, stepwise changes in vulnerability that emerge from changes in exposure (for example, air temperatures above which mortality rates or impacts on pre-natal health accelerate (Arroyo et al., 2016);(Ngo and Horton, 2016);(Abiona, 2017);(Auger et al., 2017); (Molina and Saldarriaga, 2017); (Zhang et al., 2017b)) and thresholds in adaptation processes (such as when rural out-migration rates grow due to climate-related crop failures (McLeman, 2017).

In virtually all of the research identifying particular climate-related risks to health, wellbeing, migration and conflict, specific types of individuals are identified as having higher levels of vulnerability and exposure to climate-related health hazards: people who are impoverished, undernourished, struggle with chronic or repeated illnesses, live in insecure housing in polluted or heavily degraded environments, work in unsafe conditions, are disabled, have limited education, and/or have poor access to health and social infrastructure (Organization, 2018a). Their disproportionate exposure to ongoing climate hazards and their inability to recover from extreme events, increase not only their own vulnerability, but also that of the wider communities in which they live (USGCRP, 2016). Highly vulnerable populations are not evenly distributed across regions (Figure 7.2) nor within countries. Yet even those fortunate enough to live in better neighbourhoods with greater financial means, higher-paying jobs, and good access to resources and services, may experience adverse climate-related outcomes through community-level interactions and linkages (Haines and Ebi, 2019). Increased inequity itself threatens wellbeing, and an effective response to climate change should not only avoid increased inequity but identify ways in which to reduce existing inequity.

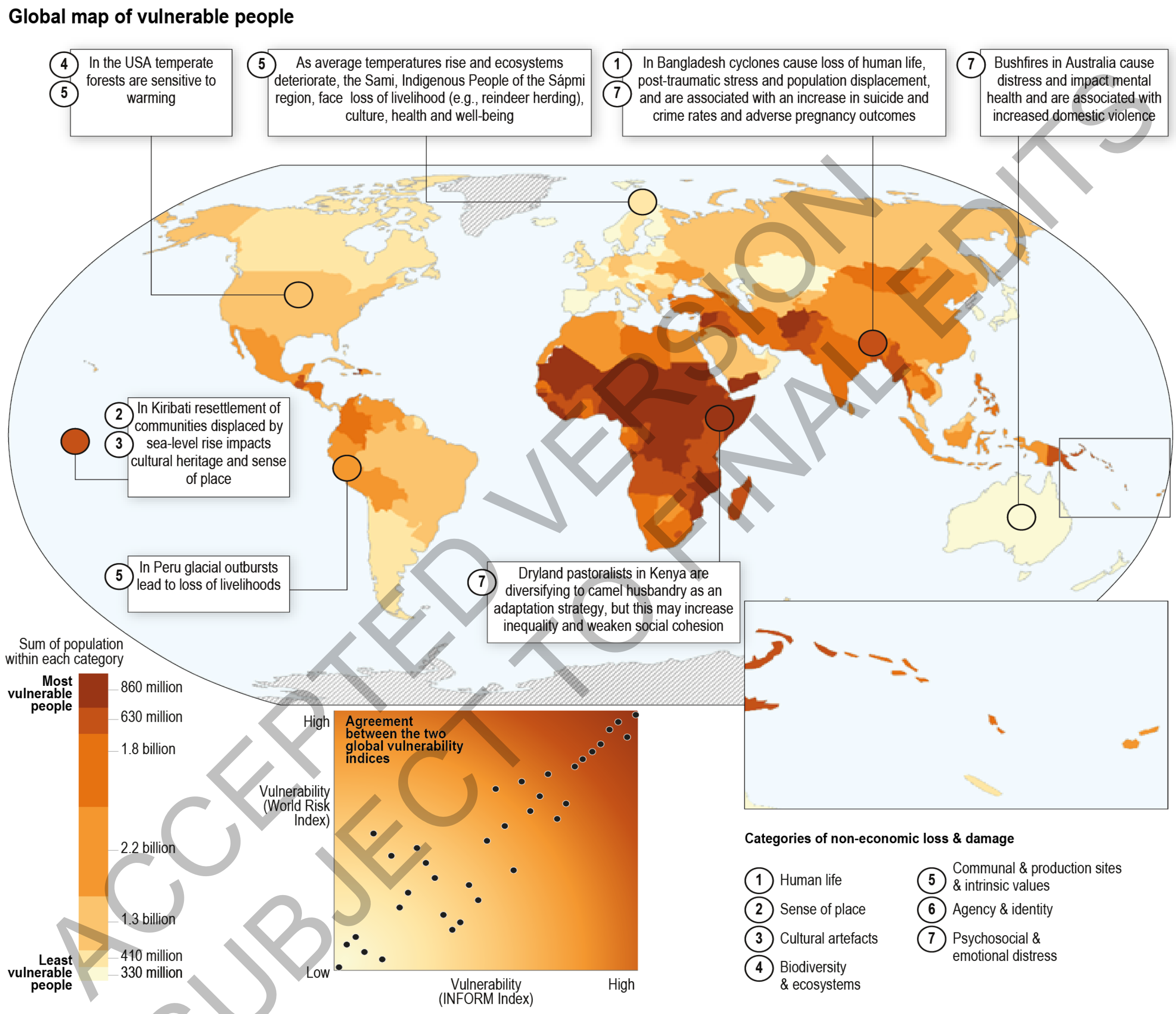

Figure 7.2: Global distribution of vulnerable people from two indices, with examples (from Technical Summary, this report)

7.1.7.3 Heightened Vulnerability to Climate-related Impacts on Health and Wellbeing experienced by specific groups and through specific pathways

7.1.7.3.1 Women and Girls

Climate change poses distinct risks to women's health. Vulnerability to climate-related impacts on health and wellbeing shows notable differentiations according to gender, beyond implications for pregnant women. In many societies, differential exposure to such risks relate to gendered livelihood practices and mobility options. Pregnancy and maternal status heighten vulnerability to heat, infectious diseases, foodborne infections, and air pollution (Arroyo et al., 2016);(Ngo and Horton, 2016);(Zhang et al., 2017b). Extreme heat events, high ambient temperatures, high concentrations of airborne particulates, water-related illnesses, and natural hazards are associated with higher rates of adverse pregnancy outcomes such as spontaneous abortion, stillbirth, low birth weight, and preterm birth (Arroyo et al., 2016);(Ngo and Horton, 2016);(Abiona, 2017);(Auger et al., 2017);(Molina and Saldarriaga, 2017); (Zhang et al., 2017b). Women and girls are at greater risk of food insecurity (FAO, 2018; (Alston and Akhter, 2016), which is particularly problematic in combination with the nutritional needs associated with pregnancy or breastfeeding. Women and girls are more likely to die in extreme weather events (Garcia and Sheehan, 2016);(Yang et al., 2019). Women are also expected to face a greater mental health burden in a changing climate (Manning and Clayton, 2018). Further, climatic extremes and water scarcity are associated with increases in violence against girls and women (Anwar et al., 2019); (Opondo et al., 2016); (Le Masson et al., 2016);(Udas et al., 2019).

7.1.7.3.2 Children

Children often have unique pathways of exposure and sensitivity to climate hazards, given their immature physiology and metabolism, and high intake of air, food, and water relative to their body weight as compared with adults (USGCRP, 2016). Climate change is expected to increase childhood risks of malnutrition and infectious disease for children in low-income countries through its impacts on household food access, dietary diversity, nutrient quality, water, and changes in maternal and childcare access and breastfeeding (Tirado, 2017);(FAO et al., 2018); (Perera, 2017)). Children living in locations with poor sanitation are especially vulnerable to gastro-intestinal illnesses, with future rates of diarrheal diseases among children expected to rise under many climate change scenarios (Cissé et al., 2018);(WHO, 2014). Outdoor recreational opportunities for children may be reduced by extreme weather events, heat, and poor air quality (Evans, 2019)). Children and adolescents are particularly vulnerable to post-traumatic stress after extreme weather events, and the effects may be long-lasting, with impacts even on their adult functioning (Brown et al., 2017; UNICEF, 2021);(Thiery et al., 2021)

7.1.7.3.3 Elderly

Population age structures and changes over time have a significant influence on vulnerability to the impacts of weather and climate. Older adults (generally defined as persons aged 65 and older) are disproportionately vulnerable to the health impacts associated with climate change and weather extremes, including a greater risk of succumbing to waterborne pathogens, due to less well-functioning thermoregulatory mechanisms, greater sensitivity to dehydration, changes in immune systems, and greater likelihood of having pre-existing chronic illnesses such as diabetes or respiratory, cardiovascular, and pulmonary illnesses (Benmarhnia et al., 2016);(Diaz et al., 2015);(Mayrhuber et al., 2018);(Paavola, 2017). Older adults may be less prompt in seeking medical attention when suffering from gastrointestinal illness, which can lead to dehydration (Haq and Gutman, 2014). Åström et al. (2017) anticipate heat-related mortality among the elderly in Europe to rise in the 2050s under RCP 4.5 and RCP 8.5 in the absence of significant preventative measures. In a study of the combined effects of warming temperatures and an aging population in Korea, Lee & Kim (Lee and Kim, 2016) projected a four- to six-fold increase in heat-related mortality by the 2090s when accounting for temperature and age structure.

7.1.7.3.4 Socio-economically Marginalized Populations and People with Disabilities

People living in poverty are more likely to be exposed to extreme heat and air pollution, and have poorer access to clean water and sanitation, accentuating their exposure to climate change-associated health risks (UNEP, 2021);(FAO et al., 2018). Poverty influences how people perceive the risks to which they are exposed, how they respond to evacuation orders and other emergency warnings, and their ability to evacuate or relocate to a less risk-prone location (USGCRP, 2016). Poorer households, who often live in highly exposed locations, are more likely to be forced into low-agency migration as a means of adapting to climate risks, and at the same time are the most likely to be immobile or trapped in deteriorating circumstances where migration would be a preferred response (Leichenko and Silva, 2014);(Fazey et al., 2016);(Sheller, 2018). Climate emergencies disproportionally affect people with disabilities because of their inherent vulnerabilities, which may impair their ability to take protective action; they are also frequently excluded from adaptation planning (Gaskin et al., 2017)

7.1.7.3.5 Urban vs Rural Populations

Rural and urban populations are often exposed to different types of climate-related health risks. For example, because of the urban heat island and high concentrations of motor vehicle pollution and industrial activity, people who live in urban areas may have higher rates of exposure to extreme heat stress and air-quality-related respiratory illnesses than rural counterparts (Hondula et al., 2014);(Heaviside et al., 2016);(Macintyre et al., 2018);(Schinasi et al., 2018). Conversely, rural populations, especially those dependent on resource-based livelihoods, may have a greater exposure to climate impacts on food production or natural hazard events, which have subsequent effects on household nutrition and food security (Springmann et al., 2016a); see also Chapters 5 & 6 of this report).

7.1.7.3.6 Indigenous People

Indigenous Peoples, especially those that live in geographically isolated, resource-dependent, and/or impoverished communities, are often at greater risk of health impacts of climate change (Ford et al., 2020) (USGCRP, 2016). The close interconnection of land-based livelihoods and cultural identity of many Indigenous groups exposes them to multiple health- and nutrition related hazards (Durkalec et al., 2015);(Sioui, 2019), with potential implications for community social relations and for individuals' mental health (Cunsolo Willox et al., 2013);(Cunsolo Willox et al., 2015). Climate change risk exposures may be complicated by changes in lifestyle, diet, and morbidity driven by socio-economic processes, further increasing health risks for Indigenous peoples (Jaakkola et al., 2018). Environmental consequences of climate change can also affect social ties and spiritual wellbeing, in part because land is often an integral part of their culture and spiritual identity.

[INSERT BOX 7.1 HERE]

Box 7.1: Indigenous Peoples' Health and Wellbeing in a Changing Climate

The Indigenous population worldwide is estimated at 476 million people spread across all geographic regions of the world (CIAT and and, 2021). Indigenous Peoples globally represent a large heterogeneity of people in terms of living conditions and social determinants of health. There is no simple definition of who is Indigenous. In this text, we refer to Indigenous Peoples as people self-identified and organized as Indigenous, according to the principles of the International Work Group for Indigenous Affairs (IWGIA), an International NGO with observer status at the United Nations. In addition, the United Nations describes Indigenous Peoples as "distinct social and cultural groups that share collective ancestral ties to the lands and natural resources where they live, occupy or from which they have been displaced" (Organization, 2021). A common experience among Indigenous Peoples are historical traumas related to overseas and/or settler/industrial colonisation.

Studies on climate change as it affects the health of Indigenous Peoples generally focus on non-displaced Indigenous groups, i.e., Indigenous people maintaining culturally important elements of a land-based traditional lifestyle. Here we use an eco-medicine perspective, in which the impacts of climate change on health are divided into primary, secondary, and tertiary effects; discussed below (Butler and Harley, 2010). Many analyses of Indigenous health in relation to climate change use the One Health concept (Mackenzie and Jeggo, 2019); (see 7.1.5).

Current Impacts of Climate Change on Health and Wellbeing of Indigenous Peoples

Primary health effects of climate change include the immediate physical effects on human health, such as health hazards due to high temperatures, extreme weather events, or accidents from exposure to a climate-related hazards. For example, in arid and semi-arid areas, an increased frequency of severe droughts is associated with immediate health problems related to overheating, and lack of water for drinking, sanitation and livestock (Hall and Crosby, 2020);(Mamo, 2020);(Rankoana, 2021). In many cases, the possibilities for Indigenous people to apply traditional strategies to mitigate droughts by migration are limited by competing land use, environmental protection, and national borders, with many examples across Africa (Mamo, 2020). In the Jordan river valley, the second most water stressed area in the world, water resources are not equally distributed to Indigenous Bedouin people, amplifying their immediate health threat during predictable as well as unpredictable droughts (Mamo, 2020).

In Arctic and sub-Arctic areas, higher temperatures with increased numbers of freeze-thaw cycles during the winter means increased occurrences of transport-related accidents in Indigenous communities due to weaker ice on travel routes that cross lakes, rivers and sea, along with changes in the snow cover and increased risk of avalanches (Durkalec et al., 2015);(Jaakkola et al., 2018). Impeded access to health care during extreme weather conditions is a primary health risk for Indigenous Peoples living in remote areas (Amstislavski et al., 2013);(Hall and Crosby, 2020);(Mamo, 2020).

Pastoralists in many regions may experience changes in livestock behaviour due to climate change, leading to increased mobility-related health hazards (Jaakkola et al., 2018);(Mamo, 2020). Indigenous Peoples living in low lying coastal areas and small island states face long term risk of flooding and the stresses of resettlement (Maldonado et al., 2021);(McMichael and Powell, 2021)).

Extreme rainfall, flooding, storms, heat waves, and wildfires lead to individual health hazards that may include injuries and thermal and respiratory traumas (Mamo, 2020) There are many examples when emergency responses to extreme events have ignored the needs of displaced Indigenous Peoples (Mendez et al., 2020);(Maldonado et al., 2021). Population-based quantitative studies documenting the direct effects of these events on Indigenous Peoples are rare. In Mexico, respiratory diseases are almost twice as common among Indigenous people compared to non-Indigenous (de Leon-Martinez et al., 2020). In Alaska and Northern Canada alarming levels of respiratory stress and disease has been reported among Inuit and First Nation communities in relation to wildfires (Howard et al., 2021), as well as increased mold in houses due to flooding resulting from increased precipitation (Furgal and Seguin, 2006);(Harper et al., 2015);(Norton-Smith et al., 2016). Climate and housing related respiratory stress is also a risk factor for severe COVID-19 infection, which has been highlighted in recent literature from an Indigenous health perspective (de Leon-Martinez et al., 2020).

Secondary effects relate to ecosystem changes, for example, increased risk of the acute spread of airborne, soilborne, vector-borne, food-, and water-borne infectious diseases (Hueffer et al., 2019). Higher proportions of climate-related infectious diseases are reported among Indigenous groups compared to their non-Indigenous neighbours, with examples from Torres Strait, Australia, showing a greater proportion of tuberculosis, dengue, Ross River virus, melioidosis, and nontuberculous mycobacterial infections (Hall et al., 2021) and in the Republic of Sakha, Russia, high levels of zoonoses (Huber et al., 2020a). Increasing levels of livestock and canine diseases are also reported (Mamo, 2020);(Bogdanova et al., 2021);(Hillier et al., 2021). Another secondary health effect is an increase in human-animal conflicts, for example human-elephant conflicts in Namibia due to plant food scarcity (Mamo, 2020), human-bear conflicts in Arctic regions within Canada (Wilder et al., 2017), human-tiger conflicts in Bangladesh (Haque et al., 2015), and increased predatory pressure on Indigenous Peoples' livestock and game worldwide (Haque et al., 2015);(Jaakkola et al., 2018);(Mukeka et al., 2019);(Mamo, 2020);(Terekhina et al., 2021). Undernutrition and metabolic disturbances associated with overnutrition and obesity due to decreased availability or safety of local and traditional foods, and increased dependency on imported substitutes, affect many Indigenous Peoples worldwide (Amstislavski et al., 2013);(Zavaleta et al., 2018);(Houde et al., 2020);(Jones et al., 2020);(Akande et al., 2021);(Bogdanova et al., 2021);(Bryson et al., 2021), especially severe for pregnant women and small children (Mamo, 2020);(Olson and Metz, 2020);(Bryson et al., 2021); these are amplified by the combination of warming and the COVID-19 situation (Zavaleta-Cortijo et al., 2020). Decreased access to wild plants and animals as food sources and medicine due to climate change is another threat to the health and wellness of Indigenous communities (Greenwood and Lindsay, 2019);(Mamo, 2020);(CIAT and and, 2021);(Rankoana, 2021);(Teixidor-Toneu et al., 2021).

Tertiary effects relate to culture-wide changes; for example, all forms of malnutrition due to climate-driven changes in food systems; and anxiety, mental illness, and suicidal thoughts related to cultural and spiritual losses. A wide range of tertiary, culture-related effects of climate change have been documented for Indigenous Peoples. These include anxiety, distress and other mental health impacts due to direct and indirect processes of dispossession of land and culture related to the combination of climate change in and other factors (Richmond and Ross, 2009);(Bowles, 2015);(Norton-Smith et al., 2016);(Jaakkola et al., 2018);(Fuentes et al., 2020);(Mamo, 2020);(Middleton et al., 2020b);(Middleton et al., 2020a);(Olson and Metz, 2020);(Timlin et al., 2021). Increased risks of conflict and abuse, including violence and homicide against females, and/or resulting from environment activism, are other tertiary health threats for Indigenous Peoples (Mamo, 2020). Between 2017 and 2019, close to 500 Indigenous people were killed for activism in 19 different countries (Mamo, 2020). In Uganda, climate change drives Indigenous men to increase their distance and time from home and their families in search of water, food, and water, leading to an increase in sexual violence against Indigenous women and girls in their communities (Mamo, 2020).

Gender inequities amplify the tertiary health effects of climate change (Williams, 2018);(Garnier et al., 2020). In an Inuit community, for instance, women reported a higher level of mental stress related to climate change than men (Harper et al., 2015). Adverse pregnancy outcomes and altered developmental trajectories have also been associated with climate change (Hall et al., 2021). Indigenous Batwa women in Uganda reported experiencing more severe circumstances of food insecurity during pregnancy due to drought and unpredictable seasons negatively impacting agricultural practices (de Leon-Martinez et al., 2020). More studies with a gender perspective on climate change as a determinant of Indigenous Peoples' health are needed, along with the perspectives of Indigenous children and youth, displaced individuals, and communities in urban settings (Kowalczewski and Klein, 2018).

Because cultural continuity is a recognized health factor (Lemelin et al., 2010);(de Leon-Martinez et al., 2020);(Middleton et al., 2020b) displaced Indigenous people may suffer from climate change by worrying about impacts on non-displaced relatives and family, and from traditional food staples turning into expensive commodified products. This is a knowledge gap with lasting implications not only on physical environments (Guo et al., 2018). Social connections and knowledge pathways are disrupted, leading to a decreased ability to share locally harvested and cultivated foods (King and Furgal, 2014);(Neufeld et al., 2020).

Tertiary effects of climate change on Indigenous Peoples' health are primarily described in smaller case studies and not designed in a way allowing for systematic international comparisons, which represents an important and significant gap in our understanding of these often-complex associations and impacts (Middleton et al., 2020b).

Future Risks for Indigenous People's Health and Wellbeing in a Changing Climate

Future risks for Indigenous Peoples' health and wellbeing in a changing climate will result foremost from exacerbations of observed impacts. Primary and secondary health risks are expected to increase as the frequency and/or severity of climate hazards grow in many regions. As one example, melting permafrost in the Siberian Arctic is projected to lead to more outbreaks of anthrax (Bogdanova et al., 2021). Tertiary health threats are expected to persist even with strong global initiatives to mitigate greenhouse gases (Butler and Harley, 2010). Climate change is expected to compound non-climatic processes that lead to social exclusion and land dispossession that underlay health inequalities experienced by Indigenous peoples (Huber et al., 2020a).

Options and Opportunities for Reducing Future Risks and Building Capacity/Resilience for Indigenous Peoples' Health and Wellbeing

Indigenous organizations worldwide stress the importance of applying a rights-based approach in responding to climate change (Mamo, 2020). Although Indigenous Peoples are often identified as being vulnerable to climate change, this framing does not always reflect the diverse responses and adaptations of Indigenous Peoples to these on-going challenges (Nursey-Bray et al., 2020). An emerging body of research is focusing on the strength and resilience of Indigenous communities globally as they adapt to these complex changes (Whyte, 2018);(CIAT and and, 2021).

During droughts and water shortages, for example, Indigenous pastoralists may face additional challenges if water supply assistance provides only for human needs and neglects water requirements of livestock (Mamo, 2020). Indigenous knowledge on how to adapt to drought, through storing and sharing strategies, for example, is valuable (Fatehpanah et al., 2020);(Mamo, 2020).

Indigenous Peoples have been adapting to changes in their environments since time immemorial by developing new practices and techniques (CIAT and and, 2021). Their beliefs, value systems, and principles include core elements and common values such as reciprocity, solidarity, co-responsibility, and community that are expressed in the dynamism of their knowledge systems (Lewis et al., 2020);(Schramm et al., 2020b). The relevance of these knowledge systems, which are holistic and tied to relationships between all living things, cannot be ignored at this critical time (Garnier et al., 2020).

The health and equity impact of climate change for Indigenous Peoples make mitigation efforts critical (Jones et al., 2020), which includes policies and actions consider the effects of colonization. Colonization constrains the design and diversity of potential climate and health responses through its historic and ongoing suppression of Indigenous knowledge systems that are critical in supporting community-led actions to reduce future risks (Billiot et al., 2019; Reid et al., 2019) (Nursey-Bray et al., 2020).

Four Brief Case Studies to Illustrate the Innovativeness of Indigenous Peoples' Adaptation to Climate Risks

Bedouin Pastoralists' Grazing Practices Decrease the Risk of Wildfires in Israel and Increase Food Sovereignty.

Wildfires are a main cause of deforestation in Israel, and in recent years climate stress decreased the forest resilience to fires (Klein et al., 2019). The original landscape, a shrubland or maquis consisting mostly of oak and pistacia, has been used since time immemorial as grazing land for goats, sheep, and camels belonging to Indigenous Bedouin people (Degen and El-Meccawi, 2009). Competing land use has reshaped the landscape with pine monocultures and cattle farming, reducing the availability of land suitable for herding goats the Indigenous way (Perevolotsky and Sheffer, 2011). In addition, since 1950, plant protection legislation has decreased Bedouin forest pastoralism in Israel, by defining Indigenous black goats as an environmental threat (FAOLEX, 2021). In nature reserves where no human interference has been allowed, these areas have regenerated into herbaceous shrublands susceptible to wildfires (Turco et al., 2017). Meanwhile, urbanized Bedouin exist on lower incomes and experience higher level of unemployment compared to other citizens, and some keep non-pastoralized livestock in cities as a strategy for food sovereignty (Degen and El-Meccawi, 2009). In 2019, many severe wildfires occurred in Israel due to extreme heat waves and, in response, plant protection legislation was appealed, allowing Bedouin pastoralists to graze their goats in areas from which they had been excluded. The amount of combustible undergrowth subsequently decreased, reducing the risk for wildfire and their related impacts, while simultaneously facilitating Indigenous food sovereignty among the Bedouin (Mamo, 2020).

Gardening in the Ashes of Wildfires in the Pacific Northwest as a Strategy to Decrease Food Insecurity and Increase Connections With the land

In the central interior of what is now known as British Columbia, 2017 was an especially severe wildfire season, with over 1.3 million hectares of land burned and 65,000 people displaced (Timler and Sandy, 2020). The unceded and ancestral lands of the Tsilhqot'in, Dakelh, and Secwépemc were impacted by two of the largest fires (Verhaeghe et al., 2017). Communities affected by the BC wildfires subsequently started Indigenous gardens closer to home, to protect medicine and food plants and thereby sustaining relationships with these plants, the land, and community (Timler and Sandy, 2020). As there are cultural teachings for fire to cleanse the territory and the land, community members and plants previously isolated became better connected because of the wildfires. The regrowth of plants is part of the healing relationship between people, plants, and other animals (Timler and Sandy, 2020). The wildfires were seen as events to catalyse action and emphasize the importance of relationships to support foodways and gardening as responsibility.

Widening our understanding of gardening, in the face of climate change and colonialism, can support health and healing for Indigenous and non-Indigenous Peoples. Gardening as a means of Indigenous food sovereignty has long been utilized by a variety of Indigenous groups within Canada and elsewhere to address circumstances of chronic food insecurity and support health and wellness (Johnson-Jennings et al., 2020);(Timler and Sandy, 2020). The concept of gardening as both a Euro-Western agricultural practice and Indigenous practice encourages an increased reverence and connection with the land, and wider engagement with the natural world (Whyte, 2018). Much of this is because Indigenous Knowledge and land management practices encompass processes that are known to be synergistic and sustainable (Ottenhoff, 2021). Indigenous worldviews offer a different perspective on social resilience to environmental change, one that is based on moral relationships of responsibility that connect humans to animals, plants, and habitats (Grey and Patel, 2015). These responsible practices not only ensure ecosystems are maintained for future generations. They centre the moral qualities necessary to carry out the responsibilities of consent, reciprocity, and trust.

Moral qualities of responsibility are the foundation for relying on each other when facing environmental challenges (Whyte, 2018);(Miltenburg et al., 2021).

To restore these sustainable relationships, a resurgence is needed of community roles and responsibilities (Cidro et al., 2015), as well as a reconsideration of the concept of food security and the role of gardening within diverse Indigenous contexts. Offering individual or community gardening as a solution to "food insecurity", a Euro-centric measure of health, ignores colonial contexts and sovereignty (Borrows, 2019);(Timler and Sandy, 2020). Indigenous communities have historic, ongoing, and evolving gardening and food gathering practices, including a wide variety of land-based and aquatic foods (Turner and Turner, 2008);(Mt. Pleasant, 2016). Euro-Western science is beginning to recognize these longstanding relationships (Kamal et al., 2015);(Hatfield et al., 2018);(Timler and Sandy, 2020). For many Indigenous communities, reconnecting with ancestral foodways holds the potential not only to address food security, but to provide the community cohesion, self-esteem, and wellness (Gordon et al., 2018).

A New Food Composition Database in Uganda May Guide Local Health Policy Workers in Healthy Eating Based on Indigenous Foods

In sub-Saharan Africa, climate change is an emerging risk factor for undernutrition, particularly in countries that rely on subsistence agriculture (Sorgho et al., 2020). In Uganda, negative health effects associated with climate change are being observed, including increased rates of food insecurity, with the highest rates recorded among the Batwa of Kanungu District, Uganda, where 97% of households are severely food insecure (Patterson et al., 2017). For many Indigenous Peoples, food security in a changing climate is a growing concern (Guyot et al., 2006);(Patterson et al., 2017). Locally harvested Indigenous foods have been adversely impacted by climate change, while connection to land is being disrupted by processes of colonization, discrimination, and lack of representation in decision-making groups, thereby restricting adaptive capacity for Indigenous communities (Bryson et al., 2021). In Uganda, the Indigenous Batwa have experienced significant disparities resulting from the forced eviction from their territory, dispossessing them of their land and ability to provide Indigenous foods to their families (Patterson et al., 2017);(Scarpa et al., 2021).

Nutrient specific knowledge of lndigenous foods is limited among many communities in Africa**.** A new food composition database in Uganda was constructed in dialogue with knowledge keepers from the Batwa and Bakiga Peoples, to assess the nutrient density of these locally harvested foods (Scarpa et al., 2021). As in other lower resource settings, no food composition tables are available for southwestern Uganda. The only existing food database was designed for central and eastern Uganda; it does not include common recipes and local foods consumed by Batwa and Bakiga communities (Scarpa et al., 2021). Using a community-based approach and collaboration with local nutritionists, a list of foods was collected through focus group discussions, an individual dietary survey, and market assessments. Including these locally familiar foods ultimately supports a focus on Indigenous justice and the importance of valuing Indigenous food systems and practices, which in many contexts have been found to have superior nutritional and environmental benefits for communities (Kuhnlein et al., 2013);(Scarpa et al., 2021). This new and unique database including Indigenous foods will not only guide local nutrition and health initiatives, but also contribute towards policies related to Indigenous food sovereignty and resilience to climate change.

Decreased Fragmentation of Winter Grazing Increases Mental and Spiritual Wellbeing in Reindeer Herding Sámi and Decreases their Dependency on Fossil Fuels

Sami are the Indigenous people of Northernmost Scandinavia and the Kola Peninsula of Russia, whose livelihoods have been traditionally sustained by reindeer herding, hunting, fishing and small-scale farming (Nilsson et al., 2011). Climate change is threatening core conditions for reindeer herding, with Sami pastoralists describing the situation as 'facing the limit of resilience' (Furberg et al., 2011). Sami pastoralists stress that an ability to continue reindeer herding is a prerequisite for their mental and spiritual health (Jaakkola et al., 2018).

In a pilot project for climate adaptation of reindeer herding run by the Swedish Sami Parliament, reindeer herding management plans (in Swedish, *renbruksplaner*) were used as a tool to develop strategies for climate adaptation (Walkepää, 2019). Four Sami reindeer herding cooperatives participated in the pilot study. They all agreed that climate change means that grazing patterns need to change. Traditionally, mountain reindeer graze in the Scandinavian mountains close to Norway in summertime, and in the coastal areas close to the Gulf of Bothnia in wintertime, representing a total migration route of up to 400 kilometres one-way. Rising temperatures are causing spring to occur earlier in the coastal winter grazing land, before the calving areas in the summer land are suitable for grazing and free from snow. When the snow cover disappears, the herds are dispersed, so it is important to migrate while snow is still present (Walkepää, 2019). Migration routes are being destabilized by weaker ice cover on water and by hazardous weather events. Competing land use due to infrastructure, extractive industries, tourism, and energy production makes it difficult to find alternative grazing land. Supplementary feeding and increased use of trucks to transport reindeer is one result. Herds that are dispersed due to bad snow conditions have an increased exposure to predators (Walkepää, 2019 (Walkepää, 2019);(Uboni et al., 2020). By working strategically to secure adequate winter grazing and reduce fragmentation of grazing areas more generally represents win-win strategies for achieving decreased mental stress levels while reducing herders' consumption of fossil fuels (Walkepää, 2019).

[END BOX 7.1]

7.1.7.3.7 Vulnerability Experienced through Food Systems

Stresses and shocks associated with climate change are drivers of food and nutrition security, particularly in sub-Saharan Africa, Asia, and Latin America (Betts et al., 2018). The most vulnerable groups include smallholder farmers, pastoralists, agricultural laborers, poorer households, refugees, Indigenous groups, women, children, the elderly, and those who are socio-economically marginalized (FAO et al., 2018);(SRCCL, 2019)*(high confidence)*. Men, women, children, the elderly and chronically ill have different nutritional needs, and these vulnerabilities may be amplified by gendered norms and differential access to resources, information and power (SRCCL, 2019). Extreme climate events have immediate and long-term impacts on food and nutrition insecurity of poor and vulnerable communities, including when women and girls need to undertake additional duties as laborers and caregivers (FAO et al., 2018).

7.1.7.3.8 Health Vulnerability Experienced through Water and Sanitation Systems

Water and sanitation systems are particularly vulnerable to extreme weather events, and damage to such systems can lead to contamination of drinking water and subsequent adverse health impacts (Howard et al., 2016);(Khan et al., 2015);(Sherpa et al., 2014). In areas with only very simple traditional excreta disposal facilities (e.g. latrines) and traditional sources of water (e.g. unprotected wells), the repeated occurrence of floods and other extreme events can negatively affect water quality at household and community levels, and increase the burden of food-borne and water-borne diseases (Cissé et al., 2016);(Khan et al., 2015);(Kostyla et al., 2015).

7.1.8 Visual Guide to this Chapter

Figure 7.3 provides a visual guide to this chapter. Section 7.1 has summarized major global frameworks and highlighted groups that exhibit heightened vulnerability to the climatic risks assessed in this chapter. Section 7.2 assesses observed impacts on health and wellbeing, migration and conflicts that have emerged from interactions of climate and weather-related hazards, exposure to such hazards, and vulnerability of communities and systems, while Section 7.3 assesses projected future risks. Section 7.4 assesses adaptation responses to climate risks, opportunities for transformative change, co-benefits, and how solutions for reducing climate impacts on health, wellbeing, migration, and conflicts may form part of wider climate resilient development pathways.

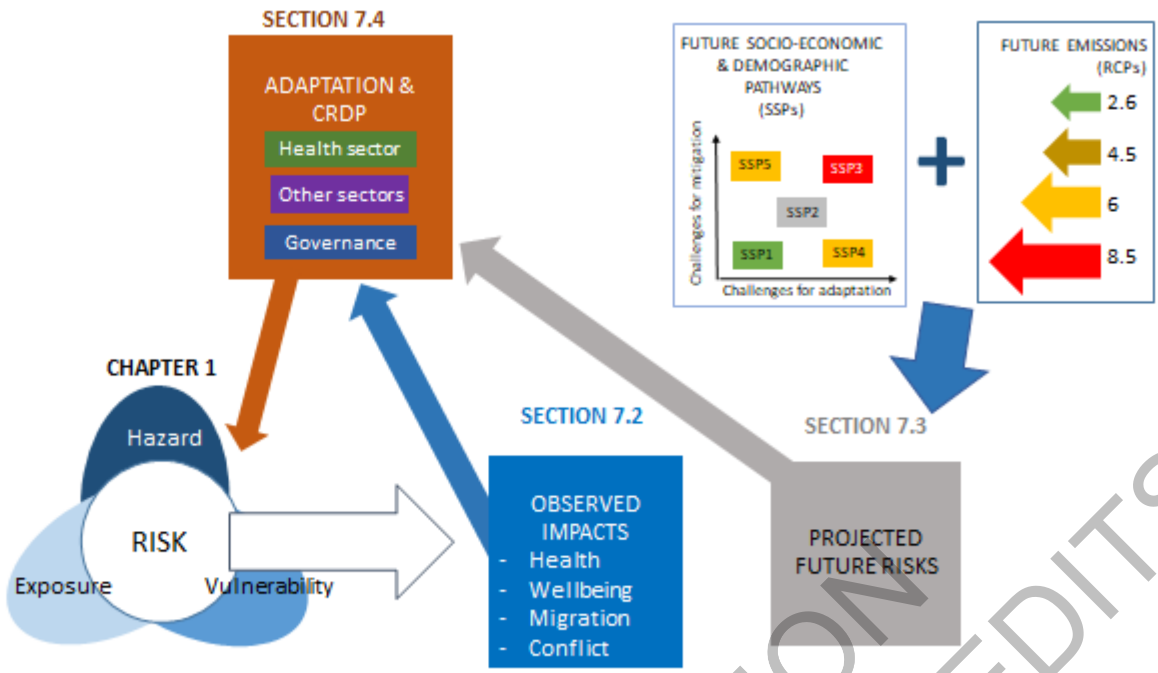

Figure 7.3: Structure of the chapter following a pathway from hazard, exposure and vulnerabilities to observed impacts, projected risks and solution space of adaptation and resilient development

7.2. Observed Impacts of Climate Change on Health, Wellbeing, Migration and Conflict

7.2.1 Observed Impacts on Health and Wellbeing

Eleven categories of diseases and health outcomes have been identified in this assessment as being climate-sensitive through direct pathways (e.g., heat, floods) and indirect pathways mediated through natural and human systems and economic and social disruptions (e.g. disease vectors, allergens, air and water pollution, and food system disruption) (high confidence). A key challenge in quantifying the specific relationship between climate and health outcomes is distinguishing the extent to which observed changes in prevalence of a climate sensitive disease or condition are attributable directly or indirectly to climatic factors as opposed to other, non-climatic, causal factors (Ebi et al., 2020). A subsequent challenge is then determining the extent to which those observed changes in health outcomes associated with climate are attributable to events or conditions associated with natural climate variability versus persistent human induced shifts in the mean and/or the variability characteristics of climate (i.e., anthropogenic climate change). The context within which the impacts of climate change affect health outcomes and health systems is described in this chapter as being a function of risk, which is in turn a product of interactions between hazard, exposure and vulnerability (Chapter 1), with the impacts in turn having the potential to reinforce vulnerability and/or exposure to risk (Figure 7.4).

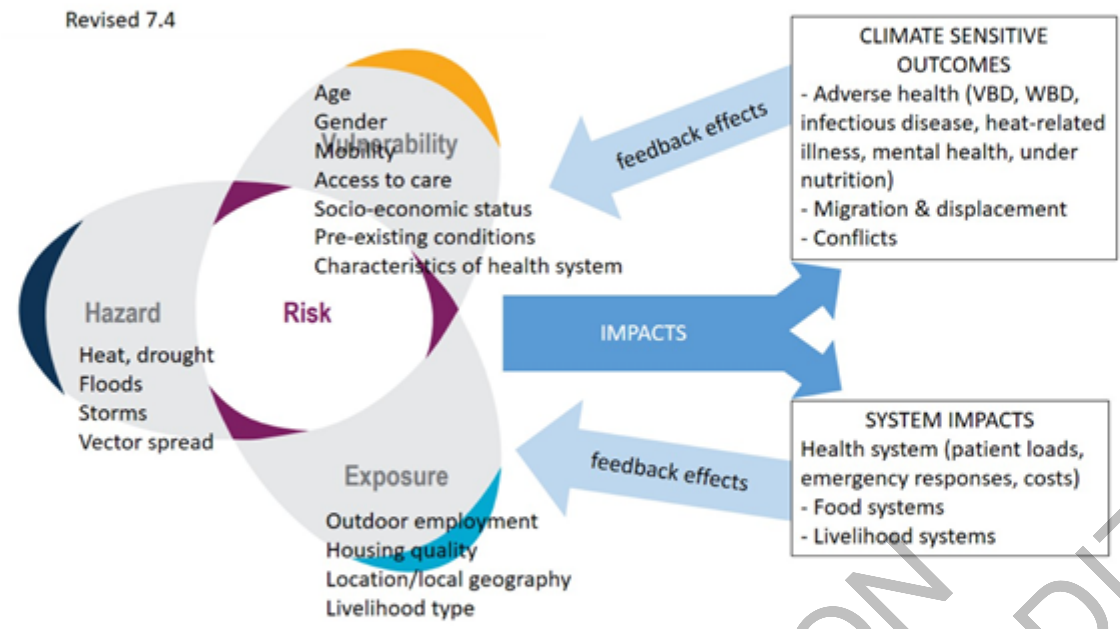

Figure 7.4: Interactions between hazard, exposure and vulnerability that generate impacts on health systems and outcomes, with selected examples.

[START BOX 7.2 HERE]

Box 7.2: The Global Burden of Climate-sensitive Health Outcomes Assessed in this Chapter

Global statistics for death and loss of health are increasingly described in terms of *burden*, which describes gaps between a population's actual health status and what its status would be if its members lived free of disease and disability to their collective life expectancy (Shaffer et al., 2019). Burden for each disease/health outcome is estimated by adding together the number of years of life a person loses because of early death (Years of Life Lost (YLL)) and the number of years a person lives with disability (Years of Life lived with Disability (YLD)) from the considered outcome. The resulting statistic, the Disability Adjusted Life Year (or DALY) represents the loss of one year of life lived in full health. The total global burden of disease (Collaborators and Injuries, 2020), expressed in DALYs, is what the world's health systems must manage, and is reported annually in Global Burden of Disease Study (Collaborators and Injuries, 2020). The estimated current global burden of climate sensitive diseases and conditions described in this chapter, and the geographical regions most affected, are summarized in Table Box 7.2.1. As was observed in the Health chapter of AR5, the "background climate-related disease burden of a population is often the best single indicator of vulnerability to climate change - doubling of risk of disease in a low disease population has much less absolute impact than doubling of the disease when the background rate is high."

The global magnitude of climate-sensitive diseases was estimated in 2019 to be 39,503,684 deaths (69.9 % of total annual deaths) and 1,530,630,442 DALYs (Collaborators and Injuries, 2020). Of these, cardiovascular diseases comprised the largest proportion of climate-sensitive diseases (32.8% of deaths, 15.5% DALYs). The next largest category consists of respiratory diseases – with chronic respiratory disease contributing to 7% of deaths and 4.1% of DALYs and respiratory infection and tuberculosis contributing to 6.5% of deaths and 6% of DALYs. The observed trend of climate-sensitive disease deaths since 1990 is marked by increasing cardiovascular mortality and decreasing mortality from respiratory infections, enteric diseases, and other infectious diseases (Collaborators and Injuries, 2020).

Table Box 7.2.1: Global burden of climate-sensitive health risks assessed in this chapter (in order of assessment) (Collaborators and Injuries, 2020) and synthesis of major observed and projected impacts in most affected regions. Blue represents an increase in positive health impacts, green represents an increase in negative health impacts, and purple represents an increase in both positive and negative impacts, but not necessarily equal. The confidence level refers to the both the attributed observed and projected changes to climate change. No assessment means the evidence is insufficient for assessment.

Legend

Climate Change Impacts		Confidence	
Positive health impacts		*Very high*	****
Negative health impacts		*High*	***
Positive and negative impacts		*Medium*	**
No assessment		*Low*	*

	Data from GBD 2019		Chapter 7 Assessment		
Health Outcome (Disease/ condition)	**Global annual deaths**	**Regions most affected (deaths)**	**Climate change observed impacts**	**Climate change projected impacts in most affected regions**	**Selected key references of the assessment**
Malaria	643,381.00	Africa (92%)	****	***	(M'Bra et al., 2018); (Caminade et al., 2019); (Gibb et al., 2020); (Tompkins and Caporaso, 2016b); (Ebi et al., 2021a)
Dengue	36,055	Asia (96%)	***	***	(Bhatt et al., 2013); (J. and R., 2020); (Messina et al., 2019); (Monaghan et al., 2018)
Diarrheal diseases	1,534,443	Asia (56%)	***	**	(Cisse, 2019); (Levy et al., 2018); (Lo Iacono et al., 2017);(Carlton et al., 2016)
Salmonella	79,046	Africa (89%)	***	**	(Cisse, 2019); (Smith and Fazil, 2019); (Lake, 2017)
Respiratory tract infections	2,493,200	Asia (47%)	**		(Geier et al., 2018); (Oluwole, 2017)
Non-communicable respiratory illness	3,741,705	Asia (74%)	***	**	(Schweitzer et al., 2018); (Hansel et al., 2016); (Collaco et al., 2018); (D'Amato et al., 2020); (Silva et al., 2017); (Doherty et al., 2017); (Beggs, 2021)
Cardiovascular disease	18,562,510	Asia (58%)	**	***	(Stewart et al., 2017); Phung, 2016; Sun. 2018; Wang, 2016; Tian, 2019; Chen, 2019; Zhang, 2018
Death from malignant neoplasms	10,079,637	Asia (55%)	***		(Ahmed et al., 2014); (Modenese et al., 2018);

					(Prueksapanich et al., 2018)
Diabetes	1,551,170	Asia (56%)	**	**	(Hajat et al., 2017) ; (Xu et al., 2019b) ; (Li et al., 2014);(Yang et al., 2016); (Velez-Valle et al., 2016); (Quast and Feng, 2019)
Environmental heat and cold exposure	47,461	Asia (46%)	***	****	(Zhang et al., 2019b); (Green et al., 2019); (Murray et al., 2020); (Ma and Yuan, 2021); (Jones et al., 2018); (Russo et al., 2019); (Gosling et al., 2017)
Nutritional deficiencies	251,577	Africa (43%)	***	***	(Mbow et al., 2019); (Lloyd, 2018); (Springmann et al., 2016b); (Zhu et al., 2018); (Weyant et al., 2018)
Mental Health*	N/A	N/A	****	****	(Cianconi et al., 2020); (Charlson et al., 2021); (Hayes and Poland, 2018); (Hrabok et al., 2020); (Obradovich et al., 2018)

Table Notes:
*Mental health data were non-available (NA) due to lack of information in GBD 2019 related to annual deaths and most affected regions.

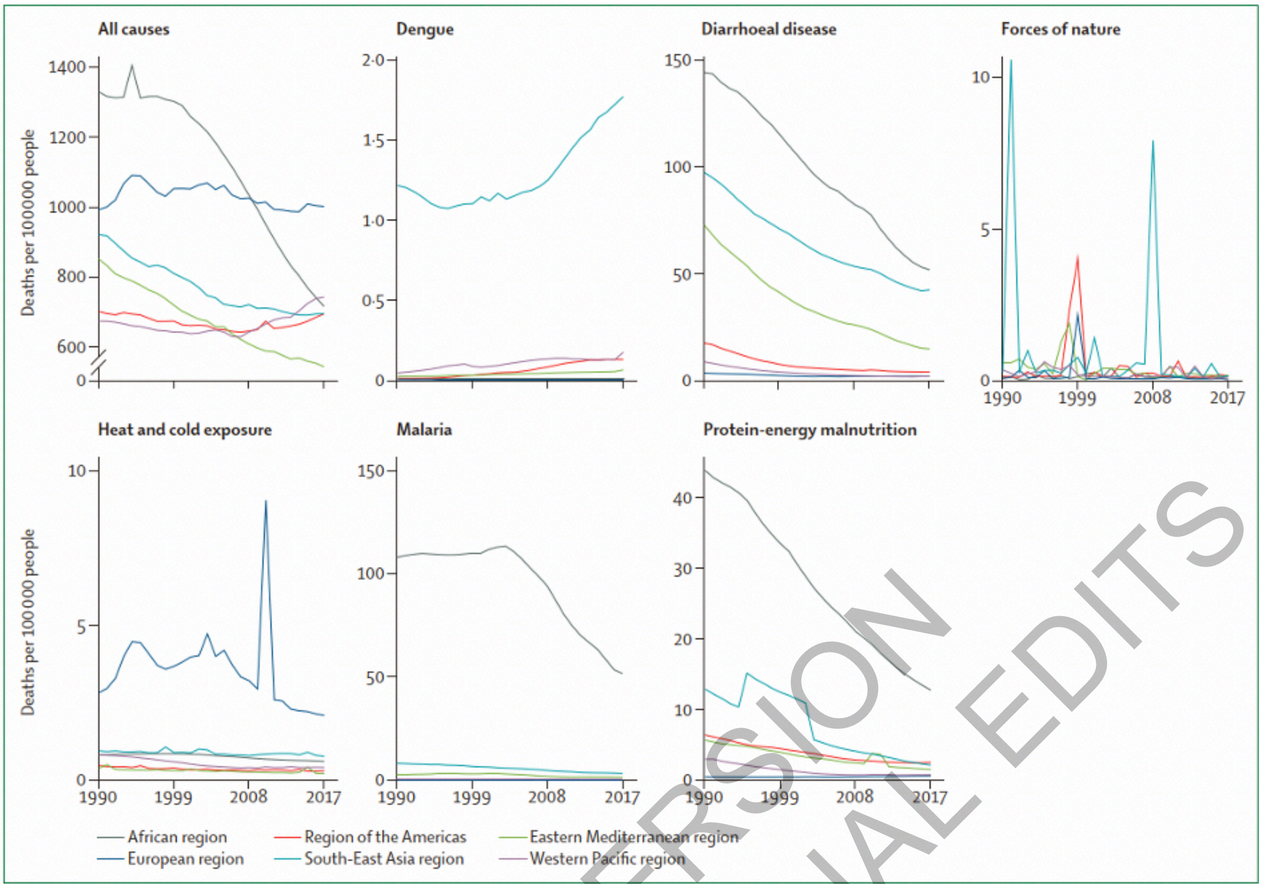

Figure Box 7.2.1: Global trends of selected health outcomes estimated by GBDs. Source: (Collaborators, 2018a)

[END BOX 7.2 HERE]

7.2.2 *Observed Impacts on Communicable Diseases*

7.2.2.1 Observed Impacts on Vector-borne Diseases

Climate-sensitive vector-borne diseases (VBDs) include mosquito-borne diseases, rodent-borne diseases and tick-borne diseases. Many infectious agents, vectors, non-human reservoir hosts, and pathogen replication rates can be sensitive to ambient climatic conditions. Elevated proliferation and reproduction rates at higher temperatures, longer transmission season, changes in ecology, and climate-related migration of vectors, reservoir hosts, or human populations contribute to this climate sensitivity (J. and R., 2020);(Semenza and Paz, 2021). Age-standardized disability-adjusted life year (DALY) rates for many VBDs have decreased over the last decade due to factors unrelated to climate. Vulnerability to VBD is strongly determined by sociodemographic factors (e.g., children, the elderly and pregnant women are at greater risk) with exposure to vectors being strongly influenced by various factors including socioeconomic status, housing quality, health care access, susceptibility, occupational setting, recreational activity, conflicts and displacement (J. and R., 2020);(Semenza and Paz, 2021). Figure 7.5 illustrates how climatic and non-climatic drivers and responses determine VBD outcomes.

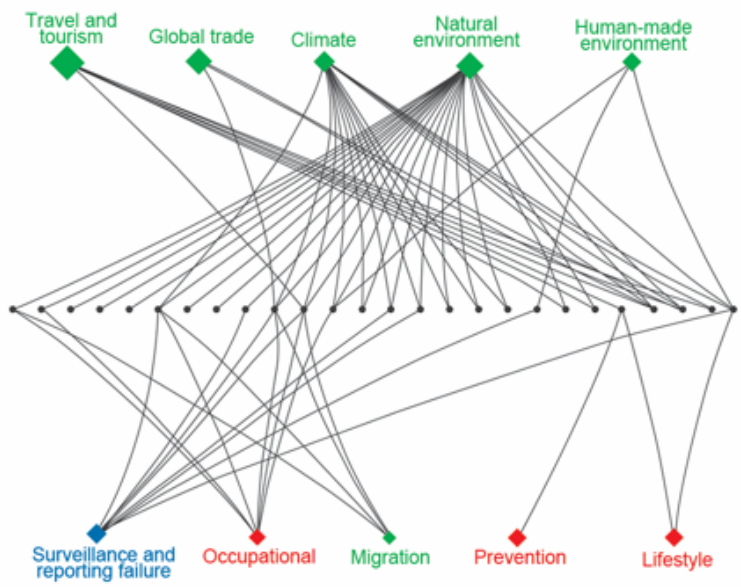

Figure 7.5: Analysis of the underlying drivers of infectious disease threat events (IDTE) detected in Europe during 2008–2013 by epidemic intelligence at the European Centre of Disease Prevention and Control. Seventeen drivers were identified and categorized into 3 groups: globalization and environment (green), sociodemographic (red), and public health system (blue). The drivers are illustrated as diamond shapes and arranged in the top and bottom row, the sizes of which are proportional to the overall frequency of the driver. Here IDTE (epidemics or first autochthonous cases) of VBD are illustrated as a horizontal row of dots in the middle. These empirical data include IDTE of VBD such as West Nile fever, malaria, dengue fever, chikungunya, or Hantavirus infection. Source: (Semenza et al., 2016)

Evidence has increased since AR5 that the vectorial capacity has increased for dengue fever, malaria, and other mosquito borne diseases, and that higher global average temperatures are making wider geographic areas more suitable for transmission (very high confidence). Transmission rates of malaria are directly influenced by climatic and weather variables such as temperature, with non-climatic socio-economic factors and health system responses counteracting the climatic drivers *(very high confidence).* The burden of malaria is greatest in Africa, where more than 90% of all malaria-related deaths occur (M'Bra et al., 2018);(Caminade et al., 2019). Between 2007 and 2017, DALYs for malaria have decreased by 39% globally. Malaria is mainly caused by five distinct species of plasmodium parasite (*Plasmodium falciparum*, *Plasmodium vivax*, *Plasmodium malariae*, *Plasmodium ovale*, *Plasmodium knowlesi*), transmitted by Anopheline mosquitoes. Evidence suggests that in highland areas of Colombia and Ethiopia, malaria has shifted in warmer years toward higher altitudes, indicating that, without intervention, malaria will increase at higher elevations as the climate warms (Siraj et al., 2014);(Midekisa et al., 2015). Each year, local outbreaks of malaria occur due to importation, in areas from which it was once eradicated, such as Europe, but the risk of re-establishment is considered low.

The transmission of dengue fever is linked to climatic and weather variables such as temperature, relative humidity, and rainfall (high confidence). The dengue virus is carried and spread by *Aedes* mosquitoes, primarily *Aedes aegypti*. Dengue has the second highest burden of VBDs, with the majority of deaths occurring in Asia (Bhatt et al., 2013). Since 1950, global dengue burden has grown, attributable to a combination of climate-associated expansion in the geographic range of the vector species and non-climatic factors such as globalized air traffic, urbanization, and ineffective vector abatement measures. Temperature, relative humidity, and rainfall variables are significantly and positively associated with increased dengue case incidence and/or transmission rates globally, including in Vietnam (Phung et al., 2015);(Xuan le et al., 2014), Thailand (Xu et al., 2019a), India (Mutheneni et al., 2017);(Rao et al., 2018);(Mala and Jat, 2019), Indonesia (Kesetyaningsih et al., 2018), the Philipines (Carvajal et al., 2018), the United States (Lopez et al., 2018);(Pena-Garcia et al., 2017);(Duarte et al., 2019);(Rivas et al., 2018);(Silva et al., 2016a), Jordan (Obaidat and Roess, 2018), and Timor-Leste (Wangdi et al., 2018). Variation in winds, sea surface temperatures and rain over the tropical eastern Pacific Ocean (El Nino Southern Oscillation) have been linked to increased dengue incidence in Colombia (Quintero-Herrera et al., 2015);(McGregor and Ebi, 2018);(Pramanik et al., 2020) and its interannual variation successfully forecasted in Ecuador using ENSO indices as predictors (Petrova et al., 2019). The observed lag time between climate exposures and increased dengue incidence is approximately 1–2 months (Chuang et al., 2017);(Lai, 2018);(Chang et al., 2018).

Changing climatic patterns are facilitating the spread of chikungunya virus (CHIKV), Zika, Japanese encephalitis and Rift Valley Fever in Asia, Latin America, North America and Europe (high confidence). Climate change may have facilitated the emergence of CHIKV as a significant public health challenge in some Latin American and Caribbean countries (Yactayo et al., 2016);(Pineda et al., 2016), and contributed to a chikungunya outbreak in Italy in 2017 (Rocklov et al., 2019) and in Europe (Chadsuthi et al., 2016);(Mascarenhas et al., 2018);(Morens and Fauci, 2014). The Zika virus outbreak in South America in 2016 was preceded by 2007 outbreaks on Pacific islands and followed a period of record high temperatures and severe drought conditions in 2015 (Paz and Semenza, 2016);(Tesla et al., 2018). Increased use of household water storage containers during the drought is correlated with a range expansion of *Aedes aegypti* during this period, increasing household exposure to the vector (Paz and Semenza, 2016). Changing climate also appears to be a risk factor for the spread of Japanese encephalitis to higher altitudes in Nepal (Ghimire and Dhakal, 2015) and in southwest China (Zhao et al., 2014). In Eastern Africa, climate change may be a risk factor in the spread of Rift Valley Fever (Taylor et al., 2016a).

Changes in temperature, precipitation, and relative humidity have been implicated as drivers of West Nile fever in southeastern Europe (medium confidence). The average temperature and precipitation prior to the exceptional 2018 West Nile outbreak in Europe was above the 1981–2010 period average, which may have contributed to an early upsurge of the vector population (Marini et al., 2020);(Haussig et al., 2018);(Semenza and Paz, 2021). In 2019 and in 2020, West Nile fever was first detected in birds and subsequently in humans in both Germany and Netherlands, respectively (Ziegler et al., 2020);(Vlaskamp et al., 2020).

Climate change has contributed to the spread of the Lyme disease vector Ixodes scapularis, and a corresponding increase in cases of Lyme disease in North America (high confidence), and of the spread of the Lyme disease and Tick-Borne Encephalitis vector Ixodes ricinus in Europe (medium confidence). In Canada, there has been a geographic range expansion of the black-legged tick *I. scapularis,* the main vector of *Borrelia burgdorferi*, the agent of Lyme disease. Vector surveillance of *I. scapularis* has identified strong correlation between temperatures and the emergence of tick populations, their range and recent geographic spread, with recent climate warming coinciding with a rapid increase in human Lyme disease cases (Clow et al., 2017);(Cheng et al., 2017);(Gasmi et al., 2017);(Ebi et al., 2017). *Ixodes ricinus*, the primary vector in Europe for both Lyme borreliosis and tick-borne encephalitis is sensitive to humidity and temperature (Daniel et al., 2018);(Estrada-Peña and Fernández-Ruiz, 2020) (*high confidence*). There has been an observed range expansion to higher latitudes in Sweden and to higher elevations in Austria and the Czech Republic.

Rodent-borne disease outbreaks have been linked to weather and climate conditions in a small number of studies published since AR5, but more research is needed in this area. In Kenya, a positive association exists between precipitation patterns and *Theileria*-infected rodents, but for *Anaplasma*, *Theileria* and *Hepatozoon*, the association between rainfall and pathogen varies according to rural land-use types (Young et al., 2017). Weather variability plays a significant role in transmission rates of haemorrhagic fever with renal syndrome (HFRS) (Hansen et al., 2015);(Xiang et al., 2018);(Liang et al., 2018);(Fei et al., 2015);(Xiao et al., 2014);(Vratnica et al., 2017);(Roda Gracia et al., 2015);(Monchatre-Leroy et al., 2017);(Bai et al., 2019). In Chongqing, HFRS incidence has been positively associated with rodent density and rainfall (Bai et al., 2015).

7.2.2.2 Observed Impacts on Water-borne Diseases

Important water-borne diseases (WBDs) include diarrhoeal diseases (such as cholera, shigella, cryptosporidium and typhoid), schistosomiasis, leptospirosis, hepatitis A and E and poliomyelitis (Cisse, 2019);(Houéménou et al., 2021);(Hassan et al., 2021);(Archer et al., 2020);(Mbereko et al., 2020);(Fan et al., 2021). The number of cases of water-borne diseases is considerable, and even in high-income countries water-borne illness continues to be a concern (Cissé et al., 2018);(Kirtman et al., 2014);(Levy et al., 2018);(Murphy et al., 2014);(Brubacher et al., 2020);(Lee et al., 2021). Nevertheless, diarrhoea mortality has declined substantially since 1990, although there are variations by country, and the global burden of WBD has decreased in line with vaccination coverage of some WBDs (such as polio and cholera), poverty reduction and improved sanitation and hygiene (Jacob and Kazaura, 2021);(Mutono et al., 2020);(Lee et al., 2019);(Semenza and Paz, 2021);(Jacob and Kazaura, 2021); (Mutono et al., 2020).

Drinking water containing pathogenic microorganisms is the main driver of the burden of WBDs (Murphy et al., 2014);(Lee et al., 2021);(Chen et al., 2021b);(Musacchio et al., 2021). WBDs outbreaks, particularly intestinal diseases, are attributable to a combination of the presence of particular pathogens (bacteria, protozoa, viruses or parasites) and the characteristics of drinking water systems in a given location (Bless et al., 2016);(Ligon and Bartram, 2016);(Mutono et al., 2021);(Ferreira et al., 2021).

[START BOX 7.3 HERE]

Box 7.3: Cascading Risk Pathways Linking Waterborne Disease to Climate Hazards

The causal linkages between climate variability and change and incidence of waterborne diseases follows multiple direct and indirect pathways, often as part of a cascading series of risks (Semenza, 2020). For example, extreme precipitation can result in a cascading hazard or disease event with implications of greater magnitude than the initial hazard, especially if there are pre-existing vulnerabilities in critical infrastructure and human populations (Semenza and Paz, 2021). Intense or prolonged precipitation can flush pathogens in the environment from pastures and fields to groundwater, rivers and lakes, consequently infiltrating water treatment and distribution systems (Howard et al., 2016);(Khan et al., 2015);(Sherpa et al., 2014);(Cissé et al., 2016);(Kostyla et al., 2015); Chapter 4). Table 7.3.1 shows the variety and complexity of pathways between climate hazard and waterborne disease outcomes (Semenza, 2020).

Table Box 7.3.1: Pathways between climate hazard and waterborne disease outcomes (source: (Semenza, 2020)

Cascading risk pathways from heavy rain and flooding
Storm runoff yields water turbidity which compromises water treatment efficiency Storm runoff and floods mobilizes and transports pathogens Overwhelmed or damaged infrastructure compromises water treatment efficiency Floods overwhelm containment system and discharge untreated wastewater Floods damage critical water supply and sanitation infrastructure Floods displace populations towards inadequate sanitation infrastructure
Cascading risk pathways from drought
Low water availability augments travel distance to alternate (contaminated) sources Intensified demand and sharing (e.g. with livestock) of limited water resources decreases water availability and quality Intermittent drinking water supply results in cross-connections with sewer lines and water contamination Uncovered household water containers are a source of vector breeding Poor hygiene due to decreased volume of source water and increased concentration of pathogens Exposure to accumulated human excrements and animal manure
Cascading risk pathways from increasing temperature
Extended transmission season for opportunistic pathogens Permissive temperature for the replication of marine bacteria Enhanced pathogen load in animal reservoirs (e.g., chicken) Pathogen survival and proliferation outside of host Wildfires during heat waves degrade water quality Exposure to contaminated water due to higher water consumption Behaviour change due to extended season; e.g., food spoilage during barbeque
Cascading risk pathways from sea-level rise
Population displacement due to powerful storm surges Disruption of drinking water supply and sanitation infrastructure due to inundation Decline in soil and water quality due to saline intrusion into coastal aquifers

Seawater infiltration into drinking water distribution and sewage lines

Table Notes:
Examples are purposely not exhaustive and should be considered illustrative.

[END BOX 7.3 HERE]

Since AR5 there is a growing body of evidence that increases in temperature (very high confidence), heavy rainfall (high confidence), flooding (medium confidence) and drought (low confidence) are associated with an increase of diarrheal diseases. In the majority of studies there is a significant positive association observed between waterborne diseases and elevated temperatures, especially in areas where water, sanitation and hygiene deficiencies are significant (Levy et al., 2018);(Carlton et al., 2016);(Levy et al., 2018);(Sherpa et al., 2014);(Guzman Herrador et al., 2015);(Levy et al., 2016);(Lo Iacono et al., 2017). In Ethiopia, South Africa and Senegal, increases in temperatures are associated with increases in diarrhoea, while in Ethiopia, Senegal and Mozambique, increases in monthly rainfall are associated with an increase in cases of childhood diarrhea (Azage et al., 2015);(Thiam et al., 2017);(Horn et al., 2018). Similar associations between weather and diarrhoea have been observed in Cambodia, China, Bangladesh, Pacific Island Countries and the Philippines (McIver et al., 2016a);(McIver et al., 2016b);(Liu et al., 2018);(Wu et al., 2014);(Matsushita et al., 2018). Heavy precipitation events have been consistently associated with outbreaks of waterborne diseases in Europe (including Scandinavia), USA, UK and Canada (Guzman Herrador et al., 2015);(Levy et al., 2016);(Lo Iacono et al., 2017);(Curriero et al., 2001);(Guzman Herrador et al., 2016);(Levy et al., 2018);(Semenza and Paz, 2021).

Impacts of floods include outbreaks of waterborne diseases, with such events disproportionately affecting the young, elderly and immunocompromised (Suk et al., 2020);(Guzman Herrador et al., 2015);(Levy et al., 2016);(Lo Iacono et al., 2017);(Zhang et al., 2019a). Water shortage and drought have been found associated with diarrheal disease peaks (Epstein et al., 2020b);(Subiros et al., 2019);(Boithias et al., 2016 while some reviews found insufficient or limited evidence of the effects of drought on diarrhea {Levy, 2016, Untangling the Impacts of Climate Change on Waterborne Diseases: a Systematic Review of Relationships between Diarrheal Diseases and Temperature, Rainfall, Flooding, and Drought);(Asmall et al., 2021);(Epstein et al., 2020b);(Subiros et al., 2019);(Boithias et al., 2016) (Ramesh et al., 2016).

Heavy rainfall and higher than normal temperatures are associated with increased cholera risk in affected regions (very high confidence). Cholera is an acute diarrheal disease typically caused by the bacterium *Vibrio cholerae* that can result in severe morbidity and mortality. Maximum and minimum temperatures and precipitation have been negatively associated with cholera cases and cholera outbreaks have occurred in several regions after natural disasters, including cholera incidence increasing three-fold in Africa El Niño-sensitive regions (Mpandeli et al., 2018);(Amegah et al., 2016);(Escobar et al., 2015);(Jutla et al., 2017);(Asadgol et al., 2019);(Moore et al., 2018);(Moore et al., 2017);(Camacho et al., 2018);(Pörtner et al., 2019); Cross-Chapter Box ILLNESS in Chapter 2; Box 3.3).

Heavy rainfall, warmer weather and drought are linked to increased risks for other gastro-intestinal (GI) infections (high confidence). As temperature increases bacterial causes of GI infection appear to increase and this association is variably influenced by humidity and rainfall (Ghazani et al., 2018);(Levy, 2016). In New York it has been found that every 1°C increase in temperature was correlated with a 0.70-0.96% increase in daily hospitalization for GI infections (Lin et al., 2016). In the Philippines, leptospirosis and typhoid fever showed an increase in incidence following heavy rainfall and flooding events (Matsushita et al., 2018).

7.2.2.3 Observed Impacts on Food-borne Diseases

Food-borne diseases (FBDs) refer to any illness resulting from ingesting food that is spoiled or contaminated by pathogenic bacteria, viruses, parasites, toxins, pesticides and/or medicines (WHO, 2015d). FBD risks are present throughout the food chain, from production to consumption, and most often arise due to contamination at source and from improper handling, preparation and/or food storage (Smith and Fazil, 2019);(Semenza and Paz, 2021). As with waterborne disease, FBD outbreaks can follow multiple causal pathways as climatic risk factors interact with food production and distribution systems, urbanization and population growth, resource and energy scarcity, decreasing agricultural productivity, price volatility, modification of diet trends, new technologies and the emergence of antimicrobial resistance (Lake, 2018);(Yeni and Alpas, 2017). The burden of FBDs is also linked to malnutrition as reduced immunity increases susceptibility to various foodborne pathogens and toxins (FAO, 2020).

A strong association exists between increases in food-borne diseases and high air and water temperatures and longer summer seasons (very high confidence). The risks occur through complex transmission pathways throughout the food chain and the wide range of foodborne pathogens (Cisse, 2019);(Hellberg and Chu, 2016);(Lake and Barker, 2018);(Park et al., 2018b);(Smith and Fazil, 2019). Food-borne pathogens of most concern are those having low infective doses, a significant persistence in the environment and high stress tolerance to temperature change (e.g. enteric viruses, *Campylobacter spp*., *E. coli* STEC strains, *Mycobacterium avium,* tuberculosis complexes, parasitic protozoa and *Salmonella*) (Lake, 2018);(Lake, 2017);(Lake and Barker, 2018);(Smith and Fazil, 2019);(Authority) et al., 2020);(Semenza and Paz, 2021). Priority risks include marine biotoxins, mycotoxins, salmonellosis, vibriosis, transfer of contaminants due to extreme precipitation, floods, increased use of chemicals (plant protection products, fertilizers, veterinary drugs) in the food chain, and potential residues in food (Authority) et al., 2020);(Organization, 2018b).

There is a strong association observed between the increase in average ambient temperature and increases in Salmonella infections (high confidence). Most types of *Salmonella* infections lead to salmonellosis, while some other types (*Salmonella* Typhi and *Salmonella* Paratyphi) can lead to typhoid fever or paratyphoid fever. The transmission to humans of the non-typhoidal *Salmonella* infection, one of the most widespread foodborne diseases, occurs usually through eating foods contaminated with animal faeces. Studies conducted in Australia (Milazzo et al., 2016), New Zealand (Lal et al., 2016), the UK (Lake, 2017), South Korea (Park et al., 2018a);(Park et al., 2018c);(Park et al., 2018a), Singapore (Aik et al., 2018) and Hong Kong, SAR of China (Wang et al., 2018a);(Wang et al., 2018b) have shown that *Salmonella* outbreaks are strongly associated with temperature increases.

Significant associations exist between food-borne diseases due to Campylobacter, precipitation and temperature (medium confidence). The timing of heat-associated Campylobacteriosis events varies across countries, whilst infection rates in the UK appear to decline immediately after periods of high rainfall (Djennad et al., 2019);(Lake et al., 2019);(Rosenberg et al., 2018);(Yun et al., 2016);(Weisent et al., 2014). This suggests the association with climate may be indirect and due to weather conditions that encourage outdoor food preparation and recreational activities (Lake, 2017);(Semenza and Paz, 2021).

Outbreaks of human and animal Cryptococcus have been reported as being associated with a combination of climatic factors, and shifts in host and vector populations (Chang and Chen, 2015);(Rickerts, 2019). The prevalence of childhood cryptosporidiosis, which is the second leading cause of moderate-to-severe diarrhoea among infants in the tropics and subtropics, shows associations with population density and rainfall, with contamination due to Cryptosporidium spp. being 2.61 times higher during and after heavy rain (Lal et al., 2019);(Young et al., 2015);(Khalil et al., 2018). Studies from Ghana, Guinea Bissau, Tanzania, Kenya and Zambia show a higher prevalence of Cryptosporidium during high rainfall seasons, with some peaks observed before, at the onset or at the end of the rainy season (Squire and Ryan, 2017).

7.2.2.4 Respiratory Tract Infections

Climatic risk factors for respiratory tract infections (RTIs) due to multiple pathogens (bacteria, viruses, fungi) include temperature and humidity extremes, dust storms, extreme precipitation events, and increased climate variability. Amongst a range of RTIs, pneumonia and influenza represent a significant disease burden (Ferreira-Coimbra et al., 2020);(Lafond et al., 2021);(McAllister et al., 2019);(Wang et al., 2020c). The drivers of pneumonia incidence are complex and include a range of possible non-climate as well as climate factors. For example, chronic diseases (e.g., lung disease, chronic obstructive pulmonary disease, asthma) and other comorbidities, a weak immune system, age, gender, community, passive smoking, air pollution, and childhood immunization may confound the climate pneumonia relationship (Miyayo et al., 2021).

In temperate regions, the incidence of pneumonia is higher in the winter months, but the exact causes of this seasonality remain debated (Mirsaeidi et al., 2016). With regards to temperature, various J-shaped, U-shaped, or V-shaped temperature-pneumonia relationships have been reported in the literature (Huang et al., 2018);(Kim et al., 2016);(Liu et al., 2014);(Qiu et al., 2016);(Sohn et al., 2019) with such relationships dependent of location. Humidity also appears important but like temperature its effect is not consistent across studies - low temperatures and low humidity (Davis et al., 2016), high temperatures and high humidity (Lam et al., 2020) and low temperatures and high humidity (Miyayo et al., 2021) have all been found to be associated with an increased incidence of pneumonia.

Day to day variations in temperature also appear important. For Australia, increases in emergency visits for childhood pneumonia are associated with sharp temperature drops (Xu et al., 2014). Large inter-daily changes in temperature are important for respiratory disease incidence in Guangzhou, China (Lin et al., 2013) and Shanghai (Lei et al., 2021) while rapidly changing and extreme temperatures during pregnancy have been linked to childhood pneumonia (Miao et al., 2017);(Zeng et al., 2017);(Zheng et al., 2021)). In tropical and subtropical areas of Africa and Asia, pneumonia incidence has been reported to be higher during the rainy season, pointing to a positive association between pneumonia patterns and temperature and precipitation (Chowdhury et al., 2018a);(Lim and Siow, 2018);(Paynter et al., 2010).

The degree to which the timing, duration and magnitude of local influenza virus epidemics is dependent on climate factors is poorly understood (Lam et al., 2020). Further, a host of non-climate confounders are likely to influence the incidence of seasonal influenza (Caini et al., 2018). This poses a number of challenges for making reliable climate-based epidemiological forecasts for influenza (Gandon et al., 2016). Although no association between anomalous climate conditions and influenza have been reported in some locations (Lam et al., 2020), generally, low winter temperatures and humidity in temperate regions and periods of high humidity and precipitation in the tropical and subtropical regions have been linked to outbreaks of influenza (Deyle et al., 2016);(Soebiyanto et al., 2015);(Tamerius et al., 2013). However, the climate sensitivity of influenza may be more complex than this with both high and low humidity, the amount and intensity of precipitation and solar activity/sunshine and latitude also important (Axelsen et al., 2014);(Chong et al., 2020b);(Geier et al., 2018);(Park et al., 2019);(Qu, 2016);(Smith et al., 2017);(Wang et al., 2017c);(Zhao et al., 2018a). Moreover, the shape of the climate variable influenza relationship may be conditioned on influenza type (Chong et al., 2020a). Further distinct periods of weather variability characterised by rapid inter-daily changes in temperature may act as precursors to influenza epidemics as has been demonstrated for the marked 2017-18 influenza season and others across the US (Liu et al., 2020a);(Zhao et al., 2018a). For the Eastern Mediterranean, such rapid weather changes are associated with the 'Cyprus Low', with the timing and magnitude of seasonal influenza related to the inter-annual frequency of this particular weather regime (Hochman et al., 2021). Potentially, large-scale modes of climatic variability such as El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole, which strongly moderate the frequency of weather regimes in some parts of the world, could affect influenza pandemic dynamics. However, studies conducted to date report inconsistent results. Some point to an increased (decreased) severity of seasonal influenza during El Nino (La Nina) (Oluwole, 2015),(Oluwole, 2017), while others find influenza to be more severe and frequent when coinciding with La Niña events (Chun et al., 2019);(Flahault et al., 2016);(Shaman and Lipsitch, 2013). This raises the possibly of non-stationary associations between large-scale modes of climatic variability and influenza dynamics (Onozuka and Hagihara, 2015) as found for other diseases (Kreppel et al., 2014), something that might be expected given El Niño's time-varying impact on global precipitation and temperature fields and associated impacts on health outcomes (McGregor and Ebi, 2018).

7.2.2.5 Other Water Shortage and Drought-associated Diseases

Water shortage and drought are associated with skin diseases (Schachtel et al., 2021);(Lundgren, 2018);(Andersen and Davis, 2017);(Kaffenberger et al., 2017);(Andersen and Davis, 2017), trachoma (Ramesh et al., 2016), and violence (Epstein et al., 2020a),

[START CROSS-CHAPTER BOX COVID HERE]

Cross-Chapter Box COVID: COVID-19

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Introduction

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which causes Coronavirus Disease 2019 (COVID-19), emerged in late 2019, halfway through the preparation of the IPCC WGII Sixth Assessment Report. This Cross-Chapter Box assesses how the massive shock of the pandemic and its response measures interact with climate-related impacts and risks, as well as its significant implications for risk management and climate resilient development.

COVID-19 and environmental connections

Infectious diseases may emerge and spread through multiple climate-related avenues, including direct effects of climatic conditions on disease reproduction and transmission and various indirect effects, often interlinked with ecosystem degradation (high confidence). Climate change is affecting the risk of emerging infectious diseases by contributing to factors that dive the movements of species, including vectors and reservoirs of diseases, into novel human populations and vice-versa (*high confidence*) {2.4.2.7; 5.2.2.3; Cross-Chapter Box Illness in Chapter 2; SRCCL; IPBES 2020}. The spillover of some emerging infectious diseases from wildlife into humans is associated with live animal-human markets, intensified livestock production and climate-related movements of humans and wild animals into new areas that alter human-animal interactions. {2.4.2.7} {Chapter 3} {5.2.2.3} {7.2} {Cross-Chapter Box ILLNESS in Chapter 2} {Cross-Chapter Box MOVING PLATE in Chapter 5}.

Human to human transmission is the prominent driver in the spread of the COVID-19 pandemic, rather than climatic drivers (high confidence). There is emerging literature on the environmental determinants of COVID-19 transmission, incidence and mortality rates, with initial evidence suggesting that temperature, humidity and air pollution contribute to these patterns (Brunekreef et al., 2021); (Xiong et al., 2020);(Zhang et al., 2020b); IPCC WGI AR6 Cross-Chapter Box). Climate change is altering environmental factors like temperature and seasonality that affect COVID-19 transmission (Choi et al., 2021).

The impact of COVID-19 containment measures resulted in a temporary reduction in greenhouse gas emissions and reduced air pollution *(high confidence)* (IPCC WGI TS and Cross-Chapter Box 6.1}. However, global and regional climate responses to the radiative effect were undetectable above internal climate variability due to the temporary nature of emission reductions. They, therefore, do not result in detectable changes in impacts or risks due to changes in climate hazards (IPCC WGI TS and Cross-Chapter Box 6.1; (Naik et al., 2021).

Cascading and compounding risks and impacts

The COVID-19 pandemic posed a severe shock to many socio-economic systems, resulting in substantial changes in vulnerability and exposure of people to climate risks (*high confidence*). The disease and response measures significantly affected human health, economic activity, food production and availability, health services, poverty, social and gender inequality, education, supply chains, infrastructure maintenance, and the environment. These COVID-19 impacts interact with many risks associated with climate change (IMF, 2020), often through a cascade of impacts across numerous sectors (van den Hurk et al., 2020). Beyond

COVID-19-related mortality and long-term COVID, mortality from other diseases (some of which may also have a climate-related component), as well as maternal and neonatal mortality, increased because of disruption in health services (Barach et al., 2020);(Maringe et al., 2020);(Zadnik et al., 2020); (Goyal et al., 2021). In addition, a rapid rise in poverty has disproportionately affected poorer countries and people (Ferreira et al., 2021), and thus increased their vulnerability. After many years of steady declines, extreme poverty increased by about 100 million people in 2020 (Bank, 2021). The effects of the pandemic increased food insecurity and malnourishment, which increased by 1.5 percentage points to around 9.9 per cent in 2020 after being virtually unchanged for the previous five years (FAO et al., 2021).

During the pandemic, extreme weather and climate events such as droughts, storms, floods, wildfires and heatwaves continued, resulting in disastrous compounding impacts (*high confidence*). Between March and September 2020, 92 extreme weather events coincided with the COVID-19 pandemic, affecting an estimated 51.6 million people; additionally, 431.7 million people were exposed to extreme heat, and 2.3 million people were affected by wildfires (Walton and van Aalst, 2020). The COVID-19 pandemic, in combination with extreme events, affected disaster preparedness, response and safe evacuations, while physical distancing regulations reduced the capacity of temporary shelters (Pacific), 2020); (Tozier de la Poterie et al., 2020);(Network, 2020); (Bose-O'Reilly et al., 2021). Complex humanitarian emergencies were aggravated, with vulnerable populations facing the combined risks of conflict, displacement, COVID-19 and climate impacts (FSIN, 2020). Compounding events are not only found in low-income countries but also in medium- and high-income countries, for instance in the case of COVID-19 and heatwaves (Network, 2020); (Bose-O'Reilly et al., 2021).

Responses and implications for adaptation and climate resilience development

The pandemic underscores the interconnected and compound nature of risks, vulnerabilities, and responses to emergencies that are simultaneously local and global (high confidence). COVID-19 is often considered a more "explosive" risk than the more gradual anthropogenic climate change. However, many climate-related risks do already appear as severe shocks at smaller scales, and infrequent or unprecedented extreme weather related events often warrant similar rapid responses (Dodds et al., 2020); (Gebreslassie, 2020); (Hynes et al., 2020); (Phillips et al., 2020); (Schipper, 2020); (Semenza et al., 2021); illustrated in Figure Cross-Chapter Box COVID in Chapter 7). Individuals, households, sub-national and national entities, and international organizations have generally delayed responses or denied the pandemic's severity before responding at the scale and urgency required; a pattern that resembles international action on climate change required; a pattern that resembles international action on climate change (Polyakova et al., 2020), (Shrestha et al., 2020).

Improved contingency and recovery planning, including disease mitigation measures, were crucial in responding to the pandemic in similar ways to those seen in the aftermath of climate-related disasters (Guo et al., 2020); (Ebrahim et al., 2020); (Baidya et al., 2020); (Shultz et al., 2020); (Mukherjee et al., 2020). The pandemic highlighted the lack of global and country-specific capacity to respond to an unexpected and unplanned-for event and the need to implement more flexible detection and response systems (Ebi et al., 2021b).

It also exposed underlying vulnerabilities, such as the lack of water access and health care in select low- and middle-income countries and among Indigenous and marginalised groups in high-income countries (see section 4.4.3, Box 4.3 and 5.12.1). Increased risks of COVID-19 transmission emerged in crowded areas such as urban settings, refugee camps, detention centres, and some workplaces, including in rural settings(Brauer et al., 2020); (Ramos et al., 2020); (Staddon et al., 2020); (Haddout et al., 2020). Public health responses to the COVID-19 pandemic, such as mandates for social distancing and advice for frequent handwashing, underlined the need for access to water and sanitation facilities and wastewater management. However, they have also interfered with access sometimes, for example, in evacuation and shelter infrastructure during climate-related disasters (Armitage and Nellums, 2020);(Adelodun et al., 2020); (Poch et al., 2020);(Hallema et al., 2020);(Patel et al., 2020); (Espejo et al., 2020).

The experience of COVID-19 demonstrates that many warnings about the risks of the emergence of zoonotic transmission ("delay is costly", "adapt early", and "prevention pays") did not result in sufficient political attention, funding, and pandemic prevention. In some countries, there has been an increased awareness of risks and the real or perceived trade-offs associated with risk management (e.g., economy vs. health; impacts vs. adaptation). Building trust, participatory processes and establishing stronger relationships with communities and other civic institutions may enable a recalibration in how the government responds to crises and society-government relationships more generally (Amat and et al., 2020); (Deslatte, 2020)

The management of the COVID-19 pandemic has highlighted the value of scientific (including medical and epidemiological) expertise and the importance of fast, accurate, and comprehensive data to inform policy decisions and to anticipate and manage risk (high confidence). It underscores the importance of effective communication of scientific knowledge (Semenza et al., 2021), decision-making under uncertainty, and decision frameworks that navigate different values and priorities. Successful policy responses were based on the emerging data, medical advice and collaboration with a wider set of societal stakeholders beyond public health experts. For instance, experience in Aotearoa New Zealand highlights the importance of pandemic responses attuned to the needs of different socio-cultural groups and Indigenous people in particular. Their strengths-based COVID-19 response goes beyond identifying vulnerabilities to unlocking the resources, capabilities and potential that might otherwise be latent in communities (McMeeking and Savage, 2020). As far as the value of information for risk management is concerned, compared to the initial uncertainties regarding COVID-19, data about near- and longer term climate-related hazards is generally very good; however, high-quality and dense meteorological data are often still lacking in lower income countries (Otto et al., 2020). Health data are particularly difficult to obtain in real-time, as is the case for biodiversity data, which has a time lag of years before being made available, and for which there is no coordinated monitoring, hampering effective risk management (Navarro et al., 2017). Therefore, both epidemiological and meteorological forecasts would benefit from more focus on (1) decision support, (2) conveying uncertainty, and (3) capturing vulnerability (Coughlan de Perez et al., 2021).

There is a considerable evidence base of specific actions that have co-benefits for reducing pandemic and climate change risks while enhancing social justice and biodiversity conservation (high confidence). The pandemic highlighted aspects of risk management that have long been recognised but are often not reflected in national and international climate policy: the value of addressing structural vulnerability rather than taking specific measures to control single hazards and drivers of risk, and the importance of decision-making capacities and transparency, the rule of law, accountability, and addressing inequities (or social exclusion) (reviewed by (Pelling et al., 2021), see also Figure Cross-Chapter Box COVID in Chapter 7).

Comprehensive and integrated risk management strategies can enable countries to address both the current pandemic and increase resilience against climate change and other risks (Reckien, 2021); (Semenza et al., 2021); (Ebi et al., 2021b). In particular, given their immense scale, COVID-19 recovery investments may offer an opportunity to contribute to Climate-Resilient Development Pathways through a green, resilient, healthy and inclusive recovery (*high confidence*) (Sovacool et al., 2020);(Rosenbloom and Markard, 2020); (Lambert et al., 2020); (Boyle et al., 2020); (Bouman et al., 2020); (Pacific), 2020);(Brosemer et al., 2020);(Dodds et al., 2020); (Hynes et al., 2020); (Markard and Rosenbloom, 2020); (Phillips et al., 2020); (Schipper, 2020); (Willi et al., 2020); (Semenza et al., 2021);(Pasini and Mazzocchi, 2020);(Meige et al., 2020); (Pelling et al., 2021). However, windows of opportunity to enable such transitions are only open for a limited period and need to be swiftly acted upon to effect change (*high confidence*) (chapter 18, (Weible et al., 2020); (Reckien, 2021). Initial indications suggest that only US$1.8 trillion of the >US$17 trillion COVID-19-related stimulus financing by G20 countries and other major economies that was committed until mid-2021 contributed to climate action and biodiversity objectives, with significant differences between countries and sectors (Economics, 2021). Moreover, responses to previous crises (e.g., the 2008-2011 global financial crisis) demonstrate that despite high ambitions during the response phase, opportunities for reform do not necessarily materialize (Bol et al., 2020), (Boin et al., 2005). In addition, heightened societal and political attention to one crisis often comes at the cost of other policy priorities (*high confidence*) (Maor, 2018); (Tosun et al., 2017), which could affect investments for climate-resilient development (Hepburn et al., 2020); (WHO, 2020a);(Bateman et al., 2020); (Meige et al., 2020); (Semenza et al., 2021).

In summary, the emerging literature suggests that the COVID-19 pandemic has aggravated climate risks, demonstrated the global and local vulnerability to cascading shocks, and illustrated the importance of integrated solutions that tackle ecosystem degradation and structural vulnerabilities in human societies. This highlights the potential and urgency of interventions that reduce pandemic and climate change risks while enhancing compound resilience, social justice and biodiversity conservation (see Figure Cross-Chapter Box COVID.1 in Chapter 7).

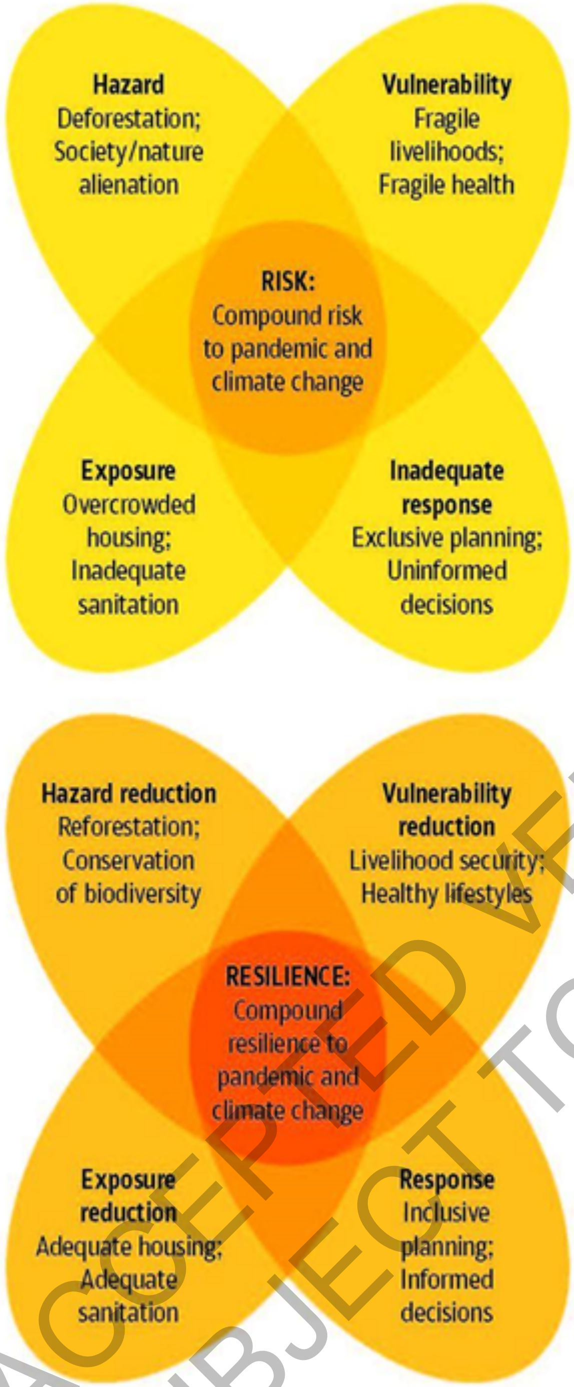

Figure Cross-Chapter Box COVID.1: Compound risk and compound resilience to pandemic and climate change. Source: (Pelling et al., 2021)

[END CROSS-CHAPTER BOX COVID HERE]

7.2.3 Observed Impacts on Non-communicable Diseases

Non-communicable diseases (NCDs) are those that are not directly transmitted from one person to another person, and impose the largest disease burden globally. NCDs constitute approximately 80% of the burden of disease in high-income countries; the NCD burden is lower in low- and middle-income countries but expected to rise (Bollyky et al., 2017). NCDs constitute a large group of diseases driven principally by environmental, lifestyle, and other factors; those identified as being climate sensitive include non-infectious respiratory disease, cardiovascular disease, cancer, and endocrine disease including diabetes. There are, additionally, potential interactions between multiple climate-sensitive NCDs and food security, nutrition, and mental health.

The literature on climate change and NCDs continues to develop. More recently, scientists have identified key gaps in the calculation of the global burden of disease due to environmental health factors (Shaffer et al., 2019).

7.2.3.1 Cardiovascular Diseases

Cardiovascular diseases (CVD) are a group of disorders of the heart and blood vessels that include coronary heart disease, cerebrovascular disease, peripheral arterial disease, rheumatic heart disease, congenital heart disease, deep vein thrombosis and pulmonary embolism. CVDs are the leading cause of death globally and over three quarters of the world's CVD deaths now occur in low- and middle-income countries (Roth et al., 2020).

Climate change affects the risk of CVD through high temperatures and extreme heat (assessed in 7.2.4.1) and through other mechanisms (medium confidence), though the degree to which non-temperature risks may increase remains unclear. For example, exposure to air pollutants including particulate matter, ozone (via its precursors), black carbon, oxides of nitrogen, oxides of sulphur, hydrocarbons and metals can invoke pro-inflammatory and prothrombotic states, endothelial dysfunction and hypertensive responses (Giorgini et al., 2017);(Stewart et al., 2017). Winter peaks in CVD events, associated with greater concentrations of air pollutants, have been reported in a range of countries and climates (Claeys et al., 2017);(Stewart et al., 2017); however, the association between air pollution, weather and CVD events is complex and seems to differ in cold *versus* warm months, particularly for gaseous pollutants such as ozone (Shi et al., 2020).

Climate change is projected to increase the number and severity of wildfires (Liu et al., 2015b);(Youssouf et al., 2014) and the evidence for wildfire smoke-related CVD morbidity and mortality is suggestive of increased CVD morbidity and mortality risk (Chen et al., 2021a)including significant increases in certain cardiovascular outcomes (e.g., cardiac arrests) (Dennekamp et al., 2015). CVD risks to highly exposed populations, such as fire firefighters, are clearer (Navarro et al., 2019), and could increase with additional exposure driven by climate change.

Other climate related mechanisms that may increase CVD risk include hot weather-related reduction in physical activity (Obradovich et al., 2017), sleep disturbance (Obradovich et al., 2017), and dehydration (Lim et al., 2015);(Frumkin and Haines, 2019) . There is little literature on how changes in winter weather may affect these risks. Sea level rise-related saline intrusion of groundwater (Taylor et al., 2012) may increase the salt intake of affected populations, a risk factor for hypertension that has been observed to increase blood pressure in exposed populations (Talukder et al., 2017);(MA. et al., 2018).

7.2.3.2 Non-communicable Respiratory Diseases

Lung diseases, including asthma, chronic obstructive pulmonary disease (COPD), and lung cancer, comprise the largest subsets of non-communicable pulmonary disease (Ferkol and Schraufnagel, 2014). Overall, the global burden of non-communicable lung disease including all chronic lung disease and lung cancer is substantial, responsible for 10.6% of deaths and 5.9% of DALYs globally in 2019 (Vos et al., 2020).

Several non-communicable respiratory diseases are climate sensitive based on their exposure pathways (very high confidence). Multiple exposure pathways contribute to non-communicable respiratory disease (Deng et al., 2020), some of which are climate-related, (Rice et al., 2014), including mobilization and transport of dust (Schweitzer et al., 2018 (Schweitzer et al., 2018); changes in concentrations of air pollutants such as small particulates (PM2.5) and ozone formed by photochemical reactions sensitive to temperature (Hansel et al., 2016), increased wildland fires and related smoke exposure (Johnston et al., 2002);(Reid et al., 2016); increased exposure to ambient heat driving reduced lung function and exacerbations of chronic lung disease (Collaco et al., 2018) (Jehn et al., 2013);(McCormack et al., 2016);(Witt et al., 2015); and modification of aeroallergen production and duration of exposure (Ziska et al., 2019).

Burdens of allergic disease, particularly allergic rhinitis and allergic asthma may be changing in response to climate change (medium confidence). (D'Amato et al., 2020);(Eguiluz-Gracia et al., 2020), (Deng et al., 2020), (Demain, 2018). This is supported by evidence showing an increase in the length of the North American pollen season attributable to climate change (Ziska et al., 2019), an association between timing of spring onset and higher asthma hospitalizations presumed to be due to higher pollen exposure (Sapkota et al., 2020), and other evidence linking aeroallergen exposure with a worsening burden of allergic disease (Demain, 2018);(Poole et al., 2019).

7.2.3.3 Cancer

Climate change is likely to increase the risk of several malignancies (high confidence), though the degree to which risks may increase remains unclear. Cancers, also known as malignant neoplasms, include a heterogeneous collection of diseases with various causal pathways, many with environmental influences. Malignant neoplasms impose a substantial burden of disease globally, responsible for slightly over 10 million deaths and 251 million DALYs globally in 2019 (Vos et al., 2020). Climatic hazards affect exposure pathways for several different chemical hazards associated with carcinogenesis (Portier et al., 2010). Most relevant literature has focused on elaborating potential pathways and producing qualitative or quantitative estimates of effect, though there is limited literature on current and projected impacts.

The vast majority of elaborated pathways point to increased risk; for example, there is concern that climate change may alter the fate and transport of carcinogenic polyaromatic hydrocarbons (Domínguez-Morueco et al., 2019) and increase mobilization of carcinogens such as bromide (Regli et al., 2015), persistent organic pollutants including polychlorinated-biphenyls that have accumulated in areas contaminated by industrial runoff (Miner et al., 2018), and radioactive material (Evangeliou et al., 2014). Exposure to these known carcinogens can occur through multiple environmental media and can be increased by climate change, for example through increased flooding related to extreme precipitation events and mobilization of sediment where carcinogens have accumulated (León et al., 2017);(Santiago and Rivas, 2012). In addition, there is concern that changes in ultraviolet light exposure related to shifts in precipitation may increase the incidence of malignant melanoma, particularly for outdoor workers (Modenese et al., 2018). Other harmful pathways include migration of and increased exposure to liver flukes, which cause hepatobiliary cancer (Prueksapanich et al., 2018) and introduction of infectious diseases such as schistosomiasis that increase cancer risk due to climate-related migration (Ahmed et al., 2014). Increased exposure to carcinogenic toxins via multiple pathways is also a concern. Aflatoxin exposure, for example, is expected to increase in Europe (Moretti et al., 2019), India (Shekhar et al., 2018), Africa (Gnonlonfin et al., 2013);(Bandyopadhyay et al., 2016), and North America (Wu et al., 2011). Other carcinogenic toxins originate from cyanobacteria blooms (Lee et al., 2017a), which are projected to increase in frequency and distribution with climate change (Wells et al., 2015);(Paerl et al., 2016);(Chapra et al., 2017).

7.2.3.4 Diabetes

Individuals suffering from diabetes are at higher risk of heat-related illness and death (medium confidence). Extreme weather events and rising temperatures ihave been found ncreasing morbidity and mortality in patients living with diabetes, especially in those with cardiovascular complications (Méndez-Lázaro et al., 2018; Zilbermint, 2020) (Hajat et al., 2017). Evidence suggests that the local heat loss response of skin blood flow (SkBF) is affected by diabetes-related impairments, resulting in lower elevations in SkBF in response to a heat or pharmacological stimulus. Thermoregulatory sweating may also be diminished by type 2 diabetes, impairing the body's ability to transfer heat from its core to the environment (Xu et al., 2019b). Observed higher rates of doctor consultations by patients with type-2 diabetes, and diabetics with cardiovascular comorbidities increased their rates of medical consultation during hot days, but there was no heightened risk with renal failure or neuropathy comorbidities.

People with chronic illness/es are at particular risk during and after extreme weather events due to treatment interruptions and lack of access to medication (medium confidence). The impacts of extreme weather events on the health of chronically ill people are due to a range of factors including disruption of transport, weakened health systems including drug supply chains, loss of power, and evacuations of populations (Ryan et al., 2015a). Evacuations also pose specific health risks to older adults (especially those who are frail, medically incapacitated, or residing in nursing or assisted living facilities) and may be complicated by the need for concurrent transfer of medical records, medications and medical equipment (Becquart et al., 2018);(Quast and Feng, 2019);(USGCRP, 2016). Emergency room visits after Hurricane Sandy rose among individuals with type-2 diabetes (Velez-Valle et al., 2016).

7.2.4 Observed Impacts on Other Climate-sensitive Health Outcomes

7.2.4.1 Heat and Cold Related Mortality and Morbidity

E*xtreme heat events and extreme temperature have well documented, observed impacts on health, mortality (very high confidence) and morbidity (high confidence).* AR5 described the thermoregulatory mechanisms and responses, including acclimatization, linking heat, cold and health, and these have been further confirmed by recent studies and reviews (e.g., (Giorgini et al., 2017);(Ikaheimo, 2018);(McGregor et al., 2015);(Stewart et al., 2017);(Schuster et al., 2017);(Zhang et al., 2018b). The health impacts of heat manifest clearly in periods of extreme heat often codified as heatwaves. For example, heatwaves across Europe (2003), Russia (2010), India (2015) and Japan (2018) resulted in significant death tolls and hospitalizations (McGregor et al., 2017), (Hayashida et al., 2019). Heat continues to pose a significant health risk due to increases in exposure, an outcome of changes in the size and spatial distribution of the human population, mounting vulnerability and an increase in extreme heat events (high confidence) (Harrington et al., 2017; Liu et al., 2017);(Mishra et al., 2017);(Rohat et al., 2019a; Rohat et al., 2019b; Rohat et al., 2019c);(Watts et al., 2019). Furthermore, some regions are already experiencing heat stress conditions approaching the upper limits of labour productivity and human survivability (high confidence). These include the Persian Gulf and adjacent land areas, parts of the Indus River Valley, eastern coastal India, Pakistan, north-western India, the shores of the Red Sea, the Gulf of California, the southern Gulf of Mexico, and coastal Venezuela and Guyana (Krakauer et al., 2020);(Li et al., 2020);(Raymond et al., 2020);(Saeed et al., 2021);(Xu et al., 2020).

Notwithstanding the variety of methods applied, estimates of the world's current population exposed to extreme heat indicate very large numbers and an increase since pre-industrial times. For example, Li et al (2020) estimate that globally and annually, 1.28 billion people experience heatwave conditions similar to that of the lethal Chicago 1995 event compared to 0.99 billion under a preindustrial climate. Further, for the 150 most populated cities of the world, a 500% increase in the exposure to extreme heat events occurred over the period 1980 – 2017 (Li et al., 2021), while for the period 1986–2005, the total exposure to dangerous heat in Africa's 173 largest cities was 4.2 billion person-days per year (Rohat et al., 2019a). Globally the present exposure to heatwave events is estimated to be 14.8 billion person-days per year, with the greatest cumulative exposures measured in person-days occurring across southern Asia (7.19 billion), sub-Saharan Africa (1.43 billion) and North Africa and the Middle East (1.33 billion) (Jones et al., 2018).

The country level percentage of mortality attributable to non-optimum temperature (heat and cold) has been found to range from 3·4% to 11·00% (Gasparrini et al., 2015);(Zhang et al., 2019b). Heat as a health risk factor has largely been overlooked in low and middle-income countries, (Campbell et al., 2018) (Green et al., 2019);(Dimitrova et al., 2021). For 2019, the Global Burden of Disease report estimates the burden of DALYs attributable to low temperature was 2.2 times greater than the burden attributable to high temperature. However, this global figure obscures important regional variations. Countries with a high socio-demographic index - mainly mid-latitude high income temperate to cool climate countries -, were found to have a cold-related burden 15.4 times greater than the heat-related burden, while for warm lower income regions, such as south Asia and sub-Saharan Africa, the heat-related burden was estimated to be 1.7 times and 3.6 times greater respectively (Murray et al., 2020). For countries where data availability permits, there is evidence that extreme heat (and extreme cold) leads to higher rates of premature deaths (Armstrong et al., 2017);(Cheng et al., 2018);(Costa et al., 2017).
Rapid changes and variability in temperatures are observed to increase heat-related health and mortality risks, the outcomes varying across temperate and tropical regions (Guo et al., 2016);(Cheng et al., 2019); (Kim et al., 2019a);(Tian et al., 2019);(Zhang et al., 2018b);(Zhao et al., 2019).

Several lines of evidence point to a possible decrease in population sensitivity to heat, albeit mainly for high-income countries (high confidence), arising from the implementation of heat warning systems, increased *awareness, and improved quality of life.* (Sheridan and Allen, 2018). Evidence manifests as, a general decrease in the impact of heat on daily mortality(Diaz et al., 2018);(Kinney, 2018);(Miron et al., 2015), a decline in the relative risk attributable to heat (Åström et al., 2018);(Barreca et al., 2016);(Petkova et al., 2014), and an increase in the minimum mortality temperature (MMT) (Åström et al., 2018);(Folkerts et al., 2020);(Follos et al., 2021);(Chung et al., 2018);(Todd and Valleron, 2015); (Yin et al., 2019). It is difficult to draw conclusions regarding trends in heat sensitivity for low to middle-income countries and specific vulnerable groups as these are under-represented in the literature (Sheridan and Allen, 2018). Trends in heat sensitivity are likely to be scale and situation dependent as considerable inter-city variability in changes in heat sensitivity as measured by trends in heat-related mortality or MMT (Follos et al., 2021);(Kim et al., 2019a);; (Lee et al., 2021) exist as well as variability amongst different population groups (Lu et al., 2021).

Temperature interacts with heat-sensitive physiological mechanisms via multiple pathways to affect health. In the worst cases these lead to organ failure and death (Mora et al., 2017a; Mora et al., 2017b). Excess deaths during extreme heat events occur predominantly in older individuals and are overwhelmingly cardiovascular in origin *(very high confidence)*. A higher occurrence of CVD mortality in association with prolonged period of low temperatures has been well documented globally (Giorgini et al., 2017);(Stewart et al., 2017); however, there is growing evidence that cardiovascular deaths are more related to heat events than cold spells (Chen et al., 2019);(Liu et al., 2015a);(Bunker et al., 2016). Whilst there is strong association between ambient temperature and cardiovascular events globally, there are complex interactions and modulators of individual response (Wang et al., 2017b). Further, some CVD morbidity sub-groups such as myocardial infarction and stroke hospitalization display temperature sensitivity, while others do not (Bao et al., 2019);(Sun et al., 2018);(Wang et al., 2016). Although older adults have inherent sensitivities to temperature-related health impacts (Bunker et al., 2016);(Phung et al., 2016), children can also be affected by extreme heat (Xu et al., 2014). Cardiovascular capacity/health is also a critical determinant of individual health outcomes (Schuster et al., 2017). Medications to treat CVD diseases, such as diuretics and beta-blockers, may impair resilience to heat stress (Stewart et al., 2017). Other mediating factors in the causal pathway range from alcohol consumption (Cusack et al., 2011);(Epstein and Yanovich, 2019) and obesity (Speakman, 2018) to pre-existing conditions such as diabetes and hyperlipidaemia, and urban characteristics (Chen et al., 2019), (Sera et al., 2019).

Under extreme heat conditions, increases in hospitalizations have been observed for fluid disorders, renal failure, urinary tract infections, septicaemia, general heat stroke as well as unintentional injuries (Borg et al., 2017);(Phung et al., 2017);(Goggins and Chan, 2017);(Hayashida et al., 2019);(Hopp et al., 2018);(Ito et al., 2018);(Kampe et al., 2016);(McTavish et al., 2018);(Ponjoan et al., 2017);(van Loenhout et al., 2018). Hospitalisations and mortality due to respiratory disorders also occur during heat events with the interactive role of air quality important for some locations but not others (Krug et al., 2019);(Pascal et al., 2021);(Patel et al., 2019). Increased levels of heat-related hospitalisation also manifest in elevated levels of emergency services call out (Cheng et al., 2016);(Guo, 2017);(Papadakis et al., 2018);(Williams et al., 2020).

Heat and cold related health outcomes vary by location (Dialesandro et al., 2021);(Hu et al., 2019);(Phung et al., 2016), suggesting outcomes are highly moderated by socio-economic, occupational and other non-climatic determinants of individual health and socio-economic vulnerability (Åström et al., 2020);(McGregor et al., 2017);(McGregor et al., 2017);(Schuster et al., 2017), (Benmarhnia et al., 2015);(Watts et al., 2019) (*high confidence*). For example, access to air conditioning is an important determinant of heat-related health outcomes for some locations (Guirguis et al., 2018);(Ostro et al., 2010). Although there is a paucity of global level studies of the effectiveness of air conditioning for reducing heat-related mortality, a recent assessment indicates increases in air conditioning explains only part of the observed reduction in heat-related excess deaths, amounting to 16.7% in Canada, 20.0% in Japan, 14.3% in Spain and 16.7% in the US (Sera et al., 2020).

Significant effects of heat exposure are evident in sport and work settings with exertional heat illness leading to death and injury (Adams and Jardine, 2020). Although most studies of heat-related sports injuries refer to high-income countries, these point to an increasing number of heat injuries with widening participation in sport and an increasing frequency of extreme heat events. The highest rates of exertional heat illness are reported for endurance type events (running, cycling, adventure races), American football and athletics (Gamage et al., 2020); (Grundstein et al., 2017);(Kerr et al., 2020);(McMahon et al., 2021);(Yeargin et al., 2019). The health, safety and productivity consequences of working in extreme heat are widespread (Ma et al., 2019);(Morabito et al., 2021);(Kjellstrom et al., 2019);(Orlov et al., 2020);(Smith et al., 2021);(Vanos et al., 2019);(Varghese et al., 2020);(Williams et al., 2020). Occupational heat strain in outdoor workers manifests as dehydration, mild reduction in kidney function, fatigue, dizziness, confusion, reduced brain function, loss of concentration and discomfort (Al-Bouwarthan et al., 2020);(Boonruksa et al., 2020);(Habibi et al., 2021);(Levi et al., 2018);(Venugopal et al., 2021);(Xiang et al., 2014). In the case of the armed forces, a global review of the available literature points to a slightly higher incidence of heat stroke in men compared to women but a higher proportion of heat intolerance and greater risk of exertional heat illness amongst women (Alele et al., 2020). There is also some evidence that for healthcare workers, the risk of occupational heat stress heightened during the COVID-19 pandemic due to the need to wear personal protective equipment (Foster et al., 2020);; (Lee et al., 2020);(Messeri et al., 2021). Based on a systematic review of the literature, one study estimates global costs from heat-related lost work time were USD 280 billion in 1995 and USD 311 billion in 2010 with low- and middle-income countries and countries with warmer climates possessing greater losses as a proportion of GDP (Borg et al., 2021). Other global level assessments note an increase in the potential hours of work lost due to heat over the period 2000 –2018; in 2018, 133·6 billion potential work hours were lost amounting to 45 billion hours more than in 2000 (Watts et al., 2019). Further, for China heat-related productivity losses have been estimated at 9·9 billion hours in 2019, equivalent to 0·5% of the total national work hours for that year with Guangdong province, one of the warmest regions in China, accounting for almost a quarter of the losses (Cai et al., 2021).

Wide ranging knowledge regarding the specific detection and attribution of heat and cold-related mortality/morbidity to observed climate change is lacking. Although there has been an observed increase in winter season temperatures for a number of regions, to date there is variable evidence for a consequential reduction in winter mortality and susceptibility to cold over time due to milder winters - some countries demonstrate decreasing trends, other countries stable or even increasing trends in cold-attributable mortality fractions over time (e.g. (Arbuthnott et al., 2020);(Åström et al., 2013);(Diaz et al., 2019);(Hajat, 2017);(Hanigan et al., 2021);(Lee et al., 2018b). While there is a burgeoning literature on the attribution of extreme heat events to climate change (e.g. (Vautard et al., 2020)), the number of studies that assess the extent to which observed changes in heat-related mortality may be attributable to climate change is small (Ebi et al., 2020). During the 2003 European heatwave, anthropogenic climate change increased the risk of heat-related mortality by approximately 70% and 20% for London and Paris respectively (Mitchell et al., 2016). For the severe heat event across Egypt in 2015, the impact on human discomfort was 69% (±17%) more likely due to anthropogenic climate change (Mitchell, 2016) and for Stockholm, Sweden it has been estimated that mortality due to temperature extremes for 1980–2009 was double what would have occurred without climate change (Åström et al., 2013). To date there has only been one multi-country attempt to quantify the heat-related human health impacts that have already occurred due to climate change. Based on an analysis of 732 locations spanning 43 countries, for the period 1991–2018, the study found that on average, 37.0% (inter-quartile range 20.5–76.3%) of warm-season heat-related deaths can be attributed to anthropogenic climate change, equivalent to an average mortality rate of 2.2/100,000 (median: 1.67/100,00; interquartile range: 1.08 - 2.34/100,000) Regions with a high attributed percentage (> 50%) include southern and western Asia (Iran and Kuwait), Southeast Asia (Philippines and Thailand) and several countries in Central and South America. Those with lower values (<35%) include western Europe (Netherlands, Germany, Switzerland), eastern Europe (Moldova, Czech Republic, Romania), southern Europe (Greece, Italy, Portugal, Spain), North America (USA) and eastern Asia (China, Japan, South Korea) (Vicedo-Cabrera et al., 2021). Due to data restrictions some of the poorest and most susceptible regions to climate change and increases in heat exposure, such as West and East Africa (Asefi-Najafabady et al., 2018);(Sylla et al., 2018) and South Asia, could not be included in the analysis (Mitchell, 2021).

7.2.4.2 Injuries Arising from Extreme Weather Events Other than Heat and Cold

Injuries comprise a substantial portion of the global burden of disease. In 2019, injuries comprised 9.82% of total global DALYs and 7.61% of deaths (Vos et al., 2020). The causal pathways for many injuries, particularly those from heat and extreme weather events, flooding, and fires, exhibit clear climate sensitivity (Roberts and Arnold, 2007);(Roberts and Hillman, 2005), as do some injuries occurring in occupational settings (Marinaccio et al., 2019);(Sheng et al., 2018), but a comprehensive assessment of climate sensitivity in injury causal pathways has not been done. Certain groups, including Indigenous Peoples, children, and elders (Ahmed et al., 2020) are at greater risk for a wide range of injuries. Extreme events impose substantial disease burden directly as a result of traumatic injuries, drowning, and burns and large mental health burdens associated with displacement (Fullilove, 1996), depression, and post-traumatic stress disorder, but the overall injury burden associated with extreme weather is not known. It is known that the Asia-Pacific region experienced the highest relative burden of injuries from extreme weather in recent decades (Hashim and Hashim, 2016).

Extreme weather imposes a substantial morbidity and mortality burden that is quite variable by location and hazard. The proportion of this burden related to injuries specifically is not established. From 1998-2017 there were 526,000 deaths from 11,500 extreme weather events, and the average annual attributable all-cause mortality incidence in the ten most affected countries was 3.5 per 100,000 population (Eckstein et al., 2017). Rates can be much higher, however; mortality incidence in Puerto Rico and Dominica from extreme weather were 90.2 and 43.7 per 100,000 population in 2017, respectively (Eckstein et al., 2017). Not all of these deaths are from injuries, and the proportion of mortality and morbidity associated with injuries varies by location and hazard. One review found that one-year post-event prevalence rates for injuries associated with extreme events (floods, droughts, heatwaves, and storms) in developing countries ranged from 1.4% to 37.9% (Rataj et al., 2016). Other literature has documented an increase in risk of motor vehicle accidents in association with extreme precipitation (Liu et al., 2017);(Stevens et al., 2019) and temperature (Leard and Roth, 2019)and in association with sandstorms (Islam et al., 2019), and an increased risk of traumatic occupational injuries associated with temperature extremes, particularly extreme heat, likely from fatigue and decreased psychomotor performance (Varghese et al., 2019).

There is clear evidence of climate sensitivity for multiple injuries from floods, fires, and storms, but limited evidence regarding current injury burden attributable to climate change. It is *as likely as not* that climate change has increased the current burden of disease from injuries related to extreme weather, particularly in low-income settings *(low confidence)*. Approximately 120 million people are exposed to coastal flooding annually (Nicholls et al., 2007), causing an estimated 12,000 deaths (Shultz et al., 2005)and there is significant concern for worsening associated with climate change (Shultz et al., 2018a);(Shultz et al., 2018b);(Woodward and Samet, 2018)but very limited quantification of attributable burden. As for projected exposures, there is sufficient evidence to assess risks related to flooding only, though there is very limited literature highlighting increased morbidity and mortality an increase in fires in sub-zero temperatures that are thought to be highly attributed to climate change (Metallinou and Log, 2017).

7.2.4.3 Observed Impacts on Maternal, Fetal, and Neonatal Health

Maternal and neonatal disorders accounted for 3.67% of total global deaths and 7.83% of global DALYs in 2019 (Vos et al., 2020). Children and pregnant women have potentially higher rates of vulnerability and/or exposure to climatic hazards, extreme weather events, and undernutrition (Garcia and Sheehan, 2016), (Sorensen et al., 2018), (Chersich et al., 2018). Available evidence suggests that heat is associated with higher rates of preterm birth (Wang et al., 2020a) low birthweight, stillbirth, and neonatal stress (Cil and Cameron, 2017);(Kuehn and McCormick, 2017) and with adverse child health (Kuehn and McCormick, 2017). Extreme weather events are associated with reduced access to prenatal care and unattended deliveries (Abdullah et al., 2019) and decreased paediatric health care access (Haque et al., 2019).

7.2.4.4 Observed Impacts on Malnutrition

Climate variability and change contribute to food insecurity that can lead to malnutrition, including undernutrition, overweight, obesity; and to disease susceptibility, particularly in low- and middle-income countries (high confidence). Since AR5, analyses of the links between climate change and food expanded beyond undernutrition to include the impacts of climate change on a wider set of diet and weight-related risk factors and their impacts on NCDs, along with the role of dietary choices for GHG emissions (SRCCL, 2019 including dietary inadequacy (deficiencies, excesses, or imbalances in energy, protein, and micronutrients), infections, and sociocultural factors {Global, 2020, Global Nutrition Report: Action on equity to end malnutrition). Undernutrition exists when a combination of insufficient food intake, health, and care conditions results in one or more of underweight for age, short for age (stunted), thin for height (wasted), or functionally deficient in vitamins and/or minerals (micronutrient malnutrition or "hidden hunger"). Food insecurity and poor access to nutrient dense food contribute not only to undernutrition, but also to obesity and susceptibility to non-communicable diseases in low- and middle-income countries (FAO et al., 2018);(Swinburn et al., 2019).

Globally, more than 690 million people are undernourished, 144 million children are stunted (chronic undernutrition), 47 million children are wasted (acute undernutrition), and more than 2 billion people have micronutrient deficiencies (FAO, 2020). More than 135 million people across 55 countries experienced acute hunger requiring urgent food, nutrition, and livelihoods assistance in 2019 (FSIN/GNAFC, 2020). The COVID-19 pandemic is projected to increase the number of acutely food insecure people to 270 million people (FSIN, 2020) and worsen malnutrition levels (FAO et al., 2020); (Rippin et al., 2020)). The relationships between climate change and obesity vary based on geography, population subgroups, and/or stages of economic growth and population growth. (An et al., 2017). Increasing temperatures could contribute to obesity through reduced physical activity, increased prices of produce, or shifts in eating patterns of populations toward more processed foods. (An et al., 2018). In the largest global study to date exploring the connections between child diet diversity and recent climate, data from 19 countries in six regions (Asia, Central America, North Africa, South America, Southeast Africa, and West Africa) indicated significant reductions in diet diversity associated with higher temperatures and significant increases in diet diversity associated with higher precipitation (Niles et al., 2021).

Climate change can affect the four aspects of food security: food production and availability, stability of food supplies, access to food, and food utilization (SRCCL, 2019). Access to sufficient food does not guarantee nutrition security. Extreme weather and climate events can result in inadequate or insufficient food consumption, increasing susceptibility to infectious diseases (Rodriguez-Llanes et al., 2016);(Gari et al., 2017);(Kumar et al., 2016);(Lazzaroni and Wagner, 2016 but also to being overweight or obese, and susceptibility to non-communicable diseases in LIMICs {FAO, 2018, The State of Food Security and Nutrition in the World 2018);(Swinburn et al., 2019).

Nearly half of all deaths in children under 5 are attributable to undernutrition, putting children at greater risk of dying from common infections (2021). Undernutrition in the first 1,000 days of a child's life can lead to stunted growth, which can result in impaired cognitive ability and reduced future school and work performance and the associated costs of stunting in terms of lost economic growth can be of the order of 10% of GDP per year in Africa (UNICEF/WHO/WBG, 2019).

At the same time, diseases associated with high-calorie, unhealthy diets are increasing globally, with 38.3 million overweight children under five years of age (GNR, 2018), 2.1 billion adults are overweight or obese and the global prevalence of diabetes almost doubled in the past 30 years (Swinburn et al., 2019). Unbalanced diets, such as diets low in fruits and vegetables and high in red and processed meat, are the number one risk factor for mortality globally and in most regions (Collaborators, 2018b);(Collaborators, 2019).

Socio-economic factors that mediate the influence of climate change on nutrition include cultural and societal norms; governance, institutions, policies, and fragility; human capital and potential; social position and access to healthcare, education, and food aid (Rozenberg, 2017); Alkerwi et al. 2015;(Tirado, 2017);(FAO et al., 2018);(Report, 2020). Extreme events may affect access to adequate diets, leading to malnutrition and increasing the risk of disease (Beveridge et al., 2019);(Rodriguez-Llanes et al., 2016);(Gari et al., 2017);(Kumar et al., 2016);(Lazzaroni and Wagner, 2016);(Thiede and Gray, 2020).

7.2.4.5 Observed Impacts on Exposure to Chemical Contaminants

Climate change in northern regions, including Arctic ecosystems, is causing permafrost to thaw, creating the potential for mercury (Hg) to enter the food chain (medium agreement, low evidence), as Methyl mercury (MeHg) is highly neurotoxic and nephrotoxic and bioaccumulates and biomagnifies throughout the food chain via dietary uptake of fish, seafood, and mammals. Mercury methylation processes in aquatic environments have been found exacerbated by ocean warming, coupled with more acidic and anoxic sediments (FAO, 2020). Consumption of mercury-contaminated fish has been found linked to neurological disorders due to methyl mercury poisoning (i.e., Minamata disease) that is associated withlimate change-contaminant interactions that alter the bioaccumulation and biomagnification of toxic and fat-soluble persistent organic pollutants, such as persistent organic pollutants (POPs) and polychlorinated biphenyls (PCBs) (J.J. et al., 2017) in seafood and marine mammals (*medium confidence)*. Indigenous peoples have a higher exposure to such risks because of the accumulation of such toxins in traditional foods (J.J. et al., 2017). Contamination of food with PCBs and dioxins that have a range of adverse health impacts (Lake et al., 2015).

Chapter 5 (5.4.3, 5.5.2.3, 5.8.1, 5.8.2, 5.8.3, 5.9.1, 5.11.1, 5.11.3, 5.12.3) discusses the possible impacts of climate change on food safety, including exposure to toxigenic fungi, PCBs, and other persistent organic pollutants, mercury, and harmful algal blooms.

Climate change may affect animal health management practices, potentially leading to an increased use of pesticides or veterinary drugs (such as preventive antimicrobials) that could result in increased levels of residues in foods (high agreement, medium/low evidence). (Beyene et al., 2015); (FAO and WHO, 2018);(Authority) et al., 2020);(Authority) et al., 2020); (MacFadden et al., 2018)).

7.2.5 Observed Impacts on Mental Health and Wellbeing

7.2.5.1 Observed Impacts on Mental Disorders

A wide range of climatic events and conditions have observed and detrimental impacts on mental health (very high confidence). The pathways through which climatic events affect mental health are varied, complex and interconnected with other non-climatic influences that create vulnerability. The climatic exposure may be direct, such as experiencing an extreme weather event or prolonged high temperatures, or indirect, such as mental health consequences of undernutrition or displacement. Exposure may also be vicarious, with people experiencing decreased mental health associated with observing the impact of climate change on others, or simply with learning about climate change. Non-climatic moderating influences range from an individual's personality and pre-existing conditions, to social support, to structural inequities (Gariepy et al., 2016);(Hrabok et al., 2020);(Nagy et al., 2018);(Silva et al., 2016b). Depending on these background and contextual factors, similar climatic events may result in a range of potential mental health outcomes, including anxiety, depression, acute traumatic stress, post-traumatic stress disorder, suicide, substance abuse, and sleep problems, with conditions ranging from being mild in nature to those that require hospitalization (Berry et al., 2010);(Cianconi et al., 2020);(Clayton et al., 2017);(Ruszkiewicz et al., 2019);(Bromet et al., 2017);{Lowe, 2019, Posttraumatic Stress and Depression in the Aftermath of Environmental Disasters: A Review of Quantitative Studies Published in 2018}. The line between mental health and more general wellbeing is permeable, but in this section we refer to diagnosable mental disorders, conditions that disrupt or impair normal functioning through impacts on mood, thinking, or behaviour.

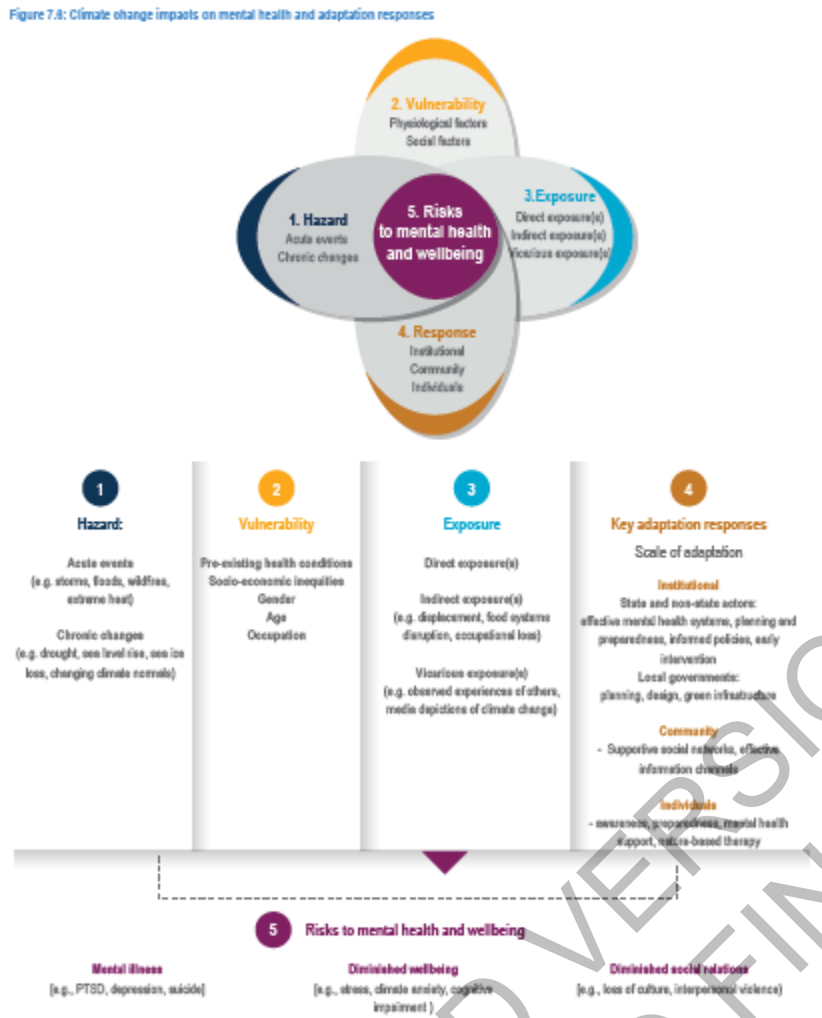

Figure 7.6: Climate change impacts on mental health and key adaptation responses

There is an observable association between high temperatures and mental health decrements (high confidence), with an additional possible influence of increased precipitation (medium agreement, medium evidence). Heat-associated mental health outcomes include suicide (Williams et al., 2015a);(Carleton, 2017);(Burke et al., 2018);(Kim et al., 2019b);(Thompson et al., 2018), (Schneider et al., 2020);(Cheng et al., 2021);(Baylis et al., 2018);(Obradovich et al., 2018); psychiatric hospital admissions and ER visits for mental disorders (Hansen et al., 2008);(Wang et al., 2014);(Chan et al., 2018);(Mullins and White, 2019);(Yoo et al., 2021), experiences of anxiety, depression, and acute stress (Obradovich et al., 2018);(Mullins and White, 2019), and self-reported mental health (Li et al., 2020). In Canada, Wang et al. (2014) found an association between mean heat exposure of 28°C within 0 to 4 days of exposure and greater hospital admissions for mood and behavioural disorders (including schizophrenia, mood, and neurotic disorders). A US study found mental health problems increased by 0.5% when average temperatures exceeded 30°C, compared to averages between 25–30°C; a 1°C warming over 5 years was associated with a 2% increase in mental health problems (Obradovich et al., 2018). Another study found a 1°C rise in monthly average temperatures over several decades was associated with a 2.1% rise in suicide rates in Mexico and a 0.7% rise in suicide rates in the US (Burke et al., 2018). A systematic review of published research using a variety of methodologies from 19 countries (Thompson et al., 2018) found increased risk of suicide associated with a 1°C rise in ambient temperature.

Discrete climate hazards including storms have significant negative consequences for mental health (very high confidence). (Kessler et al., 2008);(Boscarino et al., 2013);(Boscarino et al., 2017);(Obradovich et al., 2018), floods (Baryshnikova and Pham, 2019), heatwaves, wildfires, and drought (Hanigan et al., 2012); (Carleton, 2017);(Zhong et al., 2018) (Charlson et al., 2021).A large body of research identifies impacts of extreme weather events on post-traumatic stress disorder, anxiety, and depression; much of the research has been done in the U.S. and the UK, but a growing number of studies find evidence for similar impacts on mental health in other countries, including Spain (Foudi et al., 2017), Brazil (Alpino et al., 2016), Chile (Navarro et al., 2016), Small Island Developing States (Kelman et al., 2021), and Vietnam (Pollack et al., 2016). Approximately 20–30% of those who live through a hurricane develop depression and/or post-traumatic stress disorder (PTSD) within the first few months following the event (Obradovich et al., 2018);(Schwartz et al., 2015);(Whaley, 2009), with similar rates for people who have experienced flooding (Waite et al., 2017);(Fernandez et al., 2015). Studies conducted in South America and Asia indicate an increase in post-traumatic stress disorders and depressive disorders after extreme weather events (Rataj et al., 2016). Evidence is lacking for African countries (Otto et al., 2017). Children and adolescents are particularly vulnerable to post-traumatic stress after extreme weather events (Brown et al., 2017);(Hellden et al., 2021);(Kousky, 2016), and increased susceptibility to mental health problems may linger into adulthood (Maclean et al., 2016).

Wildfires have observed negative impacts on mental health (high confidence). This is due to the trauma of the immediate experience and/or subsequent displacement and evacuation (Dodd et al., 2018);(Brown et al., 2019);(Psarros et al., 2017);(Silveira et al., 2021b), Subclinical outcomes, such as increases in anxiety, sleeplessness, or substance abuse are reported in response to wildfires and extreme weather events, with impacts being pronounced among those who experience greater losses or are more directly exposed to the event; this may include first responders.

Mental health impacts can emerge as result of climate impacts on economic, social and food systems (high confidence). For example, malnutrition among children has been associated with a variety of mental health problems (Adhvaryu et al., 2019);(Hock et al., 2018);(Yan et al., 2018), as has food insecurity among adults (Lund et al., 2018). The economic impacts of droughts have been associated with increases in suicide, particularly among farmers (Carleton, 2017);(Edwards et al., 2015);(Vins et al., 2015); those whose occupations are likely to be affected by climate change report that it is a source of stress that is linked to substance abuse and suicidal ideation (Kabir, 2018). Studies of Indigenous Peoples often describe food insecurity or reduced access to traditional foods as a link between climate change and reduced mental health (Middleton et al., 2020b). The loss of family members, e.g. due to an extreme weather event, increases the risk of mental illness (Keyes et al., 2014). Individuals in low and middle-income countries may be more severely impacted due to lesser access to mental health services and lower financial resources to help cope with impacts, compared with high-income countries (Abramson et al., 2015).

Anxiety about the potential risks of climate change and awareness of climate change itself can affect mental health even in the absence of direct impacts (low confidence). There is not yet robust evidence about the prevalence or severity of climate change-related anxiety, sometimes called ecoanxiety, but national surveys in the U.S., Europe, and Australia show that people express high levels of concern and perceived harm associated with climate change (Steentjes et al., 2017), (Clayton and Karazsia, 2020);(Cunsolo and Ellis, 2018);(Helm et al., 2018). (Leiserowitz et al., 2017);(Reser et al., 2012);(Steentjes et al., 2017). In a U.S. sample, perceived ecological stress, defined as personal stress associated with environmental problems, predicted depressive symptoms (Helm et al., 2018);in a sample of Filipinos, climate anxiety was correlated with lower mental health (Reyes et al., 2021), and a non-random study in 25 countries showed positive correlations between negative emotions about climate change and self-rated mental health (Ogunbode et al., 2021). However, an earlier study found no correlation between climate change worry and mental health issues (Berry and Peel, 2015). Because the perceived threat of climate change is based on subjective perceptions of risk and coping ability as well as on experiences and knowledge (Bradley et al., 2014), even people who have not been directly affected may be stressed by a perception of looming danger (Clayton and Karazsia, 2020). Not surprisingly, those who have directly experienced some of the effects of climate change may be more likely to show such responses. Indigenous Peoples, whose culture and wellbeing tend to be strongly linked to local environments, may be particularly likely to experience mental health effects associated with changes in environmental risks; studies suggest connections to an increase in depression, substance abuse, or suicide in some Indigenous Peoples (Canu et al., 2017);(Cunsolo Willox et al., 2013);(Middleton et al., 2020b);(Jaakkola et al., 2018).

7.2.5.2 Observed Impacts on Wellbeing

*Overall, research suggests that climate change has already had negative effects on subjective wellbeing (medium confidence). C*limate change can affect wellbeing through a number of pathways, including loss of access to green and blue spaces due to damage from storms, coastal erosion, drought, or wildfires; heat; decreased air quality; and disruptions to one's normal pattern of behaviour, residence, occupation, or social interactions (Hayward and Ayeb-Karlsson, 2021). For example, substantial evidence shows a negative correlation between air pollution and subjective wellbeing or happiness (Apergis, 2018);(Cunado and de Gracia, 2013);(Lu, 2020);(Luechinger, 2010);(Menz and Welsch, 2010);(Orru et al., 2016);(Yuan et al., 2018);(Zhang et al., 2017a); in the reverse direction, there is evidence not only that time in nature but more specifically a feeling of connectedness to nature are both associated with wellbeing (Martin et al., 2020) and healthy ecosystems offer opportunities for health improvements (Pretty and Barton, 2020). Negative emotions such as grief - often termed 'solastalgia'(Albrecht et al., 2007) -- are associated with the degradation of local or valued landscapes (Eisenman et al., 2015);(Ellis and Albrecht, 2017);(Polain et al., 2011);(Tschakert et al., 2017);(Tschakert et al., 2019), which may threaten cultural rituals, especially among Indigenous Peoples (Cunsolo and Ellis, 2018);(Cunsolo et al., 2020). Studies conducted in the Solomon Islands and in Tuvalu found qualitative and quantitative evidence of experiences of climate change and worry about the future, with negative impacts on respondents' wellbeing (Asugeni et al., 2015);(Gibson et al., 2020).

Heat is one of the best-studied aspects of climate change observed to reduce wellbeing (high confidence). Higher summer temperatures are associated with decreased happiness and ratings of wellbeing (Carleton and Hsiang, 2016);(Miles-Novelo and Anderson, 2019). (Connolly, 2013);(Noelke et al., 2016);(Baylis et al., 2018);(Moore et al., 2019);(Wang et al., 2020b). A study of 1.9 million Americans, (Noelke et al., 2016) found that exposure to one day averaging 21–27 °C was associated with reduced wellbeing by 1.6% of a standard deviation, and days above 32°C were associated with reduced wellbeing by 4.4% of a standard deviation relative to a reference interval of 10–16 °C. A similar relationship between heat and mood has been observed in China, where expressed mood began to decrease when the average daily temperature was over 20°C (Wang et al., 2020b). The causal mechanism is unclear, but could be due to impacts on health, economic costs, social interactions (Belkin and Kouchaki, 2017);(Osberghaus and Kühling, 2016), or reduced quality or quantity of sleep (Fujii et al., 2015);(Obradovich et al., 2017);(Obradovich and Migliorini, 2018). Heat has also been associated with interpersonal and intergroup aggression, and increases in violent crime (Heilmann et al., 2021);(Mapou et al., 2017);(Tiihonen et al., 2017). For the most part, studies have measured daily response to average daily temperatures and are unable to predict whether the effect is cumulative in response to a sequence of unusually warm days. However, there is no evidence that adaptation occurs over time to eliminate the negative response to very warm temperatures (Moore et al., 2019). Some research has found a negative effect of extreme cold on wellbeing (Yoo et al., 2021); increasing winter temperatures associated with climate change could serve to compensate for the impact of increased summer temperatures. However, the effect of high temperatures is typically found to be stronger than the effect of low temperatures, and in some cases no detrimental impacts of cold weather are found (Almendra et al., 2019);(Mullins and White, 2019).

Climate change also threatens wellbeing defined in terms of capabilities, or the capacity to fulfil one's potential and fully participate in society. Heat can limit labour capacity, one study estimating that 45 billion hours of labour productivity were lost in 2018 compared to 2000 due to high temperatures (Watts et al., 2019). Both heat and air pollution also impair human capabilities through a negative effect on cognitive performance (Taylor et al., 2016b), and even impair skills acquisition, reducing the ability to learn (Park et al., 2021) and affecting marginalized groups more strongly (Park et al., 2020), although findings are inconsistent and depend in part on the nature of the task *(low confidence).*

Systematic reviews have found an association between higher ambient levels of fine airborne particles and cognitive impairment in the elderly, or behavioural problems (related to impulsivity and attention problems) in children (Power et al., 2016);(Yorifuji et al., 2017);(Younan et al., 2018) (Zhao et al., 2018b) (*medium confidence*). Malnutrition has also been associated with reduced educational achievement and long-term decrements in cognitive function (Acharya et al., 2019);(Asmare et al., 2018);(Na et al., 2020);(Kim et al., 2017);(Talhaoui et al., 2019).

7.2.6 Observed Impacts on Migration

Consistent with peer-reviewed scholarship and with the UNFCCC Cancun Adaptation Framework section 14(f) and the Paris Agreement, this Chapter assesses the impacts of climate change on four types of migration: 1) adaptive migration (i.e where migration is an outcome of individual or household choice); (2) involuntary displacement (i.e. where people have few or no options except to move); (3) organized relocation of populations from sites highly exposed to climatic hazards; and (4) immobility (i.e. an inability or unwillingness to move from areas of high exposure for cultural, economic or social reasons) (see Cross-Chapter Box MIGRATE).

A general theme across studies from all regions is that climate-related migration outcomes are diverse (high confidence) and may be manifest as decreases or increases in migration flows, and lead to changes in the timing or duration of migration, and to changes in migration source locations and destinations. Multi-country studies of climatic impacts on migration patterns in Africa have found that migration exhibits weak, inconsistent associations with variations in temperatures and precipitation, and that migration responses differ significantly between countries, and between rural and urban areas (Gray and Wise, 2016);(Mueller et al., 2020). Multidirectional findings such as these are also common in single-country studies from multiple regions (A.Call et al., 2017);(Nawrotzki et al., 2017);(Cattaneo et al., 2019);(Kaczan and Orgill-Meyer, 2020). The diversity of potential migration and displacement outcomes reflects (1) the variable nature of climate hazards in terms of their rate of onset, intensity, duration, spatial extent, and severity of damage caused to housing, infrastructure, and livelihoods; and (2) the wide range of social, economic, cultural, political and other non-climatic factors that influence exposure, vulnerability, adaptation options and the contexts in which migration decisions are made (Neumann and Hermans, 2015);(McLeman, 2017);(Barnett and McMichael, 2018);(Cattaneo et al., 2019);(Hoffmann et al., 2020) (*high confidence*).

Weather events and climate conditions can act as direct drivers of migration and displacement (e.g. destruction of homes by tropical cyclones) and as indirect drivers (e.g. rural income losses and/or food insecurity due to heat- or drought-related crop failures that in turn generate new population movements) (high confidence). Extreme storms, floods and wildfires are strongly associated with high levels of short- and long-term displacement, while droughts, extreme heat and precipitation anomalies are more likely to stimulate longer term changes in migration patterns (Kaczan and Orgill-Meyer, 2020);(Hoffmann et al., 2020). Longer term environmental changes attributable to anthropogenic climate change - such as higher average temperatures, desertification, land degradation, biodiversity loss and sea level rise - have had observed effects on migration and displacement in a limited number of locations in recent decades but are projected to have wider-scale impacts on future population patterns and migration, and are therefore assessed in section 7.3.2 (Projected Risks).

[START CROSS-CHAPTER BOX MIGRATE HERE]

Cross-Chapter Box MIGRATE: Climate-related Migration

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Key messages on migration in this report

Migration is a universal strategy that individuals and households undertake to improve wellbeing and livelihoods in response to economic uncertainty, political instability and environmental change (*high confidence*). Migration, displacement, and immobility that occur in response to climate hazards are assessed in general in Chapter 7, with specific sectoral and regional dimensions of climate-related migration assessed in sectoral and regional chapters 5 to 15 [Table Cross-Chapter Box MIGRATE.1] and involuntary immobility and displacement being identified as a representative key risk in Chapter 16 [16.2.3.8, 16.5.2.3.8]. Since AR5 there has been a considerable expansion in research on climate-migration linkages, with five key messages from the present assessment report warranting emphasis:

Climatic conditions, events and variability are important drivers of migration and displacement (high confidence) [Table Cross-Chapter Box MIGRATE.1], with migration responses to specific climate hazards being strongly influenced by economic, social, political and demographic processes (high agreement, robust evidence)[7.2.6, 8.2.1.3]. Migration is among a wider set of possible adaptation alternatives, and often emerges when other forms of adaptation are insufficient [5.5.1.1, 5.5.3.5, 7.2.6, 8.2.1.3, 9.7.2]. Involuntary displacement occurs when adaptation alternatives are exhausted or not viable, and reflects non-climatic factors that constrain adaptive capacity and create high levels of exposure and vulnerability (*high confidence*) [Cross-Chapter Box SLR in Chapter 3, 4.3.7, 7.2.6, Box 8.1, 10.3, Box 14.7]. There is strong evidence that climatic disruptions to agricultural and other rural livelihoods can generate migration (*high confidence*) [5.5.4, 8.2.1.3, 9.8.3, Box 9.8].

Specific climate events and conditions may cause migration to increase, decrease, or flow in new directions (high confidence), and the more agency migrants have (i.e. the degree of voluntarity and freedom of movement), the greater the potential benefits for sending and receiving areas (high agreement, medium evidence) [5.5.3.5, 7.2.6, 8.2.1.3, Box 12.2]. Conversely, displacement or low-agency migration is associated with poor outcomes in terms of health, wellbeing and socio-economic security for migrants, and returns fewer benefits to sending or receiving communities (*high agreement, medium evidence*) [4.3.7, 4.5.7, Box 8.1, 9.7.2, 10.3, Box 14.7].

Most climate-related migration and displacement observed currently takes place within countries (high confidence) [4.3.7, 4.5.7, 5.12.2, 7.2.6]. The climate hazards most commonly associated with displacement are tropical cyclones and flooding in most regions, with droughts being an important driver in Sub-Saharan Africa, parts of South Asia and South America (*high confidence*) [7.2.6.1, 9.7.2, 10.4.6.3, 11.4.1, 12.5.8.4, 13.8.1.3, 14.4.7.3]. Currently observed international migration associated with climatic hazards is considerably smaller, relative to internal migration, and is most often observed as flowing between states that are contiguous, have labour-migration agreements, and/or longstanding cultural ties (*high agreement, robust evidence*) [4.3.7, 4.5.7, 5.12.2, 7.2.6].

In many regions, the frequency and/or severity of floods, extreme storms, and droughts is projected to increase in coming decades, especially under high-emissions scenarios [AR6 WGI Ch12], raising future risk of displacement in the most exposed areas (high confidence) [7.3.2.1]. Additional impacts of climate change anticipated to generate future migration and displacement include mean sea level rise that increases flooding and saltwater contamination of soil and/or groundwater in low-lying coastal areas and small islands (*high confidence*) [7.3.2.1, Cross-Chapter Box SLR in Chapter 3], and more frequent extreme heat events that threaten the habitability of urban centres in the tropics and arid/semi-arid regions (*medium agreement, medium evidence*), although the links between heat and migration are less clear [7.3.2.1].

There is growing concern among researchers about the future prospects of immobile populations: groups and individuals that are unable or unwilling to move away from areas highly exposed to climatic hazards (high confidence) [4.6.9, 7.2.6.2, Box 8.1, Box 10.2]. Involuntarily immobile populations may be anticipated to require government interventions to continue living in exposed locations or to relocate elsewhere (*high agreement, medium evidence)* [Box 8.1]. Managed retreat and organized relocations of people from hazardous areas in recent years have proven to be politically and emotionally charged, socially disruptive and costly (*high confidence*) [7.4.5.4].

Climate-migration interactions and outcomes

Figure Cross-Chapter Box MIGRATE.1 presents a simplified framework for understanding how migration and displacement may emerge from the interactions of climatic and non-climatic factors, based on the risk framework introduced in Chapter 1, in which climatic risks are represented as emerging from interactions of hazard, exposure and vulnerability in a characteristic propeller-shaped diagram [1.3]. Voluntary migration can be used by households in particular locations for adapting to climate hazards, while less voluntary forms of migration and involuntary displacement emerge when other forms of adaptation (referred to in Figure Cross-Chapter Box MIGRATE.1 as *in situ* adaptation) are inadequate. The success of migration – expressed in Figure Cross-Chapter Box MIGRATE.1 as changes in future risks to the wellbeing of migrants, sending and destination communities — is heavily influenced by the political, legal, cultural and socio-economic conditions under which it occurs. Groups and individuals that are involuntary immobile may find that their exposure, vulnerability and risk increase over time. Table Cross-Chapter Box MIGRATE.1 summarizes the range of potential migration outcomes that may emerge from this dynamic, and indicates specific sections in sectoral and regional chapters of the report that describe examples of each.

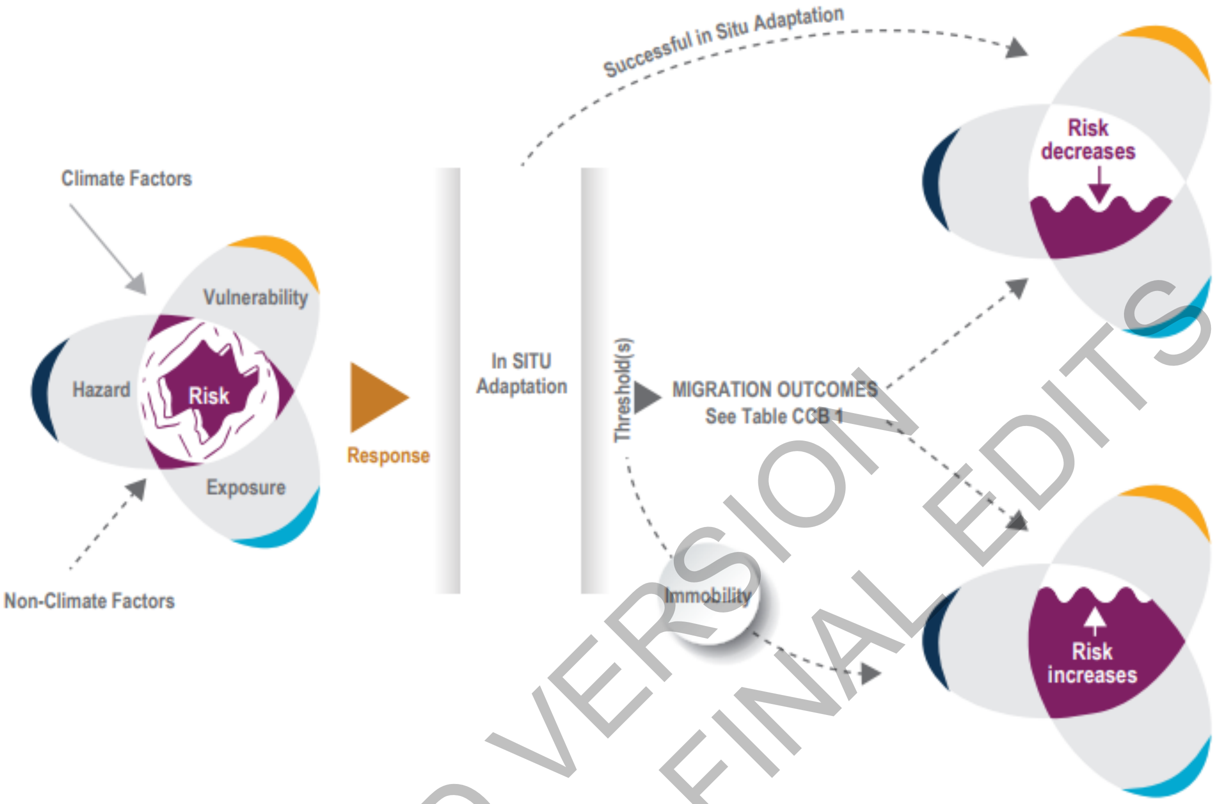

Figure Cross-Chapter Box MIGRATE.1: General interactions between climatic and non-climatic processes, adaptation, potential migration outcomes and implications for future risk. Adapted from (McLeman et al., 2021).

Table Cross-Chapter Box MIGRATE.1: Typology of climate-related migration and examples in sectoral and regional chapters of AR6

Type of climate-related migration	**Characteristics**	**Recent/current examples**	**Examples in literature**	**References in AR6**
Temporary and/or seasonal migration	Frequently used as a risk-reduction strategy by rural households in less-developed regions with highly seasonal precipitation. Includes transhumance	Pastoralists in sub-Saharan Africa; seasonal farm workers in South Asia; rural-urban labour migration in Central America	(Afifi et al., 2016), (Call et al., 2017);(Piguet et al., 2018);(Borderon et al., 2019);(Cattaneo et al., 2019);(Hoffmann et al., 2020);(Lopez-i-Gelats et al., 2015) ; (Lu et al., 2016)(detecting climate networks); (Kaczan and Orgill-Meyer, 2020)	Chapter 5.5.1.1; 5.5.3.5; Chapter 7.2.6; Chapter 8.2.1.3; Chapter 9.8.3; Chapter 13 Box 13.2
Indefinite or permanent migration	Less common than temporary or seasonal migration, particularly when the whole household permanently relocates.	Numerous examples in all regions	See reviews listed in cell above	Chapter 7.2.6; Chapter 8.2.1.3; Chapter 10 Box 10.2

Internal migration	Movements within state borders, most common form of climate-related migration	Numerous examples in all regions	See reviews in cells above	Chapter 4.3.7; Chapter 5.5.4; 5.10.1.1; Chapter 7.2.6; Chapter 9.7.2; 9.11-Box 9.8; Chapter 10.3.3, 10.2 10.4.6.3, Box 10.2; Chapter 11.4.1; Chapter 12.5.8.4; Chapter 13.8.1.3; Chapter 14.4.7.3; Chapter 15.3.4.6
International migration	Less common than internal migration; most often occurs between contiguous countries within the same region; often undertaken for purpose of earning wages to remit home	Cross-border migration within South and Southeast Asia, Sub-Saharan Africa	See reviews in cells above; also (Veronis et al., 2018);(McLeman, 2019);(Cattaneo and G., 2016);(Missirian and Schlenker, 2017);(Schutte et al., 2021)	Chapter 4.3.7; 4.5.7; Chapter 5.12.2; Chapter 7.2.6

Rural-urban or rural-rural	Typically internal, but may also flow between contiguous states; may be for temporary or indefinite periods; migration may be undertaken by an individual household member or the entire household; may be followed by remittances	Drought migration in Mexico, East Africa, South Asia	See reviews in cells above; also (Adger et al., 2015);(Gautier et al., 2016);(Nawrotzki et al., 2017);(Wiederkehr et al., 2018);(Robalino et al., 2015);(Borderon et al., 2019);(Murray-Tortarolo and Martnez, 2021)	Chapter 5.13.4; Chapter 7.2.6; Chapter 6.2.4.3; Chapter 8.2.1.3; Chapter 9.8.1.2; Chapter 12.5.8.4; Chapter 14.4.7.1
Displacement	Households are forced to leave homes for temporary or indefinite period; typically occurs as a result of extreme events and starts with seemingly temporary evacuation; risk is expected to rise in most regions due to sea level rise	Tropical cyclones in Caribbean, Southeast Asia, Bay of Bengal region;	(Islam and Shamsuddoha, 2017);(Desai et al., 2021); see annual reports of Internal Displacement Monitoring Centre for global statistics	Cross-Chapter Box SLR in Chapter 3; Chapter 4.3.7; 4.5.7; Cross-Chapter Box MOVING PLATE in Chapter 5; Chapter 7.2.6.1; Chapter 8 Box 8.1; Chapter 9.7.2; 9.9.2; Chapter 10.3; Chapter 14 Box 14.7; Chapter 15.3.4.6; CCP2.2.2

Planned/organized resettlement	Initiated in areas where settlements become permanently uninhabitable; requires assistance from governments/institutions. Government-sponsored sedentarisation of pastoral populations	Fiji; Carteret Islands, Papua New Guinea; US Gulf of Mexico coast and coastal Alaska	(Marino and Lazrus, 2015);(Hino et al., 2017);(McNamara et al., 2018);(McMichael and Katonivualiku, 2020);(Tadgell et al., 2017);(Arnall, 2014);(Wilmsen and Webber, 2015)	Chapter 4.6.9; Chapter 5.14.1; 5.14.2; Chapter 7.4.4.4; Chapter 10.4.6; Chapter 15.5.3; CCP 2.2.2; CCP 6.3.2;
Immobility	Adverse weather or climatic conditions warrant moving, but households are unable to relocate because of lack of resources, or choose to remain because of strong social, economic or cultural attachments to place	Examples in most regions	(Adams, 2016);(Zickgraf, 2018);(Nawrotzki and DeWaard, 2018);(Farbotko et al., 2020)	Chapter 4.6.9; Chapter 7.2.6.2; Chapter 8. Box 8.1; Chapter 10 Box 10.2

Policy implications

Future migration and displacement patterns in a changing climate will depend not only on the physical impacts of climate change, but also on future policies and planning at all scales of governance (high confidence) [4.6.9, 5.14.1&2, 7.3.2, 7.4.4, 8.2.1.3, Box 8.1, CCP 6.3.2]. Policy interventions can remove barriers to and expand the alternatives for safe, orderly and regular migration that allows vulnerable people to adapt to climate change (*high confidence*) [7.2.6]. With adequate policy support, migration in the context of climate change can result in synergies for both adaptation and development [5.12.2, 7.4.4, 8.2.1.3]. Migration governance at local, national and international levels will influence to a great extent the outcomes of climate-related migration, for the migrants themselves as well as for receiving and origin communities [5.13.4, 7.4.4, 8.2.1.3]. At the international level, a number of relevant policy initiatives and agreements have already been established and merit continued pursuit, including Global Compacts for Safe, Orderly and Regular Migration and for the protection of Refugees; the Warsaw International Mechanism of the UNFCCC; the Sustainable Development Goals; the Sendai Framework for Disaster Risk Reduction; and, the Platform on Disaster Displacement provide potential migration governance pathways [7.44]. Policy and planning decisions at regional, national and local scales that relate to housing, infrastructure, water provisioning, schools and healthcare are relevant for successful integration of migrants into receiving communities [5.5.4, 5.10.1.1, 5.12.2, 9.8.3]. Policies and practices on movements of people across international borders are also relevant to climate-related migration, with restrictions on movement having implications for the adaptive capacity of communities exposed to climate hazards [7.4.4.2, Box 8.1]. Perceptions of migrants and the framing of policy discussions in receiving communities and nations are important determinants of the future success of migration as an adaptive response to climate change [7.4.4.3] (*high agreement, medium evidence*).

Reducing the future risk of large-scale population displacements, including those requiring active humanitarian interventions and organized relocations of people, requires the international community to meet the requirements of the Paris Agreement and take further action to control future warming (high confidence) [Cross-Chapter Box SLR in Chapter 3, 7.3.1, Box 8.1]. Current emissions pathways lead to scenarios for the period between 2050 and 2100 in which hundreds of millions of people will be at risk of displacement due to rising sea levels, floods, tropical cyclones, droughts, extreme heat, wildfires and other hazards, with land degradation exacerbating these risks in many regions [7.3.2, IPCC Special report on Land 2019, Cross-Chapter Box SLR in Chapter 3]. At high levels of warming, tipping points may exist, particularly related to sea level rise, that, if crossed, would further increase the global population potentially at risk of displacement [IPCC 2021 Cross-Chapter Box 12.1]. Populations in low-income countries and small-island states that have historically had low greenhouse gas emissions are at particular risk of involuntary migration and displacement due to climate change, reinforcing the urgency for industrialized countries to continue lowering greenhouse gas emissions, to support adaptive capacity-building initiatives under the UNFCCC, and to meet objectives expressed in the Global Compacts regarding safe, orderly and regular migration, and the support and accommodation of displaced people [4.3.7, 4.5.7, 5.12.2, 7.4.5.5, 8.4.2, Box 8.1, Cross-Chapter Box SLR].

[END CROSS-CHAPTER BOX MIGRATE HERE]

The diversity of potential migration and displacement outcomes reflects the scale and physical impacts of specific climate hazard events and the wide range of social, economic, cultural, political and other non-climatic factors that influence exposure, vulnerability, adaptation options and the contexts in which migration decisions are made (high confidence). The diversity in drivers, contexts and outcomes make it difficult to offer simple generalizations about the relationship between climate change and migration. The characteristics of climatic drivers vary in terms of their rate of onset, intensity, duration, spatial extent, and severity of damage caused to housing, infrastructure, and livelihoods; the potential migration responses to these are further mediated by cultural, demographic, economic, political, social, and other non-climatic factors operating across multiple scales (Neumann and Hermans, 2015);(McLeman, 2017);(Barnett and McMichael, 2018);(Cattaneo et al., 2019);(Hoffmann et al., 2020).

Climate-related migration and displacement outcomes display high variability in terms of migrant success, often reflecting pre-existing socio-economic conditions and household wealth (high confidence). The decision to migrate or remain in place when confronted by climatic hazards is strongly influenced by the range and accessibility of alternative, *in situ* (i.e., non-migration) adaptation options that may be less costly or disruptive (Cattaneo et al., 2019). Migration decisions (whether climate-related or not) are typically made at the individual or household level, and are influenced by a household's perceptions of risk, social networks, wealth, age structure, health, and livelihood choices (Koubi et al., 2016b);(Gemenne and Blocher, 2017). Households with greater financial resources and higher levels of educational attainment have greater capacity to adapt *in situ* (Cattaneo and Massetti, 2019);(Ocello et al., 2015) but are also better able to migrate, and with greater agency once such a decision is made (Kubik and Maurel, 2016), (Koubi et al., 2016b);(Riosmena et al., 2018);(Adams and Kay, 2019). By contrast, poor households with limited physical, social and financial resources have less capacity to adapt *in situ* and are often limited in their migration options (Nawrotzki and DeWaard, 2018), (Suckall et al., 2017), (Zickgraf et al., 2016). Thus, when poorer households do migrate after an extreme climate event, it is often in reaction to lost income or livelihood due to an extreme climate event and occurs with low voluntarity (Mallick et al., 2017), (Bhatta et al., 2015) and may perpetuate or amplify migrants' socio-economic precarity and/or their exposure to environmental hazards (Natarajan et al., 2019); see also Chapter 8 section 8.3.1).

Climate-related migration originates most often in rural areas in low- and middle-income countries, with migrant destinations usually being other rural areas or to urban centres within their home countries (i.e., internal migration) (medium confidence). Rural livelihoods and incomes based on farming, livestock rearing and/or natural resource collection, are inherently sensitive to climate variability and change, creating greater potential for migration as a response (Bohra-Mishra et al., 2017);(Viswanathan and Kumar, 2015). Drought events have been associated with periods of higher rural to urban migration within Mexico (Chort and de la Rupelle, 2016);(Leyk et al., 2017);(Nawrotzki et al., 2017; Murray-Tortarolo and Martnez, 2021)and Senegal (Nawrotzki and Bakhtsiyarava, 2017). Extreme temperatures are associated with higher rates of temporary rural out-migration in South Africa and in Bangladesh (Mastrorillo et al., 2016);(Call et al., 2017). In rural Tanzania, weather-related shocks to crop production have been observed to increase the likelihood of migration, but typically only for households in the middle of community wealth distribution (Kubik and Maurel, 2016)Weather-related losses in rice production have been associated with small-percentage increases in internal migration in India (Viswanathan and Kumar, 2015) and the Philippines (Bohra-Mishra et al., 2017). In East Africa, temporary rural-urban labour migration does not show a strong response to climatic drivers (Mueller et al., 2020). There is a small literature on mobility as adaptation in urban populations, with a focus on resettlement of flood-prone informal settlements within cities (Kita, 2017);(Tadgell et al., 2017).

Most documented examples of international climate-related migration are intra-regional movements of people between countries with shared borders (high agreement, medium evidence). Systematic reviews find few documented examples of long-distance, inter-regional migration driven by climate events (Veronis et al., 2018);(Kaczan and Orgill-Meyer, 2020);(Hoffmann et al., 2020). One macro-economic analysis found a correlation between migrant flows from low- to high-income countries and adverse climatic events in the source country (Coniglio and Pesce, 2015), another found that high heat stimulates higher rates of international migration from middle-income countries but typically not from low-income countries (Cattaneo and G., 2016), while other studies found international climate-related migration originates primarily from the agriculture-dependent countries (Cai et al., 2016);(Nawrotzki and Bakhtsiyarava, 2017). Small-sample studies of migrants to Canada from Bangladesh, Haiti, and sub-Saharan Africa suggest environmental factors in the source country can be a primary or secondary motivation for some migrants within larger flows of economic and family-reunification migrants (Veronis and McLeman, 2014);(Mezdour et al., 2015);(McLeman et al., 2017). Research on links between climate hazards and international movements of refugees and/or asylum seekers shows differing results. One study found that asylum applications in Europe increase during climate fluctuations, due to interactions with conflict (Missirian and Schlenker, 2017), and another found links between heat, drought, conflict and asylum-seeking migration originating in the Middle East between 2011 and 2015 (Abel et al., 2019). Other studies have found that asylum claims in Europe correspond minimally with climatic hazards in source countries (Schutte et al., 2021), with choices in baseline data, timeframes for analysis and methodological approaches likely explaining the inconsistent results across studies (Boas et al., 2019). Media reports and other studies in recent years suggest that climate change has driven large numbers of migrants to the US from Central America and to Europe from the Middle East and Africa, but empirical studies were not identified for this assessment.

7.2.6.1 Relative Importance of Specific Climatic Drivers of Migration and Displacement

Reliable global estimates of voluntary climate-related migration within and between countries are not available due to a general absence of concerted efforts to date to collect data of this specific nature, with existing national and global datasets often lacking information on migration causation or motivation. Better data are available for involuntary displacements within countries for reasons associated with weather-related hazards. Data collected annually since 2008 on internal displacements attributed to extreme weather events by the Internal Displacement Monitoring Centre (IDMC) indicate that extreme storms and floods are the two most significant weather-related drivers of population displacements globally. Because of improvements in collection sources and methods since it first began reporting data in 2008, upward trends since that year in the total reported annual number of people displaced should be treated cautiously; it is reasonable to conclude that the average annual rate currently exceeds 20 million people globally, with considerable interannual variation due to the frequency and severity of extreme events in heavily populated areas. Regional distribution of displacement events has been consistent throughout the period of IDMC data collection (*high confidence*), with displacement events occurring most often in East, Southeast, and South Asia; sub-Saharan Africa; the US; and the Caribbean region (Figure 7.7). Relative to their absolute population size, Small Island states experience a disproportionate risk of climate-related population displacements (Desai et al., 2021) (*high confidence*).

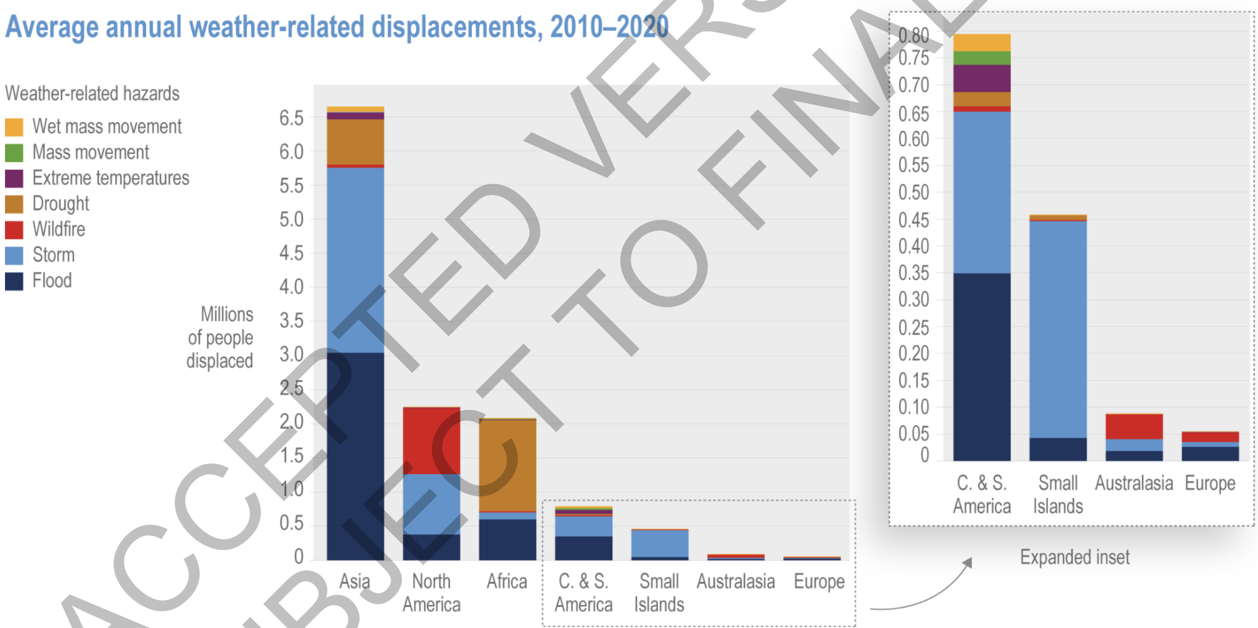

Figure 7.7: Average number of people displaced annually, 2010-2020 by selected weather-related events, by region and category of event. Source statistics provided by Internal Displacement Monitoring Centre.

Tropical cyclones and extreme storms are a particularly significant displacement risk in East and Southeast Asia, the Caribbean region, the Bay of Bengal region, and southeast Africa (IDMC 2020) (high confidence). The scale of immediate displacement from any given storm and potential for post-event migration depend heavily on the extent of damage to housing and livelihood assets, and the responsive capacity of governments and humanitarian relief agencies (Saha, 2016);(Islam et al., 2018);(Mahajan, 2020);(Spencer and Urquhart, 2018). In Bangladesh, the rural poor are most often displaced, with initial increases in short-term, labour-seeking migration followed by more permanent migration by some groups (Saha, 2016);(Islam and Hasan, 2016);(Islam and Shamsuddoha, 2017). Past hurricanes in the Caribbean basin have generated internal and interstate migration within the region, typically along pre-existing social networks, and to the US (Loebach, 2016);(Chort and de la Rupelle, 2016). In 2017, Hurricanes Irma and Maria caused widespread damage to infrastructure and health services, and a slow recovery response by authorities was followed by the migration of tens of thousands of Puerto Ricans to Florida and New York (Zorrilla, 2017);(Echenique and Melgar, 2018). In the US, coastal counties experience increased out-migration after hurricanes that flows along existing social networks (Hauer, 2017), with post-disaster reconstruction employment opportunities potentially attracting new labour migrants to affected areas (Ouattara and Strobl, 2014);(Curtis et al., 2015);(DeWaard et al., 2016);(Fussell et al., 2018).

Flood displacement can lead to increases or decreases in temporary or short-distance migration flows, depending on the local context (medium confidence). (Robalino et al., 2015);(Ocello et al., 2015);(Afifi et al., 2016);(Koubi et al., 2016b)Floods are a particularly important driver of displacement in river valleys and deltas in Asia and Africa, although large flood-related displacements have been recorded by IDMC in all regions. In Africa, populations exposed to low flood risks, as compared with other regions, are observed to have a greater vulnerability to displacement due to limited economic resources and adaptive capacity (Kakinuma et al., 2020). In areas where flooding is especially frequent, *in situ* adaptations may be more common, and out-migration may temporarily decline after a flood (Afifi et al., 2016), (Chen et al., 2017);(Call et al., 2017). Rates of indefinite or permanent migration tend not to change following riverine floods unless damage to homes and livelihood assets is especially severe and widespread, with household perceptions of short- and longer-term risks playing an important role (Koubi et al., 2016a).

Displacements due to droughts, extreme heat, and associated impacts on food and water security are most frequent in East Africa and, to a lesser extent, South Asia, and West and Southern Africa (Centre), 2020). Because droughts unfold progressively and typically do not cause permanent damage to housing or livelihood assets, there is greater opportunity for government and NGO interventions, and greater use of *in situ* adaptation options (Koubi et al., 2016b);(Koubi et al., 2016a);(Cattaneo et al., 2019). Drought-related population movements are most common in dryland rural areas of low-income countries, and occur after a threshold is crossed and *in situ* adaptation options are exhausted (Gautier et al., 2016);(Wiederkehr et al., 2018);(McLeman, 2017)). A time lag may ensue between the onset of drought and any observed population movements; one study of Mexican data found this lag to be up to 36 months after the event (Nawrotzki et al., 2017). The most common response to drought is an increase in short-distance, rural-urban migration (*medium confidence*), with examples being documented in Bangladesh, Ethiopia, Pakistan, sub-Saharan Africa, Latin America and Brazil (Neumann and Hermans, 2015);(Gautier et al., 2016);(Gautier et al., 2016);(Mastrorillo et al., 2016);(Baez et al., 2017);(Call et al., 2017);(Nawrotzki et al., 2017);(Jessoe et al., 2018)*;(Carrico and Donato, 2019)*;(Hermans and Garbe, 2019).

Few assessable studies were identified that examine links between wildfires and migration. Wildfire events are often associated with urgent evacuations and temporary relocations, which place significant stress on receiving communities (Spearing and M., 2020) but research in the US suggests fires have only a modest influence on future migration patterns in exposed areas (Winkler and D., 2021). More research, particularly in other regions, is needed.

7.2.6.2 Immobility and Resettlement in the Context of Climatic Risks

Immobility in the context of climatic risks can reflect vulnerability and lack of agency (i.e., inability to migrate), but can also be a deliberate choice (high confidence). Research since AR5 shows that immobility is best described as a continuum, from people who are financially or physically unable to move away from hazards (i.e. *involuntary immobility*) to people who choose not to move (i.e. voluntary immobility) because of strong attachments to place, culture, and people (Nawrotzki and DeWaard, 2018); (Adams, 2016);(Farbotko and McMichael, 2019);(Zickgraf, 2019);(Neef et al., 2018);(Suckall et al., 2017);(Ayeb-Karlsson et al., 2018);(Zickgraf, 2018);(Mallick and Schanze, 2020). Involuntary immobility is associated with individuals and households with low adaptive capacity and high exposure to hazard and can exacerbate inequality and future vulnerability to climate change (Sheller, 2018), including through impacts on health (Schwerdtle et al., 2018). Voluntary immobility represents an assertion of the importance of culture, livelihood and people to wellbeing, and is of particular relevance for Indigenous Peoples (Suliman et al., 2019).

Planned relocations by governments of settlements and populations exposed to climatic hazards are not presently commonplace, although the need is expected to grow in coming decades. Examples include relocations of coastal settlements exposed to storm and erosion hazards, as well as smaller numbers of cases of flood-prone settlements in river valleys, and these examples suggest that organized relocations are expensive, contentious, create multiple challenges for governments, and generate short- and longer term disruptions for the people involved (high agreement, medium evidence) (Ajibade et al., 2020);(Henrique and Tschakert, 2020);(Desai et al., 2021).

Examples of relocations of small Indigenous communities in coastal Alaska and villages in the Solomon Islands and Fiji suggest that relocated people can experience significant financial and emotional distress as cultural and spiritual bonds to place and livelihoods are disrupted (Albert et al., 2018);(Neef et al., 2018);(McMichael and Katonivualiku, 2020);(McMichael and Katonivualiku, 2020);(McMichael et al., 2021);(Piggott-McKellar et al., 2019);(Bertana, 2020). Voluntary relocation programs offered by US state governments in communities damaged by 2012's Hurricane Sandy have been subject to multiple studies, and these show participants' longer term economic outcomes, social connections and mental wellbeing can compare either favourably or unfavourably with non-participants for a range of reasons unrelated to the impacts of the hazard event itself (Bukvic and Owen, 2017);(Binder et al., 2019);(Koslov and Merdjanoff, 2021),

[START BOX 7.4 HERE]

Box 7.4: Gender Dimensions of Climate-related Migration

Migration decision-making and outcomes – in both general terms and in response to climatic risks – are strongly mediated by gender, social context, power dynamics, and human capital (Bhagat, 2017);(Singh and Basu, 2020);(Rao et al., 2019a);(Ravera et al., 2016). Women tend to suffer disproportionately from the negative impacts of extreme climate events for reasons ranging from caregiving responsibilities to lack of control over household resources to cultural norms for attire (i.e. saris in South Asia) (Belay et al., 2017);(Jost et al., 2016). In many cultures, migrants are most often able-bodied, young men (Call et al., 2017);(Heaney and Winter, 2016). Women wait longer to migrate because of higher social costs and risks (Evertsen and Van Der Geest, 2019) and barriers such as social structures, cultural practices, lack of education, and reproductive roles (Belay et al., 2017);(Afriyie et al., 2018);(Evertsen and Van Der Geest, 2019)).

Research critiques the tendency to portray women as victims of climate hazards, rather than recognizing differences between women and the potential for women to use their agency and informal networks to negotiate their situations (Eriksen et al., 2015);(Ngigi et al., 2017);(Pollard et al., 2015);(Rao et al., 2019b);(Ravera et al., 2016). Migration can change household composition and structure, which in turn affect the adaptive capacity and choices of those who do not move (Rao et al., 2019a);(Rao et al., 2019b);(Singh, 2019). When only male household members move, the remaining members of the now female-headed household must take on greater workloads and their vulnerability may increase (Goodrich et al., 2019);(Rao et al., 2019b);(Rigg and Salamanca, 2015), leading to increased workload and greater vulnerability for those left behind (Arora et al., 2017);(Bhagat, 2017);(Flat ø et al., 2017);(Lawson et al., 2019). It can, however, also increase women's economic freedom and decision-making capacity, enhance their agency (Djoudi et al., 2016);(Rao, 2019) and alter the gendered division of paid work and care and intra-household relations (Rigg et al., 2018);(Singh and Basu, 2020), a process that may reduce household vulnerability to extreme climate events (Banerjee et al., 2019b).

[END BOX 7.4 HERE]

7.2.6.3 Connections Between Climate-related Migration and Health

The number of assessable peer-reviewed studies that make connections between climate-related migration and health and wellbeing is small and merits further encouragement. The health outcomes of migrants generally, and of climate-migrants in particular, vary according to geographical context, country, and the particular circumstances of migration or immobility (Hunter and Simon, 2017; Hunter et al., 2021) (Hunter et al., 2021); (Schwerdtle et al., 2020). Such linkages are best described as "multidirectional", with studies suggesting that healthy individuals may be more likely to migrate internationally in search of economic opportunities than people in poorer health except during adverse climatic conditions, when migration rates may change across all groups; and, that migrants may have different long-term health outcomes than people born in destination areas, potentially displaying a range of positive and negative health outcomes compared to non-migrants (Kennedy et al., 2015);(Dodd et al., 2017); (Hunter and Simon, 2017);(Riosmena et al., 2017). Refugees and other involuntary migrants often experience higher exposure to disease and malnutrition, adverse indirect health effects of changes in diet or activity, and increased rates of mental health concerns attributable to sense of loss or to fear (Schwerdtle et al., 2018);(Torres and Casey, 2017) as well as due to interruption of health care, occupational injuries, sleep deprivation, non-hygienic lodgings and insufficient sanitary facilities, heightened exposure to vector- and water-borne diseases, vulnerability to psychosocial, sexual, and reproductive issues, behavioural disorders, substance abuse and violence (Farhat et al., 2018);(Wickramage et al., 2018). Linkages between climate migration and the spread of infectious disease are bidirectional; migrants may be exposed to diseases at the destination to which they have lower immunity than the host community; in other cases, migrants could introduce diseases to the receiving community (McMichael, 2015). Thus, receiving areas may have to pay greater attention to building migrant sensitive health systems and services (Hunter and Simon, 2017). Further, the risk of migration leading to disease transmission is exacerbated by weak governance and lack of policy to support public health measures and access to medicines (Pottie et al., 2015).

7.2.7 Observed Impacts of Climate on Conflict

7.2.7.1 Introduction

In AR5, conflict was addressed in Chapter 12 on Human Security. The chapter concluded that some of the factors that increase the risk of violent conflict within states are sensitive to climate change (medium evidence, medium agreement), people living in places affected by violent conflict are particularly vulnerable to climate change (medium evidence, high agreement) and that climate change will lead to new challenges to states and will increasingly shape both conditions of security and national security policies (medium evidence, medium agreement). The evidence since AR5 has strengthened the evidence for these findings and allowed statements to be made on direct associations between increased risk of conflict and climate change. AR5 characterised the major debate within the field: authors supporting an association between climate anomalies and conflict that can be extrapolated into the future (e.g. (Hsiang et al., 2013);(Hsiang and Marshall, 2014);(Burke et al., 2015a) and authors that argue that these associations are not so universal, breaking down when contextual, scale and political factors are introduced (e.g. (Buhaug et al., 2014);{Buhaug, 2016, Climate Change and Conflict: Taking Stock.

Consistent with AR5 findings, there continues to be little observed evidence that climatic variability or change cause violent inter-state conflict. In intra-state settings, climate change has been associated both with the onset of conflict, particularly in the form of civil unrest or riots in urban settings (high agreement, medium evidence). {Ide, 2020, Multi-method evidence for when and how climate-related disasters contribute to armed conflict risk} as well as with changes in the duration and severity of existing conflicts (Koubi, 2019) Climate change is conceptualised as one of many factors that interact to raise tensions (Boas and Rothe, 2016) through diverse causal mechanisms (Mach et al., 2019);(Ide et al., 2020) and as part of the peace-vulnerability and development nexus (Barnett 2019)(Abrahams, 2020);(Buhaug and von Uexkull, 2021). New areas of literature assessed in this report include the security implications of responses to climate change, and the gendered dynamics of conflict and exposure to violence under climate change, and civil unrest in urban settings. The impact of violent conflict on vulnerability is not addressed in this chapter, but does arise in other chapters [8.3.2.3; 17.2.2.2]. Other chapters address non-violent conflict over changing availability and distribution of resources, for example, competing land uses and fish stocks shifting to different territories [5.8.2.3; 5.8.3, 5.9.3, 5.13; 9.8.1.1; 9.8.5.1]. A commonly used definition of armed conflict is conflicts involving greater than 25 battle-related deaths in a year; this number represents the Uppsala Conflict Data Program threshold for inclusion in their database, a core resource in this field.

Climatic conditions have affected armed conflict within countries, but their influence has been small compared to socio-economic, political and cultural factors (Mach et al., 2019) (high agreement, medium evidence). Inter-group inequality, and consequent relative deprivation can lead to conflict, and the negative impacts of climate change lower the opportunity cost of involvement in conflict (Buhaug et al., 2020);(Vestby, 2019). Potential pathways linking climate and conflict include direct impacts on physiology from heat, or resource scarcity; indirect impacts of climatic variability on economic output, agricultural incomes, higher food prices, increasing migration flows; and the unintended effects of climate mitigation and adaptation policies (Koubi, 2019);(Busby, 2018);(Sawas et al., 2018).Relative deprivation, political exclusion and ethnic fractionalisation and ethnic grievances (Schleussner et al., 2016);(Theisen, 2017) are other key variables. Research shows that factors such as land tenure and competing land uses interacting with market-driven pressures and existing ethnic divisions produce conflict over land resources, rather than a scarcity of natural resources caused by climate impacts such as drought. (*high agreement, medium evidence*) (Theisen, 2017); (Balestri and Maggioni, 2017);(Kuusaana and Bukari, 2015);[also Box 8.3]

7.2.7.2 Impacts of Climate Change and Violent Conflict

Positive temperature anomalies, and average increases in temperature over time, have been associated with collective violent conflict in certain settings (medium agreement, low evidence). Helman and Zaitchik (2020) find statistical associations between temperature and violent conflict in Africa and the Middle East that are stronger in warmer places and identify seasonal temperature effects on violence. However, they are unable to detect the impact of regional temperature increases on violence. For Africa, Van Weezel (2019) found associations between average increases in temperature and conflict risk. Caruso et al (2016) found an association between rises in minimum temperature and violence; through the impact of temperature on rice yields [also Box 9.4]. However, the associations between temperature and violence are weak compared to those with political and social factors (e.g. (Owain and Maslin, 2018) and research focuses on areas where conflict is already present and, as such, is sensitive to bias (Adams et al., 2018). There is a body of literature that finds statistical associations between temperature anomalies and interpersonal violence, crime and aggression in the Global North, predominantly in the United States (e.g. (Ranson, 2014);(Mares and Moffett, 2019);(Tiihonen et al., 2017);(Parks et al., 2020)[14.4.8]. However, authors have cautioned against extrapolating seasonal associations into long-term trends, and against focusing on individual crimes rather than wider social injustices associated with climate change and its impacts (Lynch et al., 2020).

Variation in availability of water has been associated with international political tension and intra-national collective violence (low agreement, medium evidence). Drought conditions have been associated with violence due to impacts on income from agriculture and water and food security, with studies focusing predominantly on sub-Saharan Africa and the Middle East (Ide and Frohlich, 2015);(De Juan, 2015);(Von Uexkull et al., 2016);(Waha et al., 2017);(Abbott et al., 2017);(D'Odorico et al., 2018). A small set of published studies has argued inconclusively over the role of drought in causing the Syrian civil war (Gleick, 2014);(Kelley et al., 2015);(Selby et al., 2017) [also 16.2.3.9]. In general, research stresses the underlying economic, social and political drivers of conflict. For example, research on conflict in the Lake Chad region has demonstrated that the lake drying was only one of many factors including lack of development and infrastructure (Okpara et al., 2016);(Nagarajan et al., 2018);(Tayimlong, 2020). Fewer studies examine the relationship between flooding (excess water) and violence and often rely on migration as the causal factor (see below). However, some studies have shown an association between flooding and political unrest (Ide et al., 2020). [also 4.3.6, 12.5.3, Box 9.4].

Extreme weather events can be associated with increased conflict risk (low agreement, medium evidence). There is the potential for extreme weather events and disasters to cause political instability and increase the risk of violent conflict, although not conclusively (Brzoska, 2018). Post-disaster settings can be used to intensify state repression (Wood and Wright, 2016) and to alter insurgent groups' behaviour (Walch, 2018). Different stakeholders use disasters to establish new narratives and alter public opinion (Venugopal and Yasir, 2017). However, some research has demonstrated how post-disaster activities have had positive impacts on the social contract between people and the state, reducing the risk of conflict by strengthening relations between government and citizens and strengthened citizenship of marginalized communities (Siddiqi, 2018; (Pelling and Dill, 2010; Siddiqi, 2019). However, post-disaster and disaster-risk related activities in of themselves, have limited capacity to support diplomatic efforts to build peace (Kelman et al., 2018)

7.2.7.3 Causal Pathways Between Climate Change Impacts and Violent Conflict

Increases in food price due to reduced agricultural production and global food price shocks are associated with conflict risk and represent a key pathway linking climate variability and conflict (medium confidence).

Rises in food prices are associated with civil unrest in urban areas among populations unable to afford or produce their own food, and in rural populations due to changes in availability of agricultural employment with shifting commodity prices (Martin-Shields and Stojetz, 2019). Under such conditions, locally specific grievances, hunger, and social inequalities can initiate or exacerbate conflicts. Food price volatility in general is not associated with violence, but sudden food price hikes have been linked to civil unrest in some circumstances (Bellemare, 2015);(McGuirk and Burke, 2020);(Winne and Peersman, 2019). In urban settings in Kenya, Koren et al (2021) found an association between food and water insecurity that is mutually reinforcing and associated with social unrest (although insecurity in either one on its own was not). Analysing global food riots 2007-2008, and 2011, Heslin (2021) stresses the role of local politics and pre-existing grievances in determining whether people mobilise around food insecurity [also Chapter 5].

Climate-related internal migration has been associated with experience of violence by migrants, the prolongation of conflicts in migrant receiving areas and civil unrest in urban areas *(medium agreement, low evidence)*. Research points to the potential for conflict to serve as an intervening factor between climate and migration. However, the nature of the relationship is diverse and context specific. For example, displaced people and migrants may be associated with heightened social tensions in receiving areas through mechanisms such as ecological degradation, reduced access to services, and a disturbed demographic balance in the host area (Rüegger and Bohnet, 2020). Ghimire et al (2015) observed that an influx of flood-displaced people prolonged conflict by causing a lack of access to services for some of the host population and feelings of grievance. Migration from drought-stricken areas to local urban centres has been used to suggest a climate trigger for the Syrian conflict (e.g.(Ash and Obradovich, 2020)). However, this link has been strongly contested by research that contextualizes the drought in wider political economic approaches and existing migration patterns (De Châtel, 2014);(Fröhlich, 2016);(Selby, 2019) [16.2.3.9].

There is some evidence of an association between climate-related rural-to-urban migration and the risk of civil unrest (medium agreement, low evidence). Petrova (2021) found that while migration in general was associated with increased protests in urban receiving areas, the relationship did not hold for hazard-related migration. In other settings, the association of civil unrest with in-migration was found to depend on the political alignment of the host state with the capital (Bhavnani and Lacina, 2015), previous experience of extreme climate hazards (Koubi et al., 2021) and previous experience of violence in migrants (Linke et al., 2018). Climate-related migrants have reported higher levels of perception, and experience, of violence in their destination (Linke et al., 2018);(Koubi et al., 2018). There has been no association established between international migration and conflict. The literature highlights how unjust racial logics generate spurious links between climate migration and security (Fröhlich, 2016);(Telford, 2018).

7.2.7.4 Gendered Dimensions of Climate-related Conflict

Structural inequalities play out at an individual level to create gendered experiences of violence (high agreement, medium evidence). Violent conflict is experienced differently by men and women because of gender norms that already exist in society and shape vulnerabilities. For example, conflict deepens gendered vulnerabilities to climate change related to unequal access to land and livelihood opportunities (Chandra et al., 2017). Motivations for intergroup violence may be influenced by constructions of masculinity, for example the responsibility to secure their family's survival, or pay dowries (Myrttinen et al., 2017), and gendered roles may incentivize young men to protest or to join non-state armed groups during periods of adverse climate (Myrttinen et al., 2015), (Myrttinen et al., 2017);(Anwar et al., 2019);(Hendrix and Haggard, 2015);(Koren and Bagozzi, 2017). Research has found a positive correlation between crop failures and suicides by male farmers who could not adapt their livelihoods to rising temperatures (Bryant & Garnham 2015; (Kennedy and King, 2014); (Carleton, 2017).

Extreme weather and climate impacts are associated with increased violence against women, girls and vulnerable groups (high agreement, medium evidence). During and after extreme weather events, women, girls and LGBTQI people are at increased risk of domestic violence, harassment, sexual violence and trafficking (Le Masson et al., 2019);(Nguyen, 2019);(Myrttinen et al., 2015);(Chindarkar, 2012). For example, early marriage is used as a coping strategy for managing the effects of extreme weather events (Ahmed et al., 2019)and women are exposed to increase risk of harassment and sexual assault as scarcity and gender-based roles cause them to walk longer distances to fetch water and fuel (Le Masson et al., 2019). Within the household, violence may arise from changing gender norms as men migrate to find work in post-disaster settings may lead to violent backlash or heightened tensions (Stork et al., 2015) and men's use of negative coping mechanisms, such as alcoholism, when unable to meet norms of providing for the household (Anwar et al., 2019);(Stork et al., 2015). Rates of intimate partner violence have been found to increase with higher temperatures (Sanz-Barbero et al., 2018).

7.2.7.5 Observed impacts on non-violent conflict and geopolitics

Climate adaptation and mitigation projects implemented without taking local interests and dynamics into account have the potential to cause conflict (high agreement, medium evidence). Reforestation or forest management programs driven by reducing emissions through deforestation, land zoning and managed retreat due to sea level rise have been identified as having the potential to cause friction and conflict within and between groups and communities (de la Vega-Leinert et al., 2018);(Froese and Schilling, 2019). Conflict may arise when there is resistance to a proposed project, where interventions favour one group over another, projects undermine livelihoods or displace populations (e.g. (Nightingale, 2017);(Sovacool et al., 2015);(Sovacool, 2018) Corbera, 2017; Hunsberger 2018) [also 4.6.8, 5.13.4, 14.4.7.3]. In addition to conflict generated by the poor implementation of land-based climate mitigation and adaptation projects, Gilmore and Buhaug (2021) highlight the links between climate policy and conflict through potential effects on economic growth and unequal distribution of economic burdens, and fossil fuel markets. There is a small literature that draws attention to potential security of nuclear proliferation, if nuclear is increasingly employed as a low-carbon energy source (e.g. (Parthemore et al., 2018);(Bunn, 2019).

Economic and social changes due to changes in sea ice extent in the Arctic are anticipated to be managed as part of existing governance structures (high agreement, medium evidence). The opening-up of the Arctic and associated geopolitical manoeuvring for access to shipping routes and sub-sea hydrocarbons is often highlighted as a potential source of climate conflict (e.g. Koivurova, 2009; (Åtland, 2013);(Tamnes and Offerdal, 2014). Research assessed in AR5 focused on the potential for resource wars and Arctic land grabs. However, research since AR5 is less sensationalist in its approach to Arctic security, focusing instead on the practicalities of polycentric Arctic governance under climate change, the economic impacts of climate change, protecting the human security of Arctic populations whose autonomy is at risk (Heininen and Exner-Pirot, 2020), understanding how different regions (e.g. EU) are positioning themselves more prominently in the Arctic space (Raspotnik & Østhagen, 2019), and Arctic Indigenous People's understanding of security (Hossain, 2016) [also Chapter 3, Chapter 14, CCP6. IPCC SROCC]

7.3 Projected Future Risks under Climate Change

7.3.1 Projected Future Risks for Health and Wellbeing

7.3.1.1 Global Impacts

Climate change is expected to significantly increase the health risks resulting from a range of climate-sensitive diseases and conditions, with the scale of impacts depending on emissions and adaptation pathways in coming decades (very high confidence). Sub-sections 7.3.1.2 to 7.3.1.11 assess available studies on future projections for risks associated with specific climate sensitive diseases and conditions previously described in Section 7.2.1. In the case of diabetes, cancer, injuries, mosquito-borne diseases other than dengue and malaria, rodent borne diseases, and most mental illnesses, insufficient literature was found to allow for assessment. Adaptation pathways and options for managing such risks are detailed in Section 7.4.

Even in the absence of further warming beyond current levels, the proportion of the overall global deaths caused by climate sensitive diseases and conditions would increase marginally by mid-century (high confidence). Studies that incorporate climate forcing project an additional 250,000 deaths per year by mid-century due to climate-sensitive diseases and conditions, and under high-emissions scenarios, over 9 million additional deaths per year by 2100 (*high confidence*). Two global projections of climate change health impacts were conducted since AR5. The first focused on cause-specific mortality for eight exposures for 2030 and 2050 for a mid-range emissions scenario (A1b) and three scenarios of economic growth (WHO, 2014). The study estimated that the climate change projected to occur by 2050 (compared to 1961-1990) could result in an excess of approximately 250,000 deaths per year, dominated by increases in deaths due to heat (94,000, mainly Asia and high-income countries), childhood undernutrition (85,000, mainly Africa, also Asia), malaria (33,000, mainly Africa), and diarrheal disease (33,000, mainly Africa and Asia). Overall, more than half of this excess mortality is projected for Africa. Near term projections (2030) are predominantly for childhood undernutrition (95 200 out of 241 000 total excess deaths) (Figure 7.8). The second study focused on all-cause mortality associated with warming under both a high emissions scenario (RCP 8.5) and a low emissions scenario (RCP4.5). Under the high emissions scenario, and accounting for population growth, economic development, and adaptation, an increase of approximately 85 excess deaths per 100,000 population per year by the end of the century was projected, for a total annual excess of 9,250,000 per year based on United Nations Department of Economic and Social Affairs population projections. The authors estimate that removing adaptation and projected economic growth increased the estimate by a factor of 2.6.

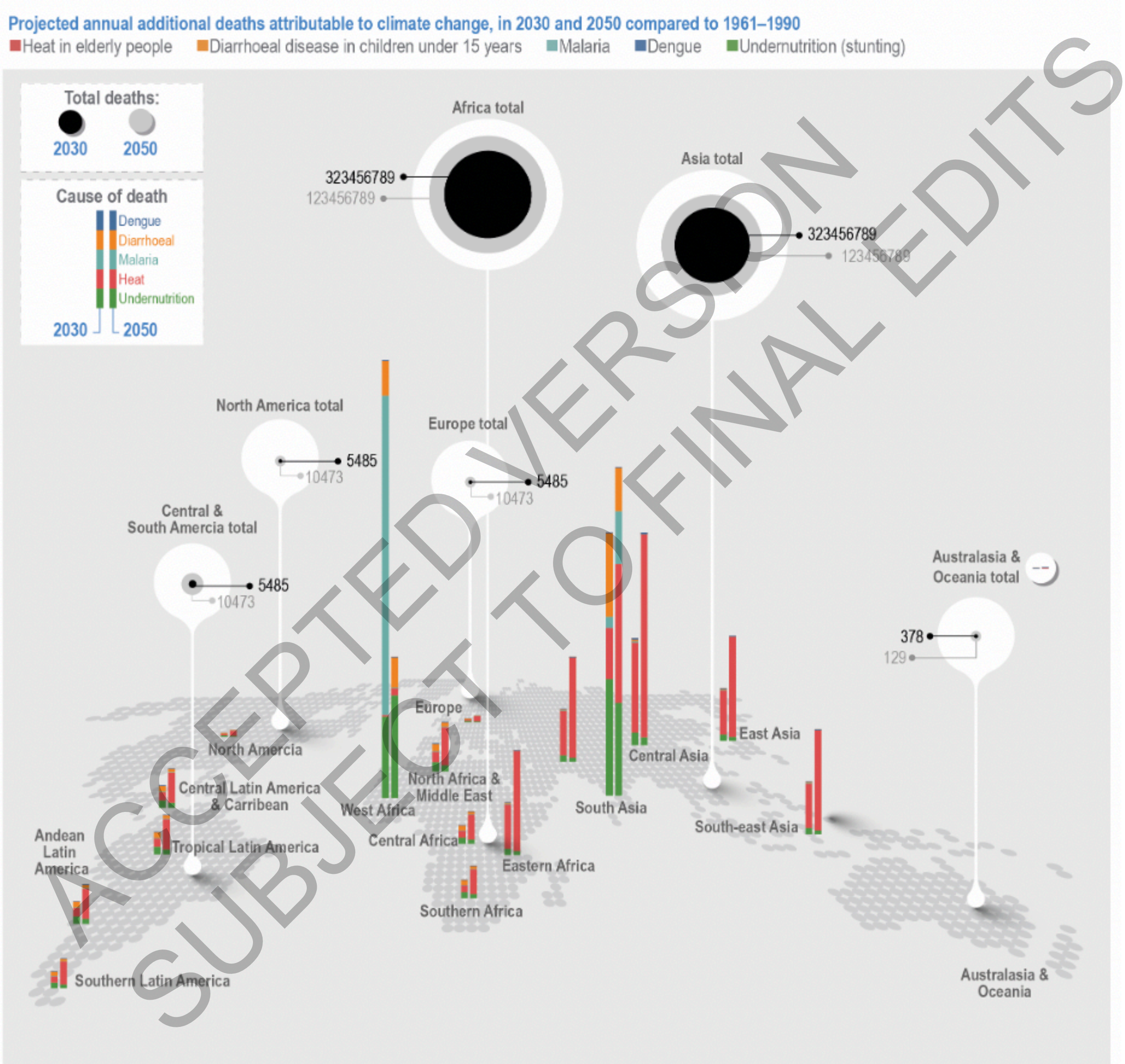

Figure 7.8: Projected additional annual deaths attributable to climate change, in 2030 and 2050 compared to 1961-1990 (WHO, 2014)

Temperature increases are projected to exceed critical risk thresholds for six key climate-sensitive health outcomes, highlighting the criticality of building adaptive capacity in health systems and in other sectors that influence health and well-being (high confidence). Recently reported research illustrates the temperature thresholds at which the following health risks change under three SSP-based adaptation scenarios: heat-related morbidity and mortality; ozone-related mortality; malaria incidence rates; incidence rates of Dengue and other diseases spread by *Aedes sp*. mosquitos; Lyme disease; and West Nile fever (Ebi et al., 2021a). As shown in Figure 7.9, adaptation under SSP1, SSP2, and SSP3 significantly alters the warming thresholds at which risks accelerate, with SSP1, an adaptation scenario that emphasizes international cooperation toward achieving sustainable development, having the greatest potential to avoid significant increases in risks under all but the highest levels of warming. SSP2 describes a world with moderate challenges to adaptation and mitigation. SSP3 describes a world with high challenges to adaptation and mitigation. In the figure, transitions are based on the peer-reviewed literature projecting risks for each of the health outcomes. Projections for time slices were changed to temperature increase above pre-industrial based on the climate models and scenarios used in the projections. The black dots are levels of confidence, from very high (four dots) to low (one dot).

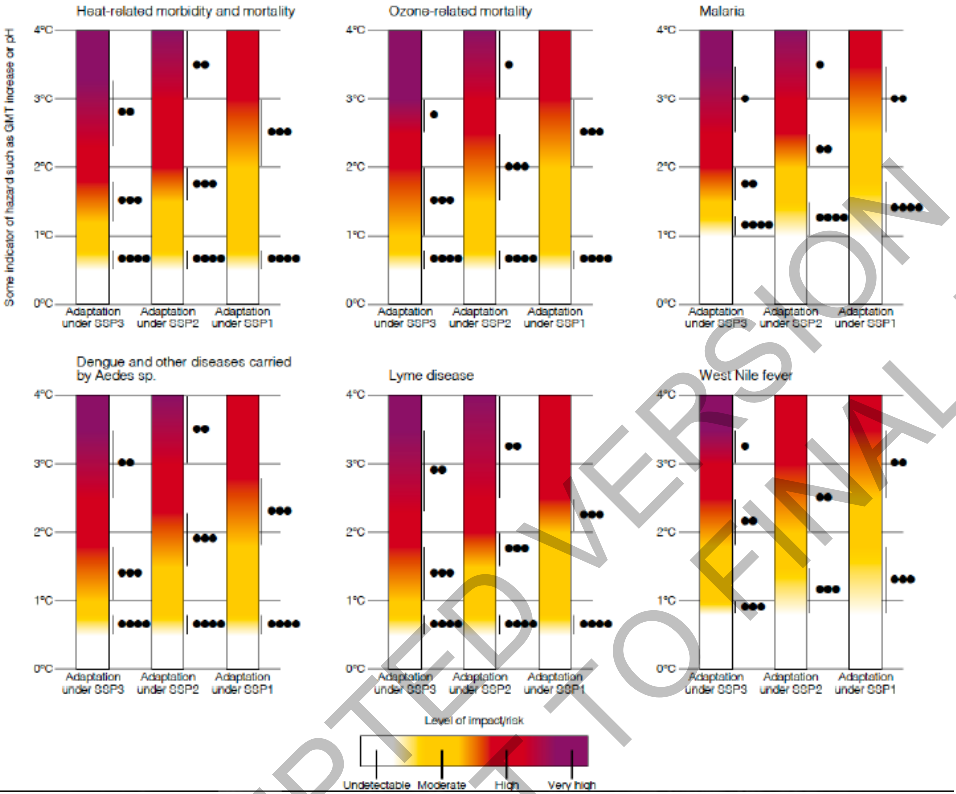

Figure 7.9: Change in risks for six climate-sensitive health outcomes by increases in temperature above pre-industrial levels, under adaptation scenarios (Ebi et al., 2021a)

7.3.1.2 Projected Changes in Heat- and Cold-related Exposure and Related Outcomes

This section considers the broad impacts of projected changes in heat- and cold-related exposure and related outcomes including mortality and work productivity. Several of the most common heat and cold-related specific health outcomes (e.g., cardiovascular disease) are assessed individually in later sections of this chapter.

Population heat exposure will increase under climate change (very high confidence). Since AR5 there has been considerable progress with quantifying the future human exposure to extreme heat (Schwingshackl et al., 2021), especially as determined by different combinations of Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP) (Chambers, 2020);(Cheng et al., 2020);(Jones et al., 2018);(Liu et al., 2017);(Ma and Yuan, 2021);(Russo et al., 2019). For example, Table 7.1 shows projections of population exposure to heatwaves, as expressed by the number of person days, for the period 2061- 2080 aggregated by geographical region and SSP/RCP. At the global level, projected future exposure increases from approximately 15-million person-days for the current period to 535 billion person-days for the high population growth under the high greenhouse gas SSP3-RCP8.5 scenario, while for the low population growth/high urbanization and business as usual SSP5-RCP4.5 scenario, the exposure is substantially lower at 170 billion person-days. Spatial variations in future heatwave frequency and population growth play out in the form of significant geographical contrasts in exposure with the largest increases projected for low latitude regions such as India and significant portions of Sub-Saharan Africa where increases in heatwave frequency and population are expected. Over East Asia and especially eastern China, exposures are projected to rise, with the effect of increases in heatwave frequency exceeding the countering effect of projected reductions in population, especially in non-urban areas. Further, for North America and Europe, where rural depopulation is projected, the predominant driver of increases in exposure is urban growth (Jones et al., 2018).

Table 7.1: Projected exposure in millions of person days by region under different RCP/SSP combinations {Supplementary material in: Jones, B., Tebaldi, C., O'Neill, B.C., Olsen K, Gao, J.. (2018) Avoiding population exposure to heat-related extremes: demographic change vs climate change. Climatic Change 146, 423–437 (2018). https://doi.org/10.1007/s10584-017-2133-7

Region	**Exposure in Millions of Person Days**				
	Current	RCP4.5/SSP3	RCP4.5/SSP5	RCP8.5/SSP3	RCP8.5/SSP5
Global	14,811	244,807	168,488	534,848	374,269
USA	375	4,769	8,671	10,802	19,646
North America	376	4,821	8,778	10,990	20,153
Europe	191	2,967	3,775	7,326	9,969
Latin America & Caribbean	803	17,287	10,856	45,612	28,435
North Africa & Middle East					
Subsaharan Africa	1,335	34,721	23,160	65,072	43,648
Russia & Central Asia	1,427	67,442	41,339	158,290	96,054
South Asia	272	3,074	1,951	6,554	4,360
East Asia	7,194	84,044	53,655	146,709	94,288
Southeast Asia	977	12,176	10,855	35,381	31,918
Oceania	711	12, 452	9,146	60,909	47,141
	37	247	492	822	1,158

Comparisons of heatwave exposure for 1.5ºC and 2.0ºC warming for different SSPs indicate strong geographical contrasts in potential heatwave risk (high confidence). One global level assessment for a 1.5°C warming projects that low-human development index countries will experience exposure levels equal to or greater than the exposure levels for very high-human-development index countries under a 2°C warming {Russo, 2019, Half a degree and rapid socioeconomic development matter for heatwave risk}. The same assessment also finds that holding global warming below 1.5°C, in tandem with achieving sustainable socioeconomic development, (e.g., SSP1 as opposed to SSP4), yields reduced levels of heatwave exposure, especially for low-human development index countries, particularly across sub-Saharan Africa (Russo et al., 2019). Similar findings were apparent in other global level assessments, such that global exposure to extreme heat increases almost 30 times under a RCP8.5/SSP3 combination, with the average exposure for Africa 118 times greater than historical levels, in stark contrast to the four-fold increase projected for Europe. Compared to a RCP8.5/SSP3 scenario, exposure was reduced by 65% and 85% under RCP4.5/SSP2 and RCP2.6/SSP1 scenarios, respectively (Liu et al., 2017).

Regional level assessments of changes in population heat exposure for Africa, Europe, the US, China and India corroborate the general findings at the global level – the impact of warming is amplified under divergent regional development pathways (e.g., SSP4 - inequality) compared to those fostering sustainable development (e.g., SSP1 - sustainability) (high confidence). (Rohat et al., 2019a);(Weber et al., 2020), (Broadbent et al., 2020);(Dahl et al., 2019);(Harrington and Otto, 2018);(Rohat et al., 2019b);(Vahmani et al., 2019);(Huang and et al., 2018);(Zhang et al., 2020a);(Liu et al., 2017). For some regions, such as Europe, changes in exposure are projected to be largely a consequence of climate change, while for others, such as Africa and to a lesser extent Asia, Oceania, North and South America, the interactive effects of demographic and climate change are projected to be important (Jones et al., 2018);(Liu et al., 2017);(Russo et al., 2016);(Ma and Yuan, 2021) (*medium confidence*).

Compared to research that estimates the temperature only impacts of climate change on heat-related mortality (see below), the number of studies that explicitly model mortality responses considering various combinations of Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP) is small and mostly restricted to the country or regional level. These studies point to increases in heat-related mortality especially amongst the elderly across a range of SSPs with the greatest increases under SSP5 and RCP8.5 (Rail et al., 2019);(Yang et al., 2021).

Estimates of heat-related mortality based solely on changes in temperature point to elevated levels of global and regional level mortality compared to the present with the magnitude of this increasing from RCP4.5 through to RCP8.5 (high confidence). (Ahmadalipour and Moradkhani, 2018);(Cheng et al., 2019);(Kendrovski et al., 2017);(Lee et al., 2020);(Limaye et al., 2018);(Morefield et al., 2018). Further support comes from the projection that heat-related health impacts for a 2°C increase in global temperatures will be greater than those for a 1.5°C warming (*very high confidence*) (Dosio et al., 2018);(Mitchell et al., 2018);(King and Karoly, 2017);(Vicedo-Cabrera et al., 2018a).

Estimates of future mortality that incorporate adaptation, using a variety of temperature adjustment methods, indicate increases in heat-related mortality under global warming, albeit at lower levels than the case of no adaptation (high confidence). (Anderson et al., 2018);(Gosling et al., 2017);(Guo et al., 2018);(Honda and Onozuka, 2020);(Vicedo-Cabrera et al., 2018b);(Wang et al., 2018b). Whether adaptation is considered or not, the consensus is Central and South America, Southern Europe, Southern and Southeast Asia and Africa will be the most affected by climate change related increases in heat-related mortality (*high confidence*). Similarly, projections of the impacts of future heat on occupational health, worker productivity and workability point to these regions as problematic under climate change (*high confidence*) (Andrews et al., 2018);(de Lima et al., 2021);(Dillender, 2021);(Kjellstrom et al., 2018);(Orlov et al., 2020);(Rao et al., 2020);(Tigchelaar et al., 2020), especially for occupations with high exposure to heat, such as agriculture and construction. This accords with the findings from independent projections of population heat-exposure as outlined above (*high confidence*).

The effect of climate change on productivity is projected to reduce GDP at a range of geographical scales (high confidence). (Borg et al., 2021);(Oppermann et al., 2021);(Orlov et al., 2020); For example, measuring economic costs using occupational health and safety recommendations, it was estimated that RCP8.5 would result in a 2.4% reduction in global GDP, compared to a 0.5% reduction under RCP2.6 (Orlov et al., 2020). For the USA, it was estimated that the total hours of labour supplied declined ~0.11 (±0.004) % per °C increase in global mean surface temperature for low-risk workers and 0.53 (±0.01) % per °C increase for high-risk workers exposed to outdoor temperatures (Hsiang et al., 2017). Further, a systematic review of the literature indicates that extreme heat exacts a substantial economic burden on health systems, which bears implications for future heat-attributable health care costs (Wondmagegn et al., 2019).

Since AR5 there has been an increase in the understanding of the extent to which a warming world is likely to affect cold/winter related health impacts. Future increases in heat-related deaths are expected to outweigh those related to cold (high confidence). (Aboubakri et al., 2020);(Achebak et al., 2020);(Burkart et al., 2021);(Huber et al., 2020b);(Martinez et al., 2018);(Rodrigues et al., 2020);(Vardoulakis et al., 2014);(Weinberger et al., 2017);(Weinberger et al., 2018a);(Weitensfelder and Moshammer, 2020). However, strong regional contrasts in heat- and cold-related mortality trends are *likely* under a RCP8.5 scenario with countries in the global north experiencing minimal to moderate decreases in cold related mortality while warm climate countries in the global south are projected to experience increases in heat-attributable deaths by end of century (Gasparrini et al., 2017);(Burkart et al., 2021)Projections of the magnitude of change in the temperature related burden of disease do however demonstrate great variability, due to the application of a wide range of climate change, adaptation and demographic scenarios (Cheng et al., 2019).

A particular focus since AR5 has been the impact of climate change on cities (see AR6 Chapter 6). Heat risks are expected to be greater in urban areas due to changes in regional heat exacerbated by 'heat island' effects (high confidence). (Doan and Kusaka, 2018);(Heaviside et al., 2016);(Li et al., 2021);(Rohat et al., 2019a);(Rohat et al., 2019c);(Varquez et al., 2020);(Wouters et al., 2017);(Zhao et al., 2021), with intra-urban scale variations in heat exposure attributable to land cover contrasts and urban form and function (Avashia et al., 2021);(Jang et al., 2020);(Macintyre et al., 2018);(Schinasi et al., 2018) . However, further research is required to establish the health implications of increasing chronic slow-onset extreme heat (Oppermann et al., 2021), in addition to the acute health outcomes of urban heat island - heatwave synergies under climate change. The latter is particularly important as studies that address urban heat island – heatwave interactions have mainly focused on changes in urban heat island intensity (e.g. (Ramamurthy and Bou-Zeid, 2017);(Scott et al., 2018). Whether significant urban mortality anomalies arise from the interplay of heatwaves and urban heat islands largely remains an open question although at least one study demonstrated higher urban compared to rural mortality rates during heatwaves (Ruuhela et al., 2021). Yet, the benefits of the winter urban heat island (UHI) effect for cold related mortality remain largely unexplored but one study for Birmingham, UK indicates the winter UHI will continue to have a protective effect in future climate (Macintyre et al., 2021).

7.3.1.3 Projected impacts on vector-borne diseases

The distribution and abundance of disease vectors, and the transmission of the infections that they carry, are influenced both by changes in climate, and by trends such as human population growth and migration, urbanization, land-use change, biodiversity loss, and public health measures. Each of these may increase or decrease risk, interact with climate effects, and may contribute to emergence of infectious disease, although there are few studies assessing future risk of emergence (Gibb et al., 2020). Unless stated otherwise, the assessments below are specifically for the effects of climate change on individual diseases, assuming other determinants remain constant.

There is a high likelihood that climate change will contribute to increased distributional range and vectorial capacity of malaria vectors in parts of Sub-Saharan Africa, Asia, and South America (high confidence) In Nigeria, the range and abundance of *Anopheles* mosquitoes are projected to increase under both lower (RCP2.6) and especially under higher emissions scenarios (RCP8.5) due to increasing and fluctuating temperature, longer tropical rainfall seasons and rapid land use changes (Akpan et al., 2018). Similarly, vegetation acclimation due to elevated atmospheric CO_2 under climate change will likely increase the abundance of *Anopheles* vectors in Kenya (Le et al., 2019). Distribution of *Anopheles* may decrease in parts of India and Southeast Asia, but there is an expected increase in vectorial capacity in China (Khormi and Kumar, 2016). In South America, climate change is projected to expand the distributions of malaria vectors to 35-46% of the continent by 2070, particularly species of the *Albitarsis* Complex (Laporta et al., 2015).

Malaria infections have significant potential to increase in parts of Sub-Saharan Africa and Asia, with risk varying according to the warming scenario (medium confidence). In Africa, where most malaria is due to the more deadly *Plasmodium falciparum* parasite, climate change is likely to increase the overall transmission risk due to the likely expansion of vector distribution and increase in biting rates (Bouma et al., 2016);(M'Bra et al., 2018);(Nkumama et al., 2017);(Ryan et al., 2015b) ; (Tompkins and Caporaso, 2016a). The projected effect of climate change varies markedly by region, with projections for West Africa tending to indicate a shortening of transmission seasons and neutral or small net reductions in overall risk, whereas studies consistently project increases in Southern and Eastern Africa, with potentially an additional 76 million people at risk of endemic exposure (10-12 months per year) by the 2080s (Nkumama et al., 2017);(Ryan et al., 2015b);(Semakula et al., 2017);(Zaitchik, 2019);(Leedale et al., 2016);(Murdock et al., 2016);(Yamana et al., 2016);(Ryan et al., 2020). In Sub-Saharan Africa, malaria case incidence associated with dams in malaria-endemic regions will likely be exacerbated by climate change, with significantly higher rates projected under RCP 8.5 in comparison to lower-emission scenarios (Kibret et al., 2016). Incidence of malaria in Madagascar is projected to increase under RCPs 4.5 through 8.5 (Rakotoarison et al., 2018). Distribution of *P. vivax* and *P. falciparum* malaria in China is likely to increase under RCPs higher than 2.6, especially RCP8.5 (Hundessa et al., 2018). In India, projected scenarios for the 2030s under RCP4.5 indicate changes in the spatial distribution of malaria, with new foci and potential outbreaks in the Himalayan region, southern and eastern states, and an overall increase in months suitable for transmission overall, with some other areas experiencing a reduction in transmission months (Sarkar et al., 2019).

Rising temperatures are likely to cause poleward shifts and overall expansion in the distribution of mosquitoes Aedes aegypti and Ae. albopictus, the principal vectors of dengue, yellow fever, chikungunya and zika (high confidence). Globally, the population exposed to disease transmission by one or other of these vectors is expected to increase significantly due to the combination of climate change and non-climatic processes including urbanization and socio-economic interconnectivity, with exposure rates rising under higher warming scenarios (Kamal et al., 2018);(Kraemer et al., 2019). For example, approximately 50% of the global population is projected to be exposed to these vectors by 2050 under RCP6.0 (Kraemer et al., 2019). The effect of climate change alone is projected to increase the population exposed to *Ae. aegypti* by 8-12% by 2061–2080 (Monaghan et al., 2018), and its abundance is projected to increase by 20% under RCP 2.6 and 30% under RCP 8.5 by the end of the century (Liu-Helmersson et al., 2019) (Figure 7.10) Exposure to transmission by *Ae. albopictus* specifically would be highest at intermediate climate change scenarios and would decrease in the warmest scenarios (Ryan et al., 2019). Under scenarios other than RCP2.6, most of Europe would experience significant increases in exposure to viruses transmitted by both vectors (Liu-Helmersson et al., 2019).

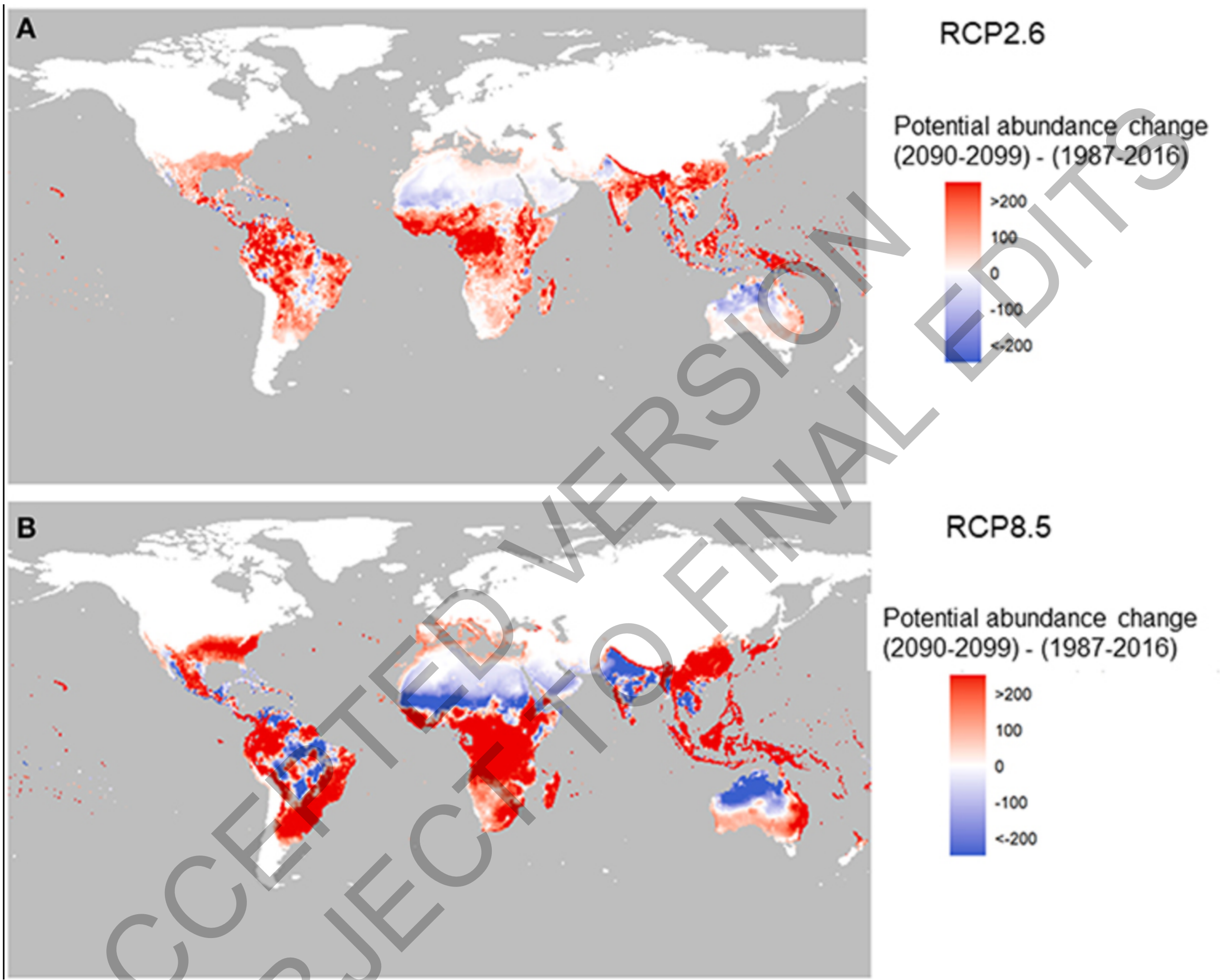

Figure 7.10: Projected change in the potential abundance of *Aedes aegypti* over the twenty-first century (2090-2099 relative to 1987-2016) (Liu-Helmersson et al., 2019)

Climate change is expected to increase dengue risk and facilitate its global spread, with the risk being greatest under high emissions scenarios (high confidence). Future exposure to risk will be influenced by the combined effects of climate change and non-climatic factors such as population density and economic development (Akter et al., 2017). Overall, risk levels are expected to rise on all continents (Akter et al., 2017);(Messina et al., 2015);(Rogers, 2015);(Liu-Helmersson et al., 2016);(Messina et al., 2019). Compared to 2015, an additional 1 billion people are projected to be at risk of dengue exposure by 2080 under an RCP4.5/SSP1 scenario, 2.25 billion under RCP6.0/SSP2, and 5 billion under RCP8.5/SSP3 (Messina et al., 2019). In North America, risk is projected to expand in north-central Mexico, with annual dengue incidence in Mexico increasing by up to 40% by 2080, and to expand from US southern states to mid-western regions, with annual dengue incidence in Mexico increasing by up to 40% by 2080 (Proestos et al., 2015);(Colon-Gonzalez et al., 2013). In China, under RCP8.5, dengue exposure would increase from 168 million people in 142 counties to 490 million people in 456 counties by the late 2100s (Fan and Liu, 2019). In Nepal, dengue fever is expected to expand throughout the 2050s and 2070s under all RCPs (Acharya et al., 2018). In Tanzania, there is a projected shift in distribution towards central and north-eastern areas and risk intensification in nearly all parts of the country by 2050 (Mweya et al., 2016). Dengue vectorial capacity is projected to increase in Korea under higher RCP scenarios (Lee et al., 2018a).

There are insufficient studies for assessment of projected effects of climate change on other arboviral diseases, such as chikungunya and zika. Zika virus transmits under different temperature optimums than does dengue, suggesting environmental suitability for zika transmission could expand with future warming (low confidence).
(Tesla et al., 2018)

Climate change can be expected to continue to contribute to the geographical spread of the Lyme disease vector Ixodes scapularis *(high confidence) and the spread of tick-borne encephalitis and Lyme disease vector* Ixodes ricinus *in Europe (medium confidence).* In Canada, vector surveillance of the black-legged tick *I. scapularis* identified strong temperature effects on the limits of their occurrence, on recent geographic spread, temporal coincidence in emergence of tick populations, and acceleration of the speed of spread (Clow et al., 2017);(Cheng et al., 2017). In Europe, increasing temperatures over the period 1950-2018 significantly accelerated the life cycle of *Ixodes ricinus* and contributed to its spread (Estrada-Peña and Fernández-Ruiz, 2020). Under RCP4.5 and RCP8.5 scenarios, projections indicate a northward and eastward shift of the distribution of *I. persulcatus and I. ricinus,* vectors of Lyme disease and tick-borne encephalitis in Northern Europe and Russia, with an overall large increase in distribution in the second half of the current century (Popov and Yasyukevich, 2014);(Yasjukevich et al., 2018) and increases in intensity of tick-borne encephalitis transmission in central Europe (Nah et al., 2020).

Climate change is projected to increase the incidence of Lyme disease and tick-borne encephalitis in the Northern Hemisphere (high confidence) (see also Figure 7.3). The basic reproduction number (R0) of *I. scapularis* in at least some regions of Canada is projected to increase under all RCP scenarios (McPherson et al., 2017). In the United States, a 2°C warming could increase the number of Lyme disease cases by over 20% over the coming decades, and lead to an earlier onset and longer length of the annual Lyme disease season (Dumic and Severnini, 2018);(Monaghan et al., 2015).

Climate change is projected to change the distribution of schistosomiasis in Africa and Asia (high confidence), with a possible increase in global land area suitable for transmission (medium confidence). A global increase in land area with temperatures suitable for transmission by the three main species of *Schistosoma* (*S. japonicum*, *S. mansoni* and *S. haematobium)* is projected under the RCP4.5 scenario for the periods 2021–2050 and 2071–2100 (Yang and Bergquist, 2018) but regional outcomes are expected to vary. In Africa, shifting temperature regimes associated with climate change are expected to lead to reduced snail populations in areas with already high temperatures, and higher populations in areas with currently low winter temperatures (Kalinda et al., 2017);(McCreesh and Booth, 2014). Infection risk with *Schistosoma mansoni* may increase by up to 20% over most of eastern Africa over the next 20-50 years but decrease by more than 50% in parts of north and east Kenya, southern South Sudan and eastern PDRC (McCreesh et al., 2015), with a possible overall net contraction (Stensgaard et al., 2013). In China, currently endemic areas in Sichuan Province may become unsuitable for snail habitats, but currently non-endemic areas in Sichuan and Hunan/Hubei provinces may see new emergence (Yang and Bergquist, 2018). In addition to the projected effects of temperature described above, distribution and transmission of schistosomiasis will also be affected positively or negatively by changes in the availability of freshwater bodies, which were not included in these models.

7.3.1.4 Projected impacts on water-borne diseases

Climate change will contribute to additional deaths and mortality due to diarrheal diseases in the absence of adaptation (medium confidence) (see Figure 7.3*).* Risk factors for future excess deaths due to diarrheal diseases are highly mediated by future levels of socio-economic development and adaptation. An additional 1°C increase in mean average temperature is expected to result in a 7% (95% CI, 3%-10%) increase in all-cause diarrhoea (Carlton et al., 2016), and an 8% (95% CI, 5%-11%) increase in the incidence of diarrheic *E. coli* (Philipsborn et al., 2016)*,* and a 3% to 11% increase in deaths attributable to diarrhoea (WHO, 2014). WHO Quantitative Risk Assessments for the effects of climate change on selected causes of death for the

2030s and 2050s project that overall deaths from diarrhoea should fall due to socioeconomic development, but that the effect of climate change under higher emission scenarios could cause an additional 48,000 deaths in children aged under 15 years in 2030 and 33,000 deaths for 2050, particularly in Africa and parts of Asia. In Ecuador, projected increases in rainfall variability and heavy rainfall events may increase diarrhoea burden in urban regions (Deshpande et al., 2020). A limit in the assessable literature is a lack of studies in the highest risk areas (Liang and Gong, 2017);(UNEP, 2018).

Climate change is expected to increase future health risks associated with a range of other waterborne diseases and parasites, with effects varying by region (medium confidence). Waterborne diseases attributable to protozoan parasites including *Cryptosporidium* spp and *Giardia duodenalis (intestinalis)* are expected to increase in Africa due to increasing temperatures and drought (Ahmed et al., 2018);(Efstratiou et al., 2017). Recent data suggest a poleward expansion of *Vibrios* to areas with no previous incidence, particularly in mid- to high- latitude regions in areas where rapid warming is taking place (Baker-Austin et al., 2017). The number of *Vibrio*-induced diarrhoea cases per year increased in past decades in the Baltic Sea region, and the projected risk of vibriosis will increase in northern areas, where waters are expected to become warmer, more saline due to reduced precipitation, and have higher chlorophyll concentrations (Escobar et al., 2015);(Semenza et al., 2017).

The risk of Campylobacteriosis and other enteric pathogens could rise in regions where heavy precipitation events or flooding are projected to increase (medium confidence). In Europe, the risk of Campylobacteriosis and diseases caused by other enteric pathogens could also rise in regions where precipitation or extreme flooding are projected to increase (Agency, 2017), although incidence rates may be further mediated by seasonal social activities (Rushton et al., 2019);(Williams et al., 2015b). Accelerated releases of dissolved organic matter to inland and coastal waters through increases in precipitation are expected to reduce the potential for solar UV inactivation of pathogens and increase risks for associated waterborne diseases (Williamson et al., 2017). The combined relative risk for waterborne campylobacteriosis, salmonellosis and diseases due to Verotoxin-producing Escherichia coli was estimated to be 1.1 (i.e. a 10% increase) for every 1°C in mean annual temperature, while by the 2080s, under RCP8.5, annual rates of cryptosporidiosis and giardiasis could rise by approximately 16% due to more severe precipitation events (Brubacher et al., 2020);(Chhetri et al., 2019).

7.3.1.5 Projected impacts on food-borne diseases

The prevalence of Salmonella *infections are expected to rise as higher temperatures enable more rapid replication (medium confidence)*. Research from Canada finds a very strong association of salmonellosis and other food-borne diseases with higher temperatures, suggesting that climate change could increase food safety risks ranging from increased public health burden to emergent risks not currently seen in the food chain (Smith and Fazil, 2019). In Europe, the average annual number of temperature-related cases of salmonellosis under high emissions scenarios could increase by up to 50% more than would be expected on the basis of on population change alone, by 2100 (Lake, 2017);(Agency, 2017). Warming trends in the southern US may lead to increased rates of Salmonella infections (Akil et al., 2014).

7.3.1.6 Projected impacts on pollution and aeroallergens related health outcomes

Global air pollution-related mortality attributable directly to climate change – the human health climate penalty associated with climate-induced changes in air quality - is likely to increase and partially counteract any decreases in air pollution-related mortality achieved through ambitious emission reduction scenarios or stabilisation of global temperature change at 2°C (medium confidence). Demographic trends in aging and more vulnerable population are likely to be important determinants of future air quality – a human health climate penalty *(high confidence)*.

Poor air quality contributes to a range of non-communicable diseases including cardiovascular, respiratory, and neurological, commonly resulting in hospitalisation or death. This section considers the possible risks for health of future climate-related changes in ozone and particulate matter (PM). The climate penalty, the degree to which global warming could affect future air quality, is better understood for ozone than particulate matter (von Schneidemesser et al., 2020). This is because increases in air temperature enhance ozone formation via associated photochemical processes (Archibald et al., 2020);(Fu and Tian, 2019). The association between climate and particulate matter is complex and moderated by a diverse range of PM components as well as formation and removal mechanisms (von Schneidemesser et al., 2020), added to which is uncertainty about future climate related PM sources such as wildfires (Ford et al., 2018) and changes in aridity (Achakulwisut et al., 2019). As noted in Chapter 6 of the WG1 report, future air quality will largely depend on precursor emissions, with climate change projected to have mixed effects. Because of the uncertainty of how natural processes will respond, there is low confidence in the projections of surface ozone and PM under climate change (Szopa et al., 2021 – Chapter 6, IPCC AR6 WGI). This bears implications for the levels of confidence in projections of the health climate penalty associated with climate-induced changes in air quality (Orru et al., 2017), (Orru et al., 2019);(Silva et al., 2017).

There is a rich literature on global and regional level projections of air quality-related health effects arising from changes in emissions. Comparatively few studies assess how changes in air pollution directly attributable to climate change are likely to affect future mortality levels. Projections indicate that emission reduction scenarios consistent with stabilisation of global temperature change at 2°C or below would yield substantial co-benefits for air quality related health outcomes(Chowdhury et al., 2018b); (von Schneidemesser et al., 2020);(Silva et al., 2016c);(Markandya et al., 2018);(Orru et al., 2019);(Shindell et al., 2018) (*high confidence*). For example, by 2030, compared to 2000, it was estimated that globally and annually 289,000 PM2.5 - related premature deaths could have been avoided under RCP 4.5 compared to 17,200 PM2.5 - related excess premature deaths under RCP 8.5(Silva et al., 2016c). Further, and notwithstanding estimated reductions in global PM2.5 levels and an associated increase in the number of avoidable deaths, the benefits of following a low emissions pathway are expected to be apparent by 2100, with avoidable deaths estimated at 2.39 million deaths per year under RCP4.5. This contrasts with the 1.31 million estimated under RCP8.5. A few projections of the health related climate-penalty indicate a possible increase in ozone and PM2.5 - associated mortality under RCP8.5 (Doherty et al., 2017);(Orru et al., 2019);(Silva et al., 2017).

At the global level for PM2.5, annual premature deaths due to climate change were projected to be 55,600 (−34,300 to 164,000) and 215,000 (−76,100 to 595,000) in 2030 and 2100, respectively, countering by 16% the projected decline in PM2.5 -related mortality between 2000 and 2100 without climate change (Silva et al., 2017). Similarly for ozone , the number of annual premature ozone-related deaths due to climate change were projected to be 3,340 in 2030 and 43,600 in 2050, with climate change accounting for 1.2% (14%) of the annual premature deaths in 2030 (2100) (Silva et al., 2017). These global level projections average over considerable geographical variations (Silva et al., 2017). Projections of the climate change effect on ozone mortality in 2100 were greatest for East Asia (41 deaths per year per million people), India (8 deaths per year per million people) and North America (13 deaths per year per million people). For PM2.5, mortality was projected to increase across all regions except Africa (−25,200 deaths per year per million people) by 2100, with estimated increases greatest for India (40 deaths per year per million people), the Middle East (45 deaths per year per million people), East Asia (43 deaths per year per million people) and the Former Soviet Union (57 deaths per year per million people). Overall, higher ozone-related health burdens were projected to occur in highly populated regions and greater PM2.5 health burdens were projected in high PM emission regions (Doherty et al., 2017).

For Central and Southern Europe, climate change alone could result in an 11% increase in ozone-associated mortality by 2050. However, projected declines in ozone precursor emissions could reduce the EU-wide climate change effect on ozone-related mortality by up to 30%; the reduction was projected to be approximately 24% if aging and an increasingly susceptible population were accounted for in projections to 2050 (Orru et al., 2019). For the US in 2069, the impact of climate change alone on annual PM2.5 and ozone-related deaths were estimated to be 13,000 and 3,000 deaths respectively, with heat-driven adaptation of air conditioning accounting for 645 and 315 of the PM2.5 and ozone related annual excess deaths, respectively (Abel et al., 2018). An aging population as a determinant of future air quality related mortality levels. An aging population along with an increase in the number of vulnerable people may work to offset the decrease in deaths associated with a low emission pathway (RCP4.5) and possibly dominate the net increase in deaths under a business as usual pathway (RCP8.5) (Chen et al., 2020) ;(Doherty et al., 2017);(Hong et al., 2019);(Schucht et al., 2015).

Complementing the longer-term changes in air quality arising from climate change are those associated with air pollution sensitive short-term meteorological events, such as heatwaves. Studies of individual heat events

(Garrido-Perez et al., 2019);(Johansson et al., 2020);(Kalisa et al., 2018);(Pu et al., 2017);(Pyrgou et al., 2018);(Schnell and Prather, 2017);(Varotsos et al., 2019) and systematic reviews (Anenberg et al., 2020) provide evidence for synergistic effects of heat and air pollution. However, the health consequences of a possible additive effect of air pollutants during heatwave events were heterogeneous, varying by location and moderated by socio-economic factors at the intra-urban scale (Analitis et al., 2014);(Fenech et al., 2019);(Krug et al., 2020);(Pascal et al., 2021);(Schwarz et al., 2021);(Scortichini et al., 2018). This, combined with the challenges associated with projecting future concentrations of health-relevant pollutants during heatwave events (Jahn and Hertig, 2021);(Meehl et al., 2018) makes it difficult to say with any certainty that synergistic effects of heat and poor air quality will result in a heatwave-air pollution health penalty under climate change.

The burden of disease associated with aeroallergens is anticipated to grow due to climate change (high confidence). The incidence of pollen allergy and associated allergic disease increases with pollen exposure, and the timing of the pollen season and pollen concentrations are expected to change under climate change (Beggs, 2021);(Ziska et al., 2019), (Ziska, 2020). The overall length of the pollen season and total seasonal pollen counts/concentrations for allergenic species such as birch (Betula) and ragweed (Ambrosia) are expected to increase as a result of CO_2 fertilization and warming, leading to greater sensitization (Hamaoui-Laguel et al., 2015);(Lake et al., 2017);(Zhang et al., 2013). Changes in pollen levels for several species of trees and grasses are projected to increase annual emergency department visits in the US by between 8% for RCP4.5 and 14% for RCP8.5 by the year 2090 (Neumann et al., 2019) with the exposure to some pollen types estimated to double beyond present levels in Europe by 2041-2060 (Lake et al., 2017). The prospect of increases in summer thunderstorm events under climate change (Brooks, 2013) may hold implications for changes in the occurrence of epidemic thunderstorm asthma (Bannister et al., 2021);(Emmerson et al., 2021);(Price et al., 2021). Similarly projected alterations in hydroclimate under climate change may bear implications for increased exposure to mould allergens in some climates (D'Amato et al., 2020); (Paudel et al., 2021).

7.3.1.7 Cardiovascular diseases

Climate change is expected to increase heat-related cardiovascular disease (CVD) mortality by the end of the 21st century, particularly under higher emission scenarios (high confidence). Most modelling studies conducted since AR5 project higher rates of heat-related CVD mortality throughout the remainder of this century(Huang and et al., 2018);(Li et al., 2015);(Li et al., 2018);(Limaye et al., 2018);(Zhang et al., 2018a);(Silveira et al., 2021a); (Yang et al., 2021). CVD mortality in Beijing, China could increase by an average of 18.4%, 47.8%, and 69.0% in the 2020s, 2050s, and 2080s, respectively, under RCP 4.5, and by 16.6%, 73.8% and 134%, respectively, under RCP 8.5 relative to a 1980s baseline (Li et al., 2015). Projections of temperature-related mortality from CVD for Beijing in the 2080s varying depending on RCP and population assumptions (Zhang et al., 2018a). Projections for Ningo, China, suggest heat-related years of life lost could increase significantly in the month of August, by between 3 and 11.5 times greater over current baselines by the 2070s, even with adaptation (Huang and et al., 2018). Yang and colleagues project that heat-related excess CVD mortality in China could increase to approximately 6% (from a 2010 baseline of under 2%) by the end of the century under RCP 8.5 and to over 3% under RCP 4.5 (Yang et al., 2021). The future burden of temperature-related myocardial infarctions (MI) in Germany is projected to rise under high emissions scenarios (Chen et al., 2019), while in the eastern US, Limaye et al. (2018) projected an additional 11,562 annual deaths (95% CI: 2,641–20,095) by mid-century due to cardiovascular stress in the population 65 years of age and above. CVD mortality in Brazil is projected to increase up to 8.6% by the end of the century under RCP 8.5, compared with an increase of 0.7% for RCP 4.5 (Silveira et al., 2021a).

It is important to note that the assessed studies typically take an observed epidemiological relationship and apply future temperature projections (often derived from regional climate projections), to these relationships. Because the relationships between temperature and CVD death are influenced by both climatic and non-climatic factors (such as population fitness and aging), future projections are highly sensitive to assumptions about interactions between climate, population characteristics, and adaptation pathways. Changes in air quality because of climate change are an additional important factor. For example, an assessment of future annual and seasonal excess mortality from short-term exposure to higher levels of ambient ozone in Chinese cities under RCP 8.5 projected approximately 1,500 excess annual CVD deaths in 2050 (Chen et al., 2018).

To the extent possible, the relationships reported above reflect changes derived from changes in heat exposure driven by climate change, and not changes in population demographics or air pollution exposure.

Climate change could impact CVD through other pathways, including exposure to fine dust. For example, Achakulwisut and colleagues found that adult mortality attributable to fine dust exposure in the American southwest could increase by 750 deaths per year (a 130% increase over baseline) by the end of the century under RCP 8.5 (Achakulwisut et al., 2018).

7.3.1.8 Maternal, foetal, and neonatal health

Additional research is needed on future impacts of climate change on maternal, foetal and neonatal health. Maternal heat exposure is a risk factor for several adverse maternal, foetal, and neonatal outcomes (Kuehn and McCormick, 2017), including foetal growth (Sun et al., 2019) and congenital anomalies (Haghighi et al., 2021). There is very limited research on this subject, an exception being Zhang et al. 2020 (Zhang et al.) that projected an 34% increase in congenital health disease risk in the US in 2025 and 2035 based on increased maternal extreme heat exposure.

7.3.1.9.1 Malnutrition

Climate change is projected to exacerbate malnutrition (high confidence). Climate change attributable moderate and severe stunting in children less than 5 years of age was projected for 2030 across 44 countries to be an additional 570,000 cases under a prosperity and low climate change scenario (RCP2.6) to one million cases under a poverty and high climate change scenario (RCP8.5), with the highest effects in rural areas.(Lloyd, 2018). Future disability-adjusted life years (DALYs) lost due to protein-energy undernutrition and micronutrient deficiencies without climate change have been projected to increase between 2010 and 2050 by over 30 million. With climate change (RCP8.5), DALYs were projected to increase by nearly 10%, with the largest increases in Africa and Asia (Sulser et al., 2021).

The projected risks of hunger and childhood underweight vary under the five SSPs, with population growth, improvement in the equality of food distribution, and income-related increases in food consumption influencing future risks (Ishida et al., 2014);(Hasegawa et al., 2015). A review of 57 studies projecting global food security to 2050 under the SSPs concluded that global food demand was expected to increase by 35% to 56% between 2010 and 2050, with the population at risk of hunger expected to change by −91% to +8% (van Dijk et al., 2021);(van Dijk et al., 2021). Taking climate change into account changed the ranges slightly but with no statistical differences overall.

7.3.1.9.2 Climate Change, Carbon Dioxide, Diets, and Health

Climate change could further limit equitable access to affordable, culturally acceptable, and healthy diets (high confidence). Climate impacts on agricultural production and regional food availability will affect the composition of diets, which can have major consequences for health. Variable by region and context, healthy diets are an outcome of the four interconnected domains of sustainable food systems, namely ecosystems, society, economics, and health (Drewnowski et al., 2020);(Fanzo et al., 2020). Climate change limits the potential for healthy diets through adverse impacts on natural and human systems that are disproportionately experienced by low-income countries and communities (FAO et al., 2021). Climate-driven droughts, floods, storms, wildfires, and extreme temperatures reduce food production potential by diminishing soil health, water security, and biological and genetic diversity (Macdiarmid and Whybrow, 2019). Models project that climate-related reductions in food availability, specifically fruit and vegetables, could result in an additional 529,000 deaths a year by 2050 (Springmann et al., 2016b).

Diets reliant on marine fisheries and fish also face complex climate-driven challenges (Hollowed et al., 2013). Rapidly warming oceans (Cheng et al., 2020) limit the size of many fish and hamper their ability to relocate or adapt; many commonly consumed fish, like sardines, pilchards, and herring could face extinction due to these pressures (Avaria-Llautureo et al., 2021). Other fisheries models project end of century pollock and Pacific cod fisheries decreasing by >70% and >35% under RCP 8.5 (Holsman et al., 2020). Climate-driven increases in marine mercury concentrations (Booth and Zeller, 2005) and harmful algal blooms (Jardine et al., 2020) could impact dietary quality and human health.

Global crop and economic models project higher cereal prices of up to 29% by 2050 under RCP 6.0, resulting in an additional 183 million people in low-income households at risk of hunger (Hasegawa et al., 2018). Climate impacts on human health disrupt agricultural labour, food supply chain workers, and ultimately regional food availability and affordability. A recent meta-analysis focused on Sub-Saharan Africa and Southeast Asia combined metrics of heat stress and labour to project that a 3°C increase in global mean temperature, without adaptation or mechanization, could reduce agricultural labour capacity by 30-50%, leading to 5% higher crop prices and a global welfare loss of $136 billion (de Lima et al., 2021).

The nutritional density of wheat, rice, barley, and other important food crops, including of protein content, micronutrients, and B-vitamins, is affected negatively by higher CO_2 concentrations (*very high confidence*). (SRCCL, 2019 5.4.3);(Smith and Myers, 2018). Projections indicate negative impacts on human nutrition of rising CO_2 concentrations by mid- to late-century (Medek et al., 2017);(Smith and Myers, 2018);(Weyant et al., 2018);(Zhu et al., 2018);(Beach et al., 2019). Staple crops are projected to have decreased protein and mineral concentrations by 5-15% and B vitamins up to 30% when the concentrations of CO_2 double above pre-industrial (Ebi and Loladze, 2019);(Beach et al., 2019);(Smith and Myers, 2018). Without changes in diets and accounting for nutrient declines in staple crops, a projected additional 175 million people could be zinc deficient and an additional 122 million people could become protein deficient (Smith and Myers, 2018).Weyant et al. (2018) projected that CO_2-related reductions in crop zinc and iron levels could result in 125.8 million DALYs lost globally, with South-East Asian and sub-Saharan African countries most affected. Zhu et al. (2018) estimated 600 million people at risk from reductions in the protein, micronutrient, and B-vitamin content of widely grown rice cultivars in Southeast Asia.

The combined effect of CO_2 and rising temperatures because of climate change could result in a 2.4% to 4.3% penalty on expected gains by mid-century in nutritional content because of technology change, market responses, and the fertilization effects of CO_2 on yield (Beach et al., 2019). These penalties are expected to slow progress in achieving reductions in global nutrient deficiencies, disproportionately affecting countries with high levels of such deficiencies.

7.3.1.10 Projected impacts on harmful algal blooms, mycotoxins, aflatoxins, and chemical contaminants

Harmful algal blooms are projected to increase globally, thus increasing the risk of seafood contamination with marine toxins (high confidence). (Authority) et al., 2020);(Gobler et al., 2017);(Barange et al., 2018);(SRCCL, 2019);(Wells et al., 2020). Climate change impacts on oceans could generate increased risks of ciguatera poisoning in some regions *(medium confidence).* Studies suggest that rising sea surface temperatures could increase rates of ciguatera poisoning in Spain (Botana, 2016), and other parts of Europe {EFSA, 2020, Climate change as a driver of emerging risks for food and feed safety`, plant`, animal health and nutritional quality.

Mycotoxins and aflatoxins may become more prevalent due to climate change (medium agreement, low evidence). Models of aflatoxin occurrence in maize under climate change scenarios of +2 °C and +5 °C in Europe over the next 100 years project that aflatoxin B1 may become a major food safety issue in maize, especially in Eastern Europe, the Balkan Peninsula and the Mediterranean regions (Battilani, 2016). The occurrence of toxin-producing fungal phytopathogens has the potential to increase and expand from tropical and subtropical into regions where such contamination does not currently occur (Battilani, 2016).

Climate change may alter regional and local exposures to anthropogenic chemical contaminants (medium agreement, low evidence). Changes in future occurrences of wildfires could lead to a 14 percent increase in global emissions of mercury by 2050, depending on the scenarios used (Kumar et al., 2018a). Mercury exposure via consumption of fish may be affected by warming waters. Warming trends in the Gulf of Maine could increase the methyl mercury levels in resident tuna by 30 percent between 2015 and 2030 (Schartup et al. (2019). An observed annual 3.5 percent increase in mercury levels was attributed to fish having higher metabolism in warmer waters, leading them to consume more prey. The combined impacts of climate change and the presence of arsenic in paddy fields are projected to potentially double the toxic heavy metal content of rice in some regions, potentially leading to a 39 percent reduction in overall production by 2100 under some models (Muehe et al., 2019).

7.3.1.11 Mental Health and Wellbeing

Climate change is expected to have adverse impacts on wellbeing, some of which will become serious enough to threaten mental health (very high confidence). However, changes (Hayes and Poland, 2018) in extreme events due to climate change, including floods {Baryshnikova, 2019 #3530} , droughts (Carleton, 2017) and hurricanes (Kessler et al., 2008);(Boscarino et al., 2013), (Boscarino et al., 2017) ; (Obradovich et al., 2018), which are projected to increase due to climate change, directly worsen mental health and wellbeing, and increase anxiety (*high confidence)*. Projections suggest that sub-Saharan African children and adolescents, particularly girls, are extremely vulnerable to negative direct and indirect impacts on their mental health and wellbeing (Atkinson and Bruce, 2015);(Owen et al., 2016). The direct risks are greatest for people with existing mental disorders, physical injuries, impacts on respiratory, cardiovascular and reproductive systems, with indirect impacts potentially arising from displacement, migration, famine and malnutrition, degradation or destruction of health and social care systems, conflict, and climate-related economic and social losses (*high to very high confidence*) (Burke et al., 2018);(Curtis et al., 2017);(Hayes et al., 2018); (Serdeczny et al., 2017);(Watts et al., 2019). Demographic factors increasing vulnerability include age, gender, and low socioeconomic status, though the effect of these will vary depending on the specific manifestation of climate change; overall, climate change is predicted to increase inequality in mental health across the globe (Cianconi et al., 2020). Based on evidence assessed in Section 7.2 of this chapter, future direct impacts of increased heat risks and associated illnesses can be expected to have negative implications for mental health and wellbeing, with outcomes being highly mediated by adaptation, but there are no assessable studies that quantify such risks. There may be some benefits to mental health and wellbeing associated with fewer very cold days in the winter; however, research is inconsistent. Any positive effect associated with reduced low-temperature days is projected to be outweighed by the negative effects of increased high temperatures (Cianconi et al., 2020).

Human behaviors and systems will be disrupted by climate change in a myriad of ways, and the potential consequences for mental health and wellbeing are correspondingly large in number and complex in mechanism (high confidence). For example, climate change may alter human physical activity and mobility patterns, in turn producing alterations in the mental health statuses promoted by regular physical activity (Obradovich and Fowler, 2017);(Obradovich and Rahwan, 2019). Climate change may affect labour capacity, because heat can compromise the ability to engage in manual labor as well as cognitive functioning, with impacts on the economic status of individual households as well as societies (Kjellstrom et al., 2016);(Liu, 2020). Migrations and displacement caused by climate change may worsen the wellbeing of those affected (Vins et al., 2015);(Missirian and Schlenker, 2017). Climate change is expected to increase aggression through both direct and indirect mechanisms, with one study predicting a 6% increase in homicides globally for a 1°C temperature increase, although noting significant variability across countries (Mares and Moffett, 2016). Broad societal outcomes such as economic unrest, political conflict, or governmental dysfunction assessed in sections 7.3.5 may undermine mental health of populations in the future (*medium confidence*). Food insecurity presents its own severe risks for mental health and cognitive function (Jones, 2017).

7.3.2 Migration and displacement in a Changing Climate

Future changes in climate-related migration and displacement are expected to vary by region and over time, according to: (1) region-specific changes in climatic drivers, (2) changes in the future adaptive capacity of exposed populations, (3) population growth in areas most exposed to climatic risks, and (4) future changes in mediating factors such as international development and migration policies (high agreement, medium evidence). (Gemenne and Blocher, 2017);(Cattaneo et al., 2019);(McLeman, 2019) Assessed in this section are future risks associated with changes in the frequency and/or severity of storms, floods, droughts, extreme heat, wildfires and other events assessed in section 7.2 that currently affect migration and displacement patterns; as well as the impacts of emerging hazards, including average temperature increases that may affect the habitability of settlements in arid regions and the tropics, and sea level rise and associated hazards that threaten low-lying coastal settlements. Studies assessed here consider projected changes in future exposure to hazards over a variety of geographical and temporal periods, with some considering changes in population numbers in exposed areas. However, the uneven distribution of exposure of age cohorts is typically overlooked in existing research. For example, people younger than age 10 in the year 2020 are projected to experience a nearly fourfold increase in extreme events under 1.5C of global warming, and a fivefold increase under 3C warming; such increases in exposure would not be experienced by a person of the age of 55 in 2020 in their remaining lifetime under any warming scenario (Thiery et al., 2021).

7.3.2.1 Region-specific changes in climatic risks

As outlined in 7.2, the most common drivers of observed climate-related migration and displacement are extreme storms (particularly tropical cyclones), floods, extreme heat, and droughts (high confidence). The future frequency and/or severity of such events due to anthropogenic climate change are expected to vary by region according to future GHG emission pathways [IPCC 2021 Chapter 12; Regional Chapters, this report], with there being an increased potential for compound effects of successive or multiple hazards (e.g., tropical storms accompanied by extreme heat events, (Matthews et al., 2019). Table 7.2 summarizes anticipated changes in future migration and displacement risks due to sudden-onset climate events, by region (and by sub-regions for Africa and Asia, where climatic risks vary within the region).

Table 7.2: Projected changes in sudden-onset climate events associated with migration and displacement, by region

Region	**Main directions of current migration flows (from (Abel and Sander, 2014))**	**Current climatic drivers of migration & displacement [7.2.6.1]**	**Expected changes in drivers (*including confidence statements*) from IPCC 2021 TS 4.3.1-4.3.2**
Asia	East and Southeast Asia: Within countries and between countries within same region. South and Central Asia: Within countries and between countries within same region; from South Asia to Middle East, North America, Europe. West Asia: Within countries and between countries within the same region; to Europe	Floods, extreme storms, extreme heat	Increased risk of flooding in East, North, South & Southeast Asia due to increases in annual mean precipitation (*high confidence*) and extreme precipitation events in East, South, West Central, North & Southeast Asia (*medium confidence*); uncertainty regarding future trends in cyclones (current trend = decreased frequency, increased intensity); higher average temperatures across region (*high confidence*)
Africa	Within countries and between countries within the same region; to Europe and the Middle East	Floods, droughts, extreme heat	Decrease in total annual precipitation in northernmost and southernmost parts of Africa (*high confidence*); west-to-east pattern of decreasing-to-increasing annual precipitation in West Africa and East Africa (medium confidence); increased risk of heavy precipitation events that trigger flooding, across most parts of Africa (*medium confidence*); increased aridity and drought risks in North Africa, southern Africa and western parts of West Africa (*medium-high confidence*)
Europe	Within countries and between countries in same region	Floods	Increased risk of floods across all areas of Europe except Mediterranean areas (high confidence); higher risks of drought, fire weather in Mediterranean areas (high confidence)
North America	Within countries and between countries in same region	Floods; tropical cyclones (US Atlantic & Caribbean coast);	Increased frequency of heavy precipitation events across most areas (high confidence); tropical cyclones to become more severe (medium confidence); increased risk of drought

		tornadoes; wildfires	and fire weather in central and western North America
Central and South America	Within countries and between countries in same region; to North America, Europe	Floods (Central and South America; extreme storms (Central America)	Increases in mean annual precipitation and extreme precipitation events with higher risks of floods in most areas of South America (*medium confidence*); increased risk of droughts in northeastern and southern South America and northern Central America (*medium confidence*); tropical cyclones becoming more extreme (*medium confidence*)
Australasia	Displacement within countries	Wildfires	Increases in fire weather across Australia and New Zealand (*medium confidence*)
Small island states	Within and between countries in same region (e.g., Pacific Islands to Australia & New Zealand; Caribbean islands to USA)	Extreme storms	Potentially fewer but more extreme tropical cyclones (medium confidence)

In low-lying coastal areas of most regions, future increases in mean sea levels will amplify the impacts of coastal hazards on settlements, including erosion, inland penetration of storm surges and groundwater contamination by salt water, and eventually lead to inundation of very low-lying coastal settlements (high confidence). (Diaz, 2016);(Hauer et al., 2016);(Neumann et al., 2015);(Rahman et al., 2019);(Pörtner et al., 2019) Projections of the number of people at risk of future displacement by sea level rise range from tens of millions to hundreds of millions by the end of this century, depending on (1) the sea level rise scenario or RCP selected, (2) projections of future population growth in exposed areas and (3) the criteria used for identifying exposure. These latter measures can include estimates of populations situated within selected elevations above sea level (with 1m, 2m and 10m being common parameters), populations situated in 1-in-100 year floodplains, or populations in areas likely to be entirely inundated under specific RCPs (Neumann et al., 2015);(Hauer et al., 2016);(Merkens et al., 2018);(McMichael et al., 2020);(Hooijer and Vernimmen, 2021). As an illustrative example, an estimated 267 million people (error range = 197-347 million at 68% confidence level) worldwide lived within 2m of sea level in 2020, 59% of whom reside in tropical regions of Asia (Hooijer and Vernimmen, 2021). At a 1m increase in sea level and holding coastal population numbers constant, the number of people worldwide living within 2m of sea level expands to 410 million (error range = 341-473 million). However, it is *unlikely* that coastal population growth rates will remain constant at global or regional scales in future decades. At present, coastal cities in many regions have relatively high rates of population growth due to the combined effects of in-migration from other regions and natural increase, with coastal areas of Africa having the highest projected future population growth rates (Neumann et al., 2015);(Hooijer and Vernimmen, 2021); see also Box 7.5. Further complicating future estimates is that many large coastal cities are situated in deltas with high rates of subsidence, meaning that locally experienced changes in relative sea level may be much greater than sea level rise attributable to climate change, thereby further increasing the number of people exposed (Edmonds et al., 2020);(Nicholls et al., 2021).

Sea level rise is not presently a significant driver of migration in comparison with hazards assessed in 7.2.6, but it has been attributed as a factor necessitating the near-term resettlement of small coastal settlements in Alaska, Louisiana, Fiji, Tuvalu, and the Carteret Islands of Papua New Guinea (Marino and Lazrus, 2015);(Connell, 2016);(Hamilton et al., 2016; Nichols, 2019). In coastal Louisiana, communities tend to resist leaving exposed settlements until approximately 50% of available land has been lost (Hauer et al., 2019). Movements away from highly exposed areas may have longer-term demographic implications for inland settlements (Hauer, 2017), but this requires further study. Based on the limited empirical evidence available, sea level rise does not appear to currently be a primary motivation for international migration originating in small island states in the Indian and Pacific Oceans; economic considerations and family reunification appear to be the dominant current drivers (McCubbin et al., 2015);(Stojanov and Du, 2016);(Heslin, 2019);(Kelman et al., 2019). However, climatic drivers of migration are anticipated to take on a much greater causal role in migration decisions in coming decades (Thomas et al., 2020), and may discourage return migration to small island states (van der Geest et al., 2020). Even under best-case sustainable development scenarios, rising sea levels and associated hazards create risks of involuntary displacement in low-lying coastal areas and should be expected to generate a need for organized relocation of populations where protective infrastructure cannot be constructed (Horton and de Sherbinin, 2021) (Hamilton et al., 2016) . In high emissions scenarios, low-lying island states may face the long-term risk of becoming functionally uninhabitable, creating the potential for a new phenomenon of climate-induced statelessness (Piguet, 2019);(Desai et al., 2021).

[START BOX 7.5]

Box 7.5: Uncertainties in projections of future demographic patterns at global, regional and national scales

Projections of future numbers of people exposed to climate change-related hazards described in this chapter and elsewhere in this report are heavily influenced by assumptions about population change over time at global, regional, and national scales. One challenge concerns global and regional variability of baseline data for current populations, which is typically aggregated from national censuses that vary considerably in terms of frequency, timing, and reliability, especially in low-income countries. A number of gridded mapping dataset initiatives emerged in recent years to support population-environment modelling research at global and regional levels, common ones being the Gridded Population of the World, the Global Rural Urban Mapping Project, and LandScan Global Population dataset (McMichael et al., 2020). For future population projections at national levels, researchers commonly draw upon data generated by the Population Division of the United Nations Department of Economic and Social Affairs, which publishes periodic projections for future fertility, mortality, and international migration rates for over 200 countries, the most recent projections being for the period 2020 to 2100 (Division and Population, 2019). There have been debates among demographers regarding the precision of DESA projections, with some debate over whether these overestimate or underestimate future population growth in some regions (Ezeh et al., 2020). Population growth rates are highly influenced by socio-economic conditions, meaning that future population levels at local, national, and regional scales are likely to respond to relative rates of progress toward meeting the Sustainable Development Goals (Abel et al., 2016). The Shared Socio-economic Pathways used in climate impacts and adaptation research include a variety of assumptions about future mortality, fertility, and migration rates, and provide a range of population growth scenarios that diverge after the year 2030 according to future development trajectories (Samir and Lutz, 2017) and which are then further modified and downscaled by researchers for national-level studies. Understanding of future risks of climate change will benefit from continued efforts by the international community to collect and share data on observed population numbers and trends, and to work toward better projected data for population characteristics that strongly influence vulnerability to climate risks, such as gender, age, and indigeneity.

[END OF BOX 7.5]

Increased frequency of extreme heat events and long-term increases in average temperatures pose future risks to the habitability of settlements in tropical and sub-tropical regions, and may in the long term affect migration patterns in exposed areas, especially under high emissions scenarios (medium agreement, low evidence). Greater research into the specific dynamics between extreme heat and population movements is required in order to make an accurate assessment of this risk. Recent studies suggest that future increases in average temperatures could expose populations across wide areas of the tropics and subtropics to ambient temperatures for extended periods each year that are beyond the threshold for human habitability (Pal and Eltahir, 2016);(Im et al., 2017);(Xu et al., 2020). This effect would be amplified in urban settings where heat-island effects occur and create heightened need for air conditioning and other adaptation measures. In addition to risks associated with average temperature changes, Dosio et al (2018) project that at 1.5°C warming, between 9% and 18% of the global population will be regularly exposed to extreme heat events at least once in 5 years, with the exposure rate nearly tripling with 2°C warming. How these changes in exposure to high temperatures will affect future migration patterns, particularly among vulnerable groups, will depend heavily on future adaptation responses (Horton and de Sherbinin, 2021). Multiple country-level studies assessed in section 7.2 observe existing associations between extreme heat, its impacts on agricultural livelihoods, and changes in rural-to-urban migration flows in parts of South Asia and sub-Saharan Africa. A study conducted in Indonesia, Malaysia, and the Philippines suggests that an increased risk of heat stress would likely influence migration intentions of significant numbers of people (Zander et al., 2019).

7.3.2.2 Interactions with non-climatic determinants and projections of future migration flows

Only a very small number of studies have attempted to make systematic projections of future regional or global migration and displacement numbers under climate change. Key methodological challenges for making such projections include the availability of reliable data on migration within and between countries, definitional ambiguity in distinguishing climate-related migration from migration undertaken for other reasons, and accounting for the future influence of non-climatic factors. The most reliable example of such studies to date is a World Bank report by Rigaud et al (2018) generated projections of future internal population displacements in South Asia, sub-Saharan Africa,, and Latin America by 2050 using multiple climate and development scenarios, resulting in a very large range of possible outcomes (from 31 to 143 million people being displaced, depending on assumptions). An important outcome is the study's emphasis on how the potential for future migration and displacement will be strongly mediated by socio-economic development pathways in low- and middle-income countries. Consistent with this, Hoffmann et al (2020) used metaregression-based analyses to project that future environmental influences on migration are likely to be greatest in low- and middle-income countries in Latin America and the Caribbean, Sub-Saharan Africa, the Middle East and most of continental Asia.

Research reviewed in AR4 and AR5 observed that at higher rates of socio-economic development, the in situ adaptive capacity of households and institutions rises, and climatic influences on migration correspondingly decline. Recent evidence adds further support for such conclusions (high confidence). (Kumar et al., 2018b);(Mallick, 2019);(Gray et al., 2020) (Box 7.5). Population growth rates are currently highest in low-income countries (Division and Population, 2019), many of which have high rates of exposure to climatic hazards associated with population displacement, further emphasizing the importance of socio-economic development and adaptive capacity building. Although country-specific scenarios for socio-economic development and population are embedded in SSPs, research into future migration flows under climate change has not to date made great use of these. One of the few studies to do so found that safe and orderly international migration tends to increase wealth at regional and global scales in all SSP narratives, which in turn reduces income inequality between countries (Benveniste et al., 2021). International barriers to safe and orderly migration may potentially impede progress toward attainment of objectives described in the Sustainable Development Goals and increase exposure to climatic hazards in low- and middle income countries (McLeman, 2019);(Benveniste et al., 2020).

7.3.3 Climate Change and Future Risks of Conflict

Climate change may increase susceptibility to violent conflict, primarily intrastate conflicts, by strengthening climate-sensitive drivers of conflict *(medium confidence).* Section 7.2.7 demonstrated how climate variability and extremes affect violent conflict through food and water insecurity, loss of income, and loss of livelihoods. Risks are amplified by insecure land tenure, competing land uses and weather-sensitive economic activities, when they occur in the context of weak institutions and poor governance, poverty, and inequality (7.2.7). These known, climate-sensitive risk factors allow projections of where conflict is more likely to arise or worsen under climate change impacts (see Chapters 1, 4, 5, 6, 16) (Mach et al., 2020). However, there is also the potential for new causal pathways to emerge as climate changes beyond the variability observed in available datasets and adaptation limits are met (Theisen, 2017);(Mach et al., 2019);(von Uexkull and Buhaug, 2021).

Future violent conflict risk is highly mediated by socio-economic development trajectories (high confidence). Development trajectories that prioritise economic growth, political rights, and sustainability are associated with lower conflict risk (medium confidence, low evidence). Hegre et al (2016) forecast future conflict under the SSPs) and found that SSP1, which prioritises sustainable development is associated with lower risks of conflict. Using data from sub-Saharan Africa, Witmer et al (2017) forecast conflict along the SSPs and find that any increases in conflict that may be associated with climate change could be offset by increases in political rights. Strong predictors of future conflict are a recent history of conflict, large populations, and low levels of socio-economic development (Hegre and Sambanis, 2006) ; (Blattman and Miguel, 2010).

Increases in conflict-related deaths with climate change have been estimated but results are inconclusive (high agreement, medium evidence). Some studies attempted to attribute observed conflict outbreaks to changes in the physical environment and quantify future conflict risk associated with climate change (von Uexkull and Buhaug, 2021);(Theisen, 2017). Burke et al (2015b) concluded that with each one standard deviation increase in temperature, interpersonal conflict increased by 2.4% and intergroup conflict by 11.3%. However, this kind of approach has been criticised for its statistical methods and underrepresenting the known role that socioeconomic conditions and conflict history play in determining the prevalence of violence (Buhaug et al., 2014);(van Weezel, 2019);(Abel et al., 2019). Forecasting armed conflict is used as a heuristic policy tool rather than a representation of the future (Cederman and Weidmann, 2017) and forecasts have limitations. What constitutes, and is experienced as, a hazard will shift over time as societies adapt to climate change (Roche et al., 2020), the drivers of conflict change over time. The SSPs assume economic convergence between countries and do not reflect growth disruptions (e.g. commodity price shocks) that are often a key conflict risk factor (Dellink et al., 2017);(Buhaug and Vestby, 2019);(Hegre et al., 2021).

Asia represents a key region where the peace, vulnerability, and development nexus has been analysed. In Central, South, and South East Asia, there are large numbers of people exposed to the changing climate (Busby et al., 2018);(Vinke et al., 2017);(Reyer et al., 2017). South Asia is one of the least peaceful regions in the world with intra-state communal conflict, international military conflict, and political tension (Wischnath and Buhaug, 2014);(Huda, 2021), and many of the factors that drive conflict risk (large populations and high levels of inequality) are present (Nordqvist and Krampe, 2018). Despite these risks, studies in this region also support the case for environmental peacebuilding and resource sharing, as it relates to transboundary water sharing(Berndtsson and Tussupova, 2020);(Huda and Ali, 2018); Sections 4.3.6; 7.4.5.2).

In Asia, there is little evidence of weather-related impacts on conflict risk or prevalence, but the region is understudied in general (Wischnath and Buhaug, 2014);(Nordqvist and Krampe, 2018). Climate stressors may have contributed, in part, to local level conflicts in Bangladesh and Nepal (Sultana et al., 2019) and intensified water use conflict in peri-urban areas (Roth et al., 2019). There is the potential for climate change to stretch the effectiveness of transboundary water agreements by raising regional geopolitical tensions (Atef et al., 2019);(Scott et al., 2019) or to generate water use conflicts between hydropower and irrigation within countries (Jalilov et al., 2018). Climate change may impact on conflict by affecting food security (Caruso et al., 2016);(Raghavan et al., 2019). There may be greater military involvement in humanitarian response to cyclones, flooding, and to other impacts of climate change that might contribute to increased instability (Pai, 2008) ; (Busby and Krishnan, 2017).

7.4 Adaptation to Key Risks and Climate Resilient Development Pathways

With proactive, timely, and effective adaptation, many observed and projected risks for human health and wellbeing, health systems, and those associated with migration and conflict, can be reduced or potentially avoided (high confidence). Given the key health risks identified in this chapter, adaptation that increases resilience and sustainability will require moving beyond incremental adaptation and to sustained, adaptive management (Ebi, 2011);(Hess et al., 2012) with the goal of transformative change. This includes differentiating adaptation to climate variability from adaptation to climate change (Ebi and Hess, 2020). Health adaptation efforts are increasingly aiming to transition to building climate-resilient and environmentally sustainable health systems (WHO, 2015b);(WHO, 2020a) and healthcare facilities, emphasizing service delivery, including climate-informed health policies and programs, management of the environmental determinants of health; emergency preparedness and management; and health information systems, including health and climate research, integrated risk monitoring and early warning systems, and vulnerability, capacity, and adaptation assessments (Marinucci et al., 2014);(Mousavi et al., 2020);; (Organization, 2015);(CDC, 2019);(WHO, 2020a).

Migration can contribute to or work against adaptation goals and progress, depending on the circumstances under which it occurs. Policies that support safe and orderly movements of people, protect migrant rights, and facilitate flows of financial and other resources between sending and receiving communities are consistent with adaptive capacity building and building sustainability, and are part of climate resilient development pathways.

Adaptation to prevent climate from exacerbating conflict risk involves meeting development objectives encapsulated in the SDGs. Conflict-sensitive adaptation, environmental peacebuilding, and climate-sensitive peace building offer promising avenues to addressing conflict risk, but their efficacy is yet to be demonstrated through effective monitoring and evaluation (Gilmore et al., 2018). Associations between environmental factors and conflict are weak in comparison to socio-economic and political drivers. Therefore, meeting the SDGs, including Goal 16 on Peace, justice, and strong institutions represent unambiguous pathways to reducing conflict risk under climate change (Singh and Chudasama, 2021). Analysing peace rather than taking conflict for granted (Barnett, 2019) improving focus on gender within peacebuilding (Dunn and Matthew, 2015);(UNEP, 2021), and understand how natural resources and their governance interact with peacebuilding (Krampe et al., 2021) present key elements of climate resilient development pathways for sustainable peace.

As documented across this chapter, there is a large adaptation deficit for health and wellbeing, with climate change causing avoidable injuries, illnesses, disabilities, diseases, and deaths (high confidence). Implementation of health adaptation has been incremental because of significant constraints, primarily relating to financial and human resources, and because of limited research funding on adaptation (Berrang-Ford et al., 2021). Current global investments in health adaptation are insufficient to protect the health of populations and communities *(high confidence)* from most climate-sensitive risks, with large variability across and within countries and regions (UNEP, 2018). Climate change adaptation in health is <1% of international climate finance despite health being a priority sector in 54% of NDCs featuring adaptation (UNEP, 2018).

As climate change progresses and the likelihood of dangerous risks to human health continue to increase (Ebi et al., 2021a), there will be greater pressure for more transformational changes to health systems to reduce future vulnerabilities and limit further dangerous climate change. Transformational resilience would need parallel investments in social and health protections, including achieving the SDGs, coupled with investments in mitigation (Ebi and Hess, 2020). Further, investments in mitigating greenhouse gas emissions will not only reduce risks associated with dangerous climate change but will improve population health and wellbeing through several salutary pathways.

This chapter section identifies and assesses specific elements in adapting to risks identified in 7.2 and 7.3 and opportunities for fostering sustainability and pursuing climate resilient development pathways.

7.4.1 Adaptation Solution Space for Health and Wellbeing

The solution space is the space within which opportunities and constraints determine why, how, when, and who adapts to climate change (Chapter 1). *There is increased understanding of exposure and vulnerabilities to climate variability and change, and of the capacities to manage the health risks, of the effectiveness of adaptation (including a growing number of lessons learned and best practices), and of the co-benefits of mitigation policies and technologies (high confidence).*

Effectively preparing for and managing the health risks of climate change requires considering the multiple interacting sectors that affect population health and the effective functioning of health systems (high confidence). Given the wide range of causal pathways through which climate change affects environmental and social systems resulting in health impacts, a systems-based approach can promote identifying, implementing, and evaluating solutions that support population health and health systems in the short and longer-term (high agreement, medium evidence). Such an approach provides insights into policies and programs that promote health and wellbeing via multiple sectors (e.g. water and food safety and security), and can ensure that health policies do not have adverse consequences in other sectors (Organization, 2015);(Ebi and Otmani del Barrio, 2017);(Wright et al., 2021).

Figure 7.11 illustrates the context within which risks to health outcomes and health systems emerge because of climate change. The figure presents the emergence of risk from interactions between specific types of climatic hazards and exposure and vulnerability to those hazards, and the responses taken within the health sector. The figure illustrates also how health risks are situated within larger interactions between the health system and other sectors and systems, with underlying enabling conditions making adaptation and transformation possible. Within this context, response options can decrease the impacts of climate change on human health, wellbeing, and health systems by 1) reducing exposure to climate-related hazards; 2) reducing vulnerability to such hazards; and 3) strengthening health system responses to future risks. Such approaches are described as "Lateral Public Health" and emphasize the importance of involving community members and stakeholders in the planning and coordination of activities (Semenza, 2021);(Semenza, 2011). Lateral public health strives for community engagement (e.g., through access to technology in decision making, such as low-cost air sensors for wildfire smoke) in preparedness and response.

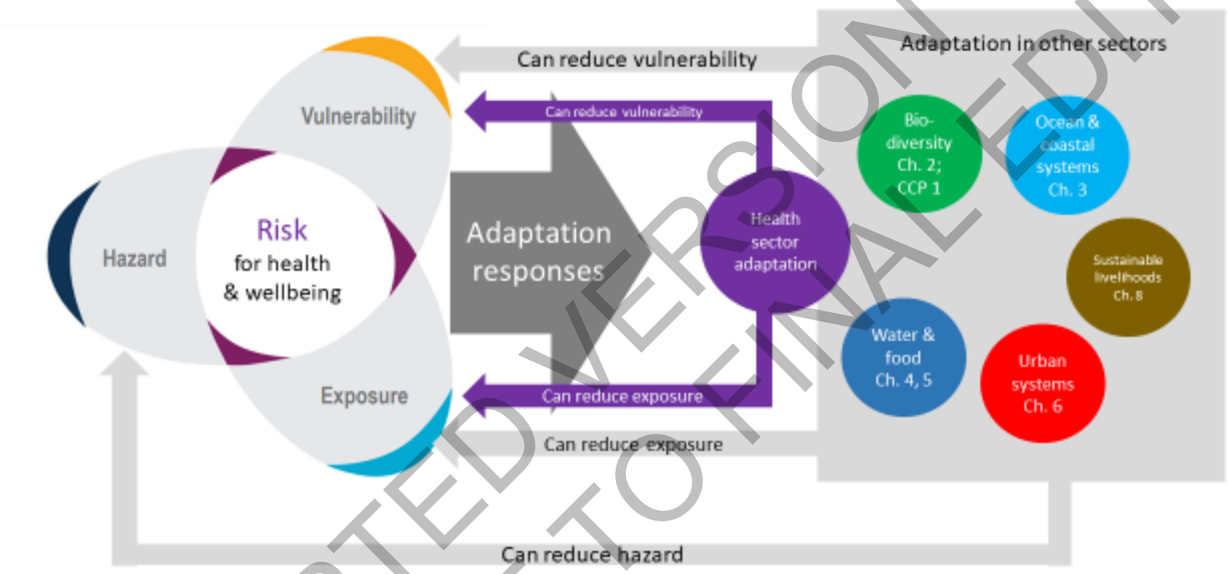

Figure 7.11: Context within which adaptation responses to climatic risks to health are implemented, in the frame of interactions between health and multiple other sectors..

Effective health risk management incorporates the magnitude and pattern of future climate risks as well as potential changes in factors that determine vulnerability and exposure to climate hazards, such as determinants of healthcare access, demographic shifts, urbanization patterns, and changes in ecosystems (very high confidence). Climate change is associated with shocks and stresses that can affect the capacity and resilience of health systems and healthcare facilities (WHO, 2020a). Figure 7.12 illustrates some possible extents to which the capacity of health systems could be reduced when exposed to a stress or shock, and possible pathways forward, from collapse to transformation. The subsequent sections assess adaptation and mitigation options to facilitate building the resilience of health systems and healthcare facilities to recover better than before or to transform.

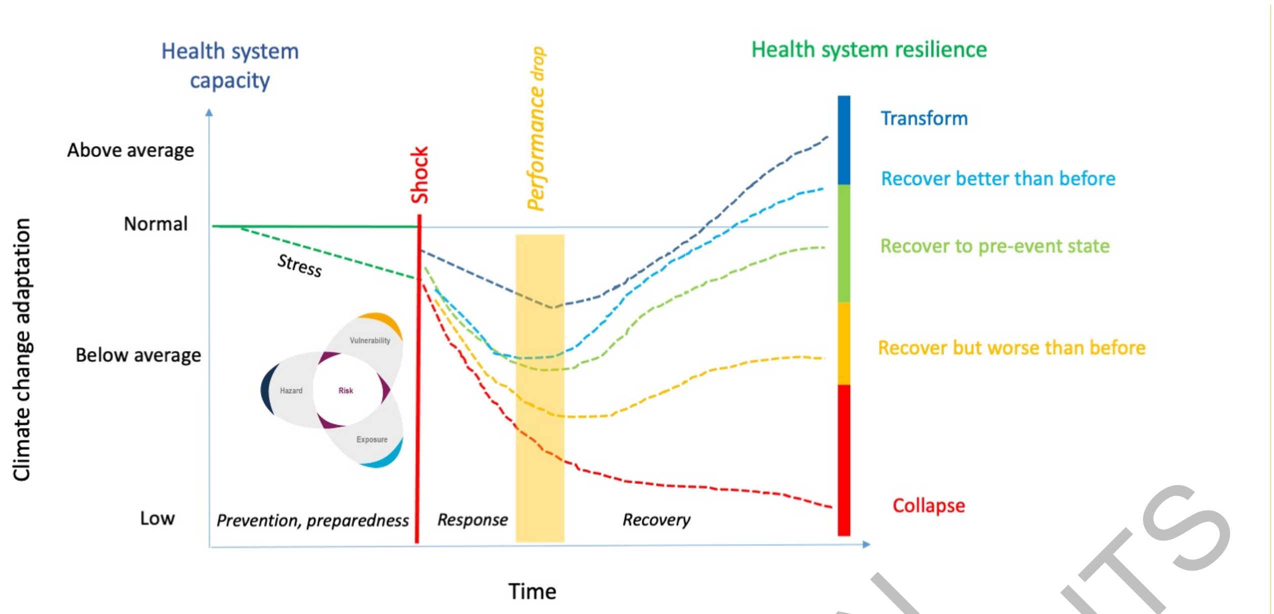

Figure 7.12: Health systems capacity and resilience to climate change-related shocks and stresses (from WHO 2020).

7.4.2 Adaptation Strategies, Policies and Interventions for Health and Wellbeing

7.4.2.1 Current state of health adaptation

Analysis of the Nationally Determined Contributions (NDC) to the Paris Agreement to determine how health was incorporated, including impacts, adaptation, and co-benefits, concluded that most low- and middle-income countries referred to health in their NDC (Dasandi et al., 2021). Figure 7.14 shows the degree of health engagement; this engagement is based on indicators measuring the specificity and detail of health references within the country NDC. Many vulnerable countries had high engagement of the health sector in the country NDC. However, this analysis did not determine whether the ambition expressed was sufficient to address the health adaptation needs.

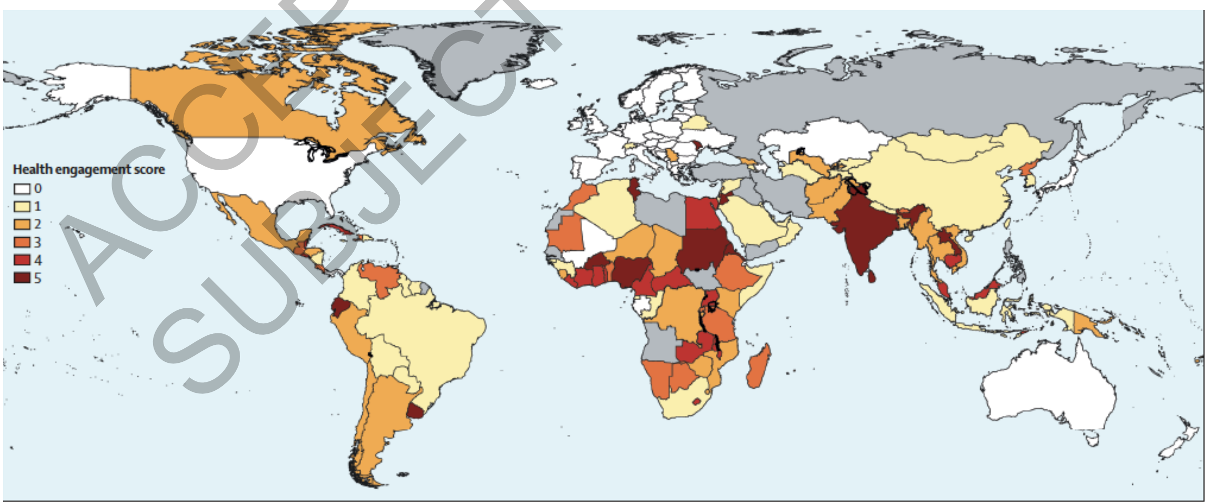

Figure 7.13: Health engagement score in NDCs by country. Source: Dasandi et al. 2021 (Dasandi et al., 2021)

The 2018 WHO Health and Climate Change Survey, a voluntary national survey sent to all 194 WHO member states, to which 101 responded, found that national planning on health and climate change is advancing, but the comprehensiveness of strategies and plans need to be strengthened; implementing action on key health and climate change priorities remains challenging; and multisectoral collaboration on health and climate change policy is evident, with uneven progress (Watts et al., 2021). Approximately 50% of respondent countries had developed national health and climate strategies, over 2/3 within the preceding five years, and 48/101 had conducted a health vulnerability and adaptation assessment (Watts et al., 2019). However, most countries reported only moderate or low levels of implementation, with financing cited as the most common barrier due to a lack of information on opportunities, a lack of connection by health actors to climate change processes and a lack of capacity to prepare country proposals. A review of public health systems in 34 countries found that only slightly more than half considered climate change impacts and adaptation needs (Berry et al., 2018).

Given the key health risks identified in this chapter, adaptation that increases resilience requires sustained, adaptive management (Ebi, 2011);(Hess et al., 2012) with the goal of transformative change. This includes differentiating adaptation to climate variability from adaptation to climate change (Ebi and Hess, 2020). Health adaptation efforts are increasingly aiming to transition to building climate-resilient and environmentally sustainable health systems (WHO, 2015b);(WHO, 2020a) and healthcare facilities, emphasizing service delivery, including climate-informed health policies and programs, management of the environmental determinants of health; emergency preparedness and management; and health information systems, including health and climate research, integrated risk monitoring and early warning systems, and vulnerability, capacity, and adaptation assessments (Marinucci et al., 2014);(Mousavi et al., 2020);(Organization, 2015);(CDC, 2019);(Organization, 2020). Previous and current projects funded by a range of groups, such as bilateral and multilateral development partners, include addressing key enabling conditions (e.g., leadership and governance) and developing the capacity of the health workforce to manage and govern changing risks. Because the health risks of climate change often vary within a country, sub-national assessments and plans are needed to help local authorities protect and promote population health in a changing climate (Aracena et al., 2021);(Basel et al., 2020);(Schramm et al., 2020a).

7.4.2.2 Adaptation in health policies and programs

Health policies were historically not designed or implemented taking into consideration the risks of climate change and as currently structured are likely insufficient to manage the changing health burdens in coming decades (very high confidence). The magnitude and pattern of future health burdens attributable to climate change, at least until mid-century, will be determined primarily by adaptation and development choices. Current and future emissions will play an increasing role in determining attributable burdens after mid-century. Increased investment in strengthening general health systems, along with targeted investments to enhance protection against specific climate-sensitive exposures (e.g., hazard early warning and response systems, and integrated vector control programs for vector-borne diseases) will increase resilience, if implemented to at least keep pace with climate change (*high confidence*). Investments to address the social determinants of health can reduce inequities and increase resilience (*high confidence).* (Thornton et al., 2016) ; (Marmot et al., 2020) (Wallace et al., 2015 measured as health, aging, retirement, are predictors of mortality and disability, with cross-country differences.) (Semenza and Paz, 2021)

Peer-reviewed publications of health adaptation to climate change in low- and middle-income countries have typically focused on flooding, rainfall, drought, and extreme heat, through improving community resilience, disaster risk reduction, and policy, governance, and finance (Berrang-Ford et al., 2021);(Scheelbeek et al., 2021). Health outcomes of successful adaptation have included reductions in infectious disease incidence, improved access to water and sanitation, and improved food security. Figure 7.14 shows a Sankey diagram of climate hazards, adaptation responses, and health outcomes, where CSA is climate-smart agriculture. The figure highlights the range of health adaptation responses that are discussed in more detail earlier in this chapter and demonstrates the potential health benefit of adaptation efforts that affect a broad range of health determinants.

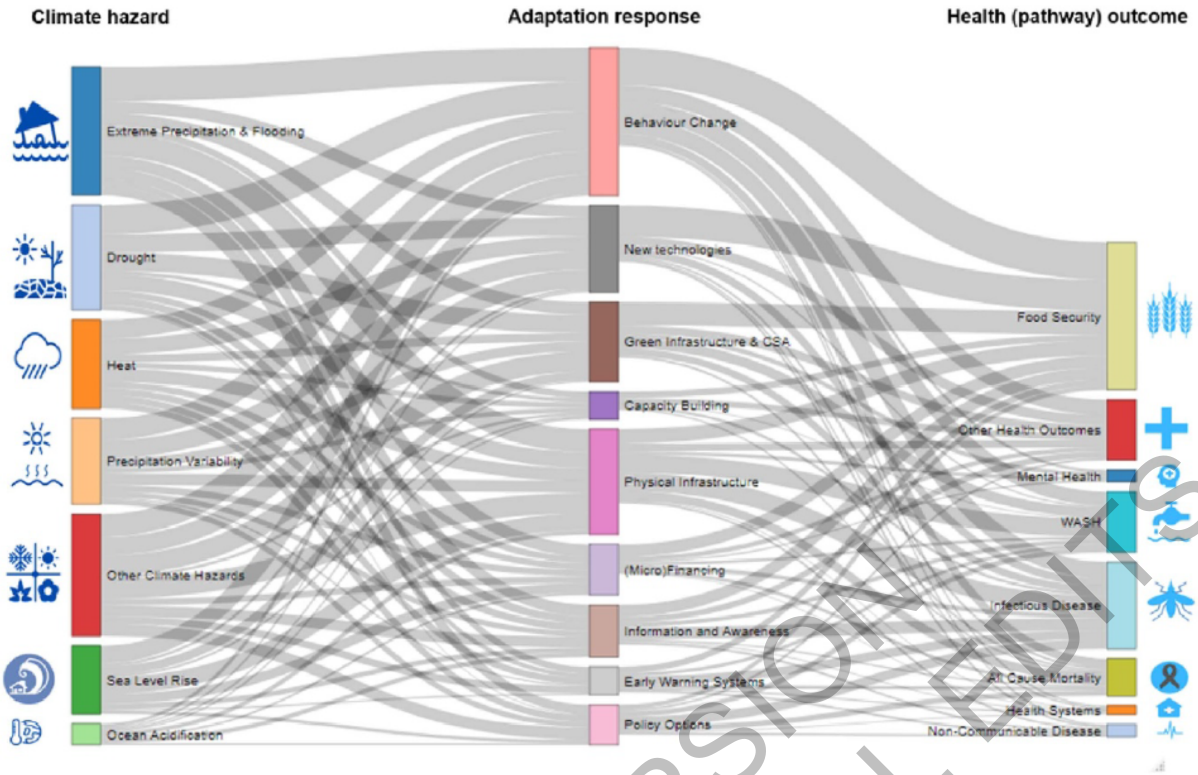

Figure 7.14: Sankey diagram of climate hazards, adaptation responses, and health outcomes. CSA is climate-smart agriculture. Source: Scheelbeek et al. 2021 (Scheelbeek et al., 2021).

Questions of the feasibility and effectiveness of health adaptation options differ from those in other sectors because public health is a societal enterprise that cuts across many different spheres of society. Consequently, there are dependencies that lie outside the jurisdiction of the health sector. All the health risks of a changing climate currently cause adverse outcomes, with policies and programs implemented in at least some health programs in some places. Policies and programs are continuously modified to increase effectiveness; this should accelerate in a changing climate. Improvements are needed as more is understood about disease aetiology, changing socioeconomic and environmental conditions, obstacles to uptake, and other factors.

A feasibility and effectiveness assessment was conducted of six adaptation strategies often used and recommended by the UN to respond to malnutrition risks, combining a literature review and expert judgment assessment of 80 peer-reviewed studies (UNSCN 2010; Tirado et al 2013; methods adapted from de Coninck et al. (2018) and Singh et al (2020). Nineteen indicators of six dimensions of feasibility (economic, technical, social, institutional, environmental, and geophysical) were considered. The lead time to initiate and expected longevity of each option were examined. Feasibility was defined as how significant the reported barriers were to implement a particular adaptation option. Highly feasible options were those where no or very few barriers were reported. Moderately feasible were those where barriers existed but did not have a strong negative effect on the adaptation option (or evidence was mixed). Low feasibility options had multiple barriers reported that could block implementation. Effectiveness ratings were based on expert consultation and reflected the potential of the adaptation option to reduce risk. The final effectiveness and feasibility scores were categorized as high, medium, or low, and reflect the combined results of all studies for a given adaptation option (Table 7.3). The assessed studies and categorizations are included as Supplementary Materials for this chapter.

Table 7.3: Feasibility and effectiveness assessments of multisectoral adaptation for food security and nutrition

Climate change impacts on food security and nutrition	Adaptation option	Evidence	Agreement	Feasibility Dimensions						Effectiveness	Enablers			
				Eco	Tec	Inst	Soc	Env	Geo		Women empowerment	Education	HDP Nexus	Rights-based approach & good governance
KEY RISK: Malnutrition in all its forms linked to decline in food availability and increased cost of healthy food	Climate-resilient, nutrition-sensitive and agroecological food production	Robust	High	M	M	H	L	H	H	Moderate	HR	HR	HR	HR
	Sustainable and healthy diets (local, equitable, diverse)	Robust	High	H	H	H	M	H	L	High	HR	HR	LR	LR
	Access to health, nutrition services and healthy environments (Water and sanitation)	Medium	High	M	M	M	H	M	L	Moderate	HR	HR	MR	HR
	Early warning systems to prevent adverse effects on nutrition	Robust	Medium	H	M	M	H	H	L	High	LR	HR	HR	LR
	Nutrition-sensitive social protection	Robust	High	H	H	L	L	H	H	High	HR	HR	MR	HR
	Nutrition-sensitive risk reduction, risk sharing and insurance	Medium	Low	L	H	L	H	H	NA	Low	MR	MR	LR	MR

Table Notes:
Abbreviations: Ec: Economic; Tec: Technical; Inst: Institutional; Soc: Socio-cultural; Env: Environmental; Geo: Geophysical. HR: high relevance, MR: medium relevance, LR: low relevance. NA = Not applicable/insufficient evidence

Policies and programs for climate-sensitive health outcomes are only beginning to incorporate the challenges and opportunities of climate change, although this is critical for increasing resilience. The fundamentals of many policies and programs in a changing climate will remain the same: implementing infectious disease control programs, preventing heat-related mortality and morbidity, and reducing the burden of other climate-related health endpoints, but activities will need to explicitly account for climate change to continue to protect health. Even with such attention to climate change, regrettably, there are limits to the feasibility and effectiveness of health adaptation options for some of these programs. For example, there are limits to adaptation to extreme heat, controlling emerging infectious diseases, and controlling cascading risk pathways.

As discussed in Chapter 1.4.2 and Chapter 1.5, an adaptation option is feasible when it is capable of being implemented by one or more relevant actors. In the health sector, the World Health Organization, UNICEF, and other organizations provide technical expertise to Ministries of Health, who then provide national to local healthcare and public health services. Generally, the question is less of overall feasibility, given the range of potential adaptation options that have yet to be fully explored and implemented, but more of readiness to buy-in to the adaptation efforts required from health and other sectors. In specific contexts, feasibility also depends on governance capacity, financial capacity, public opinion, and the distribution of political and economic power (Chapter 17). In other words, adaptation to climate change health impacts is broadly feasible with adequate investment and engagement, although this has yet to materialize, and in specific contexts, feasibility is contingent and time-varying and needs to be assessed at national to sub-national scales. For example, a scoping review in the Pacific region noted the following areas where further and significant investment and support are needed to increase feasibility of climate and health action: i) health workforce capacity development; ii) enhanced surveillance and monitoring systems; and iii) research to address priorities and their subsequent translation into practice and policy (Bowen et al., 2021). Vulnerability, adaptation, and capacity assessments include consideration of the feasibility and effectiveness of priority health adaptation options and can help decision makers identify strategies for enhancing adaptation feasibility in specific contexts.

7.4.2.3 Adaptation options for vector-borne, food-borne, and water-borne diseases

Integrated vector control approaches are crucial to effectively manage the geographic spread, distribution, and transmission of vector-borne diseases associated with climate change (high confidence). Some of the projected risks of climate change on VBD can be offset through enhanced commitment to existing approaches to integrated case management and integrated vector control management (Cissé et al., 2018);(Confalonieri et al., 2017);(Semenza and Paz, 2021). Important components include enhanced disease surveillance and early warning and response systems that can identify potential outbreaks at sub-seasonal to decadal time scales (J. and R., 2020);(Semenza and Zeller, 2014)(Table 7.4). In many cases, the exposure dynamics of VBD are strongly influenced by socio-economic dynamics that should be considered when developing and deploying adaptation options (UNEP, 2018). This is especially the case in low-income countries. For example, insufficient access to sanitation and presence of standing water are important determinants of the presence of *Ae. aegypti* populations and pathogens that cause visceral leishmaniasis (*L. donovani* and *L. infantum*) in urban and peri-urban areas; and low housing quality and lack of refuse management are associated with higher rodent infestation. Strategies expected to have important health co-benefits include those that support health systems strengthening; improve access to health coverage; increase awareness and education; and address underlying conditions of uneven development and lack of adequate housing and access to water and sanitation systems in areas endemic to mosquito-borne diseases (Semenza and Paz, 2021); Cross-Chapter Box ILLNESS in Chapter 2).

Adaptation options for climate-related risks for water-borne and food-borne diseases are strongly associated with wider, multi-sectoral initiatives to improve sustainable development in low-income communities (high confidence). Effective measures include improving access to potable water and reducing exposure of water and sanitation systems to flooding and extreme weather events (Brubacher et al., 2020);(Cisse, 2019) (Table 7.4). This requires focusing on farm-level interventions that limit the spread of pathogens into adjacent waterways, preventing the ongoing contamination of water and sanitation systems, and the promotion of food-safe human behaviours (Levy et al., 2018);(Nichols et al., 2018). It is also important to implement well-targeted and integrated WASH interventions, including at schools and ensuring proper disposal of excreta and wastewater. Cities can integrate regional climate projections into their engineering models, to produce lower-risk source waters, to increase the resilience of water and sanitation technologies and management systems under a range of climate scenarios. Technologies can help abstract source waters from depth, introduce or increase secondary booster disinfection, design or modify systems to reduce residence times within pipes, and/or coat exposed pipes (Levy et al., 2018). Other efficient interventions include source water protection, promoting water filtration, testing the presence of waterborne pathogens in shellfish, trade restrictions and improvement of hygiene at all levels (Semenza and Paz, 2021). Needed actions include early warning and response systems, strengthening the resilience of communities and health systems, and promoting water safety plans and sanitation safety plans (Brubacher et al., 2020);(Cisse, 2019);(Ford and Hamner, 2018);(Lake and Barker, 2018);(Levy et al., 2018);(Nichols et al., 2018);(Organization and Association, 2009);(Organization, 2016);(Organization, 2018b);(Semenza, 2021);(Rocklöv et al., 2021).

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Table 7.4: Summary of adaptation options for key risks associated with climate-sensitive vector-, water- and food-borne diseases

Key risk	**Geographic region(s) at higher risk**	**Consequence that would be considered severe, and to whom**	**Hazard conditions that would contribute to this risk being severe**	**Exposure conditions that would contribute to this risk being severe**	**Vulnerability conditions that would contribute to this risk being severe**	**Adaptation options with high potential for reducing risk**	**Selected key references**
Vector-borne diseases	Global	Increase in the incidence of some vector-borne diseases such as malaria, dengue, and other mosquito-borne diseases, in endemic areas and in new risk areas (e.g., cities, mountains, northern hemisphere)	Increased climatic suitability for transmission (e.g., enhanced vectorial capacity through a temperature shift)	Large increases in human exposure to vectors driven by growth in human and vector populations, globalization, population mobility, and urbanization	Few effective vaccines, weak health systems, ineffective personal and household protections, susceptibility to disease, poverty, poor hygiene conditions, insecticide resistance, behavioral factors	Improved housing, better sanitation conditions and self-protection awareness. Insecticide treated bednets and indoor spraying of insecticide. Broader access to healthcare for the most vulnerable. Establishment of disease surveillance and early warning systems for vector-borne diseases. Cross-border joint control of outbreaks. Effective vector control. Targeted efforts to develop vaccines.	(Cissé et al., 2018);(Semenza, 2021);(J. and R., 2020)
Water-borne diseases	Mostly low- and middle-income countries (Africa and Asia); small islands; global for *Vibrios*	Increase in the occurrence and intensity of waterborne diseases such as *Vibrios* (particularly *V. cholerae*), diarrheal diseases, other water-borne gastro-intestinal illnesses	Substantial changes in temperature and precipitation patterns, increased frequency and intensity of extreme weather events (e.g., droughts, storms, floods), ocean warming and acidification	Large increases in exposure, particularly in areas with poor sanitation, flood-prone areas, and favourable ecological environments for waterborne disease pathogens	Poor hygiene conditions, lack of clean drinking water and safe food, flood and drought prone areas, vulnerabilities of water and sanitation systems	Improved water, sanitation and hygiene conditions and better surveillance system. Improved personal drinking and eating habits, behaviour change	(Brubacher et al., 2020);(Ford and Hamner, 2018);(Lake, 2018);(Levy et al., 2018);(Nichols et al., 2018);(Rocklöv et al., 2021)
Food-borne diseases	Global	Increase in the occurrence and intensity of foodborne diseases such as *Salmonella* and *Campylobacter,*	Substantial changes in temperature and precipitation patterns, increased frequency and intensity of	Large increases in exposure, particularly in areas with poor sanitation, flood-prone areas and favourable ecological	Poor hygiene conditions; lack of clean drinking water and safe food; flood and drought prone areas. Vulnerabilities in water and sanitation systems, food storage	Improved water, sanitation and hygiene conditions and better surveillance system. Improved personal drinking and eating habits, behaviour change. Improved food storage, food	(Brubacher et al., 2020);(Ford and Hamner, 2018);(Lake, 2018);(Levy et al., 2018);(Nichols et

		including in high-income countries	extreme weather events (e.g., droughts, storms, floods), ocean warming and acidification	environment for foodborne disease pathogens	systems, food processes, food preservation, and cold chain/storage	processing, food preservation, cold chain/storage	al., 2018);(Rocklöv et al., 2021)

7.4.2.4 Adaptation options for heat-related morbidity and mortality

Adaptations options for heat refer to strategies implemented at short time scales such as air conditioning and heat action plans, including heat warning systems and longer-term solutions such as urban design and planning and nature -based solutions (Table 7.5).

To date, air conditioning is the main adaptation approach for mitigating the health effects of high temperatures, especially in relation to cardiorespiratory health (Madureira et al., 2021). However, air conditioning may constitute a maladaptation because of its high demands on energy and associated heat emissions, especially in high-density cities (Eriksen et al., 2021);(Magnan et al., 2016);(Schipper, 2020) and also lead to 'heat inequities' as this is not an affordable or practical option for many (Jay et al., 2021);(Turek-Hankins et al., 2021). Heat action plans (HAP) link weather forecasts with alert and communication systems and response activities, including public cooling centres, enhanced heat-related disease surveillance, and a range of individual actions designed to reduce the health effects of extreme heat events such as seeking shade and altering the pattern of work (McGregor et al., 2015). While well designed and operationalisable HAPs possess the potential to reduce the likelihood of mortality from extreme heat events (*medium confidence*) (Benmarhnia et al., 2016);(Heo et al., 2019b);(Martinez-Solanas and Basagana, 2019);(Martinez et al., 2019);(De'Donato et al., 2018);, full process and outcome based evaluations of HAPs and their constituent components are lacking, (Boeckmann and Rohn, 2014);(Chiabai et al., 2018b);(Boeckmann and Rohn, 2014);(Nitschke et al., 2016; Diaz et al., 2019);(Benmarhnia et al., 2016);(Heo et al., 2019a), (Heo et al., 2019b)); (Ragettli and Roosli, 2019). Evaluations of heatwave early warning systems as a component within HAPs show inconsistent results in terms of their impact on predicting mortality rates (Nitschke et al., 2016);(Benmarhnia et al., 2016);(Heo et al., 2019a), (Heo et al., 2019b)); (Ragettli and Roosli, 2019);(Martinez et al., 2019);(De'Donato et al., 2018);{;(Weinberger et al., 2018b), indicating climate-based heat warning systems, which use a range of heat stress metrics (Schwingshackl et al., 2021), are not sufficient as a stand-alone approach to heat risk management (*high confidence*). To support HAP and heat risk related policy development, identification and mapping of heat vulnerability 'hot spots' within urban areas have been proposed (Chen et al., 2019); (Hatvani-Kovacs et al., 2018)

A multi-sectoral approach, including the engagement of a range of stakeholders will likely benefit the response to longer term heat risks, through implementation of measures such as climate sensitive urban design and planning that mitigates urban heat island effects (high confidence). (Ebi, 2019), (Jay et al., 2021);(Alexander et al., 2016);;(Levy, 2016);(Masson et al., 2018);(McEvoy, 2019);(Pisello et al., 2018). In the shorter-term, potentially localized solutions can include awnings, louvers, directional reflective materials, altering roof albedo), mist sprays, evaporative materials, green roofs and building facades and cooling centres (Jay et al., 2021);(Macintyre and Heaviside, 2019);(Spentzou et al., 2021);(Takebayashi, 2018). Nature-based solutions (NbS) to reduce heat that offer co-benefits for ecological systems include green and blue infrastructure (e.g., urban greening/forestry and the creation of water bodies) (Koc et al., 2018);(Lai et al., 2019);(Shooshtarian et al., 2018);(Ulpiani, 2019);(Zuvela-Aloise et al., 2016), (Hobbie and Grimm, 2020). The implementation of climate-sensitive design and planning can be constrained by governance issues;(Jim et al., 2018) and the benefits are not always evenly distributed among residents. Implementation of climate-sensitive design and NbS does, however, need to be carried out within the context of wider public health planning because water bodies and moist vegetated surfaces provide suitable habitats for a range of disease vectors;(Nasir et al., 2017);(Tian et al., 2016);(Trewin et al., 2020). Solutions recommended for managing exposure to heat in outdoor workers include improved basic protection (including shade, planned rest breaks), heat-appropriate personal protective equipment, work scheduling for cooler times of the day, heat acclimation, improved aerobic fitness, access to sufficient cold drinking water, and on-site cooling facilities and mechanisation of work (Morabito et al., 2021);(Morris et al., 2020);(Varghese et al., 2020);(Williams et al., 2020).

Most adaptation options were developed in high- and middle-income countries, and typically require significant financial resources for their planning and implementation. Studies are needed of the benefits of Indigenous and non-Western approaches to managing and adapting to extreme heat risk. Recently published reviews of approaches to heat adaptation outline the nature and limitations of a range of cooling strategies with optimal solutions for a number of settings recommended (Jay et al., 2021);(Turek-Hankins et al., 2021).

1 **Table 7.5:** Summary of adaptation options for key health risks associated with heat.

Key risk	Geographic region	Consequence that would be considered severe, and to whom	Hazard conditions that would contribute to this risk being severe	Exposure conditions that would contribute to this risk being severe	Vulnerability conditions that would contribute to this risk being severe	Adaptation options with high potential for reducing risk	Selected key references
Heat-related mortality and morbidity and mental illness	Global but especially where temperature extremes beyond physical and mental health and thermal comfort threshold levels are expected to increase	Substantial increase in heat-related mortality and morbidity rates, especially in urban centres (heat island effect) and rural areas (outside workers), outdoors in general (sports and related activities) and for people suffering from obesity, weak cardiovascular capacity /physical fitness. Increased risk of respiratory diseases and cardiovascular diseases (CVD) mortality. Loss of economic productivity. Substantial increase in mental illness compared to base rate.	Substantial increase in frequency and duration of extreme heat events, especially in cities where heat will be exacerbated by urban heat island effects. Unintended increases in urban temperatures from anthropogenic heat (vehicles, air conditioning, urban metabolism) Increased number of days with high temperatures in non-urban settings such as agricultural areas.	Large increases in urban heat and population heat exposure driven by demographic change (e.g., aging) and increasing urbanization. Exposure will increase amongst agricultural and construction workers	Mortality/morbidity: Increases in the number of very young and elderly, and of those with other health conditions such as lack of physical fitness, obesity, diabetes and associated comorbidities, lack of adaptation capacity Mental illness: Lack of air conditioning. Lack of access to health care systems and services	Heat warning systems. Improved building and urban design (including green and blue infrastructure), passive cooling systems acknowledging that not all will have access to air conditioning. Broader understanding of heat hazard and better access to public health systems for the most vulnerable. Application where possible of renewable energy sources. Communication around drinking, availability of clean water, via simple effective water purification systems in low water quality settings, and water spray cooling. Mental health support.	(Benmarhnia et al., 2016);(Chen et al., 2019); (Jay et al., 2021);(Heo et al., 2019b);(Martinez-Solanas and Basagana, 2019);(Morabito et al., 2021);(Schwingshackl et al., 2021)

2

7.4.2.5 Adaptation options for air pollution

As noted in 7.3.1.6, air pollution projections indicate ambitious emission reduction scenarios or stabilisation of global temperature change at 2ºC or below would yield substantial co-benefits for air quality-related health outcomes. Improvements in air quality could be achieved by the deliberate adoption of a range of adaptation options to complement mitigation measures such as decarbonisation (e.g. renewable energy, fuel switching, energy efficiency gains, carbon capture storage and utilization) and negative emissions technologies (e.g. bioenergy carbon capture and storage, soil carbon sequestration, afforestation and reforestation, wetland construction and restoration).

Adaptation options for air pollution include implementing ozone precursor emission control programmes, developing mass transit/efficient public transport systems in large cities, encouraging car-pooling and cycling and walking (active transport), traffic congestion charges, low emission zones in cities and integrated urban planning, implementing NbS such as the green infrastructure for pollutant interception and removal, managing wildfire risk regionally and across jurisdictional boundaries, developing air quality warning systems, altering activity on high pollution days, effective air pollution risk communication and education, wearing protective equipment such as face masks, avoiding solid fuels for cooking and indoor heating, ventilating and isolating cooking areas, and using portable air cleaners fitted with high-efficiency particulate air filters (Abhijith et al., 2017);(Carlsten et al., 2020);(Cromar et al., 2020);(Ding et al., 2021);(Holman et al., 2015);(Jennings et al., 2021);(Kelly et al., 2021);(Kumar et al., 2019);(Masselot et al., 2019);(Ng et al., 2021);(Riley, 2021);(Voordeckers et al., 2021);(Xu et al., 2017)(Table 7.6). While the range of air pollution adaptation options is potentially extensive, barriers may need to be overcome to achieve successful implementation, including financial, institution, political/inter- and intra-governmental and social barriers (Barnes et al., 2014);(Ekstrom and Bedsworth, 2018);(Fogg-Rogers et al., 2021);(Schumacher and Shandas, 2019).

Table 7.6: Summary of adaptation options for key health risks associated with air pollution.

Key risk	Geographic region	Consequence that would be considered severe, and to whom	Hazard conditions that would contribute to this risk being severe	Exposure conditions that would contribute to this risk being severe	Vulnerability conditions that would contribute to this risk being severe	Adaptation options with high potential for reducing risk	Selected key references
Air pollution related health	Global but especially in regions with existing poor air quality particularly in relation to particulate matter and ozone. Greatest climate change driven ozone related mortality is expected for East Asia and North America. For particulate matter the highest climate and air quality related mortalities are projected for India, the Middle East, Former Soviet Union and East Asia	Substantial increase in air pollution-related mortality and morbidity rates, especially in urban centres related to both severe pollution episodes and longer-term deterioration of air quality. People particularly vulnerable include those with respiratory tract infections and respiratory and cardiovascular disease. Increase in mental illness (depression) as a result of poor air quality and visibility.	Non-achievement of emission reduction targets. Substantial increase in frequency and duration of meteorological conditions conducive to the build-up of both primary and secondary air pollutants (e.g. greater frequency of calm atmospheric 'blocking' conditions) and no long term improvement in air quality at a range of geographical scales (global to the local). Increase in frequency and intensity of wildfires and dust storms. Increase in the	Large increases in exposure to air pollutants driven by demographic change (e.g., aging) and increasing urbanization. For arid regions increases in exposure to dust storms. Areas adjacent/downwind of major wildfires. For urban populations intensifying urban heat islands and enhanced formation of secondary pollutants	Increases in the number of very young and elderly, and those with respiratory or cardiovascular conditions and lack of adaptation capacity (e.g., reduce reliance on solid fuel for cooking/heating) Mental illness: Lack of access to health care systems and services	Air quality management policies, air quality warning systems, efficient and cheap mass transit systems, integrated urban planning, (including NBS and green infrastructure) Broader understanding of air pollution hazard and better access to public health systems for the most vulnerable. Application where possible of renewable energy sources to reduce emissions.	(Carlsten et al., 2020);(Doherty et al., 2017);(Jennings et al., 2021);(Kumar et al., 2019);(Orru et al., 2017; Orru et al., 2019) (Schumacher and Shandas, 2019);(Silva et al., 2017);(Voordeckers et al., 2021)

			intensity of urban heat islands especially in the summer and the occurrence of ozone episodes due to anomalously high urban temperatures.				

7.4.2.6 Multisectoral Adaptation for Nutrition

Adaptation to reduce the risk of malnutrition requires multi-sectoral, integrated approaches (very high confidence). Adaptation actions include access to healthy, affordable diverse diets from sustainable food systems *(high confidence)*; a combination of access to health -including maternal, child and reproductive health-, nutrition services, water and sanitation (*high confidence*); access to nutrition-sensitive and shock-responsive social protection (*high confidence*); early warning systems (*high agreement*), risk sharing, transfer, and risk reduction schemes such as insurance index-based weather insurance *(medium confidence)*. (Mbow et al., 2019);(Swinburn et al., 2019; UNICEF/WHO/WBG, 2019);(FAO et al., 2021);(Macdiarmid and Whybrow, 2019);(Liverpool-Tasie et al., 2021);(Fakhri, 2021). Common enablers across adaptation actions that enhance the effectiveness and feasibility of the adaptation include: education, women and girls' empowerment (*high confidence*), rights-based governance, and peace-building social cohesion initiatives such as the framework of the Humanitarian Development and Peace Nexus *(medium confidence).*

Nutrition-sensitive and integrated agroecological farming systems offer opportunities to increase dietary diversity at household levels while building local resilience to climate-related food insecurity (high confidence). (Bezner Kerr et al., 2021);(IPES-Food, 2020);(Altieri et al., 2015) especially when gender equity, racial equity, and social justice are integrated (Bezner Kerr et al., 2021). Adaptation responses include a combination of healthy, culturally appropriate, and sustainable food systems and diets, soil and water conservation, social protection schemes and safety nets, access to health services, nutrition-sensitive risk reduction, community-based development, women's empowerment, nutrition-smart investments, increased policy coherence, and institutional and cross-sectoral collaboration *(high agreement, medium evidence)* (FAO et al., 2018);(Mbow et al., 2019);(Pozza and Field, 2020);(FAO et al., 2021) (Table 7.7). Nutrition security can be enhanced through consideration of nutrient flows in food systems (Harder et al., 2021).This 'circular nutrient economy' perspective highlights the potential for adaptations throughout the food supply chain, including sustainable production practices that promote nutrient diversity and density, processing, storage, and distribution that conserves nutrition, equitable access and consumption of available, affordable, appropriate, and healthy foods, and waste management that supports nutrient recovery (Harder et al., 2021);(Boon and Anuga, 2020);(FAO et al., 2021);(Pozza and Field, 2020);(Ritchie et al., 2018). Traditional, Indigenous, and small-scale agroecology and regional food systems provide context-specific adaptations that promote food and nutrition security as well as principles of food sovereignty and food systems resilience (HLPE, 2020);(Bezner Kerr et al., 2021);(IPES-Food, 2020);(IPES-Food, 2018).

Adaptive social protection programs and mechanisms that can support food insecure households and individuals include cash transfers or public work programs, land reforms, and extension of credit and insurance services that reduce food insecurity and malnutrition during times of environmental stress (Carter and Janzen, 2018), (Johnson et al., 2013); (Alderman, 2016). For example, children from families participating in Ethiopia's Productive Safety Net Program experienced improved nutritional outcomes, partly due to better household food consumption patterns and reduced child labor (Porter and Goyal, 2016). School feeding programs improve nutritional outcomes, especially among girls, by promoting education, and by reducing child pregnancy and fertility rates (Bukvic and Owen, 2017). Adaptive social protection is most effective when it combines climate risk assessment with disaster risk reduction and wider socioeconomic development objectives (Davies et al., 2013).

Transformative approaches towards healthier, more sustainable, plant-based diets require integrated strategies, policies, and measures, including economic incentives for the agroecological production and equitable access to and consumption of more fruits, vegetables, and pulses, inclusion of sustainability criteria in dietary guidelines, labelling, public education programs and promoting collaboration, good governance, and policy coherence {Glover, 2019, Principles of innovation to build nutrition-sensitive food systems in South Asia

Table 7.7: Summary of adaptation options for key risks associated with malnutrition

Key risk	Geographic region	Consequence that would be considered severe, and to whom	Hazard conditions that would contribute to this risk being severe	Exposure conditions that would contribute to this risk being severe	Vulnerability conditions that would contribute to this risk being severe	Adaptation options with high potential for reducing risk	Selected key references
Malnutrition due to decline in food availability and increased cost of healthy food	Global, with greater risks in Africa, South Asia, Southeast Asia, Latin America, Caribbean, Oceania	Substantial number of additional people at risk of hunger, stunting, and diet-related morbidity and mortality, including decreased mental health and cognitive function. Micro- and macronutrient deficiencies. Severe impacts on low-income populations from LIMICs. Risks especially high to groups that suffer greater inequality and marginalization.	Climate changes leading to reductions in crop, livestock, or fisheries yield, including temperature and precipitation changes and extremes, drought, and ocean warming and acidification	Large numbers of people in areas and markets particularly affected by climate impacts on food security and nutrition	High levels of inequality (including gender inequality), substantial numbers of people subject to poverty or violent conflict, in marginalized groups, or with low education levels. Slow economic development. Ineffective social protection systems, nutrition services, and health services.	Multi-sectoral approach to nutrition-sensitive adaptation and disaster risk reduction / management, including food, health, and social protection systems. Inclusive governance involving marginalized groups. Improved education for girls and women. Maternal and child health, water and sanitation, gender equality, climate services, social protection mechanisms.	(Glover and Poole, 2019);(Mbow et al., 2019);; (Swinburn et al., 2019)

7.4.2.7 Adaptation options for risks to mental health

Adaptation options for reducing mental health risks associated with extreme weather include preventive and post-event responses (high confidence). (Brown et al., 2017); {Cohen, 2019 #3534},(James et al., 2020) (Table 7.8). Responses include improving funding and access to mental health care, which is under-resourced (WHO, 2019); surveillance and monitoring of psychosocial impacts of extreme weather events; community-level planning for mental health as part of climate resilience planning (Clayton et al., 2017); and mental health and psychological first aid training for care providers and first responders (Hayes et al., 2018);(O'Donnell et al., 2021);(Hayes et al., 2018; Taylor, 2020);(Morgan et al., 2018);(Sijbrandij et al., 2020). Legislation can ensure access to services as well as establish a regulatory framework (Ayano, 2018). Advanced disaster risk planning reduces post-event mental health challenges. One example is from China, where pre-planning of temporary shelters resulted in significantly lower rates of anxiety, depression, and PTSD in the aftermath of flooding among displaced people who accessed them (Zhong et al., 2020). Key elements of successful initiatives include coordinated planning and action between key regional agencies and governments, with a focus on improving accountability and removing barriers to implementation and subsequent access to programs (Ali et al., 2020). As an example, following the 2019/2020 Australian bushfires, the federal government allocated funds to support mental health through free counselling for those affected, increased access to tele-health, extended hours for mental health services and programs designed specifically for youth (Newnham et al., 2020).

Because mental health is fundamentally intertwined with social and economic wellbeing, adaptation for climate-related mental health risks benefits from wider multi-sectoral initiatives to enhance wellbeing, with the potential for co-benefits to emerge (high confidence). Improvements in education, quality of housing, safety, and social protection support enhance general wellbeing and make individuals more resilient to climate risks (Lund et al., 2018);(Hayes et al., 2019). Among Indigenous Peoples, connections to traditional culture and to place are associated with health and wellbeing (Bourke et al., 2018) as well as with resilience to environmental change (Ford et al., 2020). As an example of the connection between infrastructure improvements and mental health, a study of domestic rainwater harvesting initiatives to promote household water security also improved mental health in participating households (Mercer and Hanrahan, 2017). Adaptive urban design that provides access to healthy natural spaces – an option for reducing risks associated with heat stress – also promotes social cohesion and mitigates mental health challenges *(high confidence)* (Buckley et al., 2019);(Clayton et al., 2017);(Jennings and Bamkole, 2019);(Liu et al., 2020b);(Mygind et al., 2019);(Marselle et al., 2020).

Table 7.8: Summary of adaptation options for key risks associated with mental health

Key Risk	Geographic region	Consequence that would be considered severe, and to whom	Hazard conditions that would contribute to this risk being severe	Exposure conditions that would contribute to this risk being severe	Vulnerability conditions that would contribute to this risk being severe	Adaptation options with high potential for reducing risk	Selected key references
Mental health impacts in response to floods, storms, and fires	Global; some areas at greater risk for storms, flooding, or wildfires	Substantial increase in mental illness compared to base rate	Increased frequency of major storms, weather-related flooding, or wildfires	Low-lying areas, dry areas, urban areas	Physical infrastructure that is vulnerable to extreme weather, inadequate emergency response and mental health services, social inequality	Improved urban infrastructure, warning systems, and post-disaster social support, improving funding and access to mental health care; improved surveillance and monitoring of mental health impacts of extreme weather events; climate change resilience planning in the mental health system (including at a community level); and mental health first aid training for care providers and first responders	(Ali et al., 2020);(Ayano, 2018);(Buckley et al., 2019);(Clayton et al., 2017);(Hayes et al., 2019);(James et al., 2020);(Sijbrandij et al., 2020)

7.4.2.8 Adaptation options to facilitate non-heat early warning and response systems

Early warning systems are a potentially valuable tool in adapting to climate-related risks associated with infectious diseases when based on forecasts with high skill and when there are effective responses within the time frame of the forecast (high confidence). Through advanced seasonal weather forecasting that draws upon established associations between weather/climate and infection/transmission conditions, conditions conducive to disease outbreaks can be identified months in advance, providing time to implement effective population health responses (Morin et al., 2018). Most current early warning systems are focused on malaria and dengue, but there are examples for other diseases, such as an early warning system developed for *Vibrios* monitoring in the Baltic Sea (Semenza et al., 2017). An early warning system for dengue outbreaks in Colombia based on temperature, precipitation, and humidity successfully detected 75% of all outbreaks between one and five months in advance, detecting 12.5% in the same month (Lee et al., 2017b). Dengue warning systems in Brazil, Malaysia, and Mexico have generated satisfactory results (Hussain-Alkhateeb et al., 2018). An effective early warning system for malaria was implemented in the Amhara region of Ethiopia (Merkord et al., 2017).

Early warning systems are effective at detecting and potentially reducing food security and nutrition risks (high confidence). Examples of proven systems include the USAID Famine Early Warning System, FAO's Global Information and Early Warning System, and WFP's Corporate Alert System. Such systems are fundamental for anticipating when a crisis might occur and setting priorities for interventions (Funk et al., 2019). Financial investments to develop early warning systems are cost-effective and reduce human suffering (Choularton and Krishnamurthy, 2019) (*high confidence*). For instance, during the 2017 drought-induced food crisis in Kenya, 500,000 fewer people required humanitarian assistance than would have been expected based on past experiences; this was largely due to timely and effective interventions triggered by the early warning (Funk et al., 2018).

Early warning systems have been established for other climate-sensitive health outcomes, such as respiratory diseases associated with air pollution (Shih et al., 2019);(Li and Zhu, 2018);(Yang and Wang, 2017). Early warning systems for non-heat extreme weather and climate events, such as storms and floods, are designed to protect human health and wellbeing; disaster risk management organizations and institutions typically communicate these warnings through their networks. Research is ongoing to extend the time period for warnings.

7.4.2.9 Incorporating Disaster Risk Reduction into Adaptation

Integrating health into national disaster risk management plans has wider benefits for resilience and adaptation to climate change risks (high confidence). (UNFCCC, 2017a);(Watts et al., 2019). Disaster risk reduction (DRR), including disaster preparedness, management and response, is widely recognized as important for reducing health consequences of climate-related hazards and extreme weather events (Keim, 2008);(Phalkey and Louis, 2016). A systematic review by Islam et al., (2020) identified multiple, ongoing challenges to integrating climate adaptation and DRR at global and national levels, including a lack of capacity among key actors and institutions, a lack of coordination and collaboration across scales of government, and general lack of funding – challenges that are particularly relevant for the health sector. Global events, including climate-related extreme events and public health emergencies of international concern (for example, Ebola, MERS and COVID-19) have influenced the development of national public health preparedness and response systems and attracted significant investment over the last two decades (Khan et al., 2015);(Murthy et al., 2017);(Watson et al., 2017). The Sendai Framework for Disaster Risk Reduction and the International Health Regulations establish important global and regional goals for increasing health system resilience, and reducing health impacts from biological hazards and extreme climate events (Aitsi-Selmi et al., 2015);(Maini et al., 2017);(UNFCCC, 2017b);(Wright et al., 2020). There are explicit links between the health aspect of the Sendai Framework and UN Sustainable Development Goals 1, 2, 3, 4, 6, 9, 11, 13, 14, 15 and 17 (Wright et al., 2020). More specifically, reducing the number of disaster-related deaths, illnesses and injuries, as well as damage to health facilities are key indicators for achieving the goals set out in the Sendai Framework (UNFCCC, 2017b).

The intersection of health and multisectoral disaster risk reduction and management, generally described as as Health Emergency and Disaster Risk Management (Health-EDRM), encompasses multisectoral approaches from, epidemic preparedness and response including the capacities for implementing the International Health Regulations (IHR, 2005), health systems strengthening and health systems resilience (Lo Iacono et al., 2017);(Organization, 2019);(Wright et al., 2020). Health-EDRM costs to governments are notably lower than the cost of inaction (Peters et al., 2019). Additional per capita costs in low-income countries have been estimated to range from 4.33 USD (capital) and 4.16 USD (annual recurrent costs), and in upper middle-income countries to an additional 1.35 USD in capital costs and 1.41 USD in extra annual recurrent costs (Peters et al., 2019). Adopting a Health-EDRM approach supports the systematic integration of health and multisectoral DRM to ensure a holistic approach to health risks and assists alignment of action in health security, climate change and sustainable development (Chan and Peijun, 2017);(Dar et al., 2014);(Organization, 2019);(Wright et al., 2020).

Climate-informed Health-EDRM is crucial for the climate resilience of health systems (Organization, 2015), particularly to account for additional risks and uncertainties associated with climate change and allow for well-planned, effective and appropriate DRM and adaptation (Watts et al., 2018a);(WHO, 2013);(Organization, 2015). Potential coherent approaches to addressing climate change and disaster risks to health include: strengthening health systems; vulnerability and risk assessments that incorporate disaster and climate change risk; building resilience of health systems and health infrastructure; and climate-informed EWSs (Banwell et al., 2018);(Phalkey and Louis, 2016). However, a review of DRR projects including climate change in South Asia found that the health sector was the least represented with only 2% of 371 projects relating to health (Mall et al., 2019) indicating a need to strengthen the incorporation of climate change in Health-EDRM. Current tracking under the Sendai Framework of Disaster Risk Reduction 2015-2030 shows that most countries (particularly low-income countries and lower-middle income countries) still lack robust systems for integrated risk monitoring and early warning (UNEP, 2018). The incorporation of disaster risk reduction and management strategies into climate adaptation for health and health systems at local scales is particularly important, given that it is at local scales where health services are most often delivered and where knowledge of specific needs and challenges is often greater (Amaratunga et al., 2018) (Schramm et al., 2020a). Indigenous knowledge has been shown to be valuable in disaster risk reduction, with particularly strong evidence existing for drought risk reduction in sub-Saharan Africa (Fummi et al., 2017; Muyambo et al., 2017) (Dube and Munsaka, 2018);(Macnight Ngwese et al., 2018). In the US, disaster risk reduction strategies that draw upon traditional knowledge and local expertise are being incorporated into climate adaptation planning for health in a number of Indigenous communities under the "Climate-ready Tribes Initiative" (Schramm et al., 2020b).

7.4.2.10 Monitoring, Evaluation and Learning

Monitoring, evaluation and learning (MEL) can assess the ability of nations and communities to prepare for and adequately respond to the health risks of climate change over time (high confidence). (Boyer et al., 2020). MEL describes a process that includes baseline assessment, prioritizing actions and activities, identifying key indicators to track, ongoing data collection, and periodically considering new information (Kruk et al 2015). MEL determines whether adaptation options achieved their goals and whether resources were used effectively and efficiently (Boyer et al., 2020). One of the challenges for MEL in the context of adaptation is that climate risks vary as a function of time, location, socio-economic development, demographics, and activities in other sectors (Ebi et al., 2018a). MEL indicators in the health sector need to account for factors related to governance, implementation, and learning as well as for exposures, impacts, and programmatic activities, all of which are context dependent and are often outside the health sector (Boyer et al., 2020);(Ebi et al., 2018a);(Fox et al., 2019).

No universal standardized approach exists for monitoring or evaluating adaptation activities in the health sector (high confidence). Candidate indicators of climate change health impacts and adaptation activity, typically at the national level, are available (Bowen and Ebi, 2017);(Cheng and Berry, 2013);(Kenney et al., 2016);(Navi et al., 2017);(Organization, 2015). Indicators are best grouped by category of activity, i.e., vulnerability, risk, and exposure; impacts; and adaptation and resilience (Ebi et al., 2018a). As health adaptation expands, enhanced monitoring will be needed to ensure that scientific advances are translated into policy and practice. A promising initiative that emerged since the AR5 is the *Lancet Countdown*, which represents a global effort at tracking various indicators of exposures, impacts, adaptation activities, finance, and media activity related to climate change and health (Watts et al., 2018a), although this effort is principally focused on monitoring and does not explicitly focus on evaluation adaptation efforts or learning from adaptation efforts.

Community-based monitoring of adaptation responses to health impacts, especially in Indigenous Peoples, has not been widely undertaken, despite its potential to improve monitoring of, and local adaptation to, environmental change (Kipp et al., 2019). The health sector has been particularly weak at recognizing climate impacts on and adaptation needs of Indigenous peoples and in engaging Indigenous Peoples in monitoring progress (Ford et al., 2018, (David-Chavez and Gavin, 2018); (Ramos-Castillo et al., 2017). Successful adaptation to the health impacts of climate change in Indigenous Peoples requires recognition of their rights to self-determination, focusing on Indigenous conceptualizations of wellbeing, prioritizing Indigenous knowledge, and understanding the broader agenda of decolonization, health, and human rights (*high confidence)* (Ford and King, 2015);(Green and Minchin, 2014);(Hoy et al., 2014);(Jones, 2019);(Jones et al., 2014);(Mugambiwa, 2018);(Nursey-Bray and Palmer, 2018).

Indicators should capture measures of processes that drive adaptation readiness, including leadership, institutional learning, and intersectoral collaboration (Boyer et al., 2020);(Ford and King, 2015), as well as outcome measures such as presence of programming known to reduce risks (Ebi et al., 2018a). Additionally, indicators related to scaling up of effective interventions, relying on implementation science frameworks are important (Damschroder et al., 2009);(Theobald et al., 2018 2020, Using Implementation Science For Health Adaptation: Opportunities For Pacific Island Countries);(Ebi et al., 2018a);(Fox et al., 2019). Measuring impacts attributable to climate change could be addressed with a combination of indicators related to overall health system performance and population vulnerability (Ebi et al., 2017);(Ebi et al., 2018a).

7.4.3 Enabling Conditions and Constraints for Health and Wellbeing Adaptation

7.4.3.1 Governance, Collaboration, and Coordination

Effective governance institutions, arrangements, funding, and mandates are key for adaptation to climate-related health risks (high confidence). Without integration and collaboration across sectors, health adaptation can become siloed, leading to less effective adaptation or even maladaptation (Magnan et al., 2016);(Fox et al., 2019). Integration and collaboration include working laterally across national government departments and agencies, as well as vertically, from national agencies to local governments, and with the private sector, academia, NGOs, and civil society. In this context, top-down policy design and implementation are complemented by bottom-up approaches that engage community actors in program design, and draw upon their local practices, perspectives, opinions, and experiences. Opportunities exist to better integrate public health into climate change discourse and policymaking processes and strengthen public health partnerships and collaborative opportunities (Awuor et al., 2020). Creating networks, integration across organizations and jointly developed policies can facilitate cross-sectoral collaboration (Bowen and Ebi, 2017).

7.4.3.2 Multisectoral Collaborations

Multisectoral collaborations aimed at strengthening the health sector can generate multiple co-benefits in other sectors (high agreement, medium evidence). Solutions for health and wellbeing risks described in 7.2 and 7.3 often have their origins in sectors that include water, sanitation, agriculture, food systems, social protection systems, energy, and key components of urban systems such as housing and employment (Organization, 2015);(Bowen et al., 2014b);(Machalaba et al., 2015);(Confalonieri et al., 2015);(Bowen et al., 2014a);(Semenza, 2021).Climate resilient development pursued in these other sectors, and in cooperation with the health sector, simultaneously increases the potential for adaptation and climate resilience in terms of health and wellbeing *(high confidence)* (Ahmad et al., 2017); (Watts et al., 2018b);(Levy and Patz, 2015);; (Organization, 2018b);(Chiabai et al., 2018a); (Dudley et al., 2015);(Zinsstag et al., 2018);(Sherpa et al., 2014).

7.4.3.3 Financial Constraints

Financial constraints are the most referenced barrier to health adaptation and so scaling up financial investments remains a key international priority (very high confidence). (Wheeler and Watts, 2018) (UNFCCC, 2017a). AR5 estimated the costs of adaptation in developing countries at between US$70 billion and US$100 billion annually in the year 2050, but these are likely to be a significant underestimate, particularly in the years 2030 and beyond (UNEP, 2014). National surveys conducted by the World Health Organization identified financial constraints as a major barrier to the implementation of health adaptation priorities (WHO, 2019);(Watts et al., 2021). Novel research drawing on global financial transaction data suggests that in 2019, global financial transactions with the potential to deliver adaptation in the health and healthcare sector reached US$18.4 billion, driven by transactions in high- and upper-middle income countries, with investment in Africa, South-East Asia, and the Eastern Mediterranean mostly stagnant (Watts et al., 2021).

There has been limited participation of the health sector in international climate financing mechanisms (Martinez and Berry, 2018). Of 149 projects listed in the Adaptation Fund database in October 2020, a large number were broad based initiatives that may have considerable indirect benefits for health systems, such as enhanced disaster preparedness and food security, but none were explicitly aimed at strengthening health systems or directed funds through ministries of health. A review of projects funded by the major multilateral climate funds showed that less than 1.5% of dispersed adaptation funding, and less than 0.5% of overall funding has been allocated to projects aimed at protecting health (WHO, 2015a).A survey of national public health organization representatives from a mix of low-, middle- and high-income countries found that a lack of political commitment, insufficient coordination across sectors, and inadequate funding for public health-specific adaptation initiatives were common barriers to building climate resilience (Marcus and Hanna, 2020). Under-investment in climate-specific initiatives in health systems coincides with persistent under-investment in health care more generally, especially in low- and middle-income countries (Schaferhoff et al., 2019).

Adaptation financing often does not reach places where the climate-sensitivity of the health sector is greatest (Weiler, 2019). Financial constraints in Africa are one of the key reasons for slow implementation of health adaptation measures (Nhamo and Muchuru, 2019). Strengthening health systems in vulnerable countries has the potential to reduce current and future economic costs related to environmental health risks, thus enabling reinvestment in the health system and sustainable development (WHO, 2020b);(Organization, 2015). Robust and comprehensive climate and health financing builds first on core health sector investments (Organization, 2015). Other potential opportunities for resource mobilization include health-specific funding mechanisms, climate change funding streams, and investments from multi-sectoral actions and actions in health-determining sectors (Organization, 2015). Incorporating climate change and health considerations into disaster reduction and management strategies could improve funding opportunities and increase potential funding streams (Aitsi-Selmi et al., 2015). Reinforcing cross-sectoral governance mechanisms maximizes health co-benefits and economic savings, by allowing for multisectoral costs and benefits to be comprehensively considered in decision-making (Belesova et al., 2016); (WHO, 2020b);(Organization, 2015). An additional financial need concerns health research, the existing funding for which does not match what is needed to support the implementation of the combined objectives of the UN 2030 Agenda for Sustainable Development, the Sendai Framework for Disaster Risk Reduction; and the Paris Agreement (Green and Minchin, 2014; Ebi, 2016);(Green et al., 2017)

7.4.3.4 Perceptions of Climate Change Risks and Links to Adaptation

Adaptation decisions and responses to climate change can be influenced by perceptions of risks, which are shaped by individuals' characteristics, knowledge, and experience (medium agreement, medium evidence). Institutional and governmental responses are critical for adapting to climate-related risks in health and other sectors, but individual responses also are relevant, such as choosing to implement adaptation measures. Individual responses are in turn affected not only by capabilities but also by perceptions that climate change is real and requires a response (Ogunbode et al., 2019). Perceptions of climate risks are formed by experiences of changes in local weather and extreme weather events (Sattler et al., 2018), (Sattler et al., 2020);(van der Linden, 2015),observations of environmental changes (Hornsey et al., 2016), experiences of and knowledge about climate change impacts (Ngo et al., 2020);(van der Linden, 2015), and individual characteristics such as values and worldviews (Poortinga et al., 2019) (*high agreement, medium evidence*). Risk perceptions include both logical assessments about the likelihood and severity of climate change impacts, and affective feelings about those impacts. On average, affective measures of risk perception are more strongly associated with disaster preparation than cognitive measures (Bamberg et al., 2017);(van Valkengoed and Steg, 2019).

In addition to perceptions of risk, the likelihood that an individual will implement behavioural adaptations, or support relevant public policy, is affected by subjective assessments of the response options (Bamberg et al., 2017); (van Valkengoed and Steg, 2019);(Akompab et al., 2013), (Carman and Zint, 2020);(Hornsey et al., 2016);(Brenkert-Smith et al., 2015).

Efficacy beliefs, social norms, and subjective resilience also affect adaptation behaviour (medium confidence), which has implications for communication about the need for climate adaptation. Efficacy beliefs represent the belief in one's ability to carry out particular action(s) and the belief that the action(s) will have the desired outcome. Belief that one is personally able to complete a behavior is moderately associated with engaging in disaster preparations (Navarro et al., 2021); (van Valkengoed and Steg, 2019) and with adaptation intentions (Burnham and Ma, 2017). *Collective efficacy*, the belief that a group of people working together can achieve a desired outcome, is important for participating in community adaptation behaviors (Bandura, 1982);(Chen, 2015);(Thaker et al., 2015). Related to this is *response efficacy*, a belief that a behavior will achieve its desired outcome, which is also moderately associated with engaging in disaster preparations (van Valkengoed and Steg, 2019). Collective efficacy can potentially be developed by strengthening communication networks and social ties within a community (Haas et al., 2021);(Jugert et al., 2016). Norms describing the adaptation strategies of others in a community, particularly those with high social status, can either facilitate or inhibit individual adaptation decisions (Neef et al., 2018);(Smith et al., 2021).

Distinct from efficacy beliefs, subjective resilience is a more general optimism or belief about one's ability (Jones, 2019);(Khanian et al., 2019). Subjective resilience (Clare et al., 2017) can influence preferred responses to climate change via assessment of one's ability to engage in specific response options. Identities can influence assessment of subjective resilience. Place attachment, having a strong emotional connection to a particular location, is weakly associated with disaster preparation (Brügger et al., 2015). In some cases, place attachment may inhibit adaptive responses, either by reducing perceptions of risk, or by making people reluctant to leave an area that is threatened (De Dominicis et al., 2015);(van Valkengoed and Steg, 2019). Place attachment can also contribute to enhanced community resilience (Khanian et al., 2019);(Jones, 2019);(Wang et al., 2021).

7.4.4 Migration and Adaptation in the Context of Climate Change

7.4.4.1 Linkages between Migration, Adaptation, Household Resilience

AR5 (Chapter 17 Human Security) concluded that migration is often, though not in all situations, a potential form of adaptation initiated by households. *Subsequent research indicates that the circumstances under which migration occurs, and the degree of agency under which household migration decisions are made, are important determinants of whether migration outcomes are successful in terms of advancing the wellbeing of the household and providing benefits to sending and receiving communities (high confidence)*. (Adger et al., 2015);(Cattaneo et al., 2019); Cross-Chapter Box MIGRATE in Chapter 7]. Evidence from refugee studies and general migration research indicates that higher agency migration, in which migrants have mobility options, allows migrants greater opportunities for integrating into labour markets at the destination, makes it easier to remit money home, and generally creates conditions for potential for benefits for migrant households and for sending and receiving communities (Migration, 2019). Bilateral agreements that facilitate labour migration have been identified as being especially urgently needed for Pacific small island states (Weber, 2017).

Adaptive migration and the implied assumption that people can or should simply move out of harm's way is not a substitute for investment in adaptive capacity building (high agreement). (Bettini and Gioli, 2016). Climate-related migration, and especially involuntary displacement, often occurs only after *in situ* adaptation options have been exhausted and/or where government actions are inadequate (Adger et al., 2015);(Ocello et al., 2015); Cross-Chapter Box MIGRATE in Chapter 7). The threshold at which household adaptation transitions from *in situ* measures to migration is highly context specific and reflects the degree of exposure to specific climate risks, mobility options and the socio-economic circumstances of the household and the local community (McLeman, 2017);(Adams and Kay, 2019);(Semenza and Ebi, 2019) [also Cross-Chapter Box MIGRATE in Chapter 7]. A consistent theme in the research literature reviewed for all sections of this chapter is that proactive investments in health, social, and physical infrastructure, including those not aimed specifically at climate risks, build societal adaptive capacity and household resilience. In turn, expanding the range of adaptation options available to households and increases the likelihood that, when migration does occur, it does so under conditions of high agency that lead to greater chances of success. In communities where climate-related migration and/or relocation is occurring or may be likely to occur, policymaking and planning benefits from understanding the cultural, social and economic needs of exposed populations helps in the identification of responses and policies that build resilience (Adams and Kay, 2019).

7.4.4.2 Climate, Migration and linkages to Labour Markets and Social Networks

Adaptive climate-related migration is often closely related to wage-seeking labour migration (medium confidence). Because of the circumstances under which they move, climate-related migrants' destination and labour market choices, and the returns from migration, may be more heavily constrained than are those of other labour migrants (Jessoe et al., 2018);(Wrathall and Suckall, 2016).Within low- and middle-income countries, rural-urban migrant networks are important channels for remittances that may help build socio-economic resilience to climate hazards (Porst and Sakdapolrak, 2020), with higher levels of wage-seeking labour participation observed in climate-sensitive locales in South Asia (Maharjan et al., 2020). Local level research in China and South Asia shows, however, that the potential for remittances to generate improvements in household level adaptive capacity or resilience is highly context specific, has significant gender dimensions, and depends on such factors as the nature of the hazard, the distance migrated, and the length of time over which remittances are received (Banerjee et al., 2019a; Banerjee et al., 2019b). Social networks are a key asset in helping climate migrants overcome financial and structural impediments to their mobility, but these have their limits, particularly with respect to international migration (Semenza and Ebi, 2019). Since AR5, greater restrictions have emerged on movement between many low- and high-income countries (not including those necessitated by public health measures during the COVID-19 pandemic), a trend that, if it continues, would generate additional constraints on destination choices for future climate migrants (McLeman, 2019). Transnational diasporic connections are a potential asset for building resilience in migrant-sending communities highly exposed to climatic risks, with migrants' remittances potentially providing resources for long term resilience building, recovery from extreme events, and reducing income inequality (Bragg et al., 2018);(Mosuela et al., 2015);(Obokata and Veronis, 2018);(Shayegh, 2017);(Semenza and Ebi, 2019). Safe and orderly labour migration is consequently a potentially beneficial component of wider cross sectoral approaches to building adaptive capacity and supporting sustainable development in regions highly exposed to climate risks (McLeman, 2019).

7.4.4.3 Attitudes Toward Climate Migration

The success of climate-related migration as an adaptive response is shaped by how migrants are perceived and how policy discussions are framed (high agreement, medium evidence). The possibility that climate change may enlarge international migrant flows has in some policy discussions been interpreted as a potential threat to the security of destination countries (Sow et al., 2016);(Telford, 2018), but there is little empirical evidence in peer-reviewed literature assessed for this chapter of climate migrants posing significant threats to security at state or international levels. There is also an inconsistency between framing in some policy discussions of undocumented migration (climate-related and other forms) as being "illegal'' and the objectives of the Global Compact on Safe, Orderly and Regular Migration and the Global Compact on Refugees (McLeman, 2019). Although the Global Compact on Refugees explicitly avoids the inclusion of climate-related migrants as refugees, terms such as 'climate refugees' are common in popular media and some policy discussions (Høeg and Tulloch, 2018);(Wiegel et al., 2019). The framing of migration policy discussions is relevant, for example, in discussing climate adaptation options for Pacific Island Countries, where there is considerable disagreement over policy discussions that range from a 'migration-with dignity' approach that would liberalize labour migration in the Pacific region, to those that see migration as a last resort option to be avoided as much as possible (McNamara, 2015);(Farbotko and McMichael, 2019);(Oakes, 2019);(Remling, 2020). A more beneficial policy framing in terms of ensuring that future migration contributes to climate resilience and sustainable development has been established since AR5 within the framework of the Global Compact for Safe, Orderly and Regular Migration (see 7.4.7.7).

Attitudes of residents in migrant-receiving areas with respect to climate-related migration warrant consideration when formulating adaptation policy (medium confidence). Existing research is modest and difficult to generalize with respect to the impacts of climate-related migration and displacement on social dynamics and stability in receiving destinations, with outcomes being tied to attitudes and social acceptance of receiving communities and efforts to integrate migrant arrivals into the community (Koubi and Nguyen, 2020). Research from Kenya and Vietnam shows that residents of receiving communities view environmental drivers as being legitimate reasons for people to move, and are unlikely to stigmatize such migrants (Spilker et al., 2020). In these examples, urban residents viewed environmental motivations as being comparable to economic reasons for migrating, and did not see climate-related migrants as posing any particular risks for receiving communities. However, more research is needed to determine whether such findings are generalizable. Case studies from India suggest that a lack of recognition by local authorities of climatic factors as being legitimate drivers of rural-urban migration may lead to discrimination against migrants in terms of access to housing and other social protections, thereby undermining household resilience (Chu and Michael, 2018).

7.4.4.4 Planned Relocation and Managed Retreats

There is high agreement among existing studies that immobile populations often have high vulnerability and/or high long term exposure to climate hazards, and that non-climatic political, economic and social factors within countries may strongly constrain mobility (Zickgraf, 2019);(Ayeb-Karlsson et al., 2020);(Cundill et al., 2021). Section 7.2.6.2 highlighted the particular vulnerability of immobile populations in the face of growing climatic risks. However, research suggests governments should be slow to label such populations as being ‘trapped’ or to actively promote relocations in the absence of local agreement that *in situ* adaptation options have been exhausted (Adams, 2016);(Farbotko and McMichael, 2019). In the case of Indigenous settlements, efforts made to incorporate traditional knowledge in decision making and planning increase the potential for longer term success {Manrique, 2018, Climate-related displacements of coastal communities in the Arctic: Engaging traditional knowledge in adaptation strategies and policies}. Considerable health implications can potentially emerge within populations that are relocated as part of planned retreat and represent an important consideration for planners that requires greater research (Dannenberg et al., 2019). Organized relocations are not inherently transformative in their outcomes but, depending on the circumstances under which they occur and on how issues of equity and respect for the rights of those affected, are implemented, relocation could potentially be made transformative in a positive sense (Siders et al., 2021).

Disruptive and expensive relocations of low-lying coastal settlements in many regions would become increasingly necessary in coming decades under high levels of warming (high confidence). Organized relocations require long-term innovation, planning and cooperation on the part of governments, institutions, affected populations, and civil society (Hauer, 2017; Hino et al., 2017);(Haasnoot et al., 2021);(Moss et al., 2021). Recent examples illustrate the substantial financial costs of organized relocations, ranging from US$10,000 per person in examples from Fiji, to US$100,000 per person in coastal Louisiana, USA (Hino et al., 2017). Organized relocations are politically and emotionally charged, will not necessarily be undertaken autonomously by exposed populations, and are most successful when approached proactive and strategically to avoid increasing the socio-economic vulnerability of those who are relocated (Jamero et al., 2017), (Wilmsen and Webber, 2015);(Chapin et al., 2016);(McNamara et al., 2018);(Hauer et al., 2019);(Bertana, 2020). Key considerations for protecting the rights and wellbeing of people who might need to be resettled include proactive communication with and participation of the affected communities, availability of compensation, livelihood protection, and ensuring there is permanence and security of tenure at the relocation destination (Tadgell et al., 2018). Availability of funds for resettlement, how to manage relocation from communally owned lands, how to value privately owned land to be abandoned, and the potential for loss and damage claims are just some of the many potential complications (Marino, 2018);(McNamara et al., 2018). As a proactive option, researchers in Bangladesh have suggested the creation of “migrant-friendly towns” to provide options for autonomous relocation from hazardous areas (Khan and Huq, 2021).

7.4.5 Adaptation Solutions for Reducing Conflict Risks

There has been increased activity within the international community to understand and address climate-conflict linkages since AR5, with high level actions including the UN Climate Security Mechanism, launched in 2018, tasked with providing integrated climate risk assessments to the UN Security Council and other UN bodies, in partnership with UN and external actors (DPPA et al., 2020). G7 governments initiated an integrated agenda for resilience (Rüttinger et al., 2015) and the Berlin Call for Action in 2019 sought foreign policy as a platform to address climate security concerns focusing on risk-informed planning, enhanced capacity for action within the UN and improvements to operational response to climate security risks (Federal Foreign Office 2019). The non-peer-reviewed literature that currently addresses these policy dimensions is generated by a small number of consultancies funded by governments from the Global North and can lack diverse perspectives and priorities.

7.4.5.1 Environmental Cooperation and Peacebuilding

The environment can form the basis for active peacebuilding and a sustainable natural environment is important for ongoing peace (high agreement, medium evidence). Environmental peacebuilding (EP) is a framework increasingly utilised to understand the diverse ways in which the natural environment supports peace and can be utilised in peace building: preserving the natural environment such that degradation does not contribute to violence, protecting natural resources during conflict and using natural resources in post-conflict economic recovery (Kron, 2019). EP frames natural resources as facilitating peace rather than driving conflict (Dresse et al., 2019) with emerging literature analysing what this means in practice(Kovach and Conca, 2016);(Krampe, 2017);(Ide, 2019);(Ide et al., 2021);(Johnson, 2021);(Kalilou, 2021). There is emergent evidence for the success of these pathways. For example, a natural resource sharing agreement on the Kenya-Uganda border was able to reconcile spatial, logistical and conceptual barriers to addressing climate risks in development contexts (Abrahams, 2020). However, the long-term impacts of EP approaches on sustaining peace are yet to be monitored and evaluated (Ide and Tubi, 2020). EP may be successful depending on the context and the element of peace being built (Johnson, 2021) or undermine processes when environmental arguments are co-opted for geopolitical purposes (Barquet, 2015) or depoliticise conflict (Ide, 2020).

Formal institutional arrangements for natural resource management can contribute to transnational cooperation (high confidence) (See also Chapter 4). Evidence from the transboundary water sharing agreements provides evidence for cooperation rather than conflict over resources (Timmerman et al., 2017);(Timmerman, 2020);(Dinar et al., 2015). Transboundary water agreements and river basin organizations help build robust institutions that facilitate trust and relationship building that have benefits in other domains (strong agreement, medium evidence) (Dombrowsky, 2010);(Krampe and Gignoux, 2018) ;(Barquet et al., 2014) (Ide and Detges 2018). However, outcomes can be mixed as combining issues can stall progress and the international and top down nature of these approaches limits transferability to intra-state conflict at the local level (Rigi and Warner, 2020);(Ide et al., 2021);(Krampe et al., 2021).

7.4.5.2 Adaptation in Fragile Settings

Climate-resilient peace building has the potential to limit the impact of future climate change on peace efforts (medium confidence). Practical guidance has been developed, driven by policy concerns on climate-conflict links. The United Nations Environment Programme, the European Union and Adelphi have developed a toolkit for addressing climate fragility risks in peacebuilding, adaptation and livelihoods support (Programme et al., 2019)). Crawford et al (2015) provide recommendations for climate-resilient peacebuilding consistent with the UN Secretary-General's five peacebuilding principles, including integrating ex-combatants through the construction of climate resilient infrastructure, using climate impacts as a platform to engage previously conflicting groups, developing national disaster risk reduction and management strategies, and climate-proofing economic development activities. The United States Agency for International Development, in a report prepared for the Adaptation Thought Leadership and Assessments (ATLAS) program (Adelphi and Inc, 2020) drawing on resilience and peacebuilding programs in the Horn of Africa, recommend two critical conditions to ensure activities address compound climate fragility risks. Firstly, conducting local analyses of the links between climate, conflict, and fragility to identify specific risks to target; and secondly, ensuring long term commitment with a focus on participation and flexibility.

Conflict-sensitive adaptation that focuses on institutional frameworks, conflict management, and governance mechanisms has the potential to address complex interacting risks and emergencies over the long term (medium agreement, limited evidence). (Scheffran et al., 2012);(Matthew, 2018) (Okpara et al., 2018). However, most adaptation activities are planned and implemented under development or climate finance funds without systematic integration of conflict sensitivity, and National Adaptation strategies rarely and only implicitly address conflict and potential changes to power relations (Tänzler et al., 2019). Practitioners and policy researchers have attempted to address this gap by developing guidance and delivering training (e.g. (Tänzler et al., 2019);(Bob and Bronkhorst, 2014). However, there are real challenges relating to discounting indirect impacts on conflict and maladaptation (Asplund and Hjerpe, 2020) and risks of unintended, perverse outcomes (Mirumachi et al., 2020). Crawford and Church (2020) highlight the synergies between adaptation planning under the UNFCCC's National Adaptation Plan process and conflict reduction. Discussing development more broadly, Abrahams (2020) suggests three barriers to development that incorporate conflict-climate risks: geographically disconnected impacts and outcomes, the discourse of climate as a threat multiplier (rather than underlying peace), and teleconnected risks occurring at different scales. Effective approaches rely on understanding local power dynamics and social relations (Sovacool 2018; Roth et al. 2019, Sapiains et al 2021) (*high agreement, medium evidence*).

7.4.5.3 Gender-based Approaches toPpeacebuilding

Gender-based approaches provide novel underutilised pathways to achieving sustainable peace (high confidence, high evidence). Security council resolutions have encouraged the incorporation of gender analysis into peacebuilding, and research has shown that taking into account the gendered nature of networks and dialogues opens new avenues for cooperation and are conflict-sensitive (Dunn and Matthew, 2015), creating potential for women's rights and advocacy groups to be drivers of peace (Céspedes-Báez, 2018). For example, women are working to reduce climate vulnerability security risks in urban settings by entering local politics and joining community based organised and civil society networks (Kellog, 2020). The gendered nature of vulnerability and access to natural resources [see 4.6.4, 4.7.5.3, 5.4.2.3, 5.5.2.6, 5.8.2.2, Cross-Chapter Box GENDER in Chapter 18] will influence the efficacy of interventions to prevent conflict or to build durable peace (Pearse, 2017);(Chandra et al., 2017);(Fröhlich et al., 2018). However, this understanding has not so far resulted in widespread employment of gender-led analyses (Fröhlich and Gioli, 2015). However, this understanding has not so far resulted in widespread employment of gender-led analyses (Fröhlich and Gioli, 2015). This represents a key opportunity for expansion of the solution space for climate-related conflict. Analysis of peace processes (not confined to climate drivers) demonstrates the benefits of women's participation in peace processes for devising strategies for building peace (Paffenholz, 2018);(Cárdenas and Olivius, 2021) and for the durability of that peace (Shair-Rosenfield and Wood, 2017);(Krause et al., 2018).

7.4.6 Climate Resilient Development Pathways

Climate resilient development is a set of trajectories that strengthen sustainable development and efforts to eradicate poverty and reduce inequalities, while promoting fair and equitable reductions of GHG emissions. Climate resilient development also serves to steer societies towards low-carbon, prosperous, and ecologically safer futures (WGII, Chapter 1). *All pathways to pursue climate resilient development will involve balancing complex synergies and trade-offs between development pathways and the options that underpin climate mitigation and adaptation (very high confidence; WGII, Chapter 18).* Pathways to climate resilient development can be pursued simultaneously with recovering from the COVID-19 pandemic (WHO Manifesto for a healthy recovery from COVID-19; Cross-Chapter Box COVID in Chapter 7, Ebi et al., 2021).

Meeting commitments against seven existing global priorities would facilitate climate resilient development pathways and transformational futures for health, wellbeing, conflict and migration (*high agreement, medium evidence*):

1. Fully implementing the World Health Organization (WHO) Operational Framework for building climate-resilient health systems (WHO, 2015b)
2. Achieving Universal Health Coverage (UHC) under SDG 3 (good health and wellbeing)
3. Achieving net zero GHG emissions from healthcare systems and services
4. Achieving the Sustainable Development Goals
5. Adopting mitigation policies and technologies that have significant health co-benefits (see Cross-Chapter Box, including energy systems, urban, infrastructure, societal)
6. Meeting the objectives of the Global Compact for Safe, Orderly, and Regular Migration
7. Inclusive and integrative approaches to climate resilient peace

These transformations map across all of the five system transitions identified in WGII Chapter 18 – energy systems; land, ocean, and ecosystems; urban and infrastructural systems; industrial systems, and societal systems.

7.4.7.1 Fully implementing the WHO Operational Framework

The WHO Operational Framework for building climate-resilient health systems was designed to increase the capacity of health systems and public health programming to protect health in an unstable and changing climate (WHO, 2015b). The guidance defines a climate resilient health system as *one that is capable to anticipate, respond to, cope with, recover from, and adapt to climate-related shocks and stress, so as to bring sustained improvements in population health, despite an unstable climate*. Full implementation of this framework has the potential to achieve transformational adaptation; the fundamental attributes of health system would change to anticipate and effectively manage the population health and healthcare risks of climate change. This includes having the knowledge, capacity, tools, and human and financial resources for health systems to extend beyond soft limits to adaptation.

The framework outlines 10 key components (Figure 7.15) that, when achieved, will:

- guide professionals working in health systems, and in health determining sectors (e.g. water and sanitation, food and agriculture, energy, urban planning) to understand and effectively prepare for the additional health risks posed by climate variability and change;
- identify the main health functions that need to be strengthened to build climate resilience, and to use these to develop comprehensive and practical plans (e.g., the health component of NAP (H-NAP)); and
- support health decision-makers to identify roles and responsibilities to implement this plan, for actors within and outside the formal health sector.

Achieving full implementation of the WHO Operational Framework requires determination and commitment – with associated funding – from the health community specifically, and health-determining sectors more generally. Identifying priority areas is an immediate step required to commence this implementation process, which will be different in different contexts. The active engagement with Communities of Practice to share lessons and experiences would be a useful approach to support national and sub-national efforts – many of these exist already (e.g., Climate Change Community of Practice in Canada, and the 'weADAPT' initiative under the auspices at Stockholm Environment Institute).

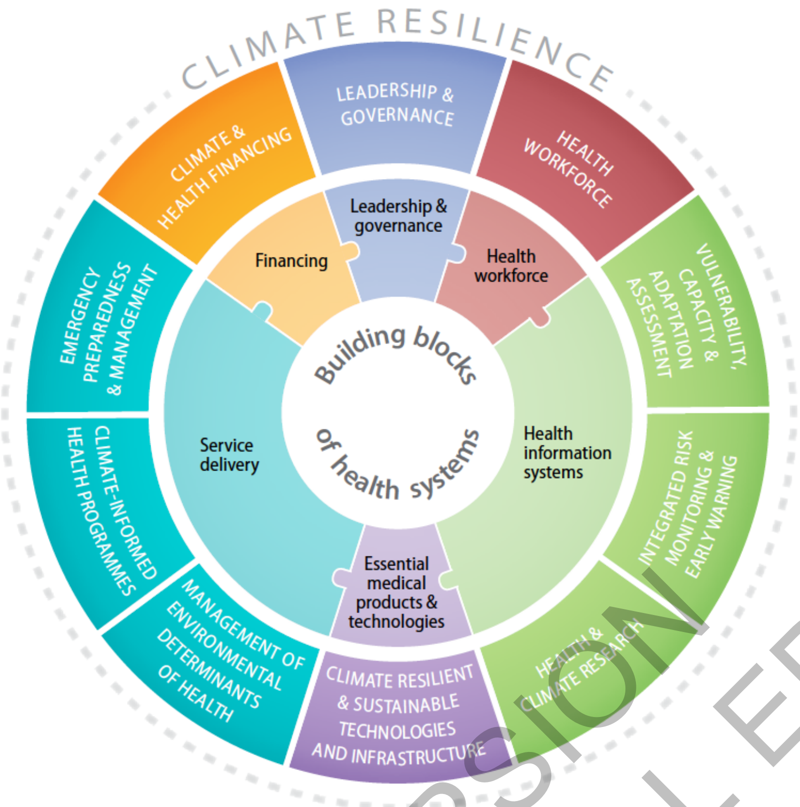

Figure 7.15: Ten components of the WHO operational framework for building climate resilient health systems, with links to the building blocks of health systems. Source (WHO, 2015b)

Table 7.9 summarizes selected characteristics of health systems under SSPs 1 (a world aiming to sustainable development), 2 (a world continuing current trends), and 3 (a world with high challenges to adaptation and mitigation). The table highlights the importance of investments that promote sustainable and resilient development, to decrease vulnerability no matter the magnitude and pattern of climate change. Adapting under SSP3 would be challenging even under pathways of limited additional climate change.

Table 7.9: Characteristics of health systems under SSPs 1, 2, and 3. Modified from Sellers and Ebi (2017) (Sellers and Ebi, 2017)

	SSP3	SSP2	SSP1
Basic characteristics	Reactive; failure to adapt; siloed information channels and national governance; limited partnerships	Incomplete planning; new information incorporated as convenient; occasional partnerships	Proactive; adaptively managed; frequent partnerships; interdisciplinary
Leadership and governance	Little focus at national and international levels on climate change and health; minimal planning conducted	Planning on climate change and health, but not comprehensive and often side-tracked on other issues	Strong climate change and health planning apparatus, including health components of national adaptation plans; regional / international partnerships
Health workforce	Climate change and health not rarely incorporated into training; few provisions for new training programs or funding for increase health worker positions in climate change-relevant specialties; health disparities not addressed	Climate change and health not systematically incorporated into training; new training programs insufficient to fill gaps in demand; limited attention to addressing health disparities	Systematic inclusion of climate change and health in worker training; expansion of funding and training; financing and incentive mechanisms to address health disparities

Health information systems	Assessments of vulnerability and adaptation rarely, if ever conducted; information not useful for planning; minimal risk monitoring or research	Vulnerability and adaptation assessments occasionally conducted, but generally of poor quality; early warnings incomplete; fiscal and political constraints on research	Vulnerability and adaptation assessments regularly conducted and used in planning; robust early warning networks; research agenda focused on vulnerable communities
Climate resilient and sustainable technologies and infrastructure	Facilities sited and constructed without climate consideration incorporated; medical supply chains no modified	Capital cost serves as key factor in siting and construction; increasing vulnerability of facilities to shocks	Health infrastructure designed to be robust to storms/floods, with redundant systems added to ensure continuity of care
Service delivery	Policies to manage environmental health hazards generally not followed; care practices not modified to accommodate climate information; few changes to emergency management procedures; health inequities worsen	Environmental health policies are not robust; marginal improvements in care practices; risk assessments and communication inadequate; no shift in health inequities	Policies to manage environmental health hazards regularly reviewed; practitioners review care practices and adjust as appropriate based on local climate and health conditions; robust communication tools developed; health service improvements reduce health inequities
Climate and health financing	Few funds devoted to climate change and health activities, particularly in low- and middle-income countries; few if any financing partnerships between high- and low- and middle-income countries; very weak regional and international coordinating bodies due to funding constraints	High-income countries generally form robust financing mechanisms; fiscal pressures in low- and middle-income countries constrain their financing abilities; financial partnerships formed across countries, but financing often not robust; regional and international coordinating bodies receive inadequate funds	Robust funding streams for climate change and health; climate change and health activities receive continuing financial support; effective financing partnerships; regional and international coordinating bodies effectively funded

Stress testing is an approach for evaluating the extent to which health systems are prepared for a future different from today (Ebi et al., 2018a). These desk-based exercises identify a desirable future outcome, such as successfully managing an extreme heatwave, flood, or storm with characteristics outside the range of recent experiences. The exercises move beyond identifying likely challenges from hazardous exposures to specifying policies and measures that could be successful under a different climate and development pathway. The exercises consider socioeconomic and political factors that can influence the extent of health system vulnerability and factors that can affect health system demands by impacting population health. Stress testing is designed to identify conditions under which it would be difficult for the health system to maintain its essential functions and to identify interventions that could maintain essential system functions despite climate-related shocks and stresses.

7.4.6.2 Achieving Universal Health Coverage Under SDG 3 (good health and wellbeing)

Universal Health Coverage (UHC) is when all people have access to the health services they need, when and where they need them, without financial hardship (WHO, 2021b). Achieving UHC is one of the targets in the SDGs. However, climate change is threatening to undermine the achievement of UHC through negative health outcomes and healthcare system disruptions (Salas and Jha, 2019);(Phillips et al., 2020);(Kadandale et al., 2020);(Roa et al., 2020). Climate change and UHC progress are closely linked to one another, as they both strive to improve health and achieve health equity (Salas and Jha, 2019). Supporting UHC is key to securing population health under a changing climate, as well as addressing structural inequalities (Roos et al., 2021);(Aleksandrova, 2020);(Phillips et al., 2020). Many regions of the world with the highest levels of vulnerability to the health impacts of climate change also have low levels of UHC; an integrated approach to

UHC planning that incorporates climate change will have great benefits particularly in improving health equity (Salas and Jha, 2019).

The COVID-19 pandemic has shown some countries taking positive steps to achieving UHC. For example, Ireland nationalized healthcare for the duration of the pandemic, and many countries including Australia have enhanced their telehealth services which has enabled specific groups to access health services, particularly those in rural and remote settings, and has allowed continuous care to the community (Monaghesh and Hajizadeh, 2020); see also Cross-Chapter Box COVID in Chapter 7).

7.4.6.3 Achieving Net Zero GHG Emissions from Healthcare Systems and Services

The health care system is a core component of UHC, supporting climate resilient and environmentally sustainable healthcare facilities (Corvalan et al., 2020). Health systems are large carbon polluters and have the potential to look beyond traditional 'green' initiatives towards more fundamental, longer-term redesign of current service models, with health practitioners participating actively in this process (Charlesworth and Jamieson, 2018). In the largest and most comprehensive accounting of national healthcare service emissions, the UK's National Health Service (NHS) quantified its health services' emissions and identified that 62% came from the supply chain, 24% from the direct delivery of case, 10% from staff commute and patient and visitor travel, and 4% from private health and care services commissioned by the NHS (Tennison et al., 2021).

The health sector has considerable opportunity to reduce its own carbon footprint, and by doing so would contribute to mitigation efforts, and help reduce health burdens associated with greenhouse gases emissions (Vidal et al., 2014);(Duane et al., 2019);(Charlesworth and Jamieson, 2019);(Charlesworth et al., 2018);(Guetter et al., 2018);(Bharara et al., 2018);(Frumkin, 2018)(high confidence). The UK's NHS National Health Service has committed to becoming the world's first net zero national healthcare system. Other examples of recent and ongoing initiatives include those undertaken by the Kaiser Permanente and the Gundersen Clinics in the US. Health Care without Harm, particularly across the Asia Pacific region; and the Green Hospital Initiative in New Delhi (Frumkin, 2018; Bharara et al, 2018).

7.4.6.4 Achieving the Sustainable Development Goals Would Increase Resilience in Health-determining Sectors and Contribute to Reducing the Risks of Involuntary Displacement and Conflict.

The Sustainable Development Goals (SDGs) are globally agreed objectives that integrate the economic, environmental, and social aspects of sustainable development, to end poverty, protect nature, and ensure that all people enjoy peace and prosperity. The SDGs were developed under the principle that the goals are integrated and indivisible, such that progress in one goal depends on progress in others (WHO, 2016a). Promoting health and wellbeing is not the sole responsibility of the health sector; it is also partially determined by strategies, policies, and options such as poverty reduction, promoting gender equality, ensuring all people enjoy peace and prosperity, eliminating nutritional insecurity, and ensuring availability and sustainable management of water and sanitation (Morton et al., 2019);(Bennett et al., 2020). Unique themes in the SDGs for health policy and systems research include social protection to protect and promote access to health services; stronger and more effective multisectoral collaborations beyond the health sector to address the upstream drivers of health and wellbeing; and participatory and accountable institutions to strengthen civic engagement and local accountability within health systems (Bennett et al. 2020).

For example, clean water, sanitation, and hygiene (WASH) are essential to human health and wellbeing. Unsafe water and sanitation and lack of hygiene caused an estimate 870,000 associated deaths in 2016 (WHO, 2021c). Only 71% of the global population have access to safely managed drinking water services; only 45% of the global population has access to safely managed sanitation services; and 60% had basic handwashing facilities in their home. About 25% of healthcare facilities lack basic water services, exposing workers and patients to higher infection risks. More than 80% of countries reported in 2018 that they lacked sufficient funding to meet national WASH targets. As detailed in 7.2.2.2, Box 7.3, 7.3.1.4, and 7.4.2.3, the burden of climate-sensitive waterborne diseases would be reduced if WASH targets were met.

The World Health Organization developed a Global Action Plan for Healthy Lives and Wellbeing for All that brings together multilateral health, development, and humanitarian agencies to support countries to accelerate progress towards the health-related SDGs (WHO, 2021c). Themes include sustainable financing to reduce unmet needs for services; community and civil society engagement to generate knowledge to inform policymaking and health responses; addressing the socio-environmental determinants of health; ensuring health and humanitarian services in fragile and vulnerable settings; research and development; and digital health. In 2020, enhanced collaboration through the Global Action Plan provided support for an equitable recovery from the COVID-19 pandemic in, for example, Lao People's Democratic Republic, Pakistan, Tajikistan, Somalia, South Sudan, Malawi, Nepal, and Columbia, highlighting the potential for multisectoral integration of economic, environmental, and social aspects of sustainable development to maintain essential health services and core public health functions during shocks and stresses (WHO, 2021a).

Meeting the SDGs also contributes toward reducing involuntary displacement and conflict, as assessed in sections 7.4.7.7 and 7.4.7.8.

7.4.6.6 Adopting Mitigation Policies and Technologies that have Significant Health Co-benefits)

Substantial benefits from climate action can result from investing in health, infrastructure, water and sanitation, clean energy, affordable healthy diets, low-carbon housing, clean public transport for all, improved air quality from transformative solutions across several economic sectors, and social protection. These benefits are in addition to the avoided health impacts associated with climate change. (see Cross-Chapter Box HEALTH in Chapter 7).

[START CROSS CHAPTER BOX HEALTH]

Cross-Chapter Box HEALTH: Co-benefits of Climate Actions for Human Health, Wellbeing and Equity

Authors: Cristina Tirado (Chapter 7 WGII); Robbert Biesbroek (Chapter 13); Mark Pelling (Chapter 6); Jeremy Hess (Chapter 7); Felix Creutzig (Chapter 5, WGIII); Rachel Bezner Kerr (Chapter 5); Siri Eriksen (Chapter 18); Diarmid Campbell-Lendrum (Chapter 7); Elisabeth Gilmore (Chapter 14); Maria Figueroa (Chapter 2, WGIII); Nathalie Hilmi (Chapter 18); Peter Newman (Chapter 10, WGIII); Sebastian Mirasgedis (Chapter 9, WGIII); Yamina Saheb (Chapter 9, WGIII); Gerardo Sanchez (Chapter 7); Pete Smith (Chapter 12, WGIII); Adrian Leip (Chapter 12, WGIII); Dhar Subash (Chapter 10, WGIII); Chris Tristos (Chapter 9); Mercedes Bustamante (Chapter 7; WGIII); Luisa Cabeza (Chapter 9, WGIII); Diana Urge-Vorsatz, (Chapter 8, WGIII),

Achieving the Paris Agreement and SDGs can result in low-carbon, healthy, resilient, and equitable societies with high-wellbeing for all (very high confidence). (Alfredsson et al., 2018);(O'Neill et al., 2018) {1.5 WGII} {5. WGIII}. Given the overlap in sources of GHGs and co-pollutants in energy systems, strategies that pursue GHG emission reductions and improvements in energy efficiency hold significant potential health co-benefits through air pollution emission reductions (*high confidence*) (Gao et al., 2018). Air quality improvements alone can substantially offset, or most likely exceed, mitigation costs at the societal level (Schucht et al., 2015);(Chang et al., 2017);(Markandya et al., 2018);(Vandyck et al., 2018);(Peng et al., 2017; Woodward et al., 2019; Sampedro et al., 2020);(Xie et al., 2018);{Fig.Ch5 WGIII[KE4] }). Pursuit of a mitigation pathway compatible with warming of +1.5 C, with associated cleaner air, avoided extreme events, and improved food security and nutrition, could result in 152 +/- 43 million fewer premature deaths worldwide between 2020 and 2100 compared with a business-as-usual scenario (Shindell et al., 2018)Reaching the Paris Agreement across nine major economies by 2040 could result in an annual reduction of 1.18 million air pollution-related deaths, 5.86 million diet-related deaths, and 1.15 million deaths due to physical inactivity (Hamilton et al., 2021). In Europe, a mitigation scenario compatible with RCP 2.6 could reduce total pollution costs, mostly from PM2.5, by 84%, with human health benefits equal to more than 1 € trillion over five years (Scasny et al., 2015). In the EU, ambitious climate mitigation policies could reduce years of lost life due to fine particulate matter from over 4.6 million in 2005 to 1 million in 2050, reduce ozone-related premature deaths from 48,000 to 7,000, and generate health benefits of 62 billion €/year in 2050 (Schucht et al., 2015).

However, there may be significant trade-offs between mitigation and other societal goals (Dong et al., 2019);(Gao et al., 2018). In some scenarios, mitigation policies consistent with the NDCs may slow poverty reduction efforts (Campagnolo and Davide, 2019) with implications for health. A framework of "co-impacts" that assumes neither a general beneficial nature of all implications from mitigation policy nor a hierarchy between climate and other types of benefits, may be more appropriate (Ürge-Vorsatz et al., 2014);(Cohen et al., 2017).

Transitioning to affordable clean energy sources for all presents opportunities for substantial wellbeing, health, and equity co-benefits (high confidence). (Gibon et al., 2017);(Lacey et al., 2017) (Peng et al., 2018);(Vandyck et al., 2018); (Williams et al., 2018);{18. WGII} {6.3. WGIII}. Residential solid fuel use affects health and degrades indoor air quality for up to 3.1 billion people in low and middle-income countries (WHO, 2016b); (Wang et al., 2017a). Adherence to planned emission reductions from the Paris Agreement related to renewables could subsequently improve air quality and prevent 71,000-99,000 premature deaths annually by 2030 (Vandyck et al., 2018). This effect increases with a 2°C pathway, with 0.7–1.5 million premature deaths avoided annually by 2050 (Vandyck et al., 2018). Co-benefits are also observed at national and regional levels. For instance, China could expect 55,000–69,000 averted deaths in 2030 if it transitioned to a half-decarbonized power supply for its residential and vehicle sectors (Peng et al., 2018).

Investing in universal basic infrastructure, including sanitation, clean drinking water, drainage, electricity, and land-rights, can transform development opportunities, increase adaptive capacity, and reduce vulnerability to climate-related risks (high agreement, high evidence). {6.1, 6.3 WGII}. Transformative approaches that reduce climate-related risks and deliver enhanced social inclusion and development opportunities for the urban poor are most likely where local governments act in partnership with local communities and other civil society actors (*high confidence*) {6.1, 6.3, 6.4 WGII}.

Rapid urbanization offers a time-limited opportunity to work at scale towards transformational adaptation and climate resilient development (medium evidence, high agreement). Multi-level leadership, institutional capacity, and financial resources to support inclusive adaptation, in the context of multiple pressures and interconnected risks, can help ensure that the additional 2.5 billion people projected to live in urban areas by 2050 are less exposed to climate-related hazards and contribute less to global warming (*high confidence*) {6.1, 6.3, 6.4 WG II}. Integrating low-carbon, inclusive adaptation into infrastructure investment driven by rapid urban population growth and COVID-19 recovery can accelerate co-benefits {Ch6, WGII, Urban X-WG Box}.

Urban planning that combines clean, affordable public transportation, shared clean vehicles, and accessible active modes can improve air quality and contribute to healthy, equitable societies and higher wellbeing for all. Stimulating active mobility (walking and bicycling) can bring physical and mental health benefits (high confidence). {6. WGII} {8.2 WG III} (Rojas-Rueda et al., 2016); (Avila-Palencia et al., 2018); (Gascon et al., 2019); (Hamilton et al., 2021). The health gains from active mobility outweigh traffic-related injuries, from a decreased incidence of chronic diseases(Ahmad et al., 2017);(Maizlish et al., 2017);(Tainio et al., 2017);(Woodcock et al., 2018).

Urban green and blue spaces contribute to climate change adaptation and mitigation and improve physical and mental health and wellbeing (high confidence). (Hansen 2017; EC, 2018; WHO, 2018; Rojas-Rueda et al. 2019). {13.7.3, WGII} {6. WGII} {8.4 WGIII). Urban green infrastructure including urban gardens, can bring benefits to social cohesion, mental health and wellbeing and reduce the health impacts of heatwaves by decreasing temperatures, thus reducing inequities in exposure to heat stress for low income, marginalized groups (Hoffman et al., 2020; Hoffmann et al., 2020){5.12.5;14.4.10.3 WGII} {7.4 WGII} {6. WGII} {13.7}. Trade-offs of increasing urban green and blue spaces include potential public health risks related to increased vectors or hosts for infectious diseases, toxic algal blooms, drowning, and aeroallergens (Choi et al., 2021);(Stewart-Sinclair et al., 2020); {6. WGII}

Climate adaptation and mitigation policies in the building sector offer multiple wellbeing and health co-benefits (high confidence). (Diaz-Mendez et al., 2018);(Macnaughton et al., 2018) {3.6.2, WGII} 9.8 WGIII}. Leadership in Energy and Environmental Design (LEED) certified buildings in the United States, Brazil, China, India, Germany, and Turkey saved $7.5 billion in energy costs and averted 33MT of CO2 from 2000-2016.(Macnaughton et al., 2018) These measures can increase health benefits through better indoor air quality, reduction of the heat island effect, improved social wellbeing through energy poverty alleviation, creation of new jobs, increased productive time and income, increased thermal comfort and lighting indoors, and reduced noise impact. (Smith et al., 2016); (McCollum et al., 2018);(Thema et al., 2017);(Mirasgedis et al., 2014);(Alawneh et al., 2019);(Diaz-Mendez et al., 2018);{9.8 WGIII}. The value of these multiple co-benefits associated with climate actions in buildings is equal or greater than the costs of energy savings (Ürge-Vorsatz et al., 2016);(Payne et al., 2015);{9.8 WGIII){14.4.5.3 WGII}.

Shifting to sustainable food systems that provide affordable diverse plant-rich diets with moderate quantities of GHG-intensive animal protein can bring health co-benefits and substantially reduce GHG emissions, especially in high income countries and where ill health related to overconsumption of animal-based products is prevalent (very high confidence). {5.12.6, WGII} {7.4, 13.5, WGII} {5.WGIII} (7.4 WGIII) (Springmann et al., 2018c);(SRCCL, 2019); (Clark and Tilman, 2017); (Poore and Nemecek, 2018); (Hayek et al., 2021). Transforming the food system by limiting the demand for GHG-intensive animal foods, reducing food over-consumption and transitioning to nutritious, plant-rich diets, can have significant co-benefits to health (*high confidence*) (Hedenus et al., 2014); (Ripple et al., 2014);(Tirado, 2017); (Springmann et al., 2018c); IPCC SR1.5, 2018). (SROC 2019).(SRCCL, 2019); (Nelson et al., 2016); (Willett et al., 2019);(Tilman and Clark, 2014);(Green et al., 2015);(Springmann et al., 2016b);(Springmann et al., 2018b);(Springmann et al., 2018a);(Springmann et al., 2018c); (Milner et al., 2015);(Milner et al., 2017);(Farchi et al., 2017);(Song et al., 2017); (Willett et al., 2019). Reduction of red meat consumption reduces the risk of cardiovascular disease and colorectal cancer; and the consumption of more fruits and vegetables can reduce the risk of cardiovascular disease, type II diabetes, cancer, and all causes of mortality (WHO, 2015c);(Tilman and Clark, 2014);(Sabate and Soret, 2014); (Willett et al., 2019). {7.4 WGIII} {5.12.5 WGII} {6.3 WGIII}. Globally, it is estimated that transitioning to more plant-based diets - in line with WHO recommendations on healthy eating - could reduce global mortality by 6–10% and food-related greenhouse gas emissions by 29–70% by 2050 (Springmann et al., 2016b). There are limitations in accessibility of affordable of healthy and diverse diets for all (Springmann et al., 2020) and trade-offs such as the potential increase of GHG emissions from producing healthy and diverse diets in low- and medium-income countries (Semba et al. 2020). Agroecological approaches have mitigation and adaptation potential, deliver ecosystem services, biodiversity, livelihoods and benefits to nutrition, health, and equity (Rosenstock et al., 2019);(Bezner Kerr et al., 2021);{5.4.4; 5.14.1 WGII} {13.5, 14.4.4 WGII}.

[END CROSS CHAPTER BOX HEALTH HERE]

7.4.6.7 International policy frameworks for migration that contribute to climate-resilient development

Climate-related migration, displacement and immobility in coming decades will coincide with global and regional demographic changes that will produce a widening distinction between high-income countries that have aging, slow-growing (or in some countries, shrinking) population numbers and low-income countries that have rapidly growing, youthful populations. Given this dynamic, coordinated national and international strategies that integrate migration and displacement considerations with wider adaptation and sustainable development policies may contribute to climate-resilient development. Since AR5, the international community has established a number of agreements and initiatives that, with continued pursuit and implementation, would create potential for climate-related migration to be a positive contribution toward adaptive capacity building and sustainable development more broadly (Warner, 2018).

The 2018 Global Compact for Safe, Orderly and Regular Migration provides an important opportunity for planning for and responding to future climate-related migration and displacement (Kälin, 2018). Among its 23 objectives, the Compact explicitly encourages the international community to implement migration policies that facilitate voluntary migration and actively prepare for involuntary displacements due to climate change, especially in low- and middle-income countries. The Compact's objectives include reducing barriers to legal and safe migration, facilitating the freer flow of remittances between sending and receiving communities, and by doing so aim to increase the potential for migration to make positive contributions to sustainable development and to adaptive capacity-building. It also contains specific provisions pertaining to climate- and disaster-related migration and displacement. Objective 2 of the Compact aims at reducing drivers of involuntary or low-agency migration, and recommends that states establish systems for sharing information on environmental migration, develop climate adaptation and resilience strategies harmonized at sub-regional and regional levels; and cooperate on disaster risk prevention and response. Other objectives in the Compact relevant to climate-related migration include Objective 5 (increasing pathways for regular migration) and Objective 19 (facilitating migrants' ability to contribute to sustainable development). Objective 18, which links migration with skills development, is consistent with the 'migration with dignity' approach to displacement risks (McNamara, 2015);(Kupferberg, 2021). The 2018 Global Compact on Refugees observes that climate hazards increasingly interact with the drivers of refugee movements. The guidelines this Compact provides to governments regarding options and actions for addressing the causes of refugee movements and considerations for assisting and supporting refugees are useful for governments seeking guidance for all forms of displacement more generally, including displacement linked to climate change.

Pursuant to the Paris Agreement, a task force was struck by the Warsaw International Mechanism to make recommendations to the Conference of the Parties to the UNFCCC on how to reduce the risks of climate-related displacement. Its 2018 report recommended that parties work toward development of national legislation, cooperate on research, strengthen preparedness, integrate mobility into wider adaptation plans, work toward safe and orderly migration, and provide assistance to people internally displaced for climate-related reasons. Such recommendations dovetail strongly with the objectives of the Compacts on Migration and Refugees, as well as the Sendai Framework for Disaster Risk Reduction and the 2030 Sustainable Development Goals (SDGs). The SDGs, which include multiple goals and targets in which migration plays an explicit role in fostering development (Nurse, 2019), may be seen as completing the international policy arrangements necessary for addressing future climate-related migration and displacement.

7.4.6.8 Inclusive and integrative approaches to climate resilient peace

Climate resilient development pathways to reduce conflict risk rely on a shift in perspective; from framings around resource scarcity and security to sustainable natural resource governance and peace (Brauch et al 2016, Barnett, 2018; Dresse et al 2018). (Day and Caus, 2020) Recognizing that conflict results from underlying vulnerabilities, development that reduces vulnerability offers the best win-win option for building sustainable, climate-resilient peace rather than specific security-focused interventions *(high confidenc*e). To this end, meeting the Sustainable Development Goals represents an unambiguous path to reducing conflict risk in a climate-changed world (Singh and Chudasama, 2021). There is growing acceptance in the development community, despite reservations about the securitization of climate, that instability and conflict exacerbated by climate change has the potential to undermine development gains (Casado-Asensio et al., 2020);(Day and Caus, 2020).

Core to achieving climate resilient peace are new ways of working, that involve cross-issue and cross-sectoral collaboration and integration as a default to policy and programming. The Security Council Resolution 1325 Women and peace and security (S/RES/1325 (2000)) and the Sustaining Peace Agenda (A/RES/70/262 (2016) are notable examples of this. The 2020 UNEP report on gender and security recommends integrating policy frameworks, better financing to strengthen women's roles in peacebuilding, integrated programme design and further research on gender, climate and security linkages. Inclusive approaches recognize that much of the vulnerability that drives conflict risk, is generated by existing inequality and marginalization of large proportions of the population – for example women and youth – and that peace cannot be achieved without their needs being taken into account, and their participation in peace processes (Mosello et al., 2021). Diverse and inclusive partnerships also require ways to better engage local level participation and improving understanding of how to build consensus, through human rights-based approaches that understand non-violent conflict and protest to be potentially positive and constructive elements of transformational approaches to building resilience (Nursey-Bray, 2017);(Ensor et al., 2018);(Schipper et al., 2021). There is an increasing focus on the role of environmental defenders in highlighting violations and gaps in state obligations through non-violent protest (Butt et al., 2019);(Scheidel et al., 2020). Addressing the lack of participation of researchers and experts from countries most at risk of conflict in many climate-related conflict and peacebuilding assessments and initiatives, would also support this objective.

Climate resilient development pathways for sustainable peace also require different ways of gathering intelligence and informing conflict risk. Dynamics that affect such risks exist across scales from the local to the regional and require response in a transboundary manner. There is increasing emphasis on engaging local stakeholders and diverse partnerships to inform context appropriate measures and better policy coordination (Bremberg et al., 2019);(Tshimanga et al., 2021);(Abrahams, 2020). The UN's Climate Security Mechanism, working across three UN departments, takes an integrated approach to analyze and support timely and appropriate responses to conflict risk focusing on risk assessments and early warning systems to aid conflict prevention, climate-informed peace and security activities and conflict-sensitive development, and promoting inter-sectoral cooperation, partnership, and information sharing (DPPA et al., 2020). There is already acknowledgement that adaptation needs to be effectively monitored and to help learning so that maladaptation can be avoided (Eriksen et al., 2021). Here the academic community, which until now has predominantly focused on understanding the causal relationship between conflict and climate, could contribute to advancing monitoring and evaluation of climate resilient peacebuilding initiatives (Mach et al., 2020);(Gilmore et al., 2018)..

[START FAQ7.1 HERE]

FAQ7.1: How will climate change affect physical and mental health and wellbeing?

Climate change will affect human health and wellbeing in a variety of direct and indirect ways, depending on exposure to hazards and vulnerabilities that are heterogeneous and vary within societies, influenced by social, economic and geographical factors as well as individual differences (see Figure FAQ7.1.1). Changes in the magnitude, frequency and intensity of extreme climate events (e.g. storms, floods, wildfires, heatwaves and dust storms) will expose people to increased risks of climate-sensitive illnesses and injuries, and, in worst cases, higher mortality rates. Increased risks for mental health and wellbeing are associated with changes caused by impacts of climate change on climate-sensitive health outcomes and systems (see Figure FAQ7.1.2). Higher temperatures and changing geographical and seasonal precipitation patterns will facilitate the spread of mosquito- and tick-borne diseases, such as Lyme disease and dengue fever, and water- and food-borne diseases. An increase in the frequency of extreme heat events will exacerbate health risks associated with cardiovascular disease, and affect access to fresh water in multiple regions, impairing agricultural productivity, increasing food insecurity, undernutrition, and poverty in low-income areas.

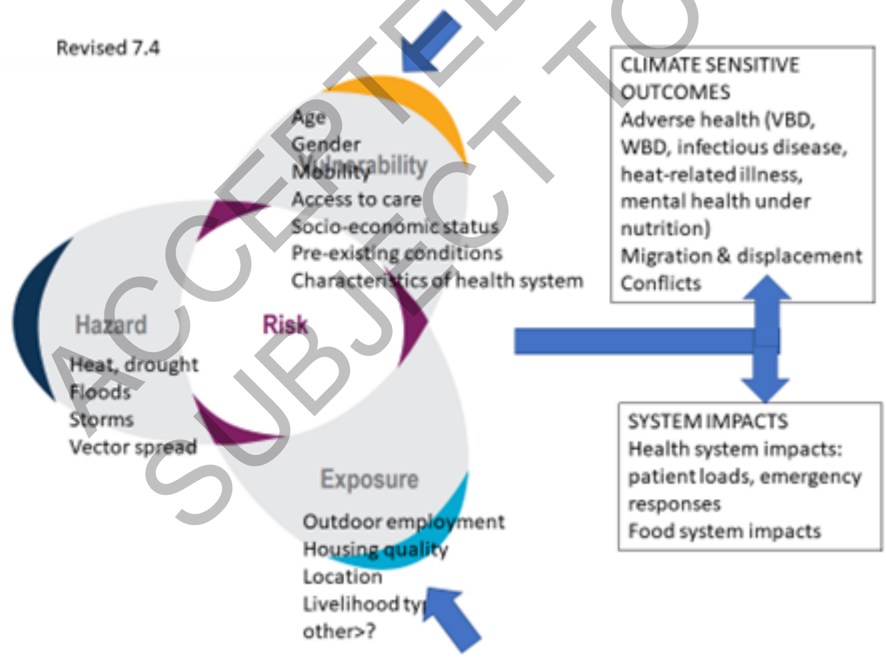

Figure FAQ7.1.1: Pathways from hazards, exposure and vulnerabilities to climate change impacts on health outcomes and health Systems

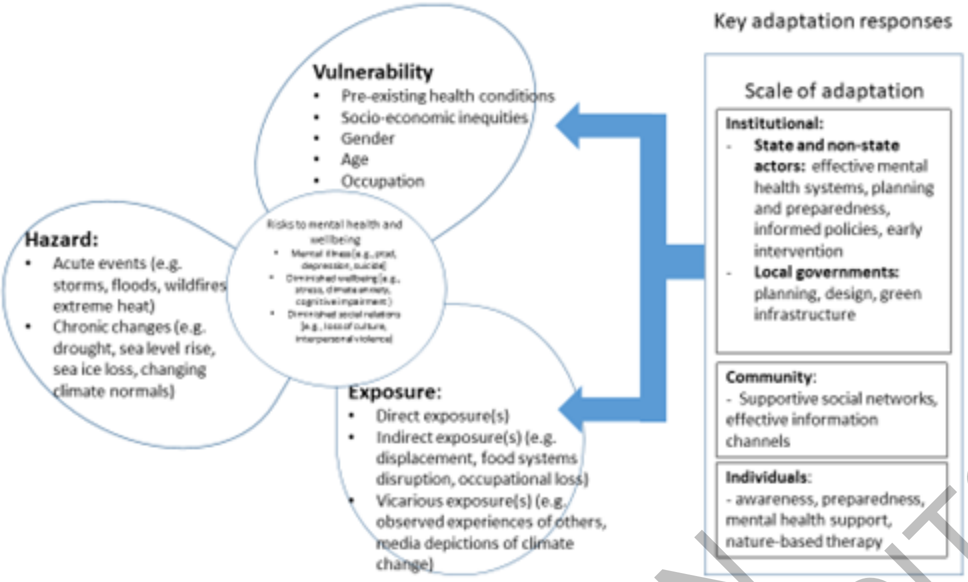

Figure FAQ7.12.: Climate change impacts on mental health and key adaptation responses

[END FAQ7.1 HERE]

[START FAQ7.2 HERE]

FAQ7.2: Will climate change lead to wide-scale forced migration and involuntary displacement?

Climate change will have impacts on future migration patterns that will vary by region and over time, depending on the types of climate risks people are exposed to, their vulnerability to those risks, and their capacity – and the capacity of their governments – to adapt and respond. Depending on the range of adaptation options available, households may use migration as a strategy to adapt to climate risks, often through labour migration. The most common drivers of involuntary climate-related displacement are extreme weather events, floods, and droughts, especially when these events cause severe damage to homes, livelihoods and food systems. Rising sea levels will present a new risk for communities situated in low-lying coastal areas and small island states. The greater the scale of future warming and extreme events, the greater the likely scale of future, involuntary climate-related migration; progress toward the sustainable development goals has the opposite effect.

[END FAQ7.2 HERE]

[START FAQ7.3 HERE]

FAQ7.3: Will climate change increase the potential for violent conflict?

Adverse impacts of climate change threaten to increase poverty and inequality, undermine progress in meetings sustainable development goals, and place strain on civil institutions – all of which are factors that contribute to the emergence or worsening of civil unrest and conflict. Climate change impacts on crop productivity and water availability can function as a 'risk multiplier' for conflict in areas that are already politically and/or socially fragile and depending on circumstances, could increase the length or the nature of an existing conflict. Institutional initiatives within or between states to protect the environment and manage natural resources can serve simultaneously as mechanisms for engaging rival groups and adversaries to cooperate in policymaking and peacebuilding.

[END FAQ7.3 HERE]

[START FAQ7.4 HERE]

FAQ7.4: What solutions can effectively reduce climate change risks to health, wellbeing, forced migration and conflict?

The solution space includes policies, strategies and programmes that consider why, how, when, and who to sustainably adapt to climate change. Effectively preparing for and managing the health risks of climate change requires considering the multiple interacting sectors that affect population health and effective functioning of health systems. Considering the close interconnections between health, migration and conflict, interventions that address climate risks in one area often have synergistic benefits in others. For example, conflicts often result in large numbers of people being involuntarily displaced and facilitate the spread of climate-sensitive diseases; tackling the underlying causes of vulnerability and exposure that generate conflict reduces risks across all areas. A key starting point for health and wellbeing is strengthening public health systems so that they become more climate resilient, which also requires cooperation with other sectors (water, food, sanitation, transportation, etc) to ensure appropriate funding and progress on sustainable development goals. Interventions to enhance protection against specific climate-sensitive health could reduce morbidity and mortality and prevent many losses and damages (Figure FAQ7.4.1). These range from malaria net initiatives, vector control programs, health hazard (syndromic) surveillance and early warning systems, improving access to water, sanitation and hygiene, heat action plans, behavioral changes and integration with disaster risk reduction and response strategies. More importantly, climate-resilient development pathways (CRDP) are essential to improve overall health and wellbeing, reduce underlying causes of vulnerability, and provide a framework for prioritizing mitigation and adaptation options that support sustainable development. Transformative changes in key sectors including water, food, energy, transportation and built environments offer significant co-benefits for health.

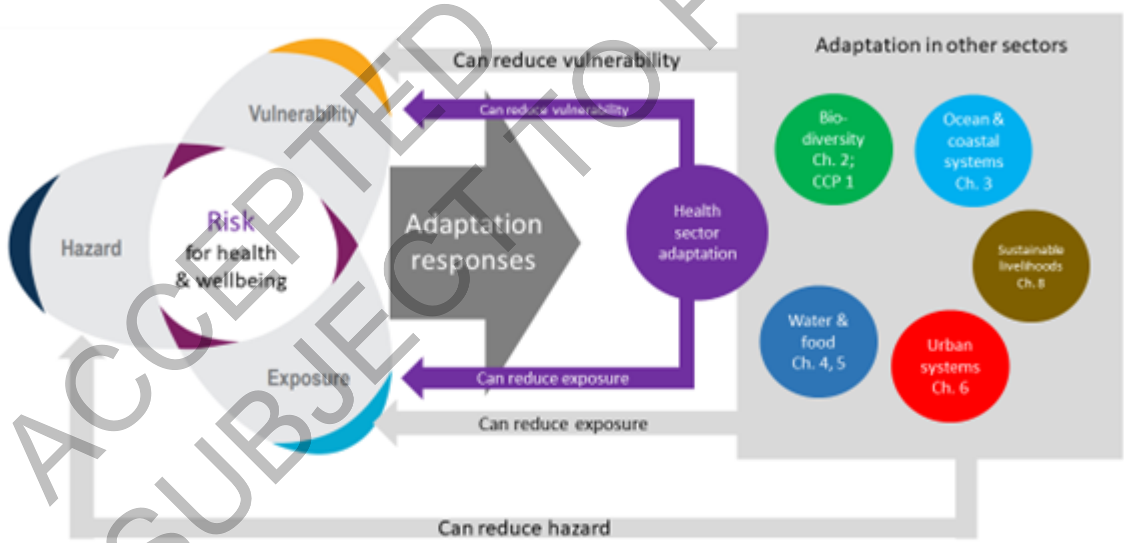

Figure FAQ7.4.1: Solution space for adaptation to climate change in health and other sectors.

[END FAQ7.4 HERE]

[START FAQ7.5 HERE]

FAQ 7.5: What are some specific examples of actions taken in other sectors that reduce climate change risks in the health sector?

Many of the greatest actions to face risks of climate change in other sectors lead to benefits for health and wellbeing. Adaptive urban design that provides greater access to green and natural spaces simultaneously enhances biodiversity, improves air quality, and moderates the hydrological cycle; it also helps reduce health risks associated with heat stress and respiratory illnesses, and mitigates mental health challenges associated with congested urban living. Transitioning away from internal-combustion vehicles and fossil fuel-powered generating stations to renewable energy mitigates GHG emissions, improves air quality and lowers risks of respiratory illnesses. Policies and designs that facilitate active urban transport (walking and bicycling) increase efficiency in that sector, reduce emissions, improve air quality, and generate physical and mental health benefits for residents. Improved building and urban design that foster energy efficiency improve indoor air quality reduce risks of heat stress and respiratory illness. Food systems that emphasize healthy, plant-centered diets reduce emissions in the agricultural sector while helping in the fight against malnutrition.

[END FAQ7.5 HERE]

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