



CLIMATE CHANGE AND
HEALTH RESEARCH

CURRENT TRENDS, GAPS AND PERSPECTIVES FOR THE FUTURE

DISCUSSION PAPER



World Health
Organization

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HEALTH RESEARCH

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GAPS AND
PERSPECTIVES
FOR THE FUTURE



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Climate change and health research: current trends, gaps and perspectives for the future

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Executive summary

The World Health Organization (WHO), in close collaboration with the Research Subcommittee of the WHO-Civil Society Working Group to Advance Action on Climate and Health, attempted to map out the trends and gaps in current research on climate and health over the past decade by implementing a comprehensive review of existing literature in this area. This exercise provided an overview of the current state of knowledge on climate and health, as well as geographic distribution of the studies, and outlined the new emerging fields of research.

This report also presents recommendations for future research, with the aim of improving the evidence base for policies to protect health from climate change. It serves as an update of the WHO publication “Protecting health from climate change: global research priorities” released in 2009.

Key findings

- Research on climate change and human health is a rapidly growing field, with the number of articles published each year surging more than six-fold over the past decade.
- Despite a significant increase in the number of articles, research on climate and health remains patchy: most of the currently available studies is focused on assessing health vulnerabilities to climate change, while there is a lack of research on the health impacts of the mitigation actions and effectiveness of adaptation measures, as well as potential health co-benefits.
- Research was unevenly distributed across geographical regions, with more studies conducted in high-income countries compared to low- and middle-income countries.
- Research on the climate impact of individual activities, such as personal dietary choice, as well as the assessment of the carbon footprint of health systems is emerging.
- Financial estimations of climate and health impacts need further investigation.
- Gender-disaggregated data, as well as the impacts of climate change on the health of vulnerable communities, require better assessment.

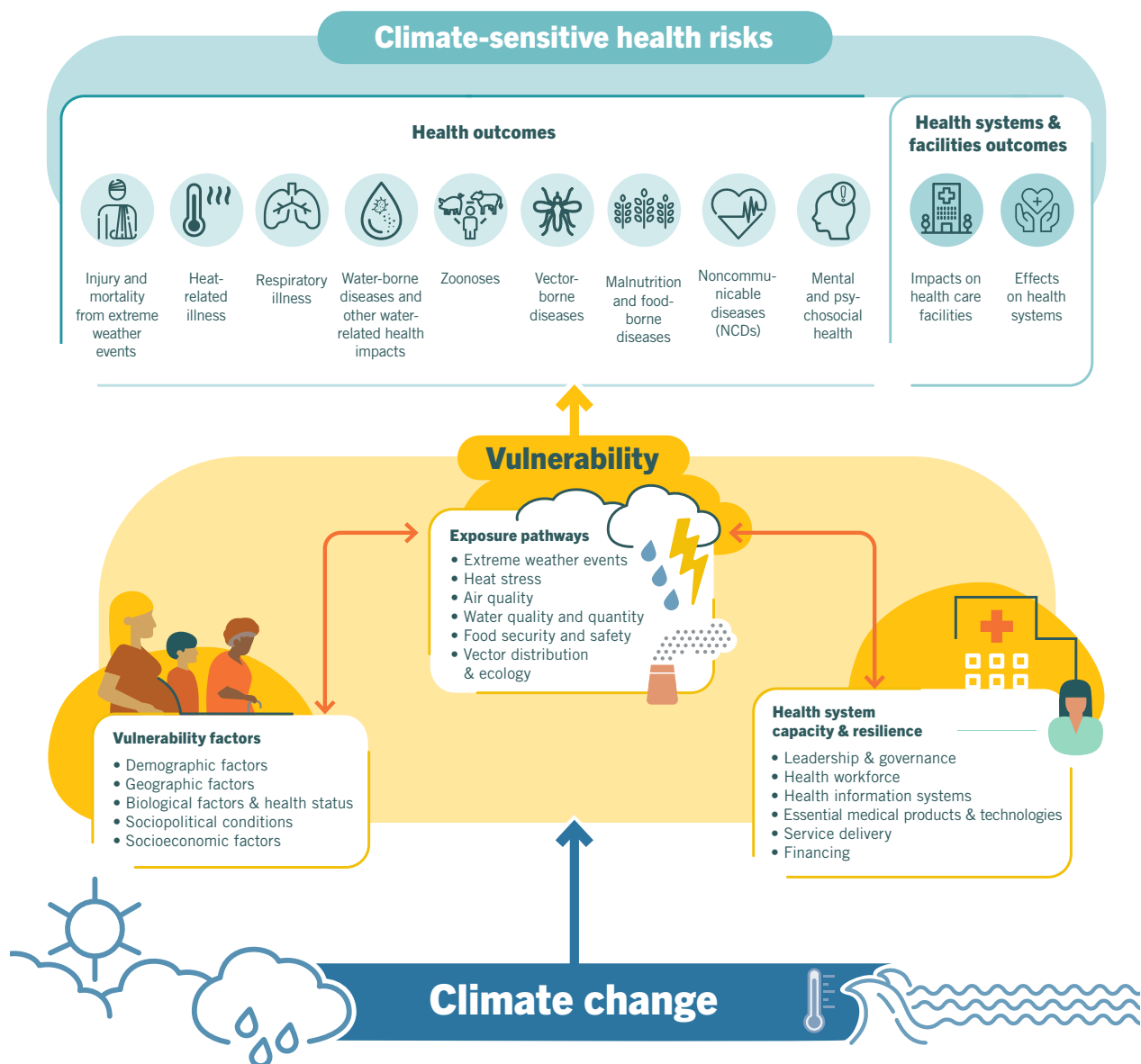


Introduction

Climate change is one of the most significant global health threats of the 21st century. Heatwaves, wildfires, flooding, droughts and other extreme weather events have been increasing in frequency and force every year, affecting the health of millions of people worldwide and causing economic losses of over US\$ 170 billion (as of 2020) (1). National governments,

United Nations (UN) organizations, health professionals, civil society and other major stakeholders face the challenge and the opportunity of responding to the climate crisis through mitigation and adaptation measures to protect and improve the health and well-being of people around the world.

Figure 1 An overview of climate-sensitive health risks, exposure pathways and vulnerability factors



Source: COP26 Special Report on Climate Change and Health. The Health Argument for Climate Action. Meeting Report. Geneva: World Health Organization; 2021 (<https://www.who.int/publications/i/item/cop26-special-report>).

For several decades UN entities have been calling for urgent action on climate change, asking national and local decision-makers to include climate considerations in their national development plans, and lately the recovery efforts for the COVID pandemic. The importance of a green recovery was highlighted by the UN Secretary-General Antonio Guterres in

his speech on 2 December 2020, urging countries and businesses for carbon neutrality and increased global finance for climate adaptation and resilience measures. The Secretary-General also underlined the significance of biodiversity protection and nature-based solutions for responding to climate change and creating green jobs (2).

WHO Manifesto for a healthy and green recovery from COVID-19 (3)

Released by the WHO in May 2020, the Manifesto calls for creating a healthier, fairer and greener world while maintaining and resuscitating the economy hit by the effects of the COVID-19 pandemic. The six prescriptions of the Manifesto lay out concrete instructions that policy makers, national and local decision-makers, and other stakeholders should follow to contribute to healthy recovery and shape the way people live, work and consume.

- 1 Protect and preserve the source of human health: Nature.
- 2 Invest in essential services, from water and sanitation to clean energy in health care facilities.
- 3 Ensure a quick healthy energy transition.
- 4 Promote healthy, sustainable food systems.
- 5 Build healthy, liveable cities.
- 6 Stop using taxpayers' money to fund pollution.

The six prescriptions are accompanied by over 70 related actionables, or practical steps for implementation at the national and local levels.

Research on climate change and health has an important role to play in understanding, projecting, preventing and preparing for climate change-induced hazards. Research is also essential to ensure that mitigation and adaptation interventions address the root causes and impacts of climate change in the most efficient,

effective and equitable way, while protecting and promoting health for all people, leaving no one behind. Global research collaboration is imperative for cultivating the evidence base in this field and for bringing health to the centre of climate change negotiations and overall climate advocacy.

Health at the 26th UN Climate Change Conference of the Parties (COP26)

Health was selected as a **science priority area** for the COP26. Anticipated activities during the Conference include a call for country commitments to endorse the principles of the newly established Adaptation Research Alliance (ARA), identify research institutions, grassroots and on-the-ground networks to join the ARA, and consultations to identify research priorities on health risks of climate change.

In partnership with the global health community, WHO has also developed the *COP26 Special Report: the health argument for climate action* (4) which aims to raise the profile, arguments and urgency of tackling the climate crisis to safeguard health. This report reflects the growing evidence and availability of solutions to maximize the health co-benefits of tackling climate change. It also offers clear tasks from the global health community to climate change policy makers at COP26, providing a list of 10 key recommendations for mainstreaming health in the global climate agenda and beyond.



Background

In 2008, health ministry representatives from around the world gathered at the World Health Assembly (WHA) and passed an unprecedented resolution on climate change and health. This resolution included a specific request for research, calling on the WHO to “develop capacity to assess the risks from climate change for human health and to implement effective response measures, by promoting further research and pilot projects in this area.” The resolution recommended that these activities be pursued “in close collaboration with Member States and appropriate United Nations organizations, other agencies and funding bodies” (5).

The Resolution outlined five priority areas for research:

- (a) **health vulnerability** to climate change and the scale and nature thereof;
- (b) **health protection strategies** and measures relating to climate change and their effectiveness, including cost-effectiveness;
- (c) the **health impacts of potential adaptation and mitigation measures** in other sectors such as marine life, water resources, land use, and transport, in particular where these could have positive benefits for health protection;
- (d) **decision-support** and other tools, such as surveillance and monitoring, for assessing vulnerability and health impacts and targeting measures appropriately;
- (e) assessment of the **likely financial costs** and other resources necessary for health protection from climate change.

In 2009, following this resolution, the WHO conducted a global consultation process to set the research agenda on climate and health. This process involved a wide range of actors, including researchers, health practitioners, representatives of funding bodies and UN agencies.

The findings of that consultation are outlined in the report “*Protecting health from climate change: global research priorities*” (6). In alignment with the five research priorities set by the WHA, this report called for accelerating research on: assessing climate-related health risks; identifying the most effective interventions to address health risks; guiding health-promoting mitigation and adaptation decisions in other sectors; improving decision support systems; and estimating the costs of protecting health from climate change.

A scoping review of climate and health research, conducted in 2012 after the consultation process to evaluate the alignment between existing scientific studies and the five recommended priorities (7), observed an uneven distribution of research across priorities and pointed to the need for more systematic and quantitative approaches. The review noted that while the field of climate and health research was growing rapidly, scientific articles addressing efficient health protection interventions (Priority 2) and adaptation strategies (Priority 3) were lacking. Also, more studies were conducted in high-income countries, while the emphasis should be on low- and middle-income countries for ensuring adequate coverage of vulnerable geographical regions.

A decade after the WHA resolution and the global consultative process set forth the above five priorities and recommendations, research exploring the intersections of health and climate change has expanded considerably. However, there is still a substantial need and opportunity for further research. Scientific evidence is needed to guide appropriate policies and interventions to reduce and protect people’s health from climate change-induced risks. It is vital that a concerted response be mounted by the global scientific community to address the current gaps in research on climate and health across all thematic areas and regions.

State of climate and health research in the Special Report on 1.5 degrees developed by the Intergovernmental Panel on Climate Change (IPCC-SR1.5)

The **1.5 Health Report**, released by the WHO, summarized the findings of the IPCC-SR1.5 in 2018, outlining the current evidence on the interlinkages between climate change and health. The 1.5 Report summarized the knowledge gaps in climate change and health research that were identified by the IPCC (8,9). These knowledge gaps include the following:

- **health and well-being risks** in the context of socioeconomic and climate change, especially in key areas such as occupational health, air quality and infectious disease. [Section 3.1 and 3.7.2]
- impacts of global and regional climate change on **public health, food distribution, nutrition, poverty, tourism and coastal infrastructure**, particularly for developing nations. [Section 3.7.2]
- implications of climate change on **livelihoods and poverty, on rural communities, indigenous groups and marginalized people**. [Section 3.4.7.1 and 3.7.2]
- limited focus on **regional risks and adaptation options** at 1.5 °C and 2 °C, as compared to research on global risks. [Section 3.4.7.1]
- **difference between the impact of 1.5 °C and 2 °C** on human health for a range of climate-sensitive health outcomes, such as diarrhoeal diseases, mental health and air quality. [Section 3.1]
- influence of global warming on **human migration**. [Section 3.7.2]
- projected impacts of **sea level rise**, which particularly influence human health, agriculture and water resources of small island nations. [Section 4.3.6]
- **co-benefits and trade-offs when reducing Short-Lived Climate Forcers** (such as better health outcomes, agricultural productivity improvements). [Section 4.3.6]
- scientific literature on **climate-SDG interactions** which is key for selecting mitigation options that maximize synergies and minimize trade-offs towards the 1.5 °C and sustainable development objectives. [Section 2.5.3]

Objectives and brief methodology

In order to identify research trends and gaps in existing scientific literature, and to assess the extent to which recently published research corresponded to the five priorities outlined in the WHA resolution, the research subcommittee of the WHO-Civil Society Working Group on Climate Change and Health undertook a **scoping review** of original scientific literature on climate change and human health that was published during the past decade. The results of this work, briefly outlined here, serve as a basis for setting future research agenda on health and climate change and contribute to the COP26 Health Programme.

A scoping review of original quantitative and qualitative research published during 2008-2019 was undertaken by a group of researchers by searching three databases (PubMed, Embase and ScienceDirect) with climate change-related terms and “human health” as search keywords. Duplicates, reviews, commentaries, event reports and articles not covering human health aspects or in languages other than English were

excluded from the database of over 10 000 identified articles, resulting in a final list of 2181 studies. These selected articles were further screened and categorized by research priority areas, thematic areas, health fields, country income level groups (based on the 2019 World Bank categories), geographic regions (based on WHO and the United Nations Framework Convention on Climate Change (UNFCCC) classifications), and several cross-cutting topics. Articles under each of the priority areas were then quantified to assess the distribution of research among topics and geographical areas and to identify trends and gaps in research on climate change and human health. For more details, please refer to the full methodology outlined in Annex 1.

It is important to note the **limitations** that could not be easily avoided while implementing this work. First, this review included studies that were available only on three selected databases. While these databases were chosen due to their pre-eminence in health research, they

WHO-Civil Society Working Group to Advance Action on Climate Change and Health

The WHO-Civil Society Working Group, established in 2017, is co-chaired by the WHO and the Global Climate and Health Alliance (GCHA) and unites 13 civil society organizations from around the world. The main goal of this working group is to increase health sector civil society mobilization to strengthen national and international responses to climate change, with a focus on health. A research subcommittee was created within this working group to advance the research agenda on climate and health. WHO, in close partnership with GCHA and other working group members, has also been instrumental in establishing dialogue across academia, public health and medical communities, civil society representatives and policy-making agencies by convening regional consultations to assess the needs and regional priorities through a participatory process. These efforts aim at fostering a demand-driven, contextualized approach to prioritizing research, funding and capacity-building activities.

may not have included studies available on other research sites. Second, only English articles were included in this review, leaving out potentially relevant articles in other languages. Third, as the scope of this work focused on documenting the trends and domains of climate and health research in the past decade, rather than exploring the details of individual studies, the review did not attempt a formal systematic review and meta-analysis of individual studies, but instead aimed to describe the geographic distribution of research output, and qualitatively review broad trends in addressed issues.

Moreover, there is an inherent risk of subjective bias in categorizing the scientific papers

due to possible differences in judgment among researcher team members who contributed to the work. However, efforts were made to reduce these differences through frequent communication between team members and joint article reviews. Finally, any review of published research may not cover the knowledge, inter-generational teachings, and adaptive technologies generated by communities that are not connected with formal academia. These may include (and not be limited to) rural, remote and indigenous communities, who due to a variety of factors including geographic vulnerability, may have developed some of the best responses to a changing climate.

Section 1

Overall summary of implemented research



Research on climate change and health during the past 10 years has progressively increased, growing more than six-fold: from 58 studies published in 2008 to 373 articles released in 2019. **A steady surge in articles has occurred in the past few years**, with the most significant year-to-year increase in articles occurring between 2018 and 2019 with a growth of 25%.

The articles identified by this scoping review suggest that research conducted since the WHA recommendations were passed did not address all five research priorities equally.

Of the 2181 analysed articles, Priority 1 focusing on assessing the health vulnerability due to climate change-related hazards, received most attention from researchers (50.6% of the analysed scientific papers), followed by Priority 4 on tackling decision support and other tools (42.7% of the analysed scientific papers). Priority 3 on health impacts of potential adaptation and mitigation measures, Priority 2 on health protection strategies, and Priority 5 on financial costs received significantly less attention (7%, 4.3% and 3.2% of the analysed scientific papers, respectively).

Figure 2 Number of articles on climate change and health published by year

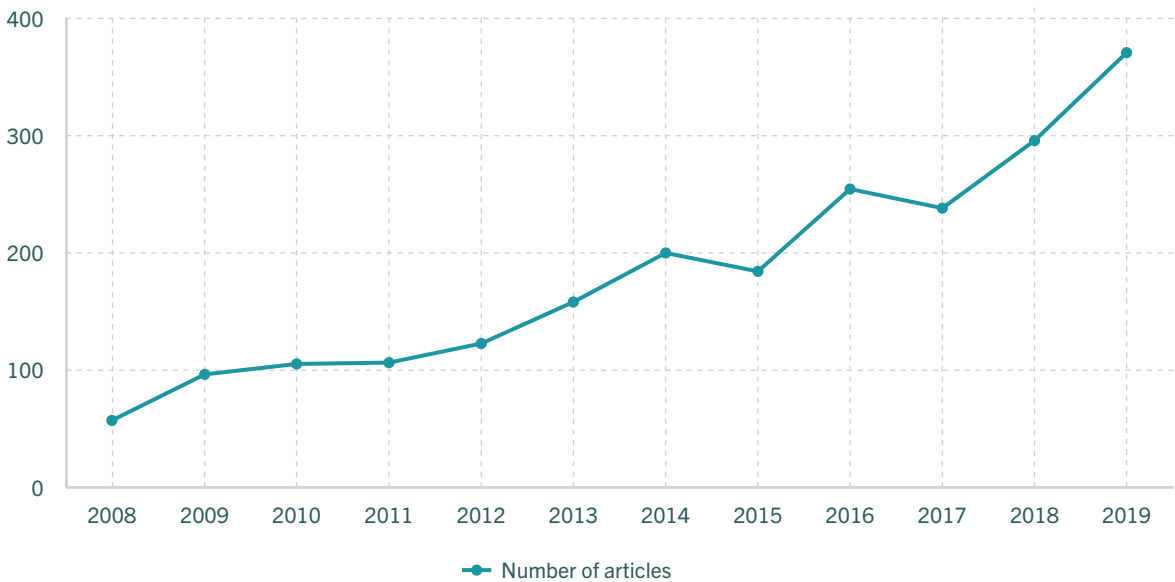
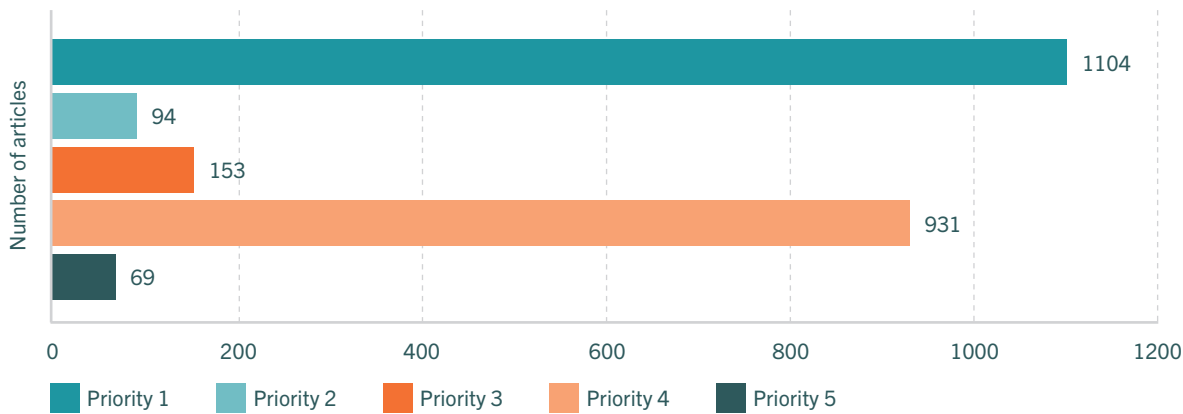


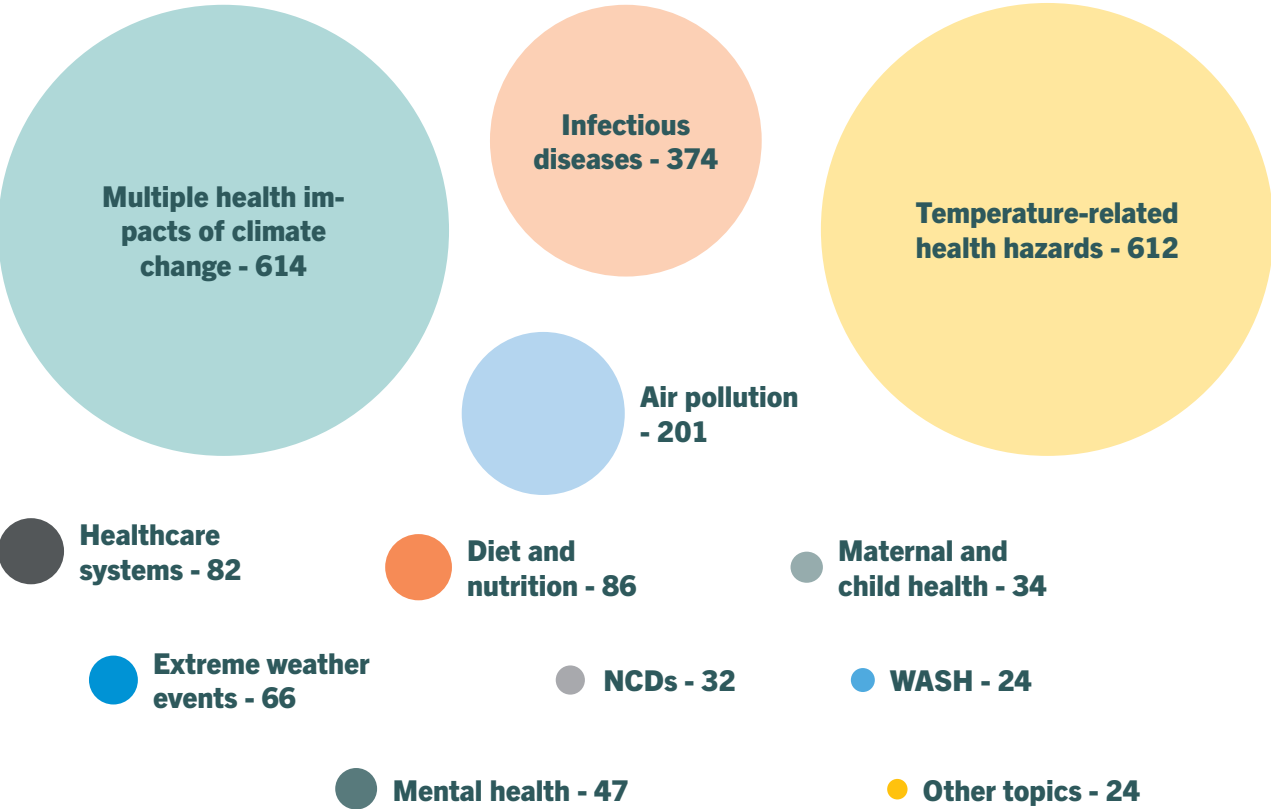
Figure 3 Distribution of articles between research priorities



There were substantial differences regarding the coverage of research by health topics. Among climate change induced hazards, temperature related health issues were identified as the most investigated topic (28%), followed by infectious diseases (17.1%) and air pollution (9.2%). Other health fields examined included interlinkages between climate change and nutrition-related health outcomes (3.9%), impacts of climate change on health care systems (3.7%), extreme

weather events (3%), mental health (2.2%), maternal and child health (1.6%), noncommunicable diseases (NCDs) (1.5%), and water, sanitation and hygiene (WASH) (1.1%). A small number of articles focused on toxicity-related diseases, nonheat-related occupational health issues, adverse health impacts caused by radiation and dermatological diseases. More than a quarter of the articles (28%) explored multiple of the above-mentioned health topics.

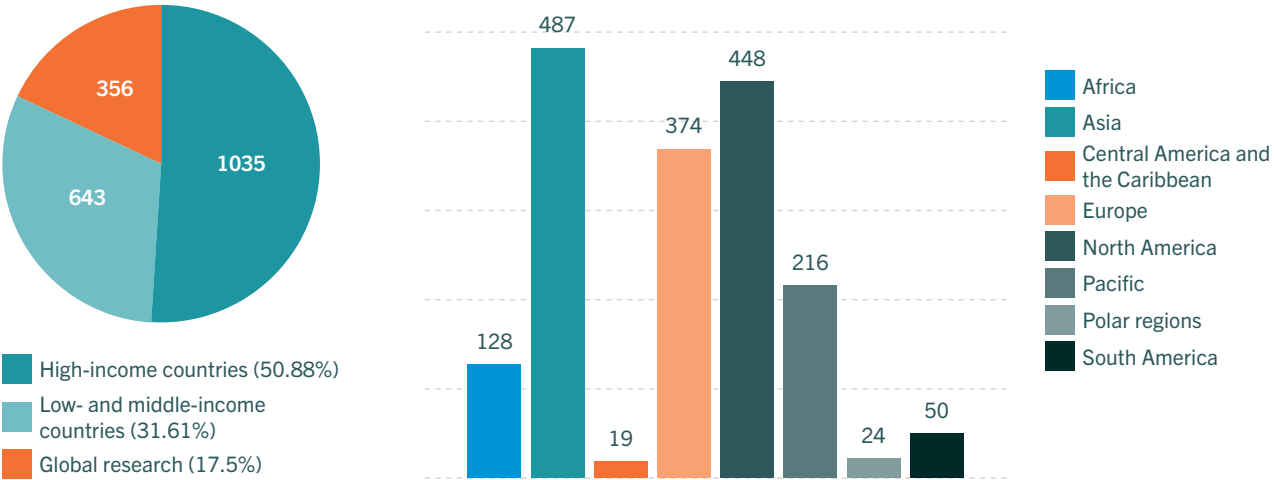
Figure 4 Distribution of all articles by health field



Articles that focused on one or more specific countries were sorted based on country income level.¹ This revealed an **uneven distribution of research between the 52 high-income countries and the 135 low- and middle-income countries**. More than half of the studies reviewed focused on high-income countries, while less than a third of the studies focused on low- and middle-income countries. It is worth noting that currently about 84% of the global population live in low- and middle-income countries (10). A smaller number of studies were either global in scope or included country specific research conducted in both high-income countries and low- and middle-income countries.

Regarding the **geographic distribution²** of country-specific research, Asian countries received the most attention with 21.5% of investigated studies on climate and health being conducted in this region. Countries in North America and Europe were the focus of 19.3% and 16.1% of the analysed articles, respectively. Much less research was devoted to countries in the Pacific region (9.8%) (where nearly all of the research was conducted in Australia or New Zealand) and the African region (5.6%). This review found extremely limited research focused on countries of the South American (2.2%), Polar (1.1%) and Central American and the Caribbean (0.8%) regions.

Figure 5 Geographical distribution of all articles by income groups and regions



1 Assessment based on the 2019 World Bank categorization of 188 member countries.
 2 WHO region, geographic region (classification used by UNFCCC).

Section 2

Summaries of implemented research by priority



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Priority 1: Health vulnerability to climate change

Global research Priority 1

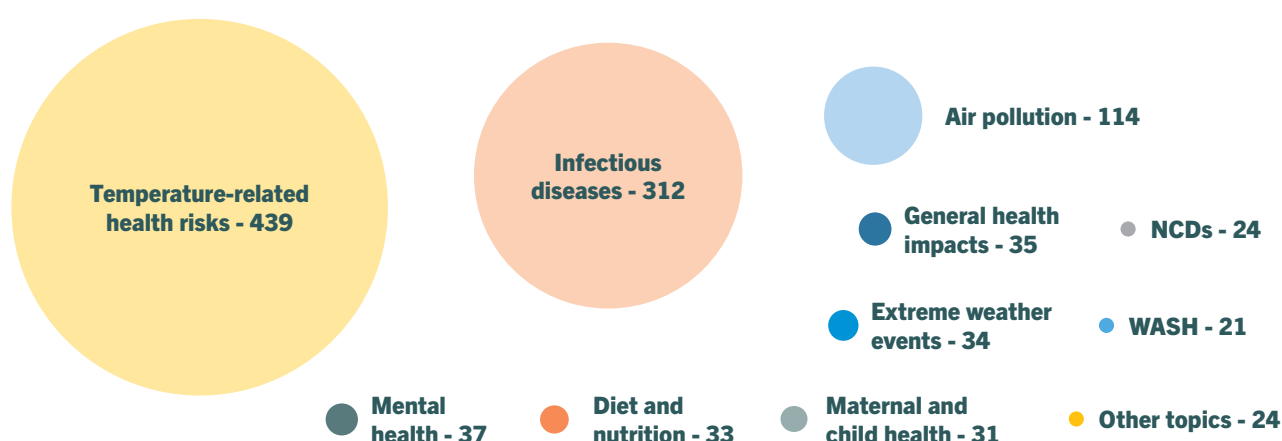
“Health vulnerability to climate change and the scale and nature thereof” includes studies that cover the following topics:

- Risks and potential effects either of global climate change (excluding individual climatic events, e.g. one-time flooding or drought) or of greenhouse gas emissions on human health;
- Comparison of the health outcomes under different global climate scenarios.

Research Priority 1 on assessing health vulnerability due to climate change-related hazards had the largest number of articles – 1104 out of 2181, or 50.6% of the analysed papers. Three quarters of the studies falling under Priority 1 explored health risks connected with temperature-related hazards (due to temperature variability, health impacts of extreme heat and influence of heatwaves on occupational health; mainly in high-income countries), infectious diseases (particularly vector-borne diseases; largely in low- and middle-income countries) and air pollution-related health issues (including allergies; predominantly in high-income countries), which had 39.5%, 28.4% and 10.4% of dedicated papers respectively.³

The other researched topics included mental health (3.3%), extreme weather events-related health problems (3%), diet and nutrition (3%), maternal and child health (2.9%), NCDs (2.2%), and WASH (1.9%), among others. A significant number of studies (3.2%) considered multiple health domains, or general health risks posed by climate change.

Figure 6 Distribution of articles under Priority 1 by topic

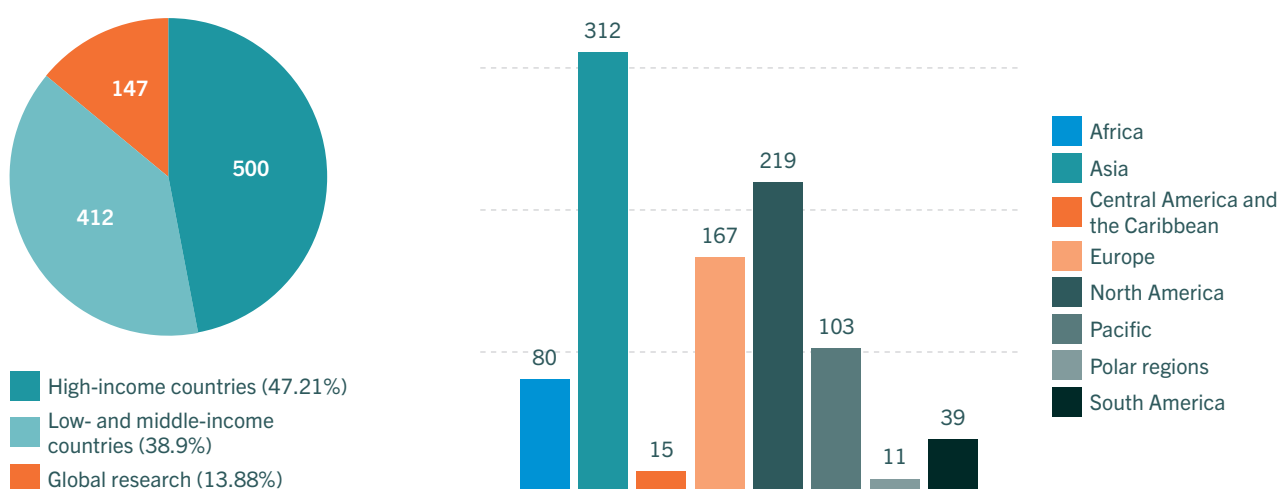


³ Please note that in this and further calculations, the total percentages may add up to more than 100% since some articles had more than one priority assigned to them and therefore were double-counted.

The **geographical distribution** of scientific articles on health risks due to climate change under Priority 1 was uneven, with two thirds of the articles focusing on North America, Europe and Asia. Fewer articles described studies conducted in the African region and the Pacific region, predominantly focusing on Australia.

Research on South America, Central America and the Caribbean was minimal. At the same time, the distribution of these articles was almost equal for high-income countries and low- and middle-income countries, with a slightly higher prevalence of articles from high-income countries.

Figure 7 Geographical distribution of articles under Priority 1 by income groups and regions



Conclusions and recommendations

A growing body of research has focused on assessing and estimating the current health risks associated with climate change-related weather variability, rather than on modeling future impacts. From 2008 to 2019, an increasing number of articles investigated the impacts of climate change on the health of vulnerable populations, including children, farmers and indigenous populations; however more research is needed in this field (see Section 3 on Cross-cutting topics and vulnerable groups).

Within the articles reviewed, the following topics related to climate change were under-researched when compared with others:

- Health impacts of extreme weather events that are projected to increase in frequency and severity due to the changing climate, including exposure to extreme cold.
- The impact of climate change-related weather variability on other broad health categories including: mental health, diet and nutrition, maternal and child health.
- Air pollution and asthma, cardio-respiratory diseases.

Priority 2: Health protection strategies

Global research Priority 2

Health protection strategies and measures relating to climate change and their effectiveness includes studies that cover the following topics:

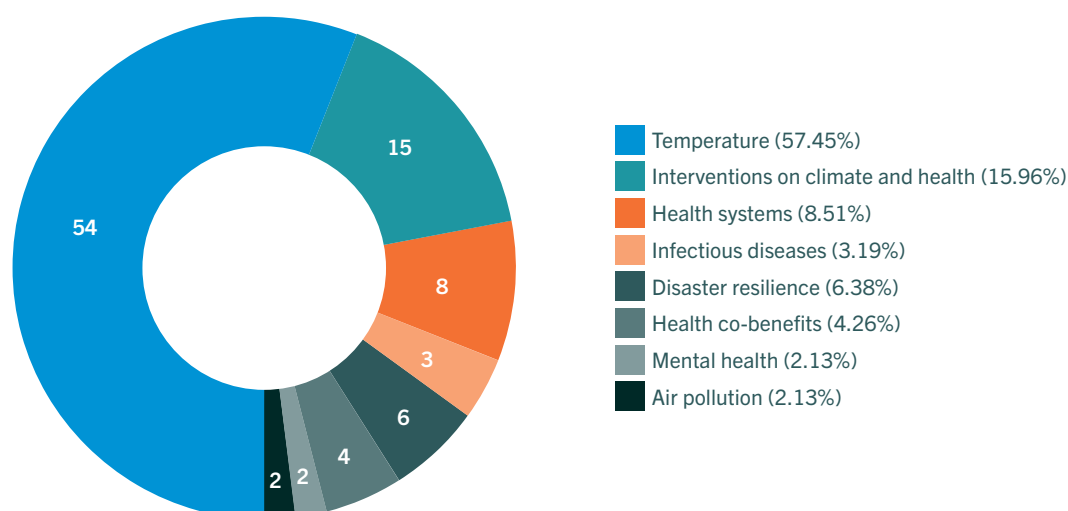
- Interventions to protect health from climate change.
- Health effects of climate change adaptation measures.
- Cost-effectiveness of interventions.

A total of 94 articles (4.3% of 2181 articles reviewed) fit the criteria for research Priority 2, in that they assess strategies and measures implemented to protect health from climate change and the effectiveness of these measures.

Over half of the articles under Priority 2 explored temperature-related health protection interventions (see Fig. 8). These articles primarily focused on minimizing the health impacts of increased temperature and included evaluation of measures that had been implemented and proposed adaptation measures. Other health protection strategies explored included general interventions on climate and health, health systems, disaster resilience, infectious diseases, health co-benefits, air pollution and mental health. There was one article each on mental health and air pollution.

Overall, research evaluating the effectiveness of health protection strategies and measures relating to climate change has increased since the publication of the WHA resolution in 2008. However, research related to cost-effectiveness of these measures and interventions was still largely lacking, which poses a barrier to decision-making and choice of the most effective interventions.

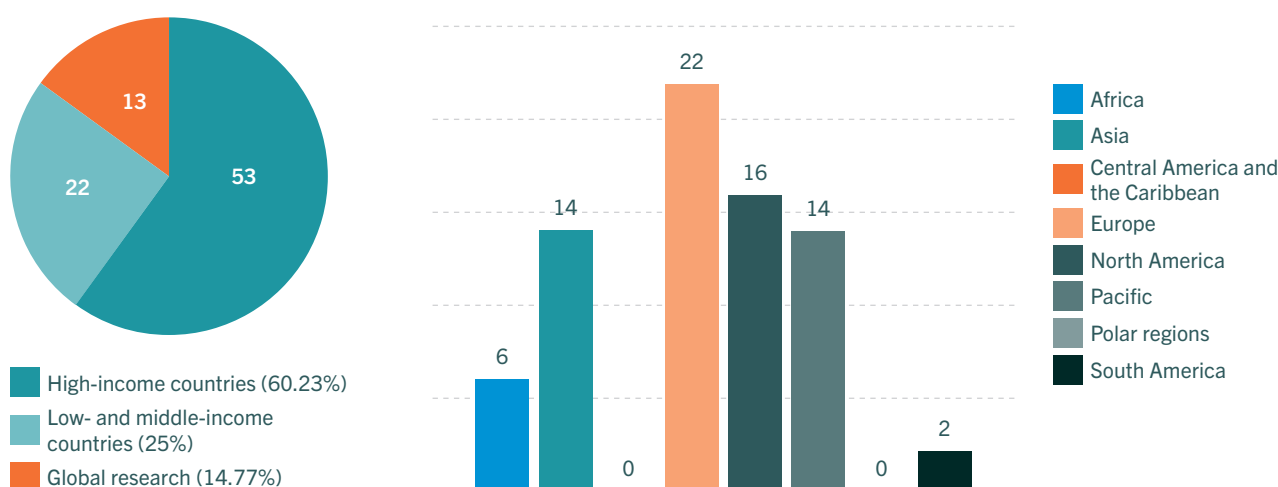
Figure 8 Distribution of articles under Priority 2 by topic



Geographical distribution of scientific articles under Priority 2 displayed a strong predominance of research in high-income countries in comparison with low- and middle-income countries. Most of these articles were focused on Europe, followed by Asia (mostly in China and Bangladesh), North America and the Pacific (mostly in Australia). Research in the regions

of Africa and South America was significantly lacking, and this review revealed no articles on health protection strategies focused on the Central America and the Caribbean region. It is worth noting the lack of articles focusing on the Small Island Developing States (SIDS), despite the high vulnerability of populations in these regions to health risks posed by climate change.

Figure 9 Geographical distribution of articles under Priority 2 by income groups and regions



Conclusions and recommendations

Research on health protection strategies remains insignificant. Most of the reviewed articles were confined to high-income countries, and studies were notably lacking in some regions of the world that are most highly vulnerable to climate change, including Africa, South East Asia, the Pacific Islands and the Central America and the Caribbean regions.

In spite of an increase in the number of articles on the effectiveness of adaptation measures, more research is required on their cost-effectiveness, to facilitate decision-making and uptake of such interventions. An increasing number of studies were dedicated to assessing the effectiveness of interventions and measures to manage extreme heat and heat stress. However, research gaps under Priority 2 still exist for the following topics:

- Mental health interventions
- Health co-benefits of climate mitigation and adaptation measures
- Disaster resilience and response
- Interventions targeting infectious disease outbreaks.

Priority 3: Health impacts of potential adaptation and mitigation measures

Global research Priority 3

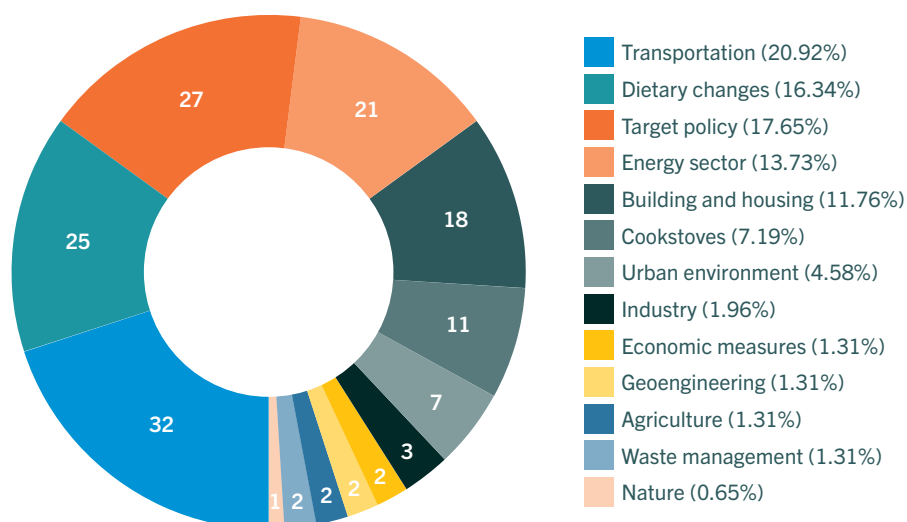
The health impacts of potential adaptation and mitigation measures include studies that cover the health effects of climate change mitigation or adaptation measures in other sectors, such as marine life, water resources, land use and transport in particular, where these could have positive benefits for health protection.

Priority 3 encompasses research that explores the health implications of climate change adaptation and mitigation efforts, both in terms of potential health risks as well as health improvement co-benefits. Of the total 2181 reviewed articles, 152 (i.e. 7%) fit this categorization. The largest group of articles in Priority 3 explored the health implications of transportation-related emissions reduction initiatives including active transportation interventions, alternative vehicle power sources, transportation emissions policies and

public transportation (30 articles in all). Articles examining emissions reduction target policies such as those outlined in the Paris Agreement were the next most frequent (26 articles), followed by dietary changes (mostly examining shifts towards plant-based diets) (24 articles), and changes in the energy sector, most of which looked at benefits of switching to low emissions alternatives (20 articles). Studies investigating the health implications of increasing the efficiency of buildings and homes, and reducing emissions and air pollution from cookstoves, as well as from urban planning, waste management, geoengineering and nature were other topic areas covered in the research analysed in this review. The vast majority of articles found in this review focused on the health implications of various mitigation strategies, with only three articles discussing the health impacts of adaptation measures, all of which had to do with heat management.

Articles categorized under Priority 3 employed both measuring and modelling in their evaluations. The health benefits most frequently measured or modelled in these articles were decrease in general morbidity and mortality, as well as respiratory health gains.

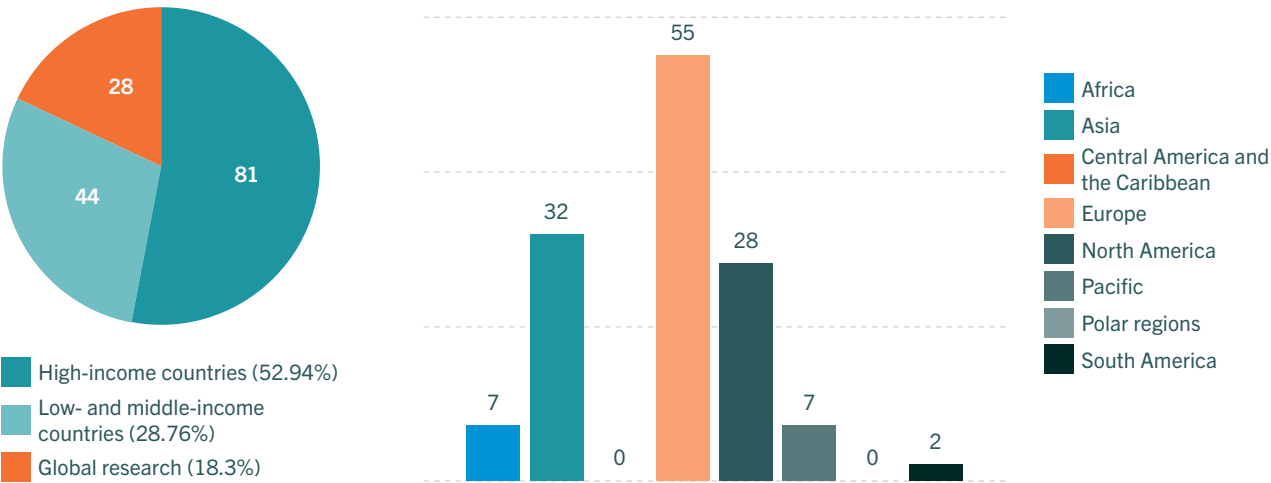
Figure 10 Distribution of articles under Priority 3 by topic



Geographical distribution of scientific articles under Priority 3, follows the pattern of the other priorities with almost half of the studies focusing on high-income countries, compared with just under a third focusing on low- and middle-income countries. The remaining studies included data from countries in both income categories. Similarly, the majority of the Priority 3 research was conducted in Europe (56 articles), Asia (31 articles) and North America (28 articles). Studies focusing on Europe were fairly evenly distributed across countries or involved multiple countries, though there were more studies from the United Kingdom than any other country. Research in the Asian region focused almost entirely on China with a few studies from India and Malaysia, and single studies from a few additional countries. Almost one third of the research from the North

American region focused on the United States. Very few studies exploring the health impacts of mitigation and adaptation measures focused on the African (8 articles), Pacific (7 articles) or South American (2 articles) regions. From the Pacific, there were only studies from New Zealand and Australia. None of the Priority 3 studies focused on the Central American, Caribbean or the Eastern Mediterranean regions. Even as major emitters (such as the United States, China, Canada and the United Kingdom) may introduce more emissions reduction activities than lower emitting countries (and thus more inclined to study the health impacts of these interventions), populations around the world would benefit from reduction in air pollution that comes with reduced burning of fossil fuels. It is concerning to see the concentration of research in the global north.

Figure 11 Geographical distribution of articles under Priority 3 by income groups and regions



Conclusions and recommendations

Research on the health impacts of mitigation and adaptation measures in various sectors is an emerging scientific field, with just a few studies evaluating the health impacts of mitigation interventions being published between 2009 and 2010. However, the number of articles has increased in recent years with a third of all studies in this area being published in 2018 and 2019. Topics such as health impacts of geoengineering, waste management, carbon taxation, and carbon capture and storage have emerged in this area since 2009. However, more research is needed on both the positive and negative implications of climate policies on human health in order to guide efficient decision-making processes.

Priority 4: Decision-support and other tools

Global research Priority 4

Decision support and other tools (such as surveillance and monitoring), for assessing vulnerability and health impacts and targeting measures appropriately include studies that cover the following topics:

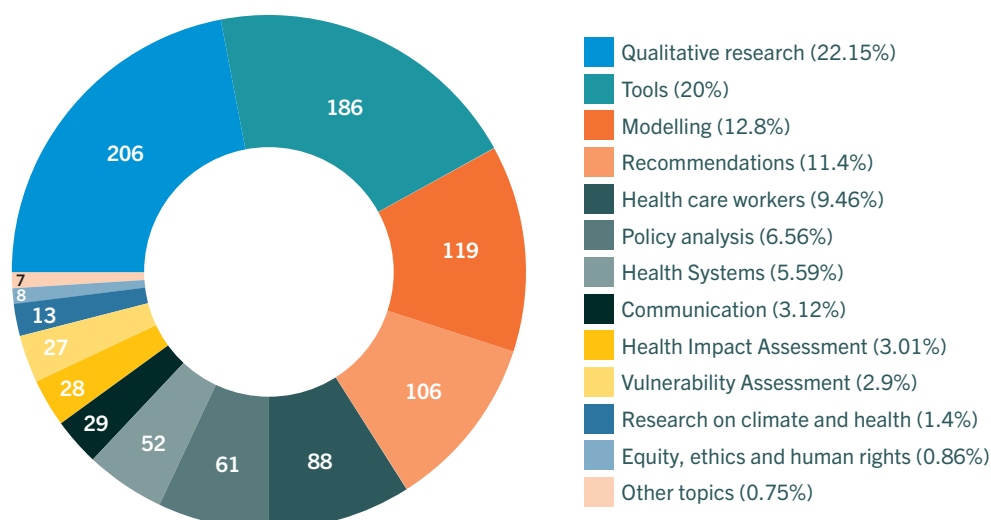
- New tools or methods that are intended to inform decisions on potential climate change interventions (including adaptation and mitigation interventions) if their objective is to address the health risks of climate change.
- Surveys of knowledge, attitudes, perceptions and behaviours relating to health and climate change.

Priority 4 (which calls for an exploration of decision support and other tools) had the second highest number of studies (931 articles, 42.7% of 2181 articles reviewed). The largest number of articles under Priority 4 were qualitative research (205 articles), including surveys evaluating public perceptions of health risks from climate change, surveys evaluating health worker understandings of health and climate change, knowledge surveys on the interconnections between climate and health, and surveys about climate change adaptations among other topics. Decision support tools were the next largest category of articles (185 articles), with the majority of these being dedicated to frameworks for decision making. Other articles evaluating or outlining “tools” focused on modelling methods, indexes, indicators, early

warning systems and data collection technologies and other topics. Articles detailing modelling activities which described the application of a modelling method and did not explicitly measure health impacts (which were included instead in Priority 3), were the third largest group of articles (117 articles), modelling heat, diseases, general health impacts, vector spread, and air and water quality. There were also articles analysing mitigation and adaptation activities (35 articles), health impact assessments (28 articles) and vulnerability assessments, research describing and evaluating communication related to climate change and health, including risk, benefit and health promotion communication, as well as those that evaluated various forms of media (including social media) (29 articles).

This review also revealed articles exploring climate change impacts and interventions related to health care workers (88 articles; such as health care worker evaluations including the importance of health care workers as advocates for climate action, as participants in mitigation activities, leaders in terms of adaptation, health protection activities and disaster response); and health care systems (52 articles). There was also a body of articles that evaluated or advocated for increased climate change education for health professionals. Studies focused on health systems looked at both mitigation and adaptation activities needed by health care systems. Articles focusing on health care workers explored the role of doctors, nurses, public health professionals and evaluated health system contributions to climate change, with a few focusing on hospital carbon footprints, as well as emissions reduction and adaptation strategies. A limited number of articles (16 out of 2181 articles, or 0.7%) addressed the emerging fields of Planetary Health and One Health.

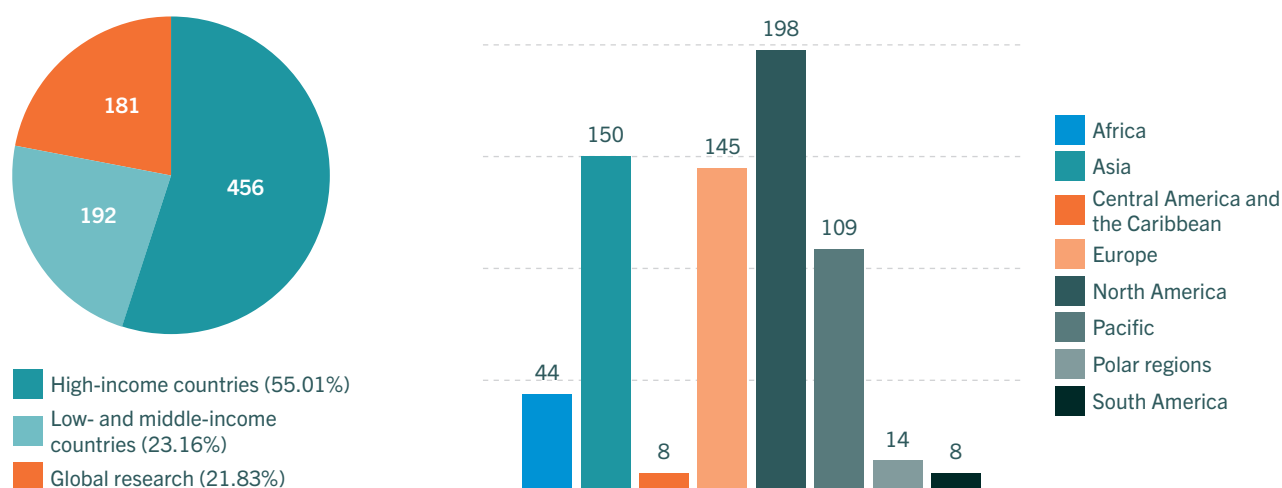
Figure 12 Distribution of articles under Priority 4 by topic



The geographical distribution of studies returned under Priority 4 was uneven. Over half of the studies that include a country or region focus on high-income countries; just over one fifth of studies focus on low- and middle-income countries; and just under one fifth explored or were relevant to both countries. A smaller proportion of articles under Priority 4 focused on a specific region, possibly because many tools and frameworks were outlined as being relevant to any context.

Of the articles that focused on a specific region, the most studied region was North America (198 articles) with the majority of research focusing on the United States. One fifth of the studies focused on Asia (150 articles) with a large portion of the research coming from China and India. However interestingly, research also focused on 17 other Asian countries and a few countries in the Eastern Mediterranean region. Another fifth of the studies focused on Europe (145 articles) which for the most part involved multiple countries or

Figure 13 Geographical distribution of articles under Priority 4 by income groups and regions



were relatively evenly distributed across countries, even though there were a large number of studies focused on the United Kingdom. 15% of the studies (109 articles) categorized as Priority 4 focused on the Pacific region with the majority of these concentrating on Australia, though there was a small cluster of articles relating to Pacific Island nations including one article each from Tuvalu, Fiji, Kiribati, Micronesia and the Solomon

Islands, and two from Vanuatu. A smaller number of studies focused on the African (44 articles), Polar (14 articles), South American (8 articles) and Central America and the Caribbean regions (8 articles). These numbers again point to the need for a greater focus on, and facilitation of adaptation research in low- and middle-income countries that are both more vulnerable and less resilient to climate change.

Conclusions and recommendations

Research on decision-support on climate change and health is a growing field, with a large number of studies being dedicated to qualitative data collection methods. Studies on modelling methods and technical frameworks that support predicting or evaluating the health impacts of climate change are emerging. Increasing attention is being allocated to the role of health professionals as a driving force in climate action. At the same time, more research is needed on the health vulnerability and adaptation assessments, as well as improved understanding of decision-making processes.

Priority 5: Likely financial costs and other resources

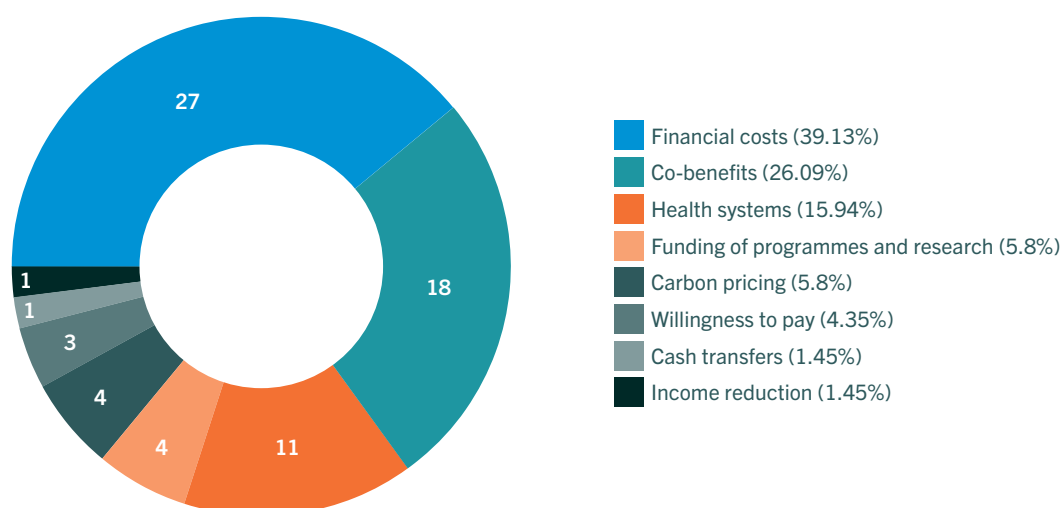
Global research Priority 5

Assessment of the likely financial costs and other resources necessary for health protection from climate change includes studies that cover the costs relating to Priority 1 (health risks), 3 (health effects of climate change mitigation or adaptation measures) or 4 (decision support and other tools on potential climate change interventions).

Priority 5 excludes studies that cover cost-effectiveness of interventions (as this topic belongs to Priority 2).

Assessment of likely financial costs and necessary resources for protection of health from climate change was addressed in the least number of articles (69 articles). Most of the studies focused on health-related financial costs and health co-benefits arising from climate mitigation and adaptation programmes. Few articles tackled health care, health systems and carbon pricing, and even fewer articles addressed other topics such as willingness to pay, programme and research funding, cash transfers and income reduction induced by climate change-related risks.

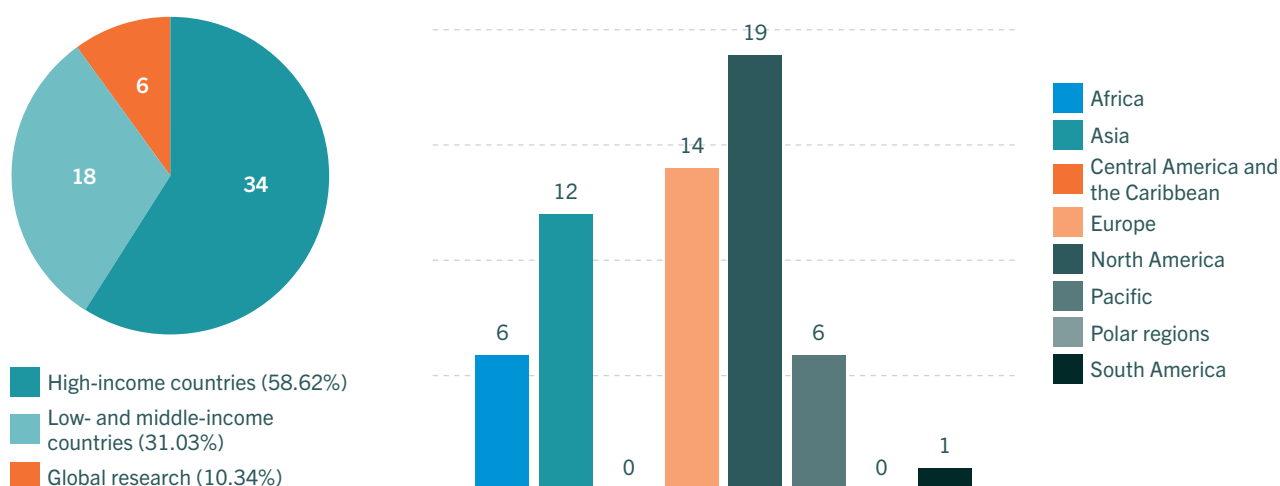
Figure 14 Distribution of articles under Priority 5 by topic



The geographical distribution of Priority 5 studies followed a pattern similar to the other priority areas. Nearly three fifths of studies focused on high-income countries with the remaining studies being almost equally distributed between focusing jointly on high-income countries and low- and middle-income countries or focusing on low- and middle-income countries alone. The largest number of studies addressed the North American region (19 articles), followed by the European

region (14 articles) and the Asian region (12 articles), two of which focused on Pakistan, a country in the Eastern Mediterranean. An equal number of articles focused on the African and Pacific Regions (6 articles each). A single article addressed costs and resources in South America, while there were no articles on the Central America and the Caribbean region, though exclusion of articles in Spanish and other language may have made this number artificially small.

Figure 15 Geographical distribution of articles under Priority 5 by income groups and regions



Based on the articles investigated in this review, it is worth noting that research on this topic was minimal from 2008 to 2018, with the number of articles ranging from two to five studies each

year during that time period. However, in 2019 there were 11 studies falling into this priority area, so it is possible that this trend will shift into the future.

Conclusions and recommendations

Despite mounting evidence on significant costs of climate change-related impacts, assessment of financial costs of protecting health from climate change remains an under-developed area of research. Health considerations should also be taken into account in climate economics in general, and economic evaluations of mitigation and adaptation measures in particular. Effectiveness and cost-effectiveness of interventions to protect health from climate change, as well as health co-benefits, should be evaluated using harmonized methodologies to promote comparability between studies. Moreover, it is important to estimate the “cost of inaction” of both financial and physical implications of lack of mitigation and adaptation interventions.

Section 3

Cross-cutting topics and vulnerable groups



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Climate change affects all regions and populations across the planet. However, the health impacts of the changing climate will disproportionately affect vulnerable population groups, exacerbating health inequity and social injustice. Climate vulnerability depends on many factors, such as age, gender, location, economic status, to mention a few. These factors greatly influence the population's sensitivity and adaptive capacity to climate change impacts, determining their vulnerabilities and risks.

Availability of research on the climate-induced health implications for some of the vulnerable groups was evaluated based on the reviewed literature, and is summarized in this section. Populations considered include SIDS, polar and indigenous populations, migrants, farmers and age-vulnerable groups (children and elders). The share of studies providing gender-disaggregated data was also assessed.

Small Island Developing States

Despite a marginal contribution to global greenhouse gas emissions that cause climate change, SIDS are experiencing a high burden of climate-sensitive diseases, and are exposed to a range of acute to long-term health risks, including increased average, rising sea levels and extreme weather events such as floods, droughts and cyclones. The review has identified a significant lack of research on climate change and health in SIDS with only 31 articles out of 2181 (1.4%) articles dedicated to these countries. More than half of the research on SIDS focuses on health risks (Priority 1), with most of these exploring climate change-related health impacts of infectious diseases, and a small number of articles tackling climate change-related dietary changes, mental health, air pollution and heatwaves. There were also several articles reporting on qualitative research, health impact assessments, and other tools, such as disease modelling (Priority 4). Research on health protection strategies and financial costs was underrepresented.

Most of the research has been conducted in the Pacific (15 articles) and Central America and the Caribbean (9 articles) regions, while global studies, as well as research on SIDS in other regions is largely missing.

Climate change and health action in SIDS

Populations of SIDS are among the most vulnerable and affected by climate change-related hazards, such as more severe extreme weather events and increased risks of communicable and non-communicable diseases. Sea-level rise threatens fragile health care facilities and affects the livelihoods of island nations. Moreover, SIDS are frequently facing such challenges as lack of financing and technical capacity necessary for implementing comprehensive adaptation measures. However, SIDS have a strong and consolidated voice in international negotiations on climate change. They are actively mobilizing joint action to address climate change-induced health threats and build climate-resilient health systems. To support these efforts, the WHO launched a *Special Initiative on Climate Change and Health in Small Island Developing States* (11) at the 23rd UNFCCC Conference of the Parties (COP23) held in Bonn in 2017. Since then, around half of SIDS have completed climate and health country profiles, carried out vulnerability and adaptation assessments, and developed a health adaptation plan. The SIDS Summit for Health (12), organized in June 2021 as part of the Special Initiative, re-emphasized the need for scaling up a consolidated response to the severe and urgent threats posed by climate change to the health and well-being of the SIDS populations.

Populations in the Polar region

Increases in annual mean temperature attributed to climate change are more pronounced in the polar regions than in other parts of the world. Consequently, health impacts of climate change among populations living in these areas are a matter of great concern. However, the research on this topic was scarce (24 out of 2181 articles, or 1.1%). Most of the studies (15 articles) were dedicated to North America, mainly focusing on the indigenous communities of Alaska and Canada. Research on the health impacts of adaptation and mitigation or financing mechanisms in this region of the world was largely missing. The identified studies discussed health impacts of climate change in the Polar region, with an emphasis on the possible expansion of zoonotic diseases and vectors, impacts on food security, mental health and changes in water availability and quality, among others. There is a perceived need to develop context-specific climate-health planning and adaptation strategies to mitigate these health effects.

Indigenous and aboriginal populations

Climate change disproportionately impacts indigenous communities and exacerbates many of existing socio-economic and political vulnerabilities. Despite this, limited research has been conducted in this field (46 out of 2181 articles, or 2%). Most of the research (29 articles) was devoted to high-income countries (predominantly Canada, Australia and the United States), with only a few studies carried out in low- and middle-income countries (9 articles). Most of the research focused on issues such as infectious diseases, food security, mental health and extreme temperatures. Several of the studies highlighted the need for more data, adaptation analysis and vulnerability assessment tools to better understand and act upon the unique challenges faced by indigenous communities around the world.

Migration and displacement

Climate change is increasingly acting as a driver of migration and an amplifier of health challenges upon resettlement. It is often the most vulnerable who are most exposed to the impacts of climate change and may have least ability to migrate (13). However, research on the health impacts of climate change-induced displacement and migration is scarce, as only 16 of the 2181 analysed articles were related to this topic (0.7%). Most of these studies (9 articles) focused on low- and middle-income countries. Research on the health effects of climate-induced migration was largely limited to reporting, rather than analysing the multi-factorial complexities, and only few publications offered examples of workable solutions. Research was lacking on the countries of the Americas and the Pacific.

Farmers

Climate change is threatening the health of farmers by amplifying the occurrence of communicable and noncommunicable diseases, increasing mental stress, as well as through occupational health hazards. Poor and marginalized farmers from low- and middle-income countries with limited adaptive capacity are especially vulnerable (13). Despite this, the effects of climate change on the health of farmers have been investigated in a very limited number of studies (28 articles out of 2181, or 1.3%). Most of the studies on farmers' health focused on food security, mental health and temperature extremes. Other health topics that these studies tackled were indoor air pollution and infectious diseases, as well as general risks to farmers' health due to climate change. Majority of the research in this field focused on estimating the health impacts, rather than assessing or modelling health and climate change interventions. Research regarding the financial costs and viability of such solutions was lacking. The studied farming communities were

predominantly located in Africa, Asia and the Pacific regions (10, 9 and 7 articles respectively). Research on climate change and farmers' health in the regions of the Americas and Europe was largely missing.

Age-disaggregated data (focusing on the ageing population and children)

Ageing population

The ageing population (60 years of age and older) faces a wide range of vulnerabilities to climate change impacts, due to a combination of chronic health issues, physical decline, frailty and many sociocultural factors. However, only a small portion of research (98 articles out of 2181, or 4.5%) was dedicated to investigating particular health effects of climate change-related hazards on this age group. Over two-thirds of the studies (70 out of 98 articles, or 71.4%) focused specifically on the impacts of extreme heat on mortality and morbidity of the ageing population, mainly in high-income countries. Further research should be conducted in the regions of Africa and Latin America, and consider a broader range of health risks and potential protection strategies to fill the identified gaps.

Children

Children are particularly vulnerable to climate change because of their increased biological sensitivity and limited adaptive capacity due to high dependence on adults. However, the impacts of climate change on the health of children have been investigated in only 81 of the analysed 2181 articles (mere 3.7%). The studies explored diverse health hazards exacerbated by climate change, most prominently maternal and child health issues, infectious diseases, such as diarrhoea, and temperature-related health risks (19, 18 and 18 articles,

respectively). While the majority of the research focused on assessing health vulnerability (63 articles), 14 articles were dedicated to qualitative research, such as using surveys to assess perceptions on the implications of climate change for maternal and child health. In terms of regional distribution, the studies conducted in low- and middle-income countries (mostly in Asia and Africa; 47 articles), were more than two-fold of the studies implemented in high-income countries (20 articles). A distinct lack of research on this topic was identified in Europe and the Americas.

Gender-disaggregated data across topics

Despite the growing evidence on gender differences in climate change-related health risks, research providing gender-disaggregated data on the health impacts of climate change remains underdeveloped. Of the 2181 analysed articles, only 112 (or 5.1%) tackled gender-specific health outcomes related to climate change. The most studied health impact was temperature extremes (45 articles) with a focus on health implications of heat. Other health impacts of climate change that were investigated through a gender-specific lens were mental health, food security and nutrition, air pollution, infectious diseases, NCDs and health implications of extreme weather events. Most scientific papers focused on assessing the health vulnerability (80 articles), as well as providing decision support and conducting qualitative research (34 articles), such as using questionnaires. The studies were conducted in both high-income countries and low- and middle-income countries in almost equal proportion. At the same time, geographical distribution of articles was uneven, with almost half of the studies being dedicated to the communities in Asia (47 articles), followed by North America (24 articles). Countries of South America and the Central American regions lacked research that considered gender-disaggregated data for understanding climate change and health linkages.

Section 4

Advancing the research on climate and health



The research that underpins action to address the various facets of climate change comprises a spectrum of basic, clinical, population and implementation research and often requires a multidisciplinary approach to assess the health, social and economic impacts. The past decade showed a marked increase in research on assessing the interlinkages between changing climate and health with a vast body of literature assessing the impacts of heat waves, droughts and water insecurity, cyclones, deteriorating air quality and diminished crop production on the health and nutrition of populations around the world. Research on assessing the specific impacts on vulnerable populations at extremes of age, pregnant women and those already at a disadvantage by virtue of their poorer health and socioeconomic status also increased in the

past decade. However, the current report further demonstrates the inequities in the distribution of research within and across countries and between high-income countries and low- and middle-income countries. While this may reflect the lack of adequate capacity to conduct requisite research, it also **likely to reflect inappropriate allocation of resources and research capacity-building efforts**. A needs-based and demand-driven strategy for the conduct of operational research that can address emergent climate crises in a timely manner is critical. However, this can only become possible if there is a focus on establishing **alliances and partnerships** that bring together the strengths of research and advocacy groups that can work towards this common goal, while ensuring adequate allocation of **funding** for these activities.

Role of WHO in advancing research on climate and health

WHO has a central role in responding to the needs of the Member States to identify, promote, facilitate and implement appropriate response measures to minimize regional climate vulnerabilities and their impacts on human health. Recognizing that no single organization or institution can either set this agenda or implement a coherent response to address the health impacts of climate change, WHO is spearheading several initiatives to address the gaps and inequities in research, and to mainstream health in the global climate agenda. Working closely with national health ministries and research centres around the world, WHO coordinates reviews of scientific evidence on the health risks induced by climate change and assesses the level of preparedness of different countries to deal with these. Through a series of health and climate change country profiles, WHO monitors the health impacts of climate change and

the progress in building climate resilient health systems in a wide range of countries (14). WHO also collects evidence on the health co-benefits from mitigation of short-lived and other climate pollutants, as well as the health gains that would result from the implementation of the submitted Nationally Determined Contributions to the Paris Agreement, and the potential for larger gains from more ambitious climate action. Aligning global and regional research priorities with appropriate technical support and periodic production and dissemination of resources and tools for applied interventions is also among the tasks conducted by the WHO. This helps to ensure that Member States are well-equipped to deliver health-promoting interventions that address climate adaptation and mitigation. Training webinars are regularly conducted along with the development of freely available virtual courses on climate change and health linkages.

Promoting and building partnerships on climate and health

In recent years, the discourse and action to address the health impacts of climate change has grown. Several actors including academic organizations, communities of researchers, alliances of health professionals and health care organizations, civil society groups, funding agencies and philanthropic groups are partnering in the efforts of government agencies in many regions. Academic institutions have a greater focus on addressing climate science through the lens of understanding exposure to climate pollutants and pathways to rising global warming, while others have studied potential mitigation measures through the adoption of programmes and policies. Most of these efforts have concentrated in developed countries prompting the need to investigate reasons for research gaps in developing countries. One area that emerges is the scope to bring climate change and impacts on human health into mainstream curricula in medical and allied health care disciplines, including dedicated funding. Rethinking capacity-building efforts to strengthen the abilities of health care professionals to not only mount adaptation efforts to address climate-related health burden but also conduct context-specific regional research is imperative. This requires strategic partnerships within and across regions, along with the allocation of dedicated resources.

Funding gaps and potential financial opportunities for research on climate and health

Several high-income countries have been allocating government resources for climate and health research in recent years. Examples include Canadian federal grants through the Natural Resources Canada's Climate Change

Impacts and Adaptation Program and Health Canada's Climate Change and Health Office, and the European Commission's Horizon Europe – the largest multinational research and innovation programme. However, the 10-90 gap that posits only 10% of global resources are used to conduct research on diseases that afflict 90% of the world's population possibly rings true also for the inequitably-distributed climate and health research.

Climate-focused finance mechanisms were also facilitated by the UNFCCC. At the 16th COP in 2010, the Green Climate Fund (GCF) was established for mobilizing funds for climate mitigation and resilience, while the Adaptation Fund was provided as a finance mechanism for all developing countries party to the Kyoto protocol. The Global Environment Facility (GEF), an international partnership of 183 countries, international institutions, private sector and civil society organizations, has provided nearly US\$ 18 billion in grants and continues to mobilize additional grants for projects addressing environmental issues around the world. At the same time, both GEF and GCF funding supports implementation of projects on the ground, rather than conducting research.

Access to available funds and the types of research conducted over the years has been far from consistent or adequate. Much effort focused on the natural, technical and social aspects of climate-induced health risks, with very limited prioritization of action-oriented research on the health effects of climate mitigation and adaptation strategies. This possibly signals the need to enhance efforts to forge strategic partnerships that can coalesce efforts both for successfully accessing funds and conducting impactful research. Drawing lessons from previous successful and innovative partnership building efforts for health research may be useful. For example, the Wellcome Trust, in the past, provided much impetus to research and capacity-building efforts for research in infectious diseases like HIV-AIDS and noncommunicable diseases. This spanned population health, applied research, humanities and social sciences research with focus on countries in Asia and Africa. In 2020, the Wellcome Trust announced

a new strategy putting “climate and health” as one of its top three priority areas of work. The Foundation is aiming at “working with the communities most affected by climate change to explore the harmful effects of global heating on health, and to use research to develop new ways of protecting people’s health” (15).

The shift in focus of such philanthropic foundations and others like Mac Arthur, Rockefeller, Ford, Robert Wood Johnson Foundation, Ikea Foundations, and others, to the capacity-building efforts for climate change has become both timely and necessary. Additionally, in accordance with the UNFCCC principle of “common

but differentiated responsibilities and respective capabilities”, developed countries have a moral responsibility and are thus expected to provide climate finance to developing countries to achieve their commitments. Assisting highly vulnerable regions like SIDS, for example, in partnerships for purpose that help leverage funds for contextually relevant research that aids their climate programmes and policies, must receive the greatest focus and attention. WHO, other UN agencies, multilateral funding agencies and communities of researchers must join hands to build the evidence base of research on climate change and human health.



Section 5

Conclusions



Several trends were observed while analysing the selected articles. Scientific papers were unevenly distributed between the research priorities. Most of the research was dedicated to the assessment of health impacts of climate change-related hazards and decision support tools, such as qualitative research, modelling and methodologies. Research on health protection strategies and health impacts of mitigation and adaptation measures was lacking.

Least attention was received by financial mechanisms and assessments of likely economic costs related to climate-induced risks, as well as health co-benefits of mitigation and adaptation interventions. The distribution of articles between income groups and geographical regions was also uneven, with a significantly lower number of scientific papers dedicated to low- and middle-income countries.

Vision for post-2020

This report is an attempt to refurbish the 2009 paper on “Protecting health from climate change: Global research priorities” (6), and did not have the aim of setting the research agenda on climate and health for the coming years. Nevertheless, more assessments on global research priorities is needed, as well as ongoing and newly emerging initiatives in this field, such as: the ARA’s exercise on setting the research agenda on climate-resilient health systems;

the Lancet Pathfinder Commission collecting evidence on the development and implementation of multisectoral actions to address climate change; and the Lancet Countdown initiative on tracking the health impacts of climate change. There is a strong need to refine future global research priorities, in close collaboration with the global health community, and more such activities should be implemented in the coming years.

To advance the global climate and health agenda, it is crucial to support and expand research activities in these areas by:

- **Promoting equity and social justice.** There is a need to enhance research on the disproportionate impacts of climate change on the vulnerable communities (such as children and ageing populations, low-income households, people of color, and those with pre-existing health conditions, among others), both in terms of availability, accessibility and geographical coverage.
- **Collecting gender-disaggregated data.** Vulnerabilities to climate change are multi-dimensional, and gender is an important determinant of health risks. However, gender-disaggregated data on the health impacts induced by climate change, as well as on the health effects of climate mitigation and adaptation measures, remains largely missing and requires better assessment.
- **Conducting economic assessments:**
 - to quantify economic impacts of climate change by taking into account health considerations.
 - of health costs of mitigation and adaptation action (and also inaction) have to be carried out in all geographical regions.
- **Promoting collaborative intersectoral research.** To guide future decisions, health co-benefits and health impacts of various mitigation and adaptation measures have to be carefully analysed in close collaboration with all the sectors involved.

→ Bridging the knowledge and action gap.

- A large discrepancy exists between scientific knowledge on climate and health and the prioritization of climate action, both globally and locally, as well as a huge gap between priority research needs and funding.
- Evidence-based guidance has to be translated into understandable products and messages that would be easily digestible and useful for policy-makers (such as in the “Summary for policy-makers” of the IPCC report).
- There is a need to break the silos between the academic community, producing scientifically sound products, and decision-makers, developing programmes and policies, and overseeing project implementation, while ensuring free and open access to crucial research findings.

→ Improving advocacy and communications.

- Effective communication on climate-related health risks and potential solutions is crucial for motivating and guiding choices and investments related to the reduction of greenhouse gases and climate change and health adaptation.
- Assessment of efficiency of previous and existing communication campaigns, as well as evidence-based guidance on how to target climate change and health communication to broad and diverse audiences are largely missing.
- Equity needs to be integrated in climate change communications.

References

- The non-COVID year in disasters: Global trends and perspectives. Geneva: United Nations Office for Disaster Risk Reduction, 2021 (<https://www.undrr.org/publication/2020-non-covid-year-disasters>, accessed 16 October 2021).
- Secretary-General's address at Columbia University: "The State of the Planet". United Nations Secretary-General. December 2020 (<https://www.un.org/sg/en/content/sg/speeches/2020-12-02/address-columbia-university-the-state-of-the-planet>, accessed 16 October 2021).
- WHO Manifesto for a healthy and green recovery from COVID-19: Prescriptions and actionables for a healthy and green recovery. Geneva: World Health Organization; 2020 (https://www.who.int/docs/default-source/climate-change/who-manifesto-for-a-healthy-and-green-post-covid-recovery.pdf?sfvrsn=f32ecfa7_8, accessed 16 October 2021).
- COP26 Special Report: the health argument for climate action. Geneva: World Health Organization; 2021 (<https://www.who.int/publications/i/item/cop26-special-report>, accessed 16 October 2021).
- Climate change and health: Resolution of the 61st World Health Assembly. Geneva: World Health Organization; 2008 (https://apps.who.int/gb/ebwha/pdf_files/WHA61-REC1/A61_REC1-en.pdf, accessed 16 October 2021).
- Protecting health from climate change: global research priorities. Geneva: World Health Organization; 2009 (<https://www.who.int/publications/i/item/protecting-health-from-climate-change-global-research-priorities>, accessed 17 October 2021).
- Hosking J, Campbell-Lendrum D. How well does climate change and human health research match the demands of policymakers? A scoping review. *Environ Health Perspect.* 2012; 120(8): 1076-1082.
- Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Geneva: Intergovernmental Panel on Climate Change; 2019 (<https://www.ipcc.ch/sr15/>, accessed 16 October 2021).
- The 1.5 Health Report. Synthesis on health and climate science in the IPCC SR1.5. Geneva: World Health Organization; 2018 (https://www.who.int/globalchange/181008_the_1_5_healthreport.pdf, accessed 20 October 2021).
- Classifying countries by income. World Bank [website] (<https://datatopics.worldbank.org/world-development-indicators/stories/the-classification-of-countries-by-income.html>, accessed 16 October 2021).
- Special Initiative on Climate Change and Health in Small Island Developing States. WHO [website] (<https://www.who.int/news/item/06-11-2017-special-initiative-on-climate-change-and-health-in-small-island-developing-states>, accessed 18 October 2021).
- The SIDS Summit for Health. Strategic Actions in Small Island Developing States. WHO [website] (<https://www.who.int/initiatives/strategic-actions-in-small-island-developing-states>, accessed 18 October 2021).
- Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Beagley J, Belesova K, et al. The 2020 report of The *Lancet* Countdown on health and climate change: responding to converging crises. *Lancet* 2021;397(10269):129-170 ([https://www.thelancet.com/journals/lancet/article/PIIS0140-6736\(20\)32290-X/fulltext](https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)32290-X/fulltext), accessed 18 October 2021).
- Health and climate change country profiles. WHO [website] (<https://www.who.int/activities/monitoring-health-impacts-of-climate-change-and-national-progress>, accessed 17 October 2021).
- Wellcome's vision and strategy (<https://wellcome.org/who-we-are/strategy>, accessed 17 October 2021).

Annex 1. Methodology

Scope of review and search strategy

In order to identify trends and gaps in existing scientific literature, a scoping review of original quantitative and qualitative research published during 2008-2019 was implemented. In May and June 2020, we searched three databases: PubMed (including Medline), Embase (excluding Medline), and ScienceDirect, using database limits. The search strategy was (all climate

change-related terms from the list below linked with OR) AND “human health”, limited to titles and abstracts. A team of researchers assessed the eligibility of all citations based on the title and abstract. When needed, the full-text paper was retrieved and reviewed. A sample of around 20% of the articles classified by each of the researchers was independently screened by the other peer members of the team. Any potential differences were resolved by discussion and led to a final agreement.

Search keywords

Climate change keywords	Human health keywords
climate change global warming extreme weather greenhouse gas emission CO ₂ emission carbon emission low carbon climate stable climate disrupt* global environmental change climate variability climate pollutant heat stress ⁴ climate adaptation climate mitigation climate resilience climate finance climate justice	health

4 Articles that were identified under the “heat stress” keyword were manually screened to ensure their relevance for climate change and health research rather than just temperature-related studies.

Eligibility criteria

The databases were searched in May and June 2020. The search included both original quantitative and qualitative research published in peer-reviewed journals during 2008-2019 and was limited to articles in English. This time range was selected to provide a basis for assessing whether the recent research was aligned with the priorities identified by the WHA Resolution in 2008.

Data collection and data items

The search included studies that reported risk factors and related human health outcomes, both quantified and not quantified. Health risks related to individual extreme weather events were excluded from the database.

During the first stage, duplicates, reviews, commentaries, event reports and research that did not cover human health aspects were excluded from the final list of over 7000 articles.

During the second stage, these filtered articles were screened and categorized by research priorities, more specific topics and subtopics and where possible by: WHO region, geographic region (classification used by UNFCCC), income group (low- and middle-income countries or high-income countries, according to World Bank classification), and some of the cross-cutting topics outlined below, including vulnerable populations, that were identified during the classification process. If an article tackled issues belonging to more than one research priority, it was assigned several ones. Health outcomes and health risks were categorized and grouped into broad “health fields”, such as infectious diseases, mental health, air pollution and respiratory diseases). If the article tackled more than one health outcome, or general health risks posed by climate change, it was categorized as belonging to “multiple” health fields.

During the third stage, these classified articles under each of the priority areas were quantified and summarized by topics and subtopics to assess the availability of research in each area

and to identify trends and gaps in research on climate change and human health.

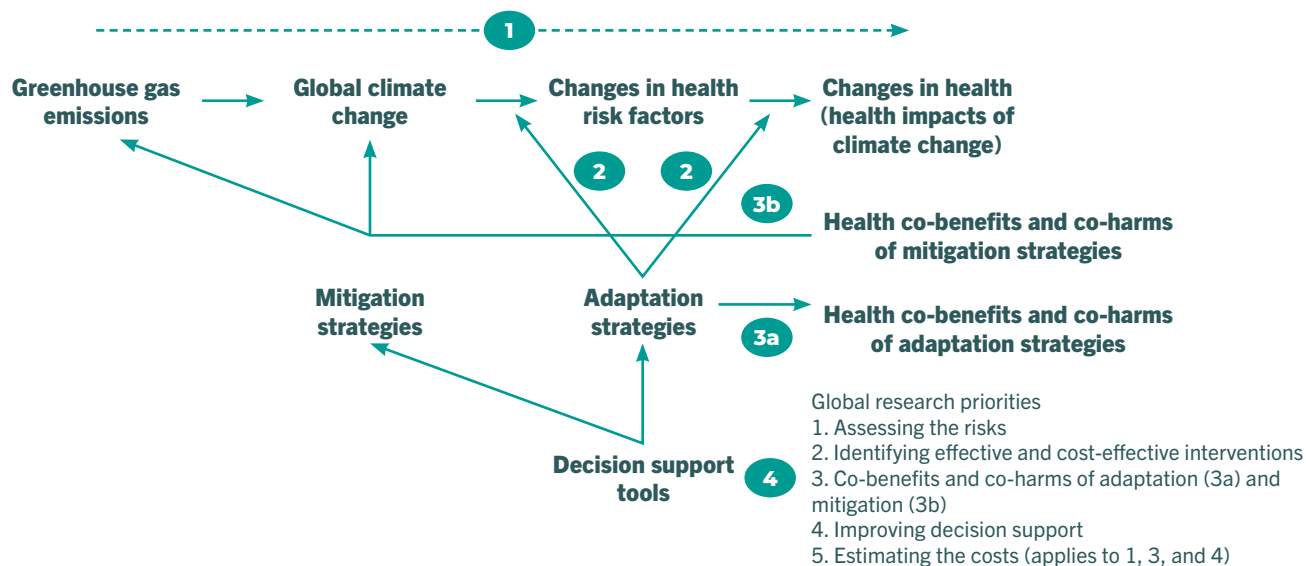
Cross-cutting topics:

- Small Island Developing States
- Indigenous and aboriginal populations
- Arctic/Polar populations
- Migration and displacement
- Farmers
- Age-disaggregated data (focusing on the ageing population and children)
- Gender-disaggregated data across topics.

Classification process

We used the logic model developed in 2012 by Hosking and Campbell-Lendrum to decide how the research topics of eligible studies corresponded to the five research priorities (see Fig. A1). Following the logic model, articles that tackled health vulnerability to climate change and related weather events (but not individual climatic events that might not have been linked directly to climate change) or effects of greenhouse gas emissions on human health were categorized as Priority 1. Priority 2 articles included health protection interventions in relation to climate change and their effectiveness, including their cost-effectiveness. Articles under Priority 3 tackled the health impacts and co-benefits of potential adaptation and mitigation measures in other sectors, such as transport, energy, water resources, land use and others. Priority 4 articles covered decision support and other tools, such as data collection, modelling, surveillance and monitoring, for assessing vulnerability and health impacts and targeting measures appropriately. It also included a broad range of qualitative studies on the interlinkages between climate change and health, such as surveys of knowledge, attitudes, perceptions, and related behaviours. Articles under Priority 5 were dedicated to assessing potential financial costs and other resources necessary for health protection from climate change, excluding cost-effectiveness of interventions (those articles belong to Priority 2).

Figure A1 Logic model for research on climate change and health in relation to global research priorities. Categories reflect the priorities set by the WHO (2009).

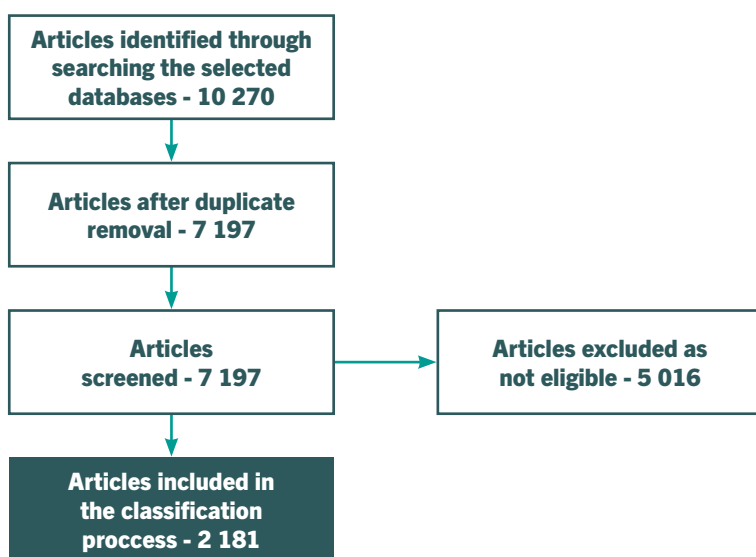


Study selection

A total of 10 270 articles were identified on the three databases. After removing duplicates, 7197 articles were brought forward and assessed during the first stage of the review for

their eligibility and relevance. Based on title and abstract, 4985 items were excluded as irrelevant or not eligible, and 31 studies were disqualified due to inability to access them. The remaining 2181 articles were advanced to the second stage of review and classification (see Fig. A2).

Figure A2 Flow diagram showing inclusion and exclusion process of articles



Limitations

It is important to note the limitations that could not be easily avoided while implementing this work. First, this review included only the studies available on three selected databases. The databases were chosen due to their pre-eminence for health research, but may not have included a body of knowledge available on other research sites. Second, only English articles were included in this review, leaving out potentially relevant articles in other languages. Third, as the scope of this work focused on documenting the trends and domains of climate and health research in the past decade, rather than exploring the details of individual studies, the review did not attempt a formal systematic review and meta-analysis of individual studies, but instead aimed to describe the geographic distribution of research output, and qualitatively review broad trends in issues addressed.

Moreover, there is also some risk of subjective bias inherent in categorizing the scientific papers due to possible differences in judgement among members of the research team who contributed to the work. However, efforts were made to reduce these differences through frequent communication between team members and joint article review. Finally, any review of published research may not cover the knowledge, intergenerational teachings, and adaptive technologies generated by communities that are not connected with formal academia. These may include (and are not limited to) rural, remote and indigenous communities, who, due to a variety of factors including geographic vulnerability, may have developed some of the best responses to a changing climate.

