In collaboration with
The Rockefeller Foundation

WORLD ECONOMIC FORUM

Better Climate, Better Health: Using Precision Public Health Tools to Tackle Climate-Sensitive Diseases in China

INSIGHT REPORT

SEPTEMBER 2023

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Foreword

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Climate change is an unprecedented public health emergency affecting the health and well-being of the global population. Scientific evidence substantiates the association between climate change and an increased risk of heat-related illnesses, respiratory and cardiovascular diseases, malnutrition, and vector- and water-borne diseases. These impacts are projected to worsen as temperatures continue to rise and extreme weather events become more frequent.

In spite of the far-reaching health impacts of climate change, "health" has hardly been at the centre of climate narratives. Public health policies and climate adaptation interventions often overlook the health impacts of climate change, and there is a lack of investment in research and solutions to address this pressing issue. Any health-related messaging must therefore be able to resonate with both the public and the private sectors to create meaningful change.

This report, developed jointly by the World Economic Forum and The Rockefeller Foundation, is the start of continuous efforts to raise climate action ambition, as well as addressing and adapting to the health impacts of climate change – the most detrimental challenge global societies face. We are committed to working closely with multistakeholder groups to drive collective action for positive change and are in a unique position to leverage political, financial, social and human capital to support upstream solutions and protect vulnerable communities. Through this partnership, we aim to gather knowledge and understanding across relevant sectors and industries, explore the needed mitigation and adaptation measures, and facilitate engagements from all sectors and at all levels to enhance advocacy and increase the visibility of the health impacts of climate change.

Executive summary

Climate change needs to be brought into the health agenda and health put at the heart of the climate change agenda.

Climate change is one of the most pressing issues facing society worldwide. As documented by the *State of the Global Climate 2022* report, the past eight years have seen the highest global mean temperature on record. Unprecedented levels of heat-trapping greenhouse gases (GHGs) are causing changes in the atmosphere and in the oceans.[1] In the face of numerous risks created by climate change, health is an increasing area of concern. Between 2030 and 2050, climate change is predicted to lead to more than 250,000 deaths globally per year due to heat, undernutrition, malaria and diarrhoeal disease alone.[2] If no additional adaptation measures are taken, the burden of climate-sensitive diseases, both infectious and non-communicable, is anticipated to rise significantly as a result of climate change. Despite accumulating evidence, the severity of the crisis has not been adequately recognized and addressed, and the domains of climate change and global health remain isolated from each other.

As the largest emitter of GHGs and the most populous country in the world, China is an important player in global efforts to combat climate change. The country's population has experienced a significant increase in health challenges caused by climate change, which has been complicated and accelerated by the nation's rapidly changing demographic and socioeconomic landscapes, as well as external shocks such as the COVID-19 pandemic. Against this backdrop, health is gradually moving up the Chinese government's climate policy agenda, both at central and local levels. The inclusion of a dedicated chapter on human health in the *National Adaptation Strategy 2035* is evidence of this.

While macro-level strategies and frameworks are essential for guiding and driving global actions on climate-related health challenges, potential tools (e.g. disease surveillance systems, climate-sensitive disease risk maps and early-warning systems)[3] and technical solutions tailored to the local context are equally important. Given the complexity of climate-driven health challenges, cutting-edge technologies such as artificial intelligence, big data and mobile health have provided an exciting opportunity for more precise detection and prediction of disease outbreaks and solution design. This has led to a growing interest in precision public health (PPH), a concept first proposed in 2013, and this trend became more prominent during and after the pandemic. However, little is known about how PPH tools have been used to tackle climate-sensitive diseases around the world, not to mention the status of PPH in China.

Therefore, this report aims to: **(1) generate knowledge of climate change threats in China and evidence of their health impacts for the Chinese population;** and **(2) document existing governance structures and PPH tools that alleviate or respond to climate-sensitive diseases and health challenges raised by climate change in China.** It is clear that capturing the lessons learned from China's experience could not only build momentum in increasing awareness of the nexus of climate change and health but also offer leads for regional and global policy-makers, donors and practitioners dedicated to developing innovative solutions to the problems that arise in this area.

The report team conducted a thorough literature review by searching academic research databases, social media platforms and the websites of relevant government agencies and organizations. Academic papers, media coverage, technical/industry reports, policy documents, book chapters and other publications written in Chinese and English were studied. Interviews were also undertaken with three leading experts with profound knowledge in climate change, PPH, disease prevention and control. These methods were used to understand the issues at the global level and in China, and to identify and select PPH tools.

This research found that, despite the absence of the term "precision public health" in official policy documents, there is genuine interest in applying the concept in predicting and responding to climate health challenges at different government levels in China. However, PPH in China is still in its infancy. The quest to build a climate-resilient society and the evolution of the socioeconomic landscape have highlighted the need to establish cross-disciplinary databases and develop disease-focused guidelines as technical enablers for the creation of PPH tools; to strengthen the scientific basis for early action and response via integrated modelling, research, monitoring and evaluation of health risks imposed by climate change; and to reinforce legislation and policies to promote cooperation among different government agencies, as well as between government and non-government stakeholders.

Abbreviations

AI	Artificial intelligence
AST	Average surface temperature
BMZ	German Federal Ministry for Economic Cooperation and Development
CCD	Climate Change Department
CCRP	Climate Change Response Plan
China CDC	Chinese Centers for Disease Control and Prevention
CMA	China Meteorological Administration
CME	Climatological, meteorological and environmental
CNY	Chinese yuan
COPD	Chronic obstructive pulmonary disease
CRR	Climate risk and resilience in China
CSD	Climate-sensitive diseases
CVD	Cardiovascular diseases
DALY	Disability-adjusted life year
EHR	Electronic health records
EHS	Environmental health science
EHT	Extreme high temperature
ER	Emergency room
EWS	Early-warning system
GCA	Global Center on Adaptation
GHGs	Greenhouse gas emissions
GIS	Geographic information systems
HCCCP	The Health and Climate Change Country Profile
HFMD	Hand, foot and mouth disease
HRM	Heatwave-related mortality
IBD	Insect-borne disease
IHME	Institute for Health Metrics and Evaluation
IoT	Internet of things
IPCC	Intergovernmental Panel on Climate Change
MEE	Ministry of Ecology and Environment
MOHURD	Ministry of Housing and Urban-Rural Development
MOST	Ministry of Science and Technology
NAP	National Adaptation Plan
NAS	National Climate Change Adaptation Strategy
NCC	National Climate Center
NCCRCG	National Climate Change Response Coordination Group
NCD	Non-communicable diseases
NDC	Nationally determined contributions
NDRC	National Development and Reform Commission
NHC	National Health Commission
NIPD	National Institute of Parasitic Diseases
NLGCCR	National Leading Group on Climate Change Response, Energy Conservation and Emissions Reduction
NOAA	US National Oceanic and Atmospheric Administration
PEGS	Personalized Environment and Genes Study
PPH	Precision public health
RCP	Representative concentration pathway
SLR	Sea-level rise
TB	Tuberculosis
UN	United Nations
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VBD	Vector-borne diseases
WBG	World Bank Group
WHO	World Health Organization
WMO	World Meteorological Organization
YLD	Years lived with disability
YLL	Years of life lost

1 Climate change and health: the global landscape

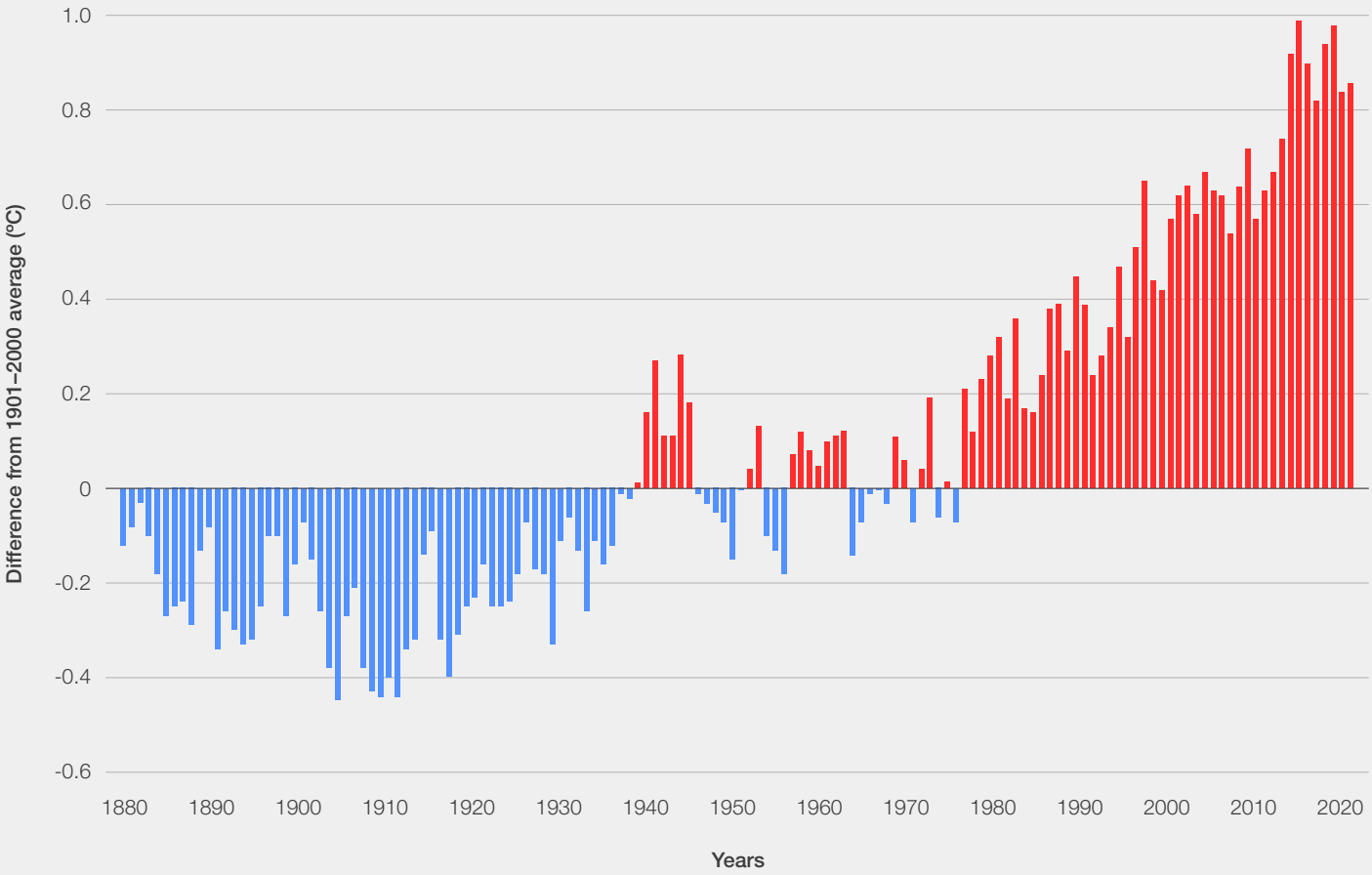
Climate change, one of the most critical global crises, is the long-term alteration of worldwide temperatures, precipitation patterns and other environmental factors.

1.1 Climate change and its natural consequences

Climate change refers to long-term shifts in temperatures and weather patterns.[4] According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), global surface temperature reached 1.1°C above 1850–1900 temperatures in 2011–2020.[5] And the changes in climate may be irreversible, despite the improved commitment to alleviating climate change. It is estimated that existing policies implemented across the globe will cause the temperature to rise by approximately 2.7°C above pre-industrial levels by 2100. Even under the optimistic assumption that country governments will achieve their net-zero emissions targets, the median warming estimate is still 1.8°C.[6]

Among the various factors contributing to climate change, greenhouse gas emissions (GHGs) are the leading cause. The data shows that current global atmospheric concentrations of carbon dioxide, methane and nitrous oxide are unprecedented compared with the past 800,000 years.[7]

FIGURE 1 **Global average surface temperature (1880–2020)**



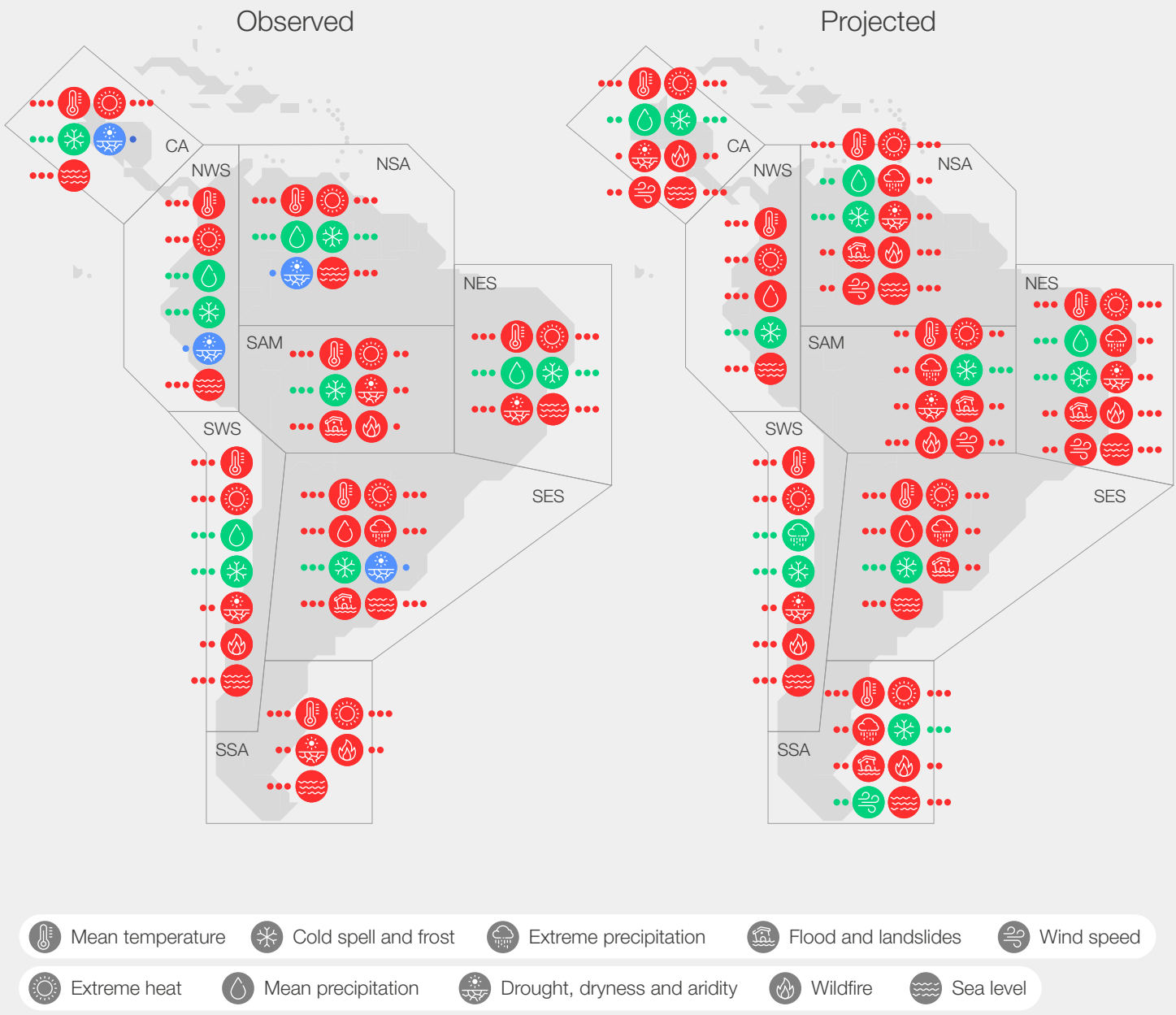
Source: *US National Oceanic and Atmospheric Administration*[8]

Climate change may lead to numerous extreme weather events, many of which interact with others and amplify the negative impacts. A 2017 study examined the relationship between the occurrence of weather-related natural disasters in 288 countries and territories. The results showed that temperature and precipitation are very important predictors of most natural disasters, and that higher temperatures are associated with more disasters caused by droughts, wildfires, heatwaves, tropical cyclones and other storms.[9] Extreme weather events also caused large-scale droughts and flooding across the world.[10] Furthermore, it is estimated that by 2080, 5–170 million additional people will be at risk of hunger due to climate change.[11,12] During the past 10 years, direct damage from climate disasters is estimated to have cost around $1.3 trillion.[13]

Tackling climate change needs both global-level cooperation and context-based solutions, as the level of exposure to climate change and its (historical and future) impact are highly varied among geographical locations. Between 2010 and 2020, human mortality from floods, droughts

and storms was 15 times higher in highly vulnerable regions compared to regions with very low vulnerability.[14] In AR6, Asia was identified as the region most exposed to sea-level rise (SLR) because 70% of the global population exposed to SLR and land subsidence reside in the region.[15] In comparison, the biggest risks posed to Africa from climate change are biodiversity loss and ecosystem disruption.[16] In Central and South America, stark variations in the type of climate-related hazards that brought the greatest impact were seen in different subregions (Figure 2). An analysis of a global dataset on subnational poverty in 134 countries published in May 2022 revealed that a 1°C rise in temperature was associated with a 9.1% increase in poverty and 1.4% rise in the Gini inequality index.[17]

FIGURE 2 **Observed and projected hazards in Central and South America**



CA Central America **NWS** North-Western South America **NSA** Northern South America **SAM** South America Monsoon
NES North-Eastern South America **SWS** South-Western South America **SES** South-Eastern South America **SSA** Southern South America

Source: *Intergovernmental Panel on Climate Change*[18]

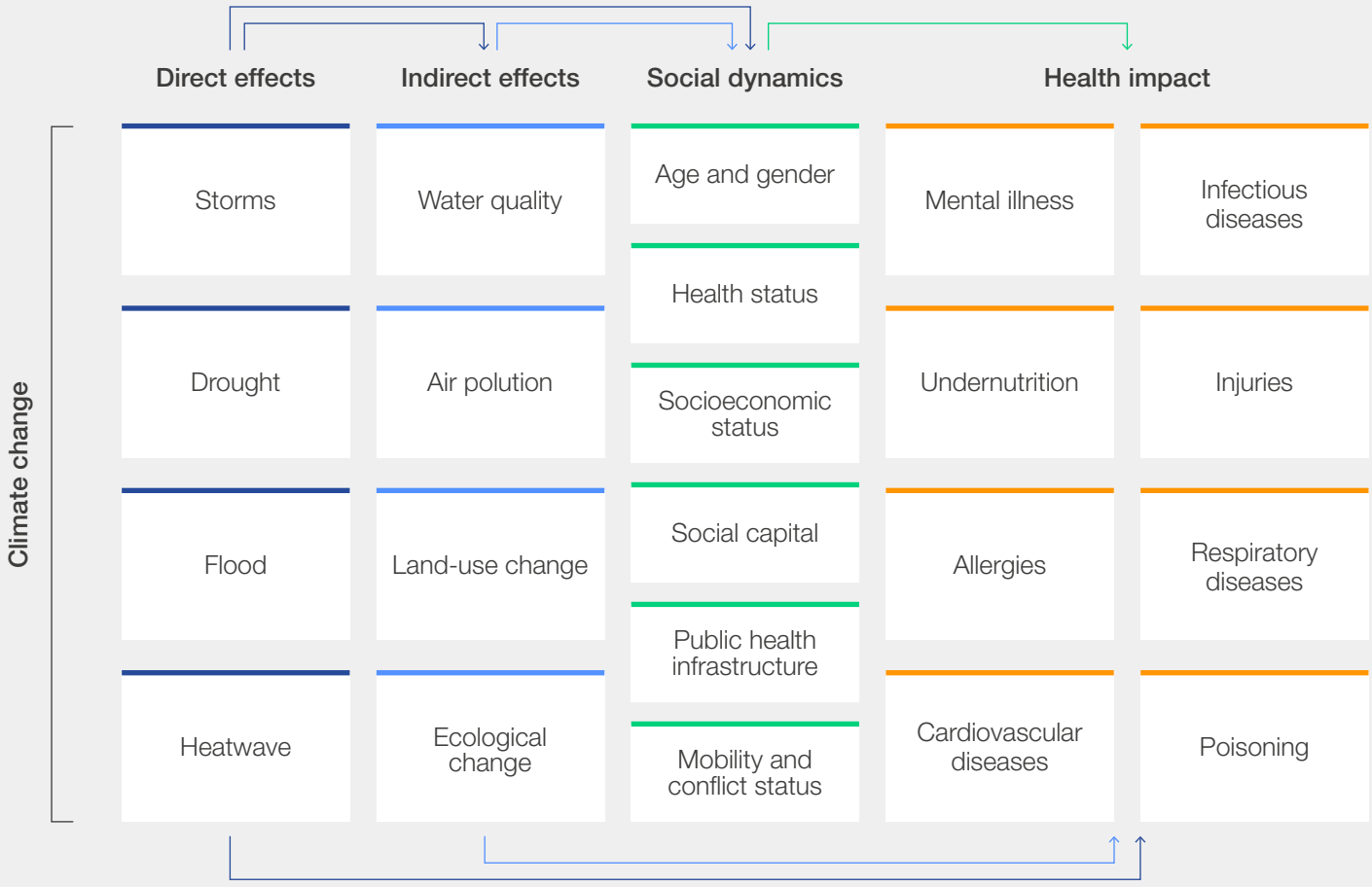
1.2 Climate change and health

Climate change affects population health through direct and indirect pathways.

The impact of climate change on health

The connection between climate change and population health is increasingly recognized as one of the major adverse impacts of climate change on human society. Climate change affects population health through direct and indirect pathways (Figure 3). The rising global temperatures caused by climate change are resulting in longer and more frequent heatwaves, which can lead to heat exhaustion, dehydration and even death. Higher temperatures also contribute to the spread of infectious diseases, such as malaria and dengue fever, as disease-carrying mosquitoes and ticks expand their geographic range. Climate change is also disrupting local ecosystems, leading to unpredictable changes in the distribution and availability of food, causing malnutrition and undernourishment. The indirect effects of climate change are particularly challenging to predict due to their lengthy causal chains.[19] The ramifications can often last a lifetime. For example, extreme weather events are becoming more frequent and severe, causing physical injuries, mental health issues and displacement of populations that may be lifelong. More importantly, the health impacts of climate change could be exacerbated by interactions with other non-climatic factors (e.g. socioeconomic status, gender, level of education). Vulnerable populations, such as elderly people, children and low-income communities, are disproportionately affected by the health impacts of climate change because of heightened physiological sensitivities, greater exposure or less capacity to take protective action.[20] Table 1 summarizes the possible mechanisms of these factors.

FIGURE 3 **The direct and indirect effects of climate change on health and well-being**



Source: *Watts, et al.*[21]

TABLE 1 **How socioeconomic, demographic and environmental factors affect the climate change–human health pathways and vulnerability to climate change**

Aspects	Variables	Impacts
Demographic	**Age**	Children and elderly people 1. *Health status:* immature or impaired functions of the body's physiological systems to deal with the effects of climate change 2. *Access to essential resources:* disadvantage in resource competition for, e.g. medical care, food, fresh water
	Gender	Women 1. *Access to essential resources:* disadvantage in resource competition and lower socioeconomic status 2. *Exposure to climate-related risk factors:* higher exposure to indoor air pollution and reduced ability/opportunity to escape floods and other natural disasters 3. *Education:* poor education levels and limited knowledge of self-protection from risks
Socioeconomic	**Socioeconomic and educational level**	Poverty 1. *Access to essential resources* 2. *Education:* limited knowledge of self-protection from risks 3. *Response to climate change:* reduced awareness of ways to mitigate and adapt to climate change 4. *Exposure to climate-related risk factors:* more outdoor work and higher exposure to outdoor air pollution and extreme temperatures
	Public health policy	Inefficient policy 1. *Access to essential resources* 2. *Health promotion:* poor health promotion regarding self-protection from risks 3. *Response to climate change:* passive attitude – less effective mitigation and adaptation 4. *Technology*: less investment in clean energy and pollution-control technologies
	Public attitudes towards climate change	Negative attitude 1. *Response to climate change:* passive attitude – less effective mitigation and adaptation
Environmental	**Land use**	Unbalanced ecosystem 1. *Biodiversity loss:* more vector-borne diseases 2. *Insufficient resources:* water and food insecurity
	Topographic character	Specific to regions 1. *City:* air pollution and temperature extremes 2. *Coastline:* storm, sea-level rise, flood 3. *Plain:* drought 4. *Basin:* air pollution (e.g. trap pollution) and temperature extremes

Source: *Zhao et al. (2022)*[22]

According to the estimate made by Vos et al. (2020), in 2019, the worldwide burden of climate-sensitive diseases (CSD)[23, 24] was 39,503,684 fatalities (69.9% of all deaths in the year) and 1,530,630,442 disability-adjusted life years (DALYs). Cardiovascular diseases (CVDs) made up the majority of these CSD, accounting for 32.8% of mortalities and 15.5% of DALYs. Following this are respiratory diseases, with chronic respiratory disease and respiratory infection and tuberculosis contributing to 7% and 6.5% of deaths, respectively. For all disease categories, either Asia or Africa was the region most affected, as measured by the number of mortalities associated with climate change. For instance, 96% of dengue-induced deaths were reported by Asian countries.[25] However, compared to other stressors, the global disease burden brought on by climate change is relatively low and poorly quantified.[26]

The AR6 synthesized findings from available studies on future projections for risks associated with specific

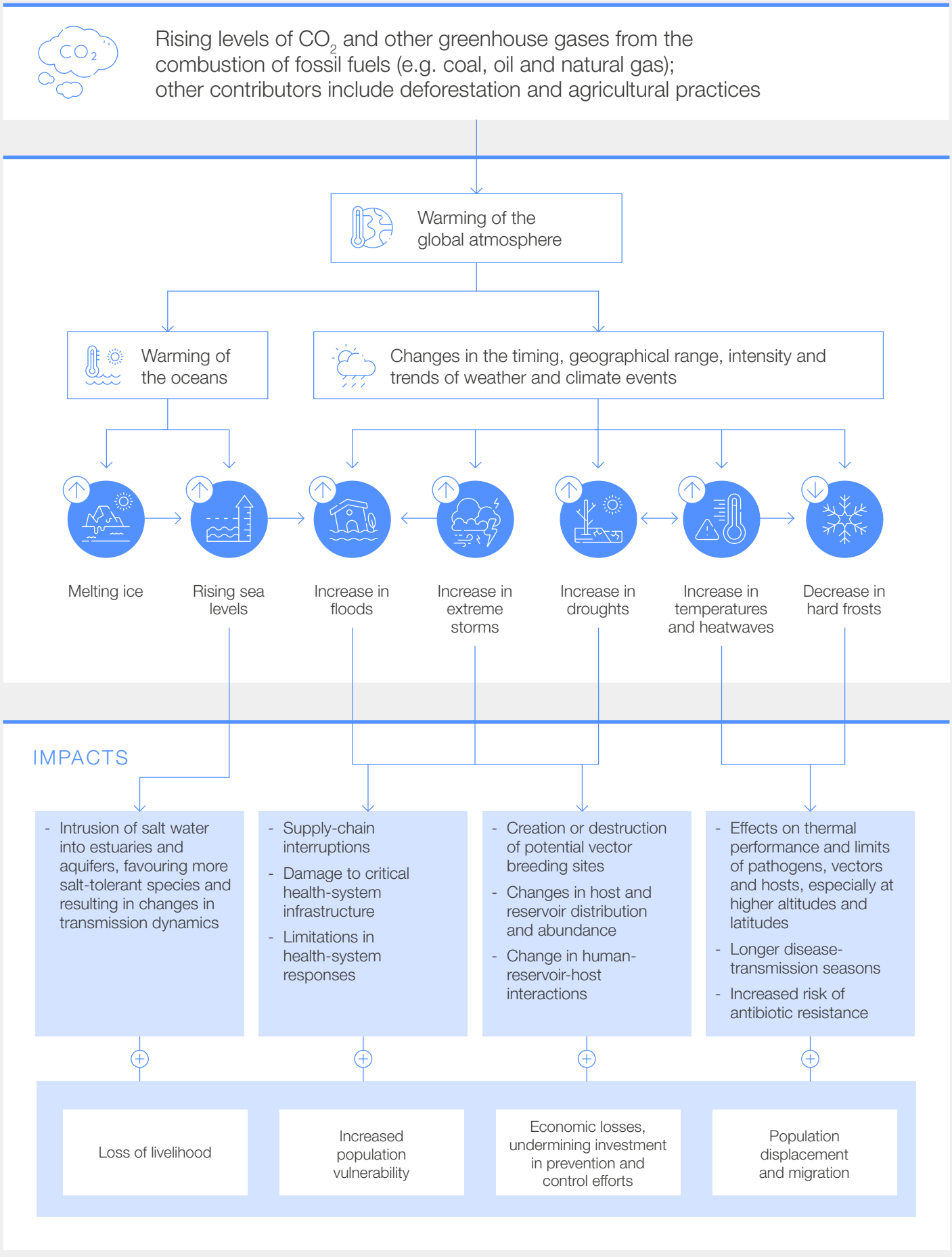
climate-sensitive diseases.[27] In 2014, the World Health Organization (WHO) published its forecast on cause-specific mortality for eight exposures under the mid-range emissions scenario (Ab1) and three economic growth scenarios. According to the study, projected climate change by 2050, as compared to 1961–1990, could result in an additional 250,000 deaths annually, with increases in deaths from heat (94,000), childhood undernutrition (85,000), malaria (33,000) and diarrhoeal disease (33,000) being the leading causes.[28] Another major study by Carleton et al. (2020) focused on all-cause deaths linked to global warming, and reported that climate change was predicted to cause 85 deaths per 100,000 people under the representative concentration pathway (RCP)[29] 8.5 scenario by 2100.[30]

Linking climate change with infectious diseases

The COVID-19 pandemic is a reminder of the intimate relationship between humanity and nature and in the context of climate change highlights the urgency of preventing zoonotic diseases, an important takeaway of the Symposium on Climatological, Meteorological and Environmental (CME) Factors in the COVID-19 Pandemic, held in August 2020.[31] While the relationship between COVID-19 and climate change (and CME factors) remains undetermined, numerous preliminary studies have unveiled a direct link between high COVID-19 infection and mortality rates and particulate matter (PM) from the combustion of fossil fuels such as PM2.5.[32] During the pandemic, extreme weather events such as droughts, floods, wildfires and heatwaves continued to occur, leading to compounded and catastrophic impacts. The pandemic also had significant effects on the socioeconomic system, escalating vulnerability and exposure to climate risks.[33]

The linkage between CME factors and other infectious diseases has been well documented by numerous studies conducted in different regions of the world. For vector-borne diseases (VBD), the geographical distribution of vectors or reservoirs, changes in the survival, development and reproduction rates of vectors, reservoirs and pathogens, and an increase in vector biting and the prevalence of infection in reservoirs or vectors are all pathways through which VBDs are sensitive to climate. These mechanisms all have an impact on disease transmission, thus exposure to VBDs will probably get worse in a warmer environment.[34]

FIGURE 4 | **Pathways between fossil fuels and rising GHGs and VBDs**



Source: *Thomson and Stanberry (2022)*[35]

> The increase in frequency and intensity of natural disasters due to climate change poses challenges to the infrastructure, support systems and supply chains on which healthcare facilities and their communities depend.

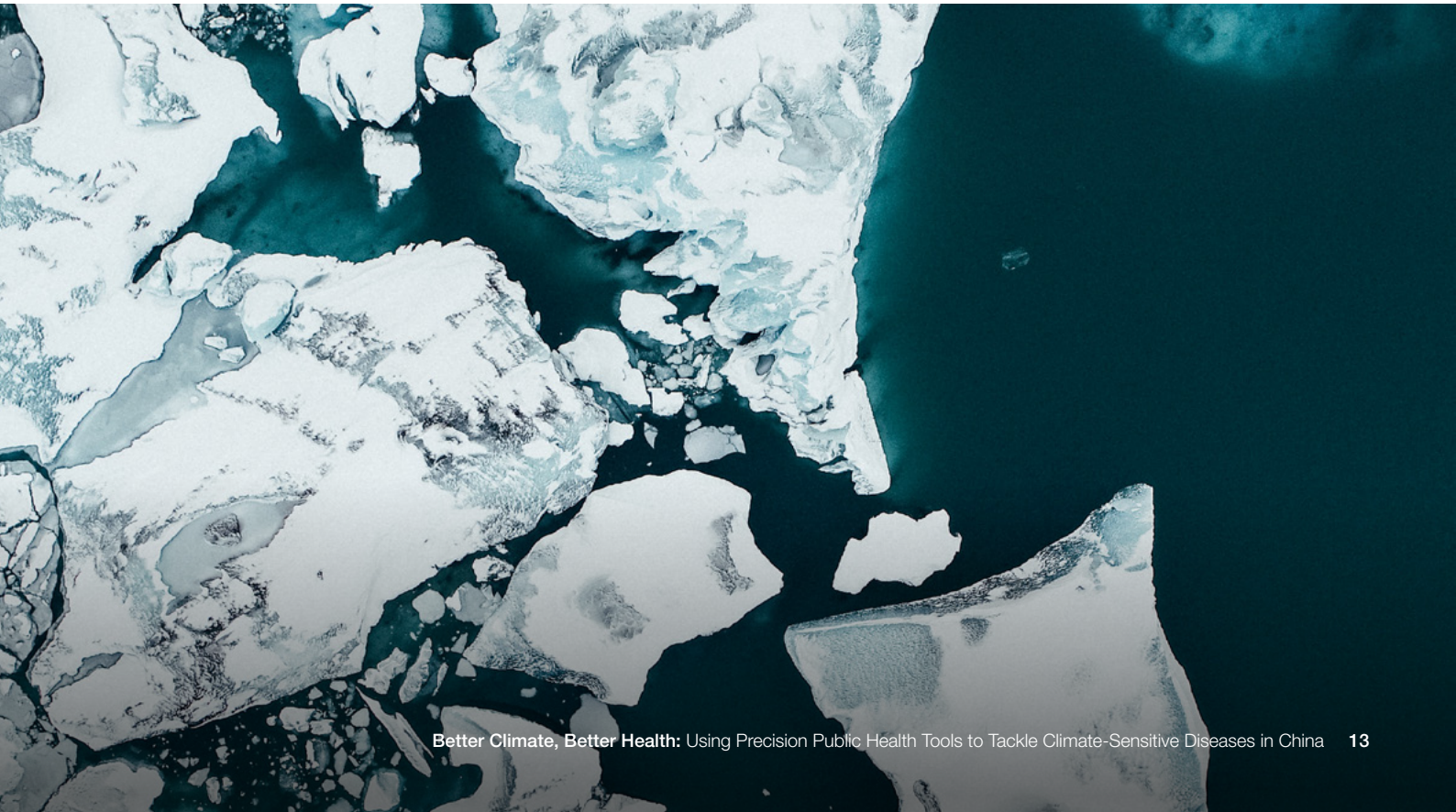
Another category of infectious diseases significantly affected by climate change is water-borne infectious diseases (WBD), particularly diarrhoeal diseases. Much of the population may be exposed to contaminated water during droughts because of inadequate sanitation. In the same way that drought can fuel outbreaks of WBDs, excessive rainfall and floods can also impose great challenges in WBD control due to poor sanitation brought on by runoff from congested sewage systems or livestock contaminating water.[36] During cyclones Idai and Kenneth, which hit Mozambique in March and April 2019, lost access to water and safe sanitation as well as displacement brought about cholera outbreaks that resulted in 6,600 cases and more than 200 fatalities.[37]

Climate change may also counteract hard-won progress in eradicating once-prevalent infectious diseases. In 2018, the National Oceanic and Atmospheric Administration (NOAA) posited that the viruses or bacteria that caused vanquished diseases such as the Spanish flu, smallpox or the bubonic plague might be frozen in permafrost – and so the melting of glaciers and permafrost caused by climate change might awaken long-dormant and dangerous microorganisms. In 2014, an experimental study found that a virus that had been sealed in permafrost for 30,000 years quickly revived after being reheated.[38]

The impact of climate change on healthcare systems

Other than the detrimental effects on people's health, climate change also has serious consequences for the healthcare system. For one thing, the increase in frequency and intensity of natural disasters due to climate change poses challenges to the infrastructure, support systems and supply chains on which healthcare facilities and their communities depend. Floods can damage healthcare facilities and disrupt supply chains, thus making it difficult to access the resources needed to provide care. During hurricanes, widespread damage to buildings, roads and other infrastructure makes it difficult for healthcare facilities to provide care to patients. Moreover, hurricanes can cause power outages and damage to medical equipment, which can further complicate healthcare delivery. Healthcare workers protect the health of their communities before, during and after disasters, but they are also exposed to the impacts of extreme weather events and climate change themselves. These consequences could overwhelm health systems financially, although the costs of managing the health risks of climate change are hard to estimate. In the United States, for instance, the annual health costs of air pollution and climate change already exceed $800 billion and are expected to escalate without a more vigorous social response.[39]

It should be borne in mind that healthcare organizations not only experience the effects of climate change but also contribute significantly to global warming. If the global healthcare sector were a nation, it would be the fifth-largest producer of GHGs, contributing nearly 4.5% of global emissions.[40] Based on the calculations by Health Care Without Harm, 17% of the health sector's emissions are produced directly by healthcare facilities. The majority of emissions (71%) are produced, transported, used and disposed of by the healthcare supply chain, which includes all of the items and services that the industry consumes. The remaining 12% are indirect emissions that come from purchased electricity, steam, cooling and heating.[41]



2 Global climate health actions

In a nutshell, there are two main categories of climate change response: mitigation and adaptation.

“ While mitigation addresses the root causes of climate change by reducing GHGs, adaptation seeks to lower the risks posed by the consequences of climatic changes.

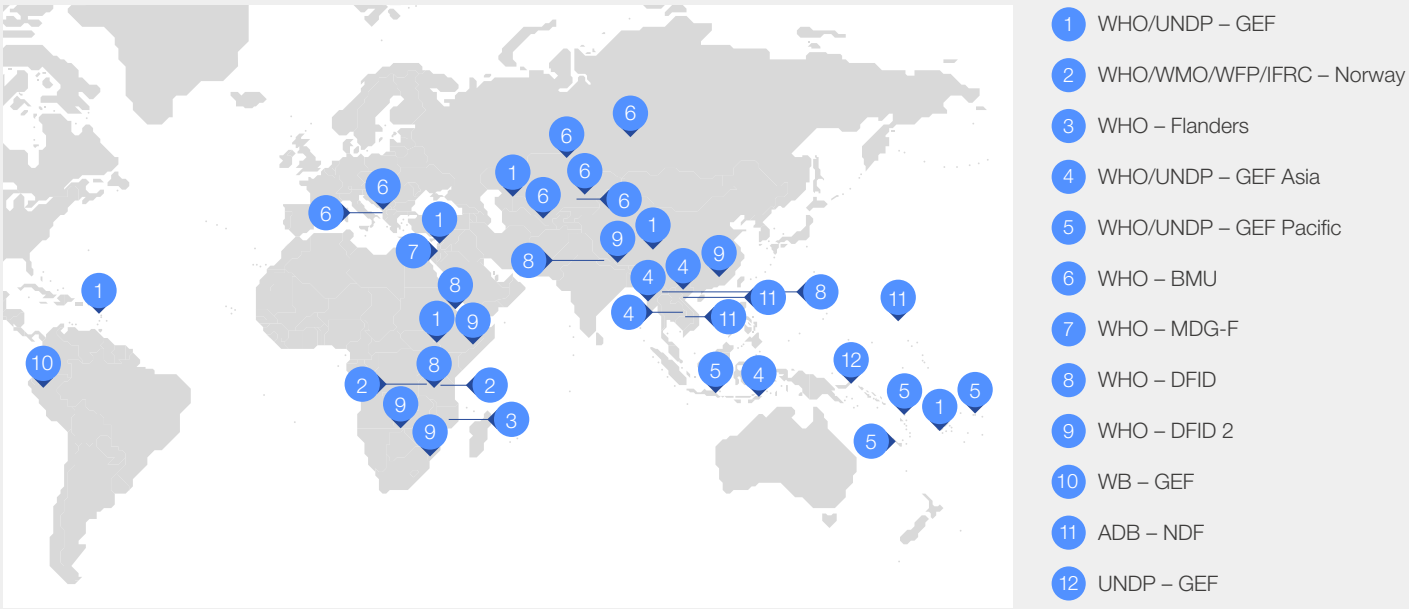
While mitigation addresses the root causes of climate change by reducing GHGs, adaptation seeks to lower the risks posed by the consequences of climatic changes.[42] According to an analysis by the Climate Policy Initiative, climate change adaptation cost approximately $46 billion in 2019–2020, an increase of 53% compared to 2017–2018, it still only accounts for 7% of global climate funds.[43] In the *Adaptation Gap Report 2022*, the United Nations Environment Programme estimated that the funding needed for adaptation is five to ten times higher than current investment in adaptation, and the gap between the two keeps growing.[44]

With regard to national-level implementation efforts, national adaptation plans (NAPs) are a crucial policy instrument in identifying sectors that are vital for strengthening resilience to climate change. NAPs can be established by all member states of the WHO as a means of identifying respective medium- and long-term adaptation needs and developing and implementing strategies and programmes to address them. Another document that embodies each country’s adaptation efforts is the plan for nationally determined contributions (NDCs),[45] essential to achieve the long-term goals of the of the Paris Agreement.[46]

In recent years, the threat from climate change due to the increased spread of disease, as well as the significance of the holistic nature of the health of human populations, animals and the environment, has come to the attention of many governments.[47] As the latest *WHO Health and Climate Change Survey Report* showed, 52% of respondent countries (49 out of 95) have a national health and climate change plan or strategy in place, with another 25% of countries (24 out of 95) having a plan or strategy under development; 51% of surveyed countries (48 out of 95) have conducted at least one climate change and health vulnerability and adaptation assessment; only a small proportion of countries reported having established health surveillance systems for health risks associated with extreme weather events.[48] Although there is a heightened awareness of the close links between climate change and health, the number of countries identifying “health” as a significant vulnerable sector in the adaptation components of their intended NDCs is less than that of “water” and “agriculture” as of 2019.[49]

Intergovernmental and non-profit organizations are also making efforts to increase the visibility of health in climate change responses through knowledge-gathering, policy advocacy, public campaigns, standard-setting and capacity-building activities. The WHO referred to the Paris Agreement as “a fundamental public health agreement”, and important works such as *The Lancet Countdown: Tracking Progress on Health and Climate Change*[50] and the *Compendium of WHO and Other UN Guidance on Health and Environment*[51] have made it clear that the health sector plays a crucial role in safeguarding the most vulnerable populations and coordinating mitigation and adaptation efforts.[52] Figure 5 summarizes large projects on health adaptation to climate change (≥ $500,000 per country) that have been approved, completed or are still ongoing since 2008.

FIGURE 5 **Completed, ongoing or approved large projects on health adaptation to climate change, 2008 to the present**



Notes: UNDP – United Nations Development Programme; **GEF** – Global Environment Fund; WMO – World Meteorological Organization; **WFP** – World Food Programme; **IFRC** – International Federation of Red Cross and Red Crescent Societies; **BMU** – Federal Minister for the Environment, Nature Conservation and Nuclear Safety (Germany); **MDG-F** – Millennium Development Goals Achievement Fund; **DFID** – Department for International Development (United Kingdom); **WB** – World Bank; **ADB** – Asian Development Bank; **NDF** – Nordic Development Fund

Source: *World Health Organization*[53]

2.1 Precision public health and its use in climate change solutions

The term "precision public health" (PPH) was first used by the Western Australian Department of Health in 2013 to describe advances resulting in personalized and precision medicine.[54] Three years later, Muin J. Khoury, Director of the Office of Genomics and Public Health at the US Centers for Disease Control and Prevention, declared 2016 to be the "Year of Precision Public Health".[55] And in 2019, The Rockefeller Foundation launched a $100 million Precision Public Health Initiative,[56] showcasing a strong belief in the value of PPH in handling the most critical public health problems among leading donor organizations.

While definitions of PPH vary, the general consensus is that PPH seeks to improve population health and well-being by providing appropriate health interventions to the right population at the right time.[57] The cornerstone of the approach is the synchronous integration of information about a range of determinants of health.[58] Therefore, the execution of PPH unavoidably involves advanced technologies such as geographic information systems (GISs), wearable devices, genomics,[59] patient-generated health data and electronic health records (EHR).[60] The emergence of PPH has the potential to transform infectious disease control, which has historically relied on methods such as incidence data and interview-based contact tracing. Ladner et al. (2019) proposed the concept of "precision epidemiology", a genomic technologies-enabled targeted approach for controlling infectious diseases at both the individual and population level.[61]

In developed countries, there are already numerous success stories about the use of big data and artificial intelligence (AI) for disease monitoring and early warnings. Before COVID-19 spread to the United States, on 30 December 2019, the automated health map system of the Boston Children's Hospital released the first public alert on the virus abroad, with the support of natural language processing technology. By mining online news, social media posts and government announcements, the tool can capture early-warning signs of infectious disease outbreaks and classify the severity of risks into five levels, giving organizations such as the WHO an awareness of the epidemic as quickly as possible, even when language barriers exists.[62]

The term "precision" has long been used by the environmental health science (EHS) community. As early as 2002, the National Institutes of Health (NIH) National Institute of Environmental Health Sciences sponsored the Personalized Environment and Genes Study, grounded in "precision environmental health".[63] In addition, practitioners have long been searching for feasible approaches to improve the accuracy of climate predictions and enhance understanding of the linkages between weather and infectious diseases. However, it was not until recently that the idea of incorporating "precision" into public health strategies related to climate change appeared in academic literature.

In 2022, the Wellcome Trust commissioned a pioneering study to map out the current software tools at the intersection of climate and infectious diseases across the globe. The study identified 37 tools that fulfilled four qualifications (i.e. that incorporated both climate and epidemiological data to generate information on disease risk in one package; were transparently described and validated; were named; and were accessible). Even though "PPH" was not a selection criterion, many of the tools were inherently PPH-oriented or could serve as an integral component of PPH tools by their nature. Analysis of the tools included showed that: (1) 81% (n=30) of the tools targeted VBDs, with malaria accounting for more than half (n=16), while only four targeted water-borne, respiratory or food-borne diseases; (2) 44% of the tools were implemented in Africa, but the developers of the qualified tools were predominately based in North America and Europe; (3) the majority (58%) of the tools used remotely sensed data products, interpolated weather station data and modelled climate predictions to inform models for infectious diseases or disease vectors.[64]

> The execution of Public Precision Health (PPH) involves advanced technologies such as geographic information systems (GISs), wearable devices, genomics, patient-generated health data and electronic health records (EHR).

3 Climate change and health: the landscape in China

China is one of the most susceptible countries in the world to the health impacts of climate change.

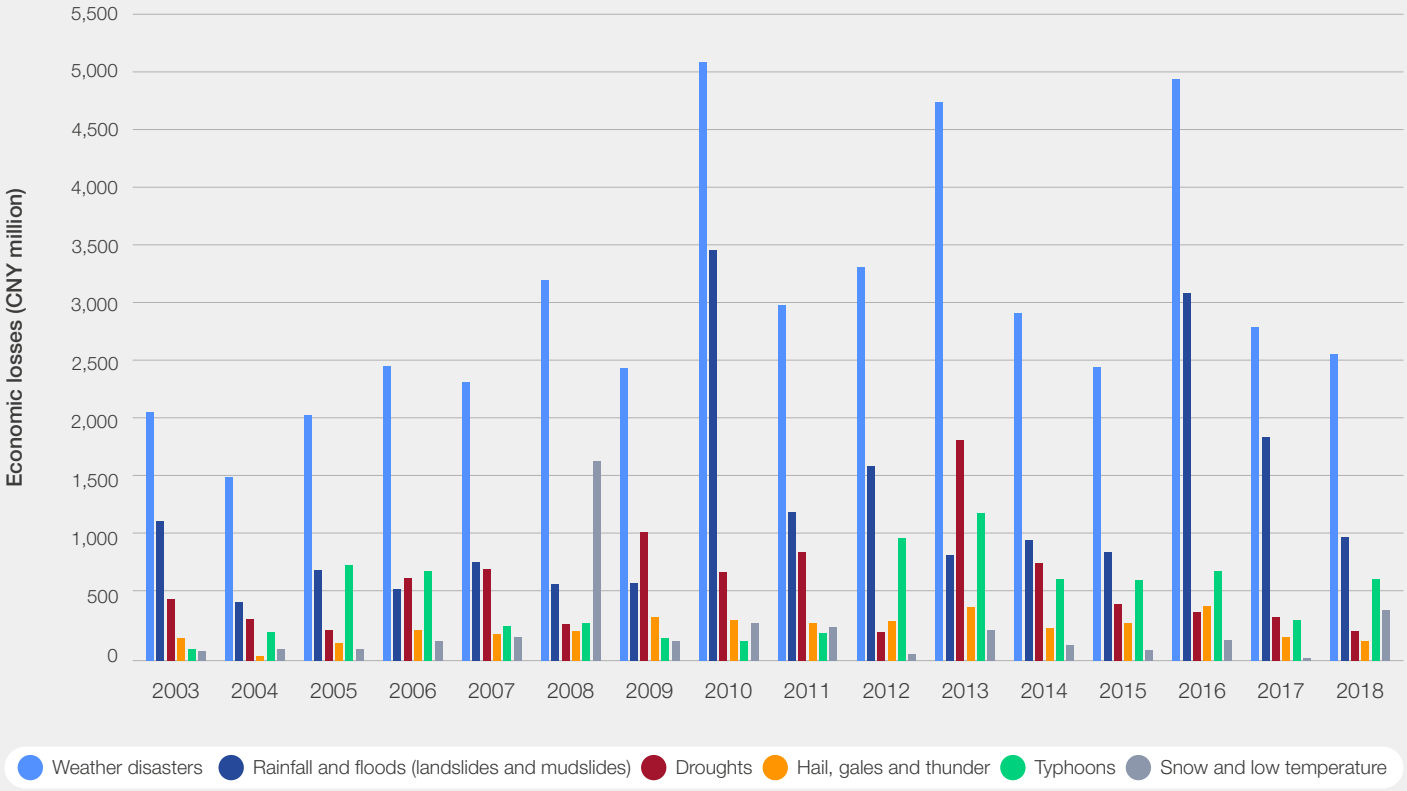
3.1 Climate change in China

> China is among the countries that are acutely vulnerable to the impacts of global climate change. Climate-related natural disasters took a heavy toll on the Chinese economy.

From 1901 to 2022, the annual average surface temperature (ASA) in China has shown a significant upwards trend, increasing by an average of 0.16°C every decade, higher than the global average temperature increase during the same period. In 2022, China's ASA was 0.92°C higher than the normal value, making it one of the three warmest years since the early 20th century. Estimations of climate warming in China indicate that this trend is hardly likely to be reversible considering the continuously increasing demand for energy and electricity and the multidimensional challenges of transitioning to a low-carbon economy. Since 2004, China has been the world's largest GHG emitter,[65] contributing to 27% of global carbon dioxide and a third of the world's GHGs as of 2022.[66] Admittedly, China has made considerable headway towards switching from coal to renewable energy. Compared to 7% a decade earlier, renewable energy sources made up approximately 15% of China's energy mix in 2019.[67]

China is among the countries that are acutely vulnerable to the impacts of global climate change. First, the frequency and intensity of extreme weather events have increased in many parts of China. In 2022, the country experienced a record frequency of extreme high-temperature events, with 366 national observatories breaking the historical extreme value of the highest temperature.[68] A predictive study showed that compared to the baseline time period (1986–2005), the frequency of heatwaves in China would increase by 10.3 times, 5.2 times and 2.6 times by the end of the 21st century under the RCP8.5, RCP4.5 and RCP2.6 scenarios, respectively.[69] Second, sea levels along China's coast have risen by around 3.3 millimetres per year since the 1980s, which is faster than the global average.[70] This has led to increased flooding and erosion in coastal areas, as well as salt-water intrusion into fresh-water systems. Glacier retreat in China has accelerated in recent decades, with many glaciers shrinking rapidly or disappearing altogether. This has significant implications for water resources in the country, as glaciers are an important source of fresh water for many regions. Moreover, air pollution in China is worsened by climate change, as higher temperatures and increased humidity can lead to more stagnant air and worsen the effects of particulate matter and other pollutants. These climate-related natural disasters took a heavy toll on the Chinese economy. In 2021, China experienced flood damages of almost $25 billion, the second worst in the world after Europe, yet just 10% of those losses were covered by insurance.[71]

FIGURE 6 **Economic losses from weather disasters in China, 2003–2018 (CNY million)**

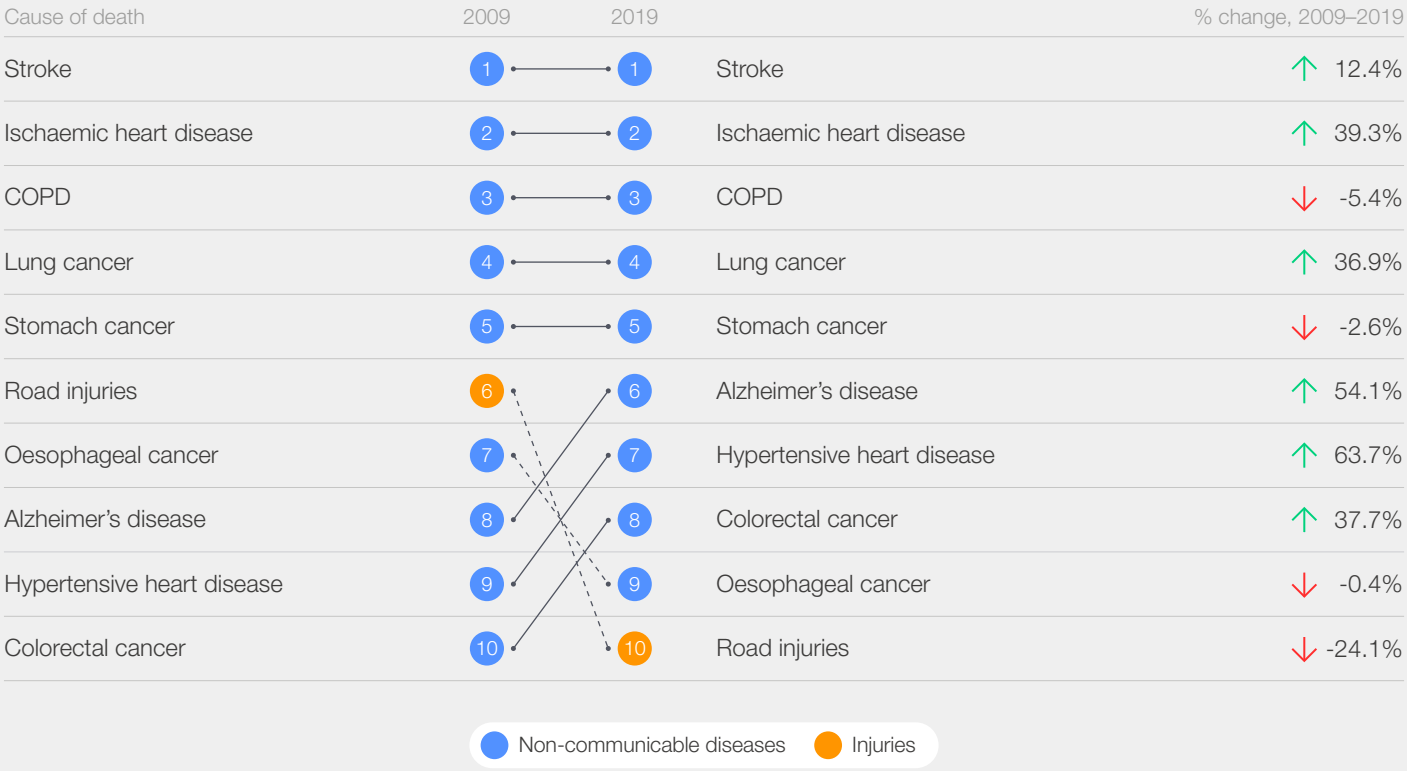


Source: *Asian Development Bank*[72]

3.2 The state of health in China

Over the past few decades, China has made significant strides in improving the health of its population. The nation achieved remarkable progress in improving health outcomes and reducing death rates, especially in areas such as child and maternal health, infectious diseases and chronic diseases. On the other hand, China faces a range of health challenges. The country has one of the highest rates of cigarette use[73] and air pollution in the world, which contribute to a range of respiratory diseases and CVDs. Non-communicable diseases (NCDs) such as cancer, diabetes and cardiovascular disease are also a growing concern, particularly as the Chinese population ages and because of lifestyle changes. As estimated by the WHO, China is expected to become the world's oldest country by 2050, with nearly 487 million people over the age of 60 years. By 2030, one in every four Chinese citizens is expected to be aged 60 years or above.[74] This has led to a faster transition from infectious to chronic diseases when compared to other countries with similar levels of economic development.[75] According to the Global Disease Burden Study, the proportion of mortalities attributable to infectious diseases in China declined from around 12% in 1990 to less than 3% in 2019. Conversely, the percentage of deaths brought on by NCDs increased by 17% to reach 90.1% in 2019, with ischaemic heart disease, chronic obstructive pulmonary disease (COPD) and strokes being the three main causes.[76]

FIGURE 7 **Top 10 causes of death in 2019 and % change 2009–2019, all ages combined**



Source: *Institute for Health Metrics and Evaluation*[77]

Although NCDs have grown to be more of a pressing issue, infectious diseases still pose a serious threat to China. One of the major challenges is the emergence and re-emergence of infectious diseases, which has been a persistent problem. The COVID-19 pandemic, which originated in Wuhan, China, has caused significant public health and economic impacts around the world. As of 23 December 2022, China had reported 397,195 confirmed cases of COVID-19 and a total of 5,241 deaths.[78]

Even without the pandemic, the presence of VBDs, such as dengue fever and malaria, is an enduring challenge in China, especially for the southern and central Chinese regions. Since 1978, new instances of dengue fever have been reported every year and there has been a noticeable increase in numbers.[79] From 2005 to 2020, China reported 94,354 dengue cases, including 12,701 imported cases and 81,653 indigenous cases.[80] Dengue outbreaks with a

high incidence and widening areas occurred in China in 2019.[81] Malaria is another major concern in China, particularly in regions bordering other countries in South-East Asia. Despite China being recognized as a malaria-free country by the WHO in 2021,[82] the surge in Chinese overseas travel and rising international trade activities during the past decades had seen imported malaria being recorded more frequently in China. From 2011 to 2015, there were 17,745 cases of malaria in mainland China, of which only 1,905 (11%) were locally transmitted.[83] Contagious respiratory diseases are also prevalent in China. It was estimated that between 2010 and 2020 there were approximately 50–170 million individuals with influenza virus infections in the country.[84] Influenza was found to be associated with an annual average of 88,100 excess respiratory deaths in 2010–2015.[85] Another public health threat is tuberculosis (TB). With around 0.9 million new cases of TB each year, China has the third-highest TB burden in the world,[86] not to mention the increasingly prevalent drug-resistant TB as recorded in many regions in the country.[87]

Precision public health in China

In a process similar to the evolution of PPH on a global level, China began with precision medicine before gradually turning its attention to PPH. In the first Expert Panel on National Precision Medicine Strategy, held in 2015, the Chinese government committed to an investment of CNY 60 billion ($8.4 billion) in precision medicine, making the industry part of a national strategy. In 2016, the Ministry of Science and Technology (MOST) announced precision medicine as a priority of the National Key Research and Development Program.[88] Later, the 13th Five-Year Plan of the People's Republic of China identified "precision medicine" as part of an emerging field of measures the country should promote to spur innovation in the industry sector; this was followed by the 13th Five-Year Plan for Strategic Emerging Industries Development, promulgated by the State Council, where the importance of the technology was again emphasized.

As far as is known, the term "precision public health" has not been mentioned in any policy documents (e.g. action plans, regulations, guidelines) in China. However, the notion of "precision prevention and control" gained popularity among health policy-makers in China during the COVID-19 pandemic. The term appeared in a number of COVID-related policies and opinions of high-profile government officials.[89] In many provinces and cities, local governments have been exploring how to control the pandemic precisely to minimize the socioeconomic cost of COVID-19 policies. As a result, big data and information technologies were used in activities such as health risk information delivery and contact tracing.[90] The Chinese government has been highlighting this approach as an advantage of China's responses to COVID-19.[91] This has also sparked conversations on how to make use of the legacy of the pandemic to standardize PPH processes and infrastructures for future disease outbreaks,[92,93] including the publication of the first PPH-focused review study written in Chinese in February 2021.[94]

While PPH is still in its infancy in China, there are many factors in favour of the actualization of PPH in the country. On the one hand, China has established itself as a global leader in the use and innovation of information and communication technologies,[95] witnessing rapid advances in next-generation technologies such as 5G, mobile payments, internet of things (IoT) and AI.[96] In the health sector, a 76.7% growth of the average adoption rates of electronic health records (EHRs) from 2007 to 2018 was recorded in a survey of Chinese hospitals conducted by the Chinese Health Information Management Association,[97] driven by the government's vigorous promotion of health information technology as a vital medical reform.[98] On the other hand, China has a sizeable patient population that is increasingly vying for personalized health interventions and is producing a massive volume of data across the disease spectrum. Without a doubt, concrete barriers exist in the development of PPH in China, including, but not restricted to: huge regional disparities in the availability of technical and financial resources; the public's rising concern about privacy; and difficulties in integrating the highly dispersed and varied databases and information systems for effective decision-making.

"China has a sizeable patient population that is increasingly vying for personalized health interventions and is producing a massive volume of data across the disease spectrum. However, concrete barriers exist in the development of PPH in China.

The evidence of climate change's health impacts in China

The impacts of climate change on communicable diseases and NCDs in China have been increasingly documented in the literature. Findings from recently published studies by health area are summarized below.

Suboptimal temperature and heatwave-related mortality (HRM) and morbidity: Liu et al. (2021) investigated the effects of temperature on years of life lost (YLL) in 364 locations of five provinces in 2011–2017. Both high and low temperatures can cause increases in residents' YLL, with low temperatures having a greater impact in southern regions, while northern regions were more affected by high temperatures. Overall, temperature was responsible for an average of 1.02 YLL per death in the studies areas.[99] Under the RCP8.5 scenario, the number of temperature change-related injury deaths in China is projected to increase by 156,586 between the 2010s and the 2090s,[100] corroborating the findings from another study by Yang et al. (2021), which forecast a rise in heat-related excess mortality from 1.9% to 5.5% during the same period under the same scenario.[101] For China's 51 largest cities, the incidence of excess HRM was predicted to be roughly 37,800 and 31,700 deaths per year in 2041–2060 under RCP8.5 and RCP4.5 relative to 1970–2000, respectively.[102]

Infectious diseases: When it comes to the relationship between climate change and VBDs, a J-shape or reverse U-shape was usually observed, indicating that the risks either grew continuously or climbed and subsequently dropped with the growth of specific meteorological conditions.[103] In general, there is a trend for a northwards shift of the endemic area and acceleration of the spread of VBDs in China.[104] Temperature probably helped spread insect-borne diseases (IBDs) in southern China while suppressing them in the northern area. Conversely, the impact of temperature change on rodent-borne disease cases is exactly the opposite of that of IBDs.[105] Hodges et al. (2014) drew attention to the association of climate change with water-borne diseases. In their study, it would take China 8–85 months to reduce the burden of infectious diseases attributable to water, sanitation and hygiene in the presence of climate change to the level projected in the absence of climate change.[106] Furthermore, numerous studies were conducted to examine the relationship between climate change and specific infectious diseases:

– **Dengue:** Between 2004 and 2020, the vectorial potential for dengue transmission increased significantly in 19 Chinese provinces as a result of changing climatic conditions.[107] Based on surveillance data collected from 259 sites in China, Liu et al. (2023) found that the prevalence of *A. albopictus*, the primary vector of dengue, was significantly correlated with winter to early spring temperatures (November to February) from 1970 to 2021 (prediction accuracy ranges from 93.0% to 98.8%) – the higher the temperature, the higher the prevalence.[108] It was estimated that, by 2100, the number of dengue risk-free cities in China would reduce from 150 under RCP 2.6 to 55 under RCP 8.5. In places with mid-to-low latitudes, particularly the coastal areas, hydrometeorological changes are anticipated to have a significant impact on the risk of dengue. Under the RCP 8.5 scenario, the yearly average increased excess risk was projected to vary from 12.56% in north-west China to 173.62% in south China.[109]

> Studies have looked at the relationship between climate change and hospital admissions, emergency room visits and ambulance dispatches in China.

- **Malaria:** A literature review of 27 papers demonstrated relationships between climatic factors and malaria in various provinces in China. These investigations all discovered a strong correlation between temperature and malaria transmission.[110] Reviewing 58 articles, Yi et al. (2019) concluded that the monthly malaria cases in China may increase by 0.90% with each 1°C rise and by 3.99% with each 1% increase in relative humidity.[111] It is anticipated that *P. vivax* and *P. falciparum* malaria distributions will grow in the vast majority of areas in China. In some counties in the north-west, north and north-east regions, substantial increases (>50%) would occur. Under both RCP 4.5 and RCP 8.5 scenarios, *P. vivax* exhibits a more pronounced spatial change than *P. falciparum*, suggesting that the latitudinal extension of malaria is uncertain.[112]

- **Hand, foot and mouth disease (HFMD):** According to Yi et al. (2019), each 1°C rise could result in an increase of 1.8–5.9% in the number of weekly notified HFMD cases in west China.[113] Other researchers found a significant correlation between temperature rise and an increased incidence of HFMD using meteorological and HFMD data from 2009 to 2014 in Huainan City, in Anhui Province.[114]

Non-communicable diseases: Evidence on the interlink between NCDs and climate change has been accumulating in recent years, although this association is still unclear in relation to several diseases. Using CVD and climate data from 15 Chinese megacities in 2007–2013, Yang et al. (2015) reported that 17.1% of 330,352 deaths related to CVD were caused by ambient temperature.[115] Projective studies conducted in Beijing predicted a 10.2–74% rise in the number of cardiovascular deaths attributable to temperature by 2050 or 2060.[116] Factoring in accelerating urbanization and population ageing, future temperature-related CVD mortality would increase by 44.1–256.6% in Beijing, depending on the GHG scenarios.[117] Another major study by Wen et al. (2023) reports significant associations between temperature variability and disease prevalence in China, with cardio-cerebrovascular disease, stomach diseases, asthma and chronic lung diseases generating the highest estimates.[118]

- **Mental health:** Projections of mortality under various climate-change scenarios predicted rising trends in excess HRM for mental illnesses but declining trends in cold-related excess mortality.[119] In a case-control study by Zhou et al. (2023) that engaged more than 430,000 individual deaths by suicide from all counties in mainland China, a positive correlation was found between death risks and temperatures.[120]

Several studies have looked at the relationship between climate change (or meteorological parameters) and hospital admissions, emergency room (ER) visits and ambulance dispatches in China, extending understanding about the impact of climate change at the broader health-system level. For example, based on 10-year (2007–2017) outpatient and ER visit data provided by two hospitals in Shanghai, environmental parameters were founded to be significantly associated with childhood allergic diseases, particularly for temperature and air pressure.[121] Similarly, in Hong Kong Special Administrative Region (SAR), hospital admissions due to respiratory and infectious diseases increased substantially during extreme heat and cold-weather events.[122] However, limited information is available to elucidate the level of preparedness of the Chinese health system to deal with emerging and re-emerging climate-related infectious diseases.

3.3 Responding to climate-related health challenges: national and local actions

Climate (and climate health) governance in China

China's climate governance has always operated within a hierarchical system in line with the characteristics of the Chinese political system, namely "top-level design – national strategy – sectoral and local action".[123] The establishment of the National Climate Change Response Coordination Group (NCCRCG) in 1998 marked the growing importance of climate change in the government's policy agenda since the country's economic reforms began in the 1980s. In 2007, China's National Climate Change Programme[124] was published, further elevating climate change to the responsibility of the highest level of the government, the State Council, and making it a key milestone in the evolution of China's climate governance. In the same year, the National Leading Group on Climate Change Response, Energy Conservation and Emissions Reduction (NLGCCR) was established to improve cross-ministerial coordination in climate policy-making.[125] The NLGCCR, which is led by the premier and includes more than 30 ministers as members, serves as the State Council's advisory and coordinating body for interministerial climate action. After the 12th Five-Year Plan was introduced, a policy shift towards a new low-carbon development model gradually emerged.[126] In the first NDC submission, China pledged to peak its carbon dioxide emissions before 2030.[127] In April 2018, the Ministry of Ecology and Environment (MEE) established the Climate Change Department (CCD) to promote synergy between environmental protection and climate change policies. Since then, the CCD has been leading China's efforts to combat climate change.[128] At the same time, all related ministries have set up climate change "anchor" offices to facilitate ministry-wide climate policy coordination.

Unlike overall climate governance, climate-health governance in China remains vague and the accountability mechanism is yet to be established. Committees and government bodies designing, implementing and evaluating climate-health policies are currently scattered across different ministries. For instance, the National Institute of Environmental Health is overseen by the Chinese Center for Disease Control and Prevention (China CDC), while the Environmental Health Research Center of the China Academy of Environmental Planning is directed by the MEE. There are many overlaps in the duties of these two agencies and the projects they are running.

The *National Climate Change Adaptation Strategy 2035* highlights the importance of monitoring, early warning and risk management of climate change.

Government actions on the intersection between climate change and health

Domestic policy

China's first national strategy for adaptation, which was released in 2013, focused on strengthening monitoring and early-warning capabilities, raising public awareness and protecting water resources, among other topics. The *National Climate Change Adaptation Strategy 2013* (NAS 2013) outlined steps to integrate national and regional adaptation strategies, as well as high-priority tasks for seven sectors, including human health.[129] To further strengthen adaptation actions and improve the climate resilience of natural ecosystems, as well as economic, health and social systems,[130] 17 government ministries jointly issued the *National Climate Change Adaptation Strategy 2035* (NAS 2035) in June 2022. The NAS 2035 envisages that by 2035 China will have established a nationwide climate impact and risk assessment system, with improved early-warning capabilities.[131] The NAS 2035 highlights the importance of monitoring, early warning and risk management of climate change and proposes measures such as improving climate change observation networks and enhancing the impact and risk assessment of climate change. Although a short chapter on "health" was included in the NAS 2035, China still does not have a stand-alone national adaptation plan for health.[132] As far back as 2007, 18 central government departments jointly issued the National Environment and Health Action Plan (2007–2015),[133] in which climate change, environment protection and population health were brought together. However, the implementation progress of the action plan was poorly documented, and it is unclear whether it was extended or not.

The adaption strategy for specific topic areas was also clarified by the Chinese central government. In 2016, the National Development and Reform Commission (NDRC) and the Ministry of Housing and Urban-Rural Development (MOHURD) jointly released China's first guidance document on urban adaptation to climate change, entitled *Climate Change Adaptation Action Plan for Cities*, which set the strategic goal of building 30 climate adaptive cities by 2020. Based on this document, the two ministries successively issued, in 2016 and 2017, the *Pilot Work Plan for Climate Adaptive Cities*[134] and the *Notice on Printing and Issuing the Pilot Work for Climate Adaptive Cities*.[135]

Other than the regularly updated NAS, general rules and planned measures related to climate and health adaptation were dispersed across a number of policy documents produced by different government bodies. As illustrated in Table 2, frequently mentioned climate health adaptation measures include health impact assessments, forecasting and early warning of climate-related hazards, standard-setting and technology-enabled climate health actions, representing a strategic alignment with the NAS 2035. An analytical report by the World Bank Group suggested that all key ministries of the central government have either formulated their own sectoral strategies on climate adaptation or included requirements on adaptation in ongoing projects.[136] However, this does not hold true for health adaptation because ministries other than the China Meteorological Administration (CMA), the State Council, the MOST and the NDRC have not published guidelines or strategic plans on the nexus of climate change and health based on research. Notably, without a formal cross-departmental coordination mechanism, the planned actions will very likely work in silos under varying schedules.

TABLE 2 **Key policy documents mentioning climate health actions issued by China's central government**

Document title	Issuance year	Released department	Contents referring to climate/climate change and health
National Plan for Meteorological Disaster Prevention and Preparedness (2009–2020)[137]	2009	CMA	Monitor and analyse scientific facts about climate change and its evolution patterns; strengthen research into the occurrence and development of meteorological disasters in the context of global warming; carry out impact assessments and studies of response measures to climate change on extreme meteorological disaster events, as well as on the economy, society, energy, water resources, agriculture and food, ecological environment, etc.; launch climate change services integrating climate change monitoring, prediction, impact assessment and response.

TABLE 2 | **Key policy documents mentioning climate health actions issued by China's central government (continued)**

Document title	Issuance year	Released department	Contents referring to climate/climate change and health
China National Plan for Tackling Climate Change (2014–2020)[138]	2014	NDRC	Pour more resources into assessing the impact of climate change on population health. Upgrade public health facilities in areas vulnerable to climate change; promote research on the epidemiological characteristics, rules, adaptation strategies and technologies of climate change-related diseases, especially infectious and acute diseases; explore the establishment of mechanisms for monitoring and early warning of climate-sensitive diseases and public information dissemination for emergency response; and establish mechanisms for psychological intervention after extreme weather and climate disasters. The government should also establish a mechanism for post-disaster psychological intervention after extreme weather and climate disasters. Develop contingency plans to deal with the impacts of climate change on population health. Conduct regular risk assessments and identify the priorities for seasonal and regional prevention and control; strengthen the monitoring, prevention and control of VBDs under climate change; invest more in health resources and health education related to climate change; enhance public awareness of self-protection measures and the ability to adapt to climate change; improve living environments.
The Opinions on Promoting "Internet + Healthcare" Development[139]	2018	State Council	Encourage medical and health institutions to collaborate with internet companies; strengthen the integration of regional medical and health information resources; explore the use of big data technology and related analytical tools (e.g. population migration and climate change) in disease prediction; strengthen intelligent monitoring of infectious diseases and other diseases.
Priorities of the "Healthy China" Initiative in 2022[140]	2022	Committee for Advancing the Healthy China Initiative	Carry out pilot projects to establish environmental health risk assessment systems; undertake national monitoring of environmental health literacy among members of the public; promote health-related actions in response to climate change.
China's Science and Technology Actions on Climate Change[141]	2007	MOST	Conduct research on the impacts of climate change on China's agriculture and animal husbandry, water resources, coastal zones, forests, grasslands and other natural ecosystems, human health and public health systems, endemic ecosystems and endangered species, and develop corresponding adaptation technologies and propose countermeasures.
National Climate Change Science and Technology Development Plan in the 13th Five-Year Plan[142]	2017	MOST	Carry out integration and demonstration of key technologies for climate change adaptation in megacities and urbanization and population health. Perform comprehensive assessment of the co-benefits and sustainable transition effects of China's climate policies, including the impacts (and uncertainties) on the economy, trade, industrial competitiveness, environment, resources, well-being (high-priority areas are air pollution, water resources, water pollution and population health). Research into the relationship between climate change and human health, in alignment with the monitoring, prediction and early warning of major epidemics.
National Meteorology Development Plan in the 14th Five-Year Plan[143]	2021	CMA	Strengthen research on the climate change mechanism, and on detection and attribution, the numerical model and impact assessment; improve the climate change database; undertake risk prediction and forecasting and develop early-warning products in key areas such as food security, water resources, the ecological environment, human health, infrastructure, disaster prevention and mitigation, and build a climate change risk early-warning platform.
Bioeconomy Development Plan in 14th Five-Year Plan[144]	2021	NDRC	Establish sensing technology-based environmental monitoring and early-warning platform.
National Health Plan in the 14th Five-Year Plan[145]	2022	State Council	Strengthen environmental health risk assessment in public and indoor venues; improve technical methods, monitoring systems and standards for environmental health risk assessment; establish a nationwide system for monitoring, investigating and assessing the risks of environmental health issues; explore the formulation of health impact assessment technical framework.
Action Plan for Meteorological Service to Win the Battle of Pollution Prevention and Control (2023–2025)[146]	2023	CMA	Steadily improve the capability of ecological and meteorological monitoring and evaluation; explore the establishment of ecological and meteorological disaster risk warning for weather events such as high temperature and drought.

Source: *Compiled by the authors based on public information*

> **To be frank, evaluation of the strategic goals and activities outlined in the NAS was not well executed. For example, the first version of NAS mentioned 'building 28 climate-adaptive cities as pilots'. The MEE conducted some follow-up research on this goal. The results showed that many policy-makers in these cities did not know exactly what adaptation stands for. Some believed that installing more electric car charging stations could be considered as an adaptation measure. Overall, investment in and awareness of adaptation are weaker than those for mitigation.**
>
> Cai Wenjia, Associate Professor, Department of Earth System Science, Tsinghua University

Tackling the climate change crisis from the health perspective requires the creation and adoption of technically sound policies, but this alone is insufficient because any policy is only as good as its execution. However, guided by the aforementioned policy documents, important advances in have been made in health adaptation across China, including:

- Vulnerability assessment of the health impacts of climate change and intervention-focused research (e.g. intelligent monitoring of imported vector organisms using advanced technologies) or financial support for these studies. Areas including air pollution, extreme weather events, VBDs and parasitic diseases have been prioritized.

- Nationwide monitoring systems to provide technical support for climate change health risk assessment and the identification of climate-sensitive diseases and vulnerable populations. By the end of 2022, 167 monitoring points to measure the impact of air pollution on human health had been set up in 87 cities of 31 provinces.[147] Regarding the construction of surveillance networks, the Institute of Infectious Disease Prevention and Control of the China CDC has taken the lead in establishing the National Vector Biological Surveillance System, covering 91 localities in 31 provinces, and the National Important Vector Biological Resistance Surveillance System, covering 58 localities in 22 provinces. Based on these systems, China's capacity to monitor key vector organisms has been strengthened.[148]

- Enhanced monitoring and prediction of extreme weather events associated with climate change. For instance, in collaboration with research institutes and universities, the CMA has established a typhoon monitoring and forecasting system powered by AI, which has been proved to increase prediction accuracy.[149]

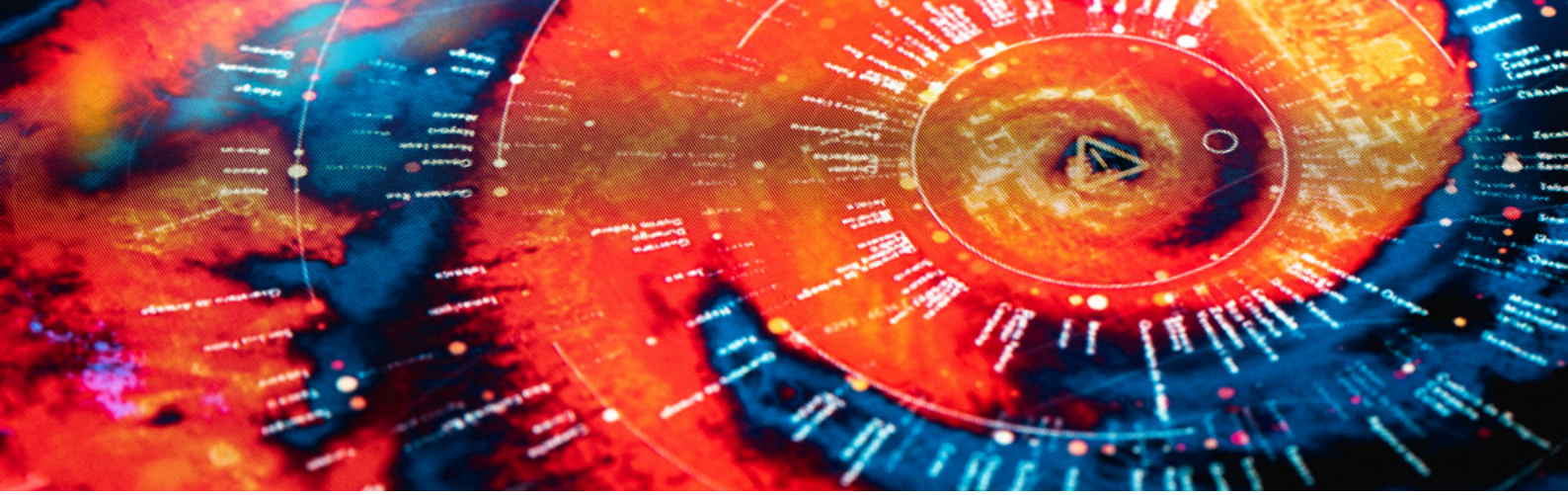
- Public health emergency plans and rescue mechanisms in close relation to climate change-induced epidemics such as Middle East Respiratory Syndrome, H7N9 and dengue fever.[150]

- Raised public awareness and understanding of the interlink between climate change and health, with behavioural changes driven by educational materials and campaigns. In July 2020 the MEE compiled and published a brochure entitled *Ecological Environment and Health Literacy of the Chinese Citizen,* including principles, key terms and recommendations for individual behaviour.[151] In June 2023, China CDC released the first *Guidelines for Public Health Protection in High Temperatures and Heatwaves*,[152] which provides structured information about the health impacts of heatwaves and self-protection guidelines for the general public in China.

- Data-sharing and development of databases. China has established multiple population health databases. Various types of data that are closely related to climate change can be found in the National/Local Statistical Yearbook, the Health Statistics Yearbook, population census data, the Notifiable Infectious Diseases Database, the National Disease Surveillance System's Causes of Death Monitoring Network Reporting Database and the Chinese Mental Health Database. This data is usually available for direct public access or is accessible on registration. Detailed individual-level patient data is managed by local disease prevention and control centres, local hospitals or health centres in China, but this data is generally confidential and not publicly accessible. Regarding climate change data, the National Meteorological Science Data Center has developed a set of basic meteorological data products by integrating meteorological observations collected since the 1970s and digitizing historical data, including the observational data from national meteorological stations,[153] which are downloadable from the National Integrated Meteorological Information Sharing Platform.[154]

To promote health adaptation efforts at the local level, the MEE issued the *Guidelines for the Formulation of Provincial Climate Change Adaptation Action Plan* in 2022,[155] after the NDRC released the *Guidelines on Formulating Policies Responding to Climate Change for Local Governments* in 2011.[156] Since the 14th Five-Year Plan was unveiled in March 2021, Anhui,[157] Guangdong,[158] Inner Mongolia,[159] Ningxia,[160] Beijing,[161] Chongqing,[162] Jilin,[163] Jiangxi,[164] Jiangsu[165] and Hubei[166] have issued provincial climate change response plans (CCRPs) in the 14th Five-Year Plan. The cities of Wuhan,[167] Shenzhen[168] and Guangyuan[169] have

> **Tackling the climate change crisis from the health perspective requires the creation and adoption of technically sound policies, but this alone is insufficient.**



taken the lead in formulating city-level CCRPs. Despite paying disproportionate attention to mitigation actions,[170] all these plans encompassed climate health measures. Seven provinces (77.8%) mentioned "infectious diseases" and/or its subcategories as a significant health area. In April 2023, the first provincial action plan for climate adaptation in China was made public by the government of Sichuan province, in which adaptation from the "health" perspective was listed as one of the 10 priority action areas.[171] It seems that there has been no systematic review to track the extent and effectiveness of the implementation of planned activities at subnational levels. Random evidence indicated that policy execution is fairly varied among provinces, cities and counties, largely depending on resource availability, political dynamics and socioeconomic situations.

> **Currently, China's response to climate and health issues is relatively scattered and lacks organization and regularity. This has resulted in fragmented assessment efforts, leading to unclear understanding of various issues. We need to improve the capability of all regions across the country to conduct climate risk assessments and develop technical guidelines.**
>
> Cai Wenjia, Associate Professor, Department of Earth System Science, Tsinghua University

Cross-border collaboration

China has actively participated in global climate governance and has shown a readiness to contribute more to the overall effort to combat climate change both in mitigation and adaptation. The purpose of this section is to document recently launched or impactful projects, initiatives and platforms that: (1) are relevant for mitigating climate change-related health challenges; and (2) were initiated by China or have China as a key participant. It should be noted that some cases that seemingly fail to meet these criteria nevertheless indirectly address climate change's health impact and hazards and so were included in this report.

Collaboration with foreign governments

- In 2018, China and the Netherlands jointly initiated the establishment of the Global Commission on Adaptation. In 2019, the first regional office of the Global Center on Adaptation (GCA) was established in Beijing.[172] As a key partner of the Chinese government, GCA China conducted an in-depth review of the NAS during its fine-tuning stage. Furthermore, the city of Beijing is collaborating with GCA China to design and launch its water eco-restoration plan,[173] which has close ties with human health in the face of climate change.
- In March 2023, the meteorology departments of China and the United Arab Emirates signed strategic agreements on facilitating and strengthening collaboration in meteorological technologies, highlighting the development of an early-warning system (EWS) for disastrous weather events.[174]
- Launched in 2020, Climate Risk and Resilience in China (CRR) is a public-private partnership project established by the German International Cooperation Agency and Swiss Re, commissioned by the German Federal Ministry for Economic Cooperation and Development. CCR aims to enhance the climate resilience of China's urban centres and their rural surroundings to reduce human and economic losses.[175] Significant activities completed since CCR's inception include: (1) advising the municipal governments of Shenzhen City[176] and Haikou City[177] in risk assessment and formulating policies to enhance climate adaptation in urban settings; (2) publishing case studies to document best practices in responding to climate change and its associated challenges (e.g. extreme weather events) in cities;[178] (3) organizing technical workshops and policy dialogues to strengthen the understanding and capacity of national and local decision-makers when managing climate-change risks.[179]

China has actively participated in global climate governance and has shown a readiness to contribute more to the overall effort to combat climate change both in mitigation and adaptation.

- The Climate Science for Service Partnership China established in 2014 is an initiative that encourages scientific cooperation between research institutions in the United Kingdom (UK) and China. Since its inception, more than 400 peer-reviewed studies have been published as a joint effort of UK-based and Chinese academics, some of which have examined the health impact of climate change on the Chinese population. Beyond multidisciplinary research, the project has also promoted the development of climate services and climate models, both of which are essential for climate health responses.[180] The two countries have also completed and published the UK-China Cooperation on Climate Change Risk Assessment and developed indicators of climate risks in 2015 and 2018, respectively.[181]

Collaboration with international organizations

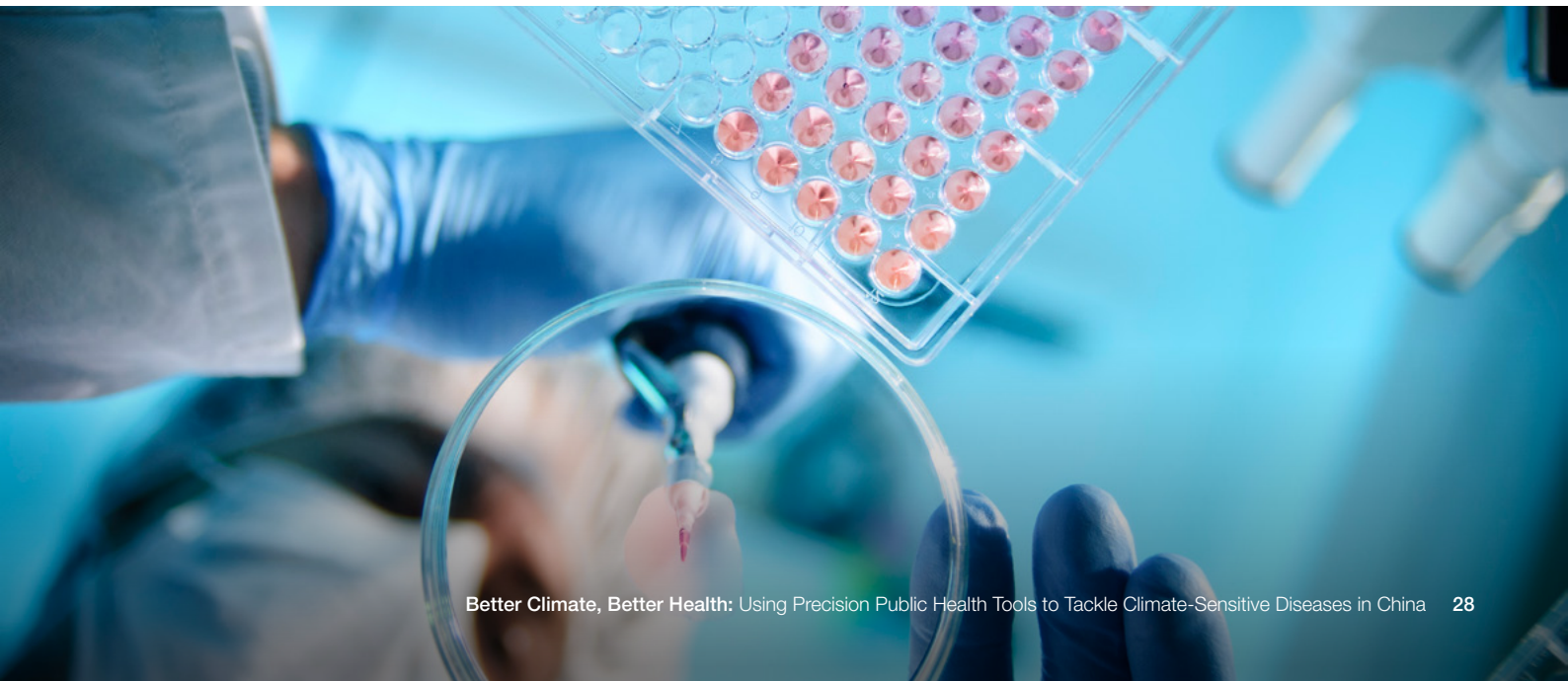
- In 2016, China and the WHO signed the China-WHO National Cooperation Strategy (2016–2020), in which addressing "the impact of the environment and climate change on health" was outlined as one of the six strategic priorities. The Strategy was updated in 2018 and the climate-health-related priority was reframed to "promote the Healthy Cities movement and the attainment of health in all policies".[182] In 2015, the WHO worked with the China CDC and other international partners (e.g. the United Nations Framework Convention on Climate Change) to publish a health and climate change country profile (HCCCP) for China. As one of the first 15 HCCCP reports released by the WHO, the document provided evidence of the relationship between climate change and health and identified opportunities for China to reduce GHGs while improving health.[183]

- The National Health Commission (NHC), the MEE and other government departments partnered in a series of environmental health projects at national and local levels between 2016 and 2020. Key outputs of the partnership included: (1) piloting gender-sensitive and climate-smart sanitation facilities for schools and health facilities in Qinghai; (2) working with the China CDC to promote children's environmental health indicators, including developing an online portal to track the indicators[184] and publishing the report *Prioritizing Children: Environmental Health Indicators for China*;[185] and (3) piloting climate adaptation intervention in Jiangsu Province. Using traditional and novel approaches, health education activities targeting primary school students and their parents were carried out, focusing on the health impacts of climate change and self-protection in high temperatures and heatwaves. The implementation of the project yielded a set of intervention toolkits and established a comprehensive school-based intervention model.[186]

- The CMA assembled more than 100 specialists to complete the government assessment of three reports, providing 90 pieces of advice to the IPCC, all of which were accepted.[187]

- China has pledged its support for the UN's Early Warnings for All initiative. The Belt and Road Forum on Early Warnings for All was held in Beijing in April 2023.[188] During this event, the MEE and the CMA signed a cooperation agreement on supporting this UN initiative with the WMO.[189] In addition, since 2004, the CMA and the WMO have co-organized the Forum on Regional Climate Monitoring, Assessment and Prediction for Asia every year.[190]

- Malaria, a major climate-sensitive infectious disease, has been an area of focus for China's global health engagement strategy. As the WHO's Collaborating Centre for Tropical Diseases, the National Institute of Parasitic Diseases (NIPD) at the China CDC has been instrumental in organizing and coordinating the efforts of international networks on the surveillance and response system. Six networks have been established, including the Regional Network on Malaria Surveillance in Greater Mekong Sub-Region Countries.[191]



4 Using PPH tools to address climate-related health challenges in China

This section outlines the most representative PPH tools aiming to address climate-related health challenges in China.

Aside from providing a brief overview of PPH tools, this section summarizes any significant findings and implications based on a thorough comparison of the reviewed tools and inputs from experts.

4.1 Inclusion criteria and research methods

In this report, PPH is defined as tools that use big data and predictive analytics for granular and timely surveillance to deliver public health interventions to the right population at the right time.[192] It could be a software tool or an integrated platform incorporating a complex of data-collection components, analytical tools, predictive techniques and health interventions.

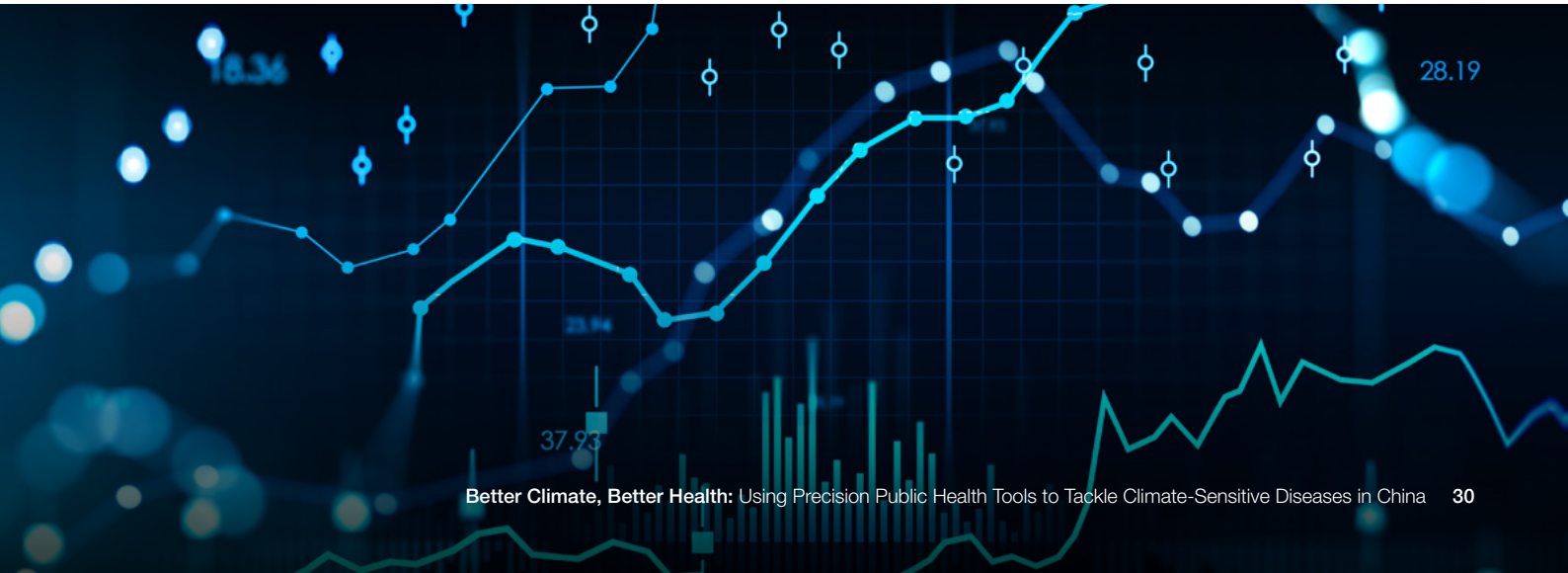
To be included in the report, a PPH tool needed to meet the following requirements:

- **To have been developed within the past 10 years:** To better identify recent trends in PPH tool development in China, the only tools and projects considered were those developed in or since 2013 and still in use when the search was conducted.
- **To be focused on targeting disease areas:** The tool should focus on climate-sensitive diseases, especially infectious diseases. Tools intended to tackle non-infectious diseases might be included when they exhibit substantial potential to be duplicated for infectious diseases.
- **To be operation-oriented:** The tool should have been developed to facilitate public health decisions and reduce the burden of targeting diseases, meaning that its ultimate goal is operationalization. Therefore, tools and models created merely for theoretical/methodological exploration purposes are excluded (e.g. one designed to develop a simulation model to examine which climatic parameter has the biggest contribution to the incidence of a specific disease and make predictions on future dynamics).
- **To have been validated:** The tool should have been or will be applied and validated in the field, either through short-term pilots or long-term operation.
- **To provide documentation on technical details and impacts:** In cases where there are multiple PPH tools targeting the same health topic, the tools that are the most exemplary and/or have better documentation of their technical details and impacts are chosen.

Due to practical constraints, this report cannot provide an exhaustive review of all PPH tools which are, or used to be, active in China. For instance, in China, many government-owned data platforms are either not accessible or are not disclosed by any public sources. Three approaches were adopted to make the tool search as comprehensive as possible:

- **Academic database search:** A search was performed in academic papers published from 2013 to 2023 via Chinese National Knowledge Infrastructure, CQVIP Information Database, Wanfang Database and the Chinese Biomedical Literature Database, using different combinations of keywords such as “climate”, “infectious disease”, “meteorology”, “surveillance”, etc. Publications written in Chinese and English were considered.
- **Web searches:** For tools and projects not documented in academic papers, a search was performed in other information sources (e.g. WeChat, websites of government agencies, knowledge portals of major climate-health organizations), with a focus on Chinese content.
- **Inputs from experts:** Experts in the field of climate change, public health (particularly infectious diseases) and CME modelling were consulted towards the end of each interview to capture any existing PPH tools that meet the selection criteria.

> PPH is defined as tools that use big data and predictive analytics for granular and timely surveillance to deliver public health interventions to the right population at the right time.



4.2 Key findings and implications

A total of nine tools were included in this report (Table 3), including two that were combined as one (Tool No. 9) due to their resemblance. The identified tools were analysed according to the four dimensions outlined in the sections below. Overall, the fact that only nine eligible tools were identified shows that PPH is a rather novel concept for policy-makers and other stakeholders responsible for responding to the health impacts of climate change in China.

TABLE 3 **PPH tools included in the report**

No.	PPH Tool	Disease area	Implementation level	Key participants
1	**China CDC Scientific Investigation of Regional Meteorological Sensitive Diseases**	All climate-sensitive infectious diseases	National	China CDC, CMA, National Climate Center (NCC), regional CDC, academia
2	**Dengue Fever Early-Warning System of Guangdong Province**	Dengue	Provincial	Provincial CDC, NCC, Provincial Meteorological Service
3	**Dengue Fever Early-Warning System of Ningbo City, Zhejiang Province**	Dengue	City-level	Municipal CDC, tech company
4	**Malaria Infection Risk Modelling for Active Surveillance Planning in Yunnan Province**	Malaria	Provincial	China CDC, local CDC, academia
5	**The Lancang-Mekong Sub-Region for Vector-Borne Infectious Disease Prevention and Control Platform**	VBDs (malaria and dengue)	Multinational	China CDC, provincial CDC, health authorities of foreign countries
6	**Schistosomiasis Surveillance and Forecast Tools by Local CDC and China CDC**	Schistosomiasis	National and city-level	China CDC, local CDC
7	**Influenza Forecasting Tool with Self-Adaptive AI Model and Multi-Source Data of Chongqing**	Influenza	Provincial	Local CDC, tech company, academia
8	**China CDC Heatwave and Health Risk Early-Warning System**	Heatwave and NCDs	National	China CDC, CMA, regional CDC, WHO, UNDP
9	**Heatwave and Climate-Sensitive NCDs Early-Warning Systems in Shanghai and Tianjin**	Heatwave and NCDs (COPD, stroke)	Provincial	City meteorological service departments

Source: *Compiled by the authors based on public information*

Dimension 1: **Focused disease areas**

The identified PPH tools are dedicated to a range of climate-sensitive diseases (CSD). When comparing the targeted diseases of these tools with the CSD highlighted in the NAS 2035, gaps were found in data relating to the plague and Japanese encephalitis as no tools were focused on these two diseases. Although Tool No. 1 is an all-encompassing project without a specific disease focus, the results of the completed surveys are likely to uncover disease areas that should be prioritized and show regional differences in terms of establishing priorities. Disease areas seem to be selected according to the risk of emergence and local transmission. For instance, tools for VBDs are primarily implemented in provinces located in southern China, an area susceptible to irregular VBD outbreaks and facing increasing pressure to control imported cases. Although only one tool for influenza was identified, the prevalence of the disease across China and the growing body of literature investigating how climate affects the transmission of influenza in the country[193] would likely facilitate the development of an increasing number of tools for this CSD. Furthermore, there has been a rise in heatwave-focused EWSs and a plethora of publicity about the negative health outcomes associated with heatwaves. A possible reason for this is that heatwaves and their impacts on health are often more discernible than other health areas. These tools often incorporate alert services for populations with a high risk of NCDs – the correlation with extreme high temperature (EHT) events has already been proved in numerous scientific research projects. Given the changing disease burden profile due to accelerated population ageing in China, the future emergence of more tools in this area is expected.

Dimension 2: **Participating stakeholders**

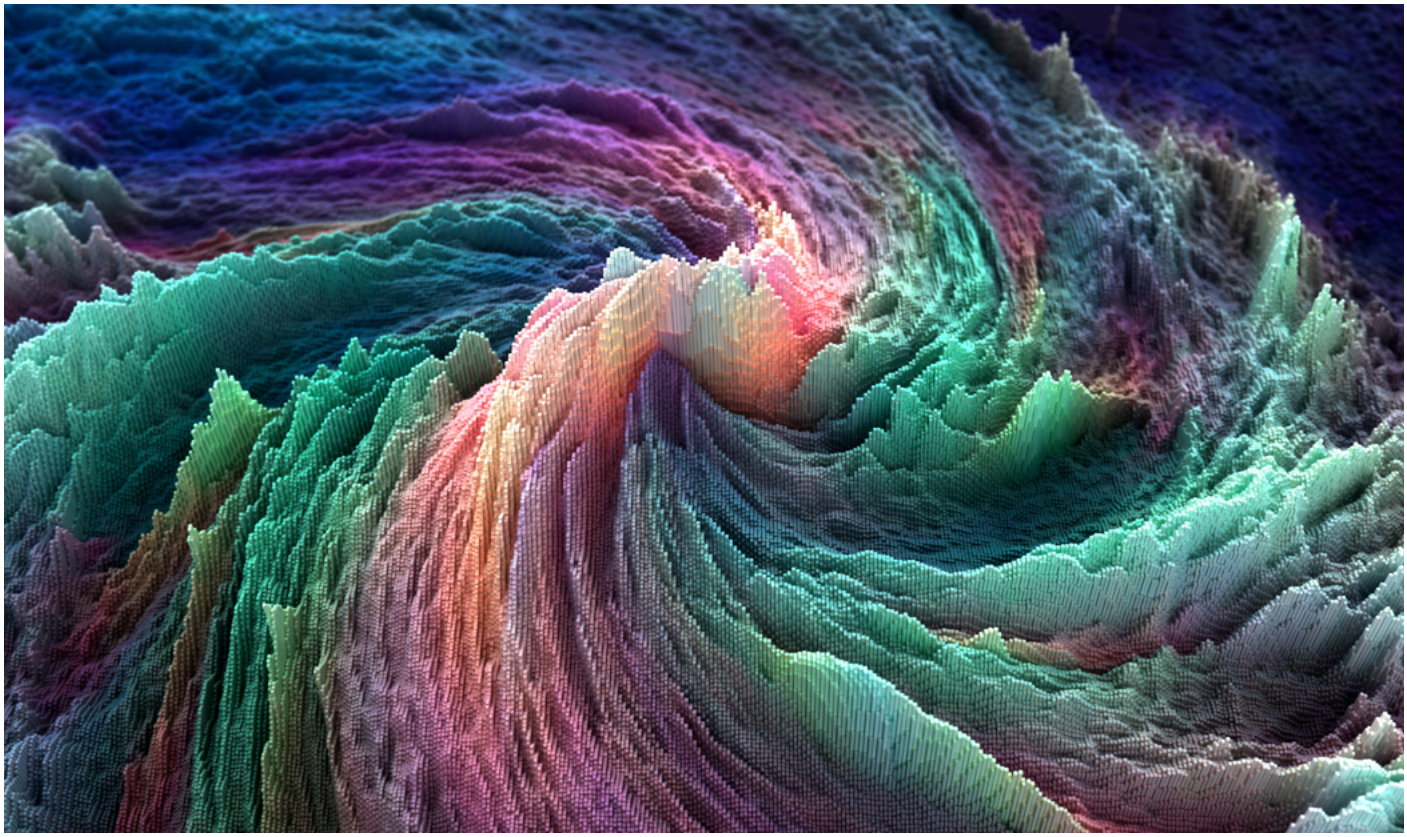
Cross-sectoral stakeholders, including central government, local government, academia and the private sector, have participated in the development and implementation of the PPH tools included in the report. At both national and subnational levels, disease control and meteorological service departments are key drivers of the identified PPH tools. There is also evidence of international collaboration on developing PPH tools for the surveillance and control of VBDs (Tool No. 5). In fact, Tool No. 8 is part of a project on developing heatwave EWSs to strengthen health-system resilience funded by the Global Environment Facility, with the United Nations Development Programme taking on the role of implementing agency, thus also entailing the engagement of international partners. Furthermore, the participation of tech companies was identified in two tools; their roles were relatively marginal and neither had been involved in tasks other than platform development.

In spite of the considerable variations in participating organizations and institutions, most tools focused on a single geographical region, indicating that the replicability of these tools in other contexts has not been substantiated and there exists a lack of scale-up strategy. The collaboration mechanism for climate adaptation actions on health challenges in China needs more clarity to maximize the positive impacts and to ensure resources are deployed to areas with the greatest need. Currently, local-level efforts are not guided by a nationwide policy, and ministries at the central level have not reached an agreement on the division of responsibilities. An effective governance structure, including important elements such as political mandate, funding mechanisms and the sharing of data, tools and best practices, should be established.

FIGURE 8 **Stakeholder map of the included PPH tools**

Note: NADCP = National Administration of Disease Control and Prevention

Source: *Created by the authors based on public information*



Dimension 3:
Purpose and operationalization

The selected PPH tools can be categorized by purpose and means of operationalization as either: (1) pilot and foundational tools that are research-oriented; or (2) practical tools that generate data and insights to inform decision-making as opposed to validation exercises. Among the nine reviewed tools, all except No. 1 and No. 8 belong to the second category. In terms of the application of scientific knowledge for public health practices, national-level foundational research (Tool No. 8) and city-level applied tools (Tool No. 9) in heatwave and NCD areas suggest that the transition between research and technical applications is burgeoning. Looking ahead, sufficient communication between the developers and policy-makers to decide targeted investment is a vital success factor for tools falling into the first group, while for the second group, well-planned knowledge transition procedures and the efficient duplication or repurposing of validated tools are crucial for the rapid launch of PPH tools in particular.

> **We are in the early stage of PPH tool development. From what I have observed, many of the disease surveillance and forecast projects are more like a toolkit, which could be used to improve efficiency and accuracy, but they are not independent operational tools.**
>
> Zhou Xiaonong, Director of the National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention

Dimension 4:
Data input and methodology

The tools included in this report use different data sources to identify climate health impact factors and improve the accuracy of prediction results, with data on disease vector, meteorological factors (e.g. temperature, precipitation, humidity, sunshine duration), air quality and geography being the most used. Internet search and social media data were widely used in EWSs for infectious diseases with apparent seasonality, such as dengue fever and flu, echoing the trend for innovative methods of disease surveillance used by the global community. AI-empowered data learning and mining are also starting to be integrated into PPH tools, which provides a solid foundation for the development and upgrading of PPH tools in the future. However, the low number of available tools for taking advantage of cutting-edge data and AI technologies implies that the development of climate-related PPH tools in China has deficiencies in the underlying technology and data access, necessitating greater capacity-building, data-sharing and focused investment.

5 Conclusion and recommendations

Human health will continue to be affected by climate change, including rising sea levels, increasing temperatures, more extreme weather events, and greater instances of droughts, flooding and wildfires.

The challenges climate change poses to health have increasingly been recognized by national and international decision-makers, leading to a proliferation of scientific research, policy dialogues, frameworks and practical solutions.[194] Among the many approaches taken to address the issues, precision public health (PPH) is a novel yet complex concept that has significant synergy with the fundamentals of recognized climate services (e.g. early-warning systems) and enormous potential in climate-sensitive disease (CSD) forecasting, risk assessment and intervention design, particularly in light of the rapid development of big data technologies in the past decade.

In China, as in other areas, mitigation has taken precedence over adaptation, and health has been a relatively low priority in adaptation policies when compared to other sectors. However, mounting evidence of the impact of climate change on population health and the overall health system has boosted political commitments to incorporate health as a key component of the national strategy on climate change. Despite significant strides in the field of health adaptation in China, a defined governance structure for climate health issues with a well-designed accountability framework and information-sharing mechanism is yet to be formulated.

This report, the first effort to map out active PPH tools for climate-sensitive diseases in China, highlights that there is much room for future development as few tools matching the inclusion criteria were identified. In terms of the focus areas, local epidemiology, demographic shifts, socioeconomic profiles and the extent of the influence of climatic and meteorological factors all have potential. Meanwhile, using existing tools for other CSDs and replicating these in various Chinese provinces, cities and municipalities would further the understanding of regional disparities in terms of vulnerability to climate change. This would also lay the foundation to create a platform on which data stored on different tools could be collated and interlinked and other advanced big data technologies integrated. To achieve such goals, institutional design tailored to the Chinese landscape and an effective coordination mechanism are needed whereby public health authorities, meteorology service departments, academia and the private sector could work together on PPH tool development. Lastly, substantial financial, technical and human resources should be allocated to PPH tools to encourage the sharing of scientific knowledge and activities to promote the monitoring and evaluation of the implemented tools and interventions.

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This report was made possible with grant funding from The Rockefeller Foundation. The information provided in this report is for informational purposes only. The findings and conclusions shared are those of the authors and do not necessarily reflect positions or policies of The Rockefeller Foundation.

Production

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Endnotes

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