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Building and strengthening climate resilient health systems in low- and middle-income country contexts

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Title Building and strengthening climate resilient health systems in low- and middle-income country contexts

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Table of Contets

Executive summary

Climate change poses a significant threat to health systems, particularly in low- and middle-income countries (LMICs), which often face resource constraints and heightened vulnerabilities. This report, commissioned by NORAD and conducted by the Norwegian Institute of Public Health, provides a comprehensive overview that addresses seven critical aspects necessary for building and strengthening climate resilient health systems in these contexts, supported by a scoping review. The report explores effective strategies for health system resilience; addresses the opportunities and challenges in implementing these strategies; assesses the vulnerabilities of health systems to climate change; identifies key stakeholders involved in climate resilient health systems; examines the data needs for informed decision-making; highlights the importance of addressing equity and the needs of vulnerable populations; and identifies research gaps that need to be addressed to support the development of climate resilient health systems.

Background and Rationale

Climate resilient health systems are essential to ensure that health services can anticipate, respond to, cope with, recover from, and adapt to climate-related shocks and stresses. This report addresses the urgent need for resilient health systems that can sustain improvements in population health despite an unstable climate. The review builds on extensive evidence from the World Health Organization (WHO), the Intergovernmental Panel on Climate Change (IPCC), and various scientific publications, aiming to fill the gap in understanding how to build climate resilient systems in resource-constrained settings. The report is organized into seven chapters that address specific research questions dedicated to different aspects of climate-resilient health systems.

Methodology

A scoping review methodology was employed to explore the range and breadth of studies on climate change and health systems in LMICs.

Key Findings

The first chapter organizes the findings according to the WHO health system pillars.
Chapter 1 - Key Strategies for Climate Resilient Health Systems:

- *Service Delivery:* Enhancing infrastructure resilience, ensuring basic public health standards, empowering primary healthcare, expanding local health services, addressing mental health needs, and integrating emergency preparedness into the health system culture are critical strategies.
- *Health Workforce:* Comprehensive training programs for health professionals on climate-related health issues and building an adaptable workforce are essential.
- *Health Information Systems:* Developing robust health information systems that integrate climate, health and environmental data to support decision-making.

- *Access to Medical Products:* Ensuring the availability of essential medical supplies through strategic procurement and storage solutions.
- *Financing:* Establishing sustainable financing mechanisms that integrate climate resilience into national health budgets.
- *Leadership and Governance:* Strengthening governance structures to incorporate climate adaptation into health policy and practice.

Chapter 2 - Opportunities and challenges of climate resilient health systems strategies: engaging local communities, leveraging innovative technologies, and fostering multi-sectoral collaboration and integrated policies are emerging opportunities, while addressing the lack of climate financing, improving preparedness, and overcoming barriers related to coordination and governance are crucial challenges for building climate resilient health systems.

Chapter 3 - Vulnerability of health systems: Assessing and understanding the vulnerabilities of health systems to climate change is crucial for effective adaptation and mitigation. Studies highlight the increased risks to health from climate variability, emphasizing the need for detailed vulnerability assessments at national and regional levels.

Chapter 4 - Stakeholders of climate resilient health systems: effective climate resilience requires the involvement of various stakeholders, including government agencies, NGOs, international organizations, and local communities. Their roles and contributions are essential for comprehensive disaster response and health system resilience.

Chapter 5 - Data for climate resilient health systems: high-quality data on health status, health systems, and climate-related factors are essential for informed decision-making. Strengthening Health Information Systems and integrating climate data are critical for assessing risks and planning effective responses.

Chapter 6 - Equity and vulnerability in climate change and health: addressing health disparities and promoting equity are crucial for climate resilient health systems. Vulnerable populations require targeted interventions to ensure their health and safety in the face of climate change.

Chapter 7 - Future investigation: there is a need for further research on sustainable financing, effective communication strategies for diverse vulnerable groups, and comprehensive policies to support climate resilient health systems.

Concluding remarks

Building climate resilient health systems in LMICs requires a comprehensive approach that addresses the vulnerabilities and capacities of health systems. This report provides valuable insights and practical strategies to support the development of resilient health systems capable of withstanding the impacts of climate change.

This report sets the stage for a detailed exploration of the strategies and practices necessary for building climate resilient health systems, offering a valuable resource for policymakers, health practitioners, and researchers committed to improving health outcomes in the face of climate change.

Introduction

Background

According to the World Health Organization (WHO), a climate resilient health system is one that is able to anticipate, respond to, cope with, recover from and adapt to climate-related shocks and stress, and to bring sustained improvements in population health, despite an unstable climate [1,2]. Resilience, unlike adaptation, is related to the capacity of the systems to cope with and manage health risks so that its essential functions and structure of the system are maintained. Despite the shocks and stresses health systems may face from climate variability and change, climate resilient systems still need to be efficient and responsive to improve health, reduce inequities and vulnerability, and provide adequate social and financial protection.

To achieve whole-system resilience, the independent building blocks of health systems (i.e., leadership and governance, health workforce, health information systems, essential medical products and technologies, service delivery and financing)[1,2] also must be climate resilient. This process occurs in two ways: (i) by reducing overall vulnerability, and (ii) by developing specific system capacities [1,2]. The effort for building climate resilient health systems in LMIC contexts should start by reducing existing health system vulnerabilities. To achieve this, continued investments to reduce poverty and inequity, universal access to essential services, adequate workforce and infrastructure, surveillance systems and good practices of health governance are recommended by WHO [1,2].

Health system capacity building involves understanding how climate change will affect population and service delivery, evaluating effectiveness of interventions and systems under diverse climatic conditions and enhancing institutional capacity.

More specifically, capacity building entails:

- recognizing, monitoring, anticipating, communicating, and preparing for changing climate-related health risks
- preventing, responding to, managing, and coping with uncertainty, adversity, and stress

[1] Operational framework for building climate resilient and low carbon health systems. Geneva: World Health Organization; 2023.

[2] Operational framework for building climate resilient health systems. Geneva: World Health Organization; 2015.

- adapting operations to changing risk conditions
- recovering from crisis and setbacks with minimal external support
- learning from experience and improving system capacity for the future

Rationale

This scoping review builds on an extensive foundation of evidence on climate change and health published by organizations such as the World Economic Forum[3], the WHO[4], the Lancet Countdown on health and climate change[5,6,7,] the Intergovernmental Panel on Climate Change (IPCC) reports[8], scientific publications[9,10], and systematic reviews[11,12,13,14], to name a few.

Similarly, the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCC) has, for many years, focused on climate change and health. In 2017, at COP23, WHO announced a Special Initiative on Climate Change and Health in Small Island Developing States to address climate-related health issues. A special report on health and climate change was released at COP24 with contributions from over 80 health professionals, academic experts, representatives

[3]World Economic Forum. Quantifying the impact of climate change on human health. Insight report, 2024.

[4] Kovats, S, Ebi, KL, Menne, B. Methods of assessing human health vulnerability and public health adaptation to climate change, 2016, WHO Regional Office for Europe, Copenhagen, Denmark.

[5] Romanello, M, et al. 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centered response in a world facing irreversible harms.

[6] Watts N, et al. The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. Lancet. 2021 Jan 9;397(10269):129-170. doi: 10.1016/S0140-6736(20)32290-X. Epub 2020 Dec 2. Erratum in: Lancet. 2020 Dec 14; PMID: 33278353.

[7] Watts N, Amann M, Ayeb, Karlsson S, et al. The Lancet countdown on health and climate change: from 25 years of inaction to a global transformation for public health. Lancet 2015; 386: 1861-914.

[8] Smith, KR, Woodward A, Campbell-Lendrum D, Chadee DD, Honda Y, Liu Q, Olwoch JM, Revich B, Sauerborn R. (2014). Human health: impacts, adaptation, and co-benefits. In: Field, CB et al (Eds), Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge and New York, pp. 709-754.

[9] Haines, A, Kovats, RS, Campbell-Lendrum, D, Corvalan, C. (2006). Climate change and human health: Impacts, vulnerability, and public health. Public Health, 120, 585-596. https://doi.org/10.1016/j.puhe.2006.01.002

[10] Costello, A, Abbas, M, Allen, A, Ball, S, Bell, S, Bellamy, R, Friel, S, Groce, N, Johnson, A, Kett, M, Lee, M. Managing the health effects of climate change. The Lancet. 2009; 373 (9676): 1693-733.

[11] Liu, F., Chang-Richards, A., Wang, K.-K., & Dirks, K. N. (2023). Effects of climate change on health and wellbeing: A systematic review. Sustainable Development, 31(4), 2067–2090. https://doi.org/10.1002/sd.2513

[12] Rocque RJ, Beaudoin C, Ndjaboue R, Cameron L, Poirier-Bergeron L, Poulin-Rheault RA, Fallon C, Tricco AC, Witteman HO. Health effects of climate change: an overview of systematic reviews. BMJ Open. 2021 Jun 9;11(6): e046333. doi: 10.1136/bmjopen-2020-046333. PMID: 34108165; PMCID: PMC8191619.

[13] Berrang-Ford, L., Siders, A.R., Lesnikowski, A. et al. A systematic global stocktake of evidence on human adaptation to climate change. Nat. Clim. Chang. 11, 989–1000 (2021). https://doi.org/10.1038/s41558-021-01170-y

[14] Berrang-Ford, L, et al. Systematic mapping of global research on climate and health: a machine learning review. The Lancet. July 13, 2021. https://doi.org/10.1016/S2542-5196(21)00179-0

of civil society, and international agencies that had worked on climate change and health for over three decades.[15] COP26 featured a Special Report on Climate Change and Health proposing priority actions and recommendations developed by over 150 organizations and 400 experts and health professionals. This report included recommendations and case studies highlighting opportunities for governments to prioritize health and equity in the international climate movement to help inspire and guide policymakers and practitioners in implementing solutions.[16]

And most recently, COP28 was the first year to have a dedicated thematic health day and introduced a special focus on health systems in the 2023 Sharm El-Sheik Adaptation Agenda implementation report which also emphasized the urgency of building climate resilient health systems.[17] In brief, this report includes goals that ensure vulnerable populations have access to safe and quality health services. Additionally, it stresses the importance of developing multi-sectoral heat action plans to protect high-risk populations, improving climate-informed health surveillance, and establishing early warning systems for climate-sensitive diseases. A major focus is also on increasing financial flows to support the development of climate-resilient health systems.

The United Arab Emirates Declaration (UAE) Declaration on Climate and Health (2023), signed by 151 countries, places significant emphasis on transforming health systems to be climate-resilient, low-carbon, sustainable, and equitable[18]. This declaration highlights the need for the integration of health and climate policies, strengthening collaborations across sectors, the importance of climate-health surveillance systems, early warning systems, and a well-trained, climate-ready health workforce, as well as investments in sustainable and low-emission healthcare systems, and promoting better access to climate and health financing.

Similarly, the World Economic Forum recently released a report quantifying the impact of climate change on human health and projected that by 2050, climate-related events will lead to 14.5 million deaths and over $12.5 trillion in economic losses, with an additional $1.1 trillion in healthcare costs globally.[19] These projections emphasize the urgent need for healthcare systems to be resilient and prepared to manage not just the health impacts, but also the broader socioeconomic disruptions caused by climate-related events.

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[15] COP24 Special Report: Health and climate change. Geneva: World Health Organization; 2018. License: CC BY-NC-SA 3.0 IGO.

[16] COP26 Special Report: The health argument for climate action. Geneva: World Health Organization; 2021. License: CC BY-NC-SA 3.0 IGO.

[17] 2023 Sharm El-Sheik Adaptation Agenda. (https://climatechampions.unfccc.int/wp-content/uploads/2024/01/Sharm-El-Sheikh-Adaptation-Agenda-2023-Implementation-Report.pdf)

[18] COP28 UAE Declaration on Climate and Health. (https://www.cop28.com/en/news/2023/12/Health-Declaration-delivering-breakthrough-moment-for-health-in-climate-talks)

[19] Quantifying the Impact of Climate Change on Human Health, Insight report, World Economic Forum, January 2024. (https://www.weforum.org/publications/quantifying-the-impact-of-climate-change-on-human-health/)

Climate change has direct and devastating effects on human health that go beyond traditional healthcare needs, with projections indicating 14.5 million additional deaths by 2050 due to climate-related causes. In addition, the economic losses caused by climate change are staggering, projected to reach $12.5 trillion by 2050, with an additional $1.1 trillion in healthcare costs, representing not only direct healthcare expenses but also productivity losses, infrastructure damage, and broader societal costs. Hence, strengthening health systems is essential, but it is not enough to merely increase capacity. Systems must be designed to anticipate and mitigate the unique risks posed by climate change. Without this resilience, health systems will fail in their primary mission—to save lives.

The aim of this scoping review is to build on this comprehensive foundation and advance the discourse by studying the impact of climate change on health systems in low and middle-income countries (LMICs). As noted above, research has extensively documented the implications of climate change on human health ranging from heightened mortality rates to exacerbating societal inequities and displacing populations, yet there is a gap in how to build resilient health systems in resource-constrained settings.

Understanding what makes a health system resilient is necessary to understand what strategies and capacities may foster resilience to climate shocks such as extreme weather events or climate shocks that could impact demand for health care services. There is global consensus that increasing the climate resilience of health systems and health facilities is an urgent priority.[20] Thus, it is timely to be focusing on questions related to what can enhance climate-resilience of health systems in LMICs to mitigate climate-related negative health outcomes.

The resilience of a public health system is concerned with its capacity to maintain health services among vulnerable populations during and after external perturbations. Several models dedicated to health system resilience have been developed over the years that describe frameworks to strengthen these systems.[21,22,23]

How climate change impacts health is, at the same time, straightforward and complex. Research examining how climate change and variability impacts human health has found that this occurs through different pathways including:

- Direct effects (health impacts from extreme weather events such as deaths or injuries and heat-related illnesses and disease)

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[20] World Health Organization. Initiative on Building Climate Resilient and Environmentally Sustainable Health Systems. https://cdn.who.int/media/docs/default-source/climate-change/who-initiative-on-climate-resilient-health-systems.pdf?sfvrsn=73bdfd15_5

[21] Kruk ME, Ling EJ, Bitton A, et al. Building resilient health systems: a proposal of a resilience index. BMJ 2017; 357; j2323.

[22] Barasa EW, Cloete K, Gilson L. From bouncing back to nurturing emergence: reframing the concept of resilience in health systems strengthening. Health Policy Plan 2017; 32: iii91-4.

[23] Grimm PY, Oliver S, Merten S, et al. Enhancing the understanding of resilience in health systems of low-and middle-income countries: a qualitative evidence synthesis. International J Health Policy Manage 2021. doi:10.34172/ijhpm.2020.261. [Epub ahead of print: 16 Jan 2021].

- Indirect effects (e.g., water and food security and safety, vector-borne diseases, zoonoses, respiratory illnesses, skin and other disorders)
- Diffuse or delayed effects (e.g., disruptions to health services, non-communicable diseases, mental health, and forced relocation)

Climate change exacerbates inequities in society by increasing the challenge of accessing clean water and food, maintaining livelihoods, or taking shelter in homes and communities, while the number of climate migrants is estimated to grow to 1.2 billion by 2050. Thus, segments of society most likely to be impacted by climate change are among the most vulnerable, including poor and marginalized populations. Understanding and enhancing the resilience of health systems to climate change is important to ensure that all segments of the population, including the most marginalized, receives essential services amidst increasing climate-related challenges.

Key concepts and definitions

Adaptation – Adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to the expected climate and its effects[24].

Adaptive capacity – Ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences[25].

Climate change – Change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use[26].

Climate change adaptation – Process of adjustment to actual or expected climate and its effects[27]. Climate change adaptation options can be drawn on a range of possible technological, behavioral changes and socio-economic status. Among these are: improved surveillance of infectious epidemic diseases in potential areas, early warning systems for human health, health vulnerability assessments to climate change, public health and environmental education and institutional coordination and disaster preparedness[28].

[24]Climate change and health - Vulnerability and adaptation assessment. WHO 2021.

[25] *Ibid.*

[26] *Ibid.*

[27] IPCC (2014). Climate-resilient pathways: adaptation, mitigation, and sustainable development. In C. B. Field et al. (Eds.), Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II, AR5 IPCC (pp. 1101–1131). Cambridge: Cambridge University Press.

[28] Nhamo G & Muchuru S. 2019. Climate adaptation in the public sector in Africa: Evidence from United Nations Framework Convention on Climate Change National Communications, Journal of Disaster Risk Studies 11(1), a644

Climate resilient health system – Health system capable to anticipate, respond to, cope with, recover from and adapt to climate-related shocks and stress, to bring sustained improvements in population health, despite an unstable climate[29].

Early warning system – Set of technical, financial, and institutional capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare to act promptly and appropriately to reduce the possibility of harm or loss[30].

Health equity – Equity is the absence of unfair, avoidable or remediable differences among groups of people, whether those groups are defined socially, economically, demographically, or geographically or by other dimensions of inequality (e.g., sex, gender, ethnicity, disability, or sexual orientation). Health is a fundamental human right. Health equity is achieved when everyone can attain their full potential for health and well-being[31].

Health systems – Ensemble of all public and private organizations, institutions and resources mandated to improve, maintain, or restore health and incorporate disease prevention, health promotion, and efforts to influence other sectors to address health concerns in their policies[32].

Health system strengthening – Efforts to improve or strengthen the system to operate more effectively, efficiently, and equitably[33].

Resilience – Ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management[34].

Vulnerability – Conditions determined by physical, social, economic, and environmental factors or processes that increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards[35].

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[29] Operational framework for building climate resilient and low carbon health systems. Geneva: World Health Organization; 2023.

[30] Climate change and health vulnerability and adaptation assessment. Geneva: World Health Organization; 2021. Licence: CC BY-NC-SA 3.0 IGO.

[31] Health Equity. WHO. URL: *https://www.who.int/health-topics/health-equity#tab=tab_1*

[32] *Ibid.*

[33] De Savigny D, Adam T. 2009. Systems thinking for health systems strengthening. Geneva: WHO.

[34] Climate change and health vulnerability and adaptation assessment. Geneva: World Health Organization; 2021. Licence: CC BY-NC-SA 3.0 IGO.

[35] *Ibid.*

Objective and research questions

Our objective was to review and report findings from empirical studies on reducing vulnerabilities and building capacities for climate resilient health systems in LMICs. We identified and mapped existing knowledge from systematic reviews, scoping reviews and primary empirical studies, published in peer reviewed journals, to provide a broad overview of the current state of research in climate resilient health systems in LMIC settings.

The specific research questions were as follows:

1. What are the key strategies and interventions to build climate resilient health systems?
2. What are the health systems vulnerabilities associated with climate change?
3. What are the barriers and facilitators for the integration of capacity building activities for climate change resilience into health systems, and what strategies have been successful in overcoming these barriers?
4. What is the role of different stakeholders in building and strengthening climate resilient health systems?
5. What are the indicators and metrics used to assess the effectiveness of climate resilient health systems, and what are the current gaps in measurement and evaluation?
6. What are the ethical considerations and equity implications of climate resilient health systems, and how can these be addressed in policy and practice?
7. What is the current state of research on climate resilient health systems, and what are the emerging trends and areas for future investigation?

The above research questions were slightly refined to enhance clarity, but these minor editorial adjustments did not alter the core meaning or intent. The revised questions are noted at the beginning of each chapter dedicated to findings.

Methods

A scoping review approach was utilized to explore the range and breadth of studies on climate change and health systems in low- and middle-income settings. This approach was chosen due to its suitability for mapping the extent, range, and nature of research on this broad and complex topic. Unlike a systematic review, which aims to answer specific research questions by synthesizing high-quality evidence from quantitative or qualitative studies, a scoping review includes a wider array of articles and is not limited by specific study designs, reported outcomes, or quality-assessed research.

The flexibility of a scoping review approach is particularly appropriate when exploring a topic that may not have a large volume of studies that have followed validated methodological approaches. In other words, the search in a scoping review may find publications with differing levels of quality according to the research methods used. Due to this limitation, unlike systematic reviews, it is not appropriate to assess the quality of the studies nor are the studies suitable for comparison or pooling as in systematic reviews. However, this step is a necessary prelude to identify the status of the research landscape. Given the current knowledge on this topic, this approach lends itself to providing an overview of the scope of research on this topic, highlighting key concepts, identifying gaps and potential areas for future research.

This study followed Arksey and O'Malley's (2005)[36] framework for conducting a scoping review which consists of five specific steps noted below:

1. Identify the research question(s): Define overarching questions to guide the review that are broad and exploratory in nature.
2. Identify relevant studies: Focus on breadth and comprehensiveness to ensure a thorough review, determining what databases to use and sources to search.
3. Study selection: Develop inclusion and exclusion criteria based on the available evidence rather than predefining them.
4. Chart the data: Use a narrative review or descriptive analytical method to organize evidence.
5. Collate, summarize, and report results: Present an overview of the evidence acknowledging that scoping reviews do not aggregate findings and *are not designed to make definitive recommendations.*

[36] Arksey, H, O'Malley, L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol. 2005; 8(1): 19-32.

There are key distinctions between scoping and systematic reviews with regard to the use of the resulting report. The latter are designed to provide high-quality evidence and assess quality of the findings to inform practice and policy-making and, often to provide recommendations. Scoping reviews, on the other hand, do not conduct quality assessments of included studies and are, thus, more limited in the type of conclusions that can be inferred. In addition, scoping reviews are not designed or intended to infer or provide policy or other recommendations. A scoping review method, however, was considered the most appropriate method given that it would facilitate a broad exploration of the existing research.

Inclusion criteria

We had the following inclusion criteria.

Population	People experiencing, or being at risk for climate related natural disasters as part of health system
Concept	• Studies assessing the impact of climate change or natural disasters on health systems, • studies implementing and assessing the implementation of measures (i.e. early warning systems) for building or strengthening climate resilient health systems, • studies identifying indicators for measuring or assessing climate resilience in health systems, • studies suggesting frameworks for building or strengthening climate resilient health systems.
Context	Low and Middle-Income Countries (LMICs) as defined by the World Bank in 2023 [37]
Study design	Empirical studies with a methods description
Publication date	Studies published after 1973
Language	English
Other	Studies must have an abstract to be included in screening

[37] World Bank Country and Lending Groups. Data. URL: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

Exclusion criteria

The following were excluded:

- Climate-Related Terms: Studies not including terms related to climate change or not focused on preparedness or response to climate-related natural disasters (e.g., fires, storms, heatwaves, floods, droughts), for example earthquakes.
- Exploratory focus: Studies focused solely on assessing the impact of climate-related disasters or climate change on the prevalence of diseases through prediction modeling. Studies focused on comparing the performance of different mathematical or prediction models for developing early warning systems without implementing them.
- Non-Health System Focus: Studies not focused on health systems or any of the health systems pillars as described by the WHO framework.
- Types of References: Opinions, conference proceedings, perspectives, commentaries, letters to the editor
- Non-Human Studies: Studies not involving humans or not related to human health.
- LMICs Exclusion: Studies where subjects are not from LMICs.

Literature search

Database search

An information specialist developed a search strategy in collaboration with the project team and performed the literature searches in various databases (Appendix 1). The search included relevant indexed terms (e.g., Medical Subject Headings), text words (words in title and abstract) reflecting the inclusion criteria. We searched the following databases:

- Epistemonikos, Epistemonikos Foundation (www.epistemonikos.org/) searched 01 September 2023)
- Ovid MEDLINE(R) ALL 1946 to August 04, 2023 (searched 05 August 2023)
- Global Health 1973 to 2023 Week 30, Ovid (searched 05 August 2023)
- Global Index Medicus, World Health Organization (WHO) (www.globalindexmedicus.net/) (searched 06 August 2023)
- VHL Regional Portal, Bireme (bvsalud.org/) (searched 06 August 2023)

Study selection

All references resulting from the literature search were screened independently by two reviewers. Consensus was required for a study to be included or excluded. In cases of disagreement, the two reviewers discussed and reconciled. We utilized the priority screening feature in EPPI-Reviewer

(Version 6)[38] to allow for the prioritization of studies most likely to meet the inclusion criteria based on machine learning algorithms, enhancing efficiency. Using prioritization tools in EPPI-Reviewer for conducting a scoping review enhances efficiency by automating the initial screening process and ranking studies based on relevance, thus reducing manual effort and focusing on high-priority studies. This approach ensures optimal use of resources, minimizes selection bias, and improves the overall quality of the review.

Titles and abstracts of all retrieved studies were screened using EPPI-Reviewer (Version 6)[35]. The screening was based on the predefined inclusion and exclusion criteria. A set of 80 references was screened by all reviewers to ensure consistency and understanding on how to select publications according to the predefined inclusion and exclusion criteria. Once we had double-screened 200 publications without including any of them as relevant, and after running a classifier to determine the possible number of relevant studies remaining, we stopped screening for pragmatic reasons. We believe the number of remaining relevant studies to be extremely low based on the results of the classifier.

Full texts of potentially eligible studies were retrieved following the initial screening. Each full text was independently assessed by two reviewers. The reasons for excluding studies at this stage were recorded in EPPI-Reviewer and are reported in the PRISMA study flow diagram [39].

Data extraction

Four project members retrieved data from the included studies, and another checked the data against the relevant publications. In case of disagreement, we discussed, until we reached a consensus.

Data charting

We sorted the publications into logical categories, generally according to the review's problem statements, but also according to study characteristics (authors, year of publication, country of study, study design, specific climate-related challenge), and key findings related to the review objectives.

[38] Thomas J, Graziosi S, Brunton J, Ghouze Z, O'Driscoll P, Bond M, et al. EPPI-Reviewer: advanced software for systematic reviews, maps and evidence synthesis. EPPI-Centre Software London: UCL Social Research Institute. 2020.

[39] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. International journal of surgery. 2021;88:105906.

Presentation of the data

We extracted occurrences of studies by the different categories using the frequency and cross-tabulation functions in EPPI-Reviewer.

Conceptual Frameworks

This section presents two WHO frameworks that were instrumental in addressing the research questions, given their relevance and focus on health systems and the intersection of climate change and health. These frameworks helped organize information and categorize findings and thereby assist readers in understanding the research scope.

This scoping review assessed the study findings using the WHO´s model of the building blocks of a health system.[40] These six building blocks offer a useful organizational structure for understanding and categorizing findings relevant to health system strengthening. This framework highlights six core dimensions of a health system as described below:

- ***Leadership and Governance:***
  Effective leadership and strategic planning are necessary to address the complex and long-term challenges facing health systems. Collaboration among diverse stakeholders and cross-sectoral planning are essential to ensure coherent and health-promoting policies.
- ***Health Workforce:***
  Adequate staffing and training are crucial for the functioning of health systems. This includes ensuring a sufficient number of trained personnel and providing ongoing education to address evolving health needs.
- ***Health Information Systems:***
  Robust information systems are vital for monitoring and evaluating health outcomes. This involves collecting, analyzing, and disseminating data to inform decision-making and improve health service delivery.
- ***Essential Medical Products and Technologies:***
  Access to essential medical products and technologies is fundamental for delivering quality healthcare services. This includes ensuring the availability of safe and effective treatments and diagnostic tools.
- ***Service Delivery:***

[40] Monitoring the building blocks of health systems: a handbook of indicators and their measurement strategies. 1.Delivery of health care. 2.Monitoring. 3.Health care quality, access, and evaluation. 4.Health care evaluation mechanisms. 5.National health programs–organization and administration. I. World Health Organization.

Efficient and effective service delivery is essential for meeting the healthcare needs of populations. This includes ensuring access to quality health services and promoting equitable distribution of resources.

- ***Financing:***
  Sustainable financing mechanisms are necessary to ensure the availability and affordability of healthcare services. This involves allocating resources efficiently and mobilizing funding from various sources.

Health systems operate in many different contexts. Societal issues influence health systems such as economic, cultural, environmental, legal, and political factors, which need to be considered. To address the potentially immense impact of climate variability and change on health systems around the world, the model described above was later expanded by WHO to include 10 components necessary for the resilience of health systems to climate change.

The revised framework, called WHO's Operational Framework[41,42] includes the 10 components noted below and in Figure 1 which overlays the 10 components next to the original six building blocks:

1. Leadership and governance
2. Health workforce
3. Vulnerability, capacity, and adaptation assessment
4. Integrated risk monitoring and early warning
5. Health and climate research
6. Climate resilient and sustainable technologies and infrastructure
7. Management of environmental health determinants
8. Climate-informed health programs
9. Emergency preparedness and management
10. Climate and health finance

Figure 1 Six Core Dimensions of a Health System

[41] WHO. Operational framework for building climate resilient and low carbon health systems. Geneva: World Health Organization; 2023.

[42] WHO. Operational framework for building climate resilient health systems. Geneva: World Health Organization; 2013.

The WHO frameworks and their requisite components, collectively, provided an overall structure on how to approach and frame the findings of this scoping review. In addition, a World Bank blog written by Palmeiro and colleagues provided a useful graphical depiction that shows how factors may reduce the impacts of climate change and strengthen climate resilient health systems. This figure offered inspiration in how we approached this work[43] (Figure 2). For example, leadership and governance and strong and innovative financing mechanisms cut across the other four health system building blocks that are considered essential in reducing harmful impacts of climate change to promote better population health and well-being.

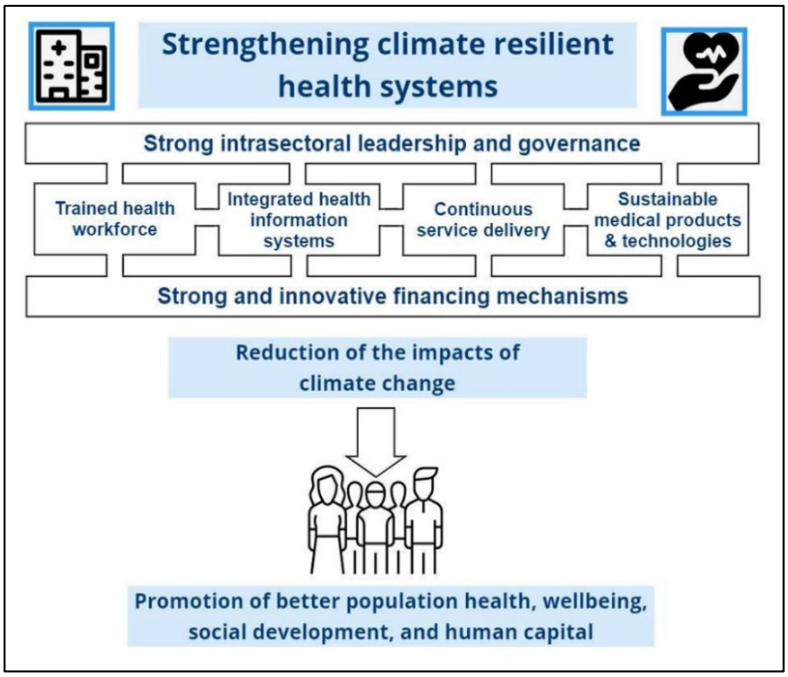

Figure 2 Strengthening Climate Resilient Health Systems

[43] Palmeiro, Y, Plaza Reneses, T, Velenyi, E, Guanais, F, Herrera, C. "Health systems resilient to climate change, an opportunity for sustainable human development" April 19, 2023. https://blogs.worldbank.org/en/latinamerica/health-systems-resilient-climate-change

Findings

Findings of the literature search and study selection

The database searches yielded 7514 hits before the removal of duplicates (Figure 2). After removing the duplicates, we were left with 7189 references. Of these, we excluded 6890 references that clearly did not fulfil our inclusion criteria. We obtained and assessed 289 full-text publications, of which we excluded 223 (full texts of n=10 publications were not available). We included 66 studies (Appendix 2). Among the most important excluded studies, the exclusion reason was lack of a methods section or was a commentary for 76 studies (26%), study design for 17 studies (6%), country for 21 studies (7%), not climate related for 33 studies (11%) and not health systems related for 76 studies (26%). All excluded studies and the reason for exclusion are presented in Appendix 3.

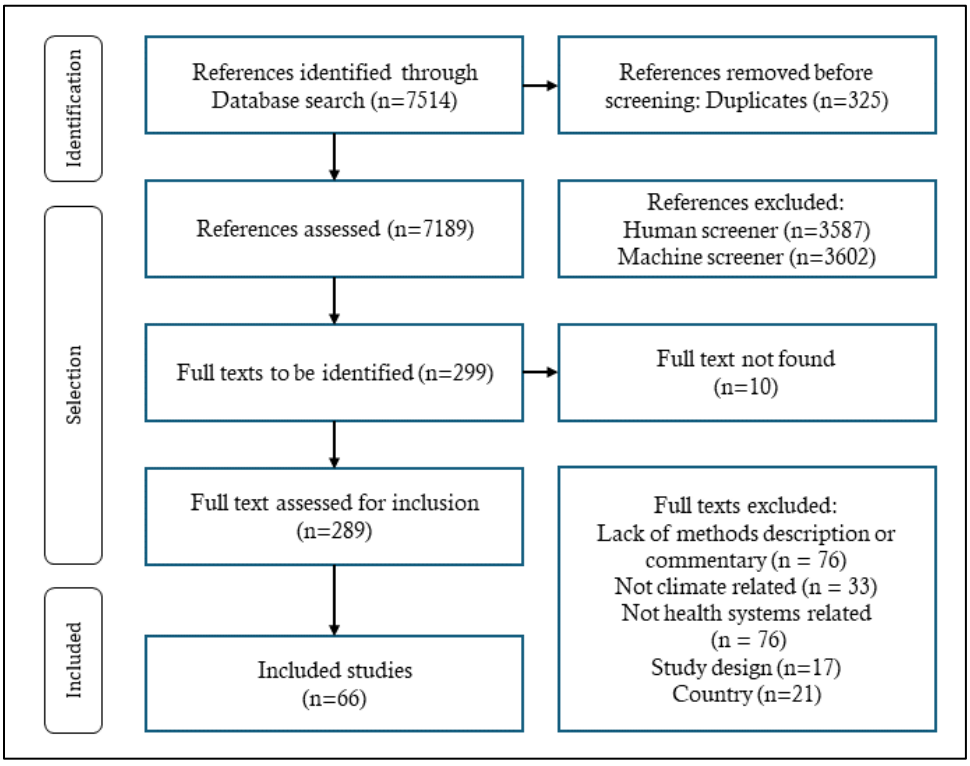

Figure 2 Flow chart over study selection

Study characteristics

We included 66 unique studies (Appendix 2).

Year of publication

The publication years ranged from 2006 to 2023 (Figure 3). There was an increase in publications from 2013 onwards and a decrease after 2022 and in these years 88% of the included publications were published. Most publications were in 2018 (n=9, 14%), followed by 2022 (n=8, 12%) and 2021 (n=7, 11%).

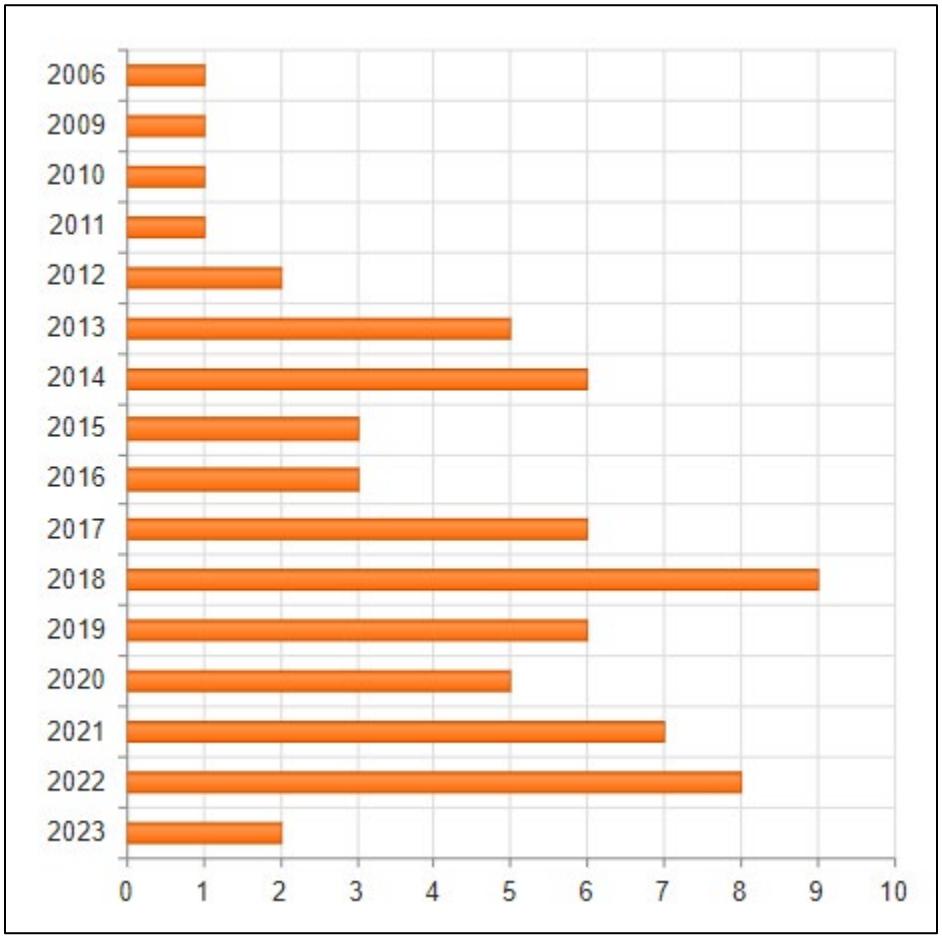

Figure 3 Overview of publication year

Country

We included studies from 30 countries and seven records were based on multi-country analyses (Figure 4). African countries were represented by 25 studies in 12 countries, with Ethiopia being the country with most studies. Asia was represented by 30 studies in 9 countries, with most studies from Philippines.

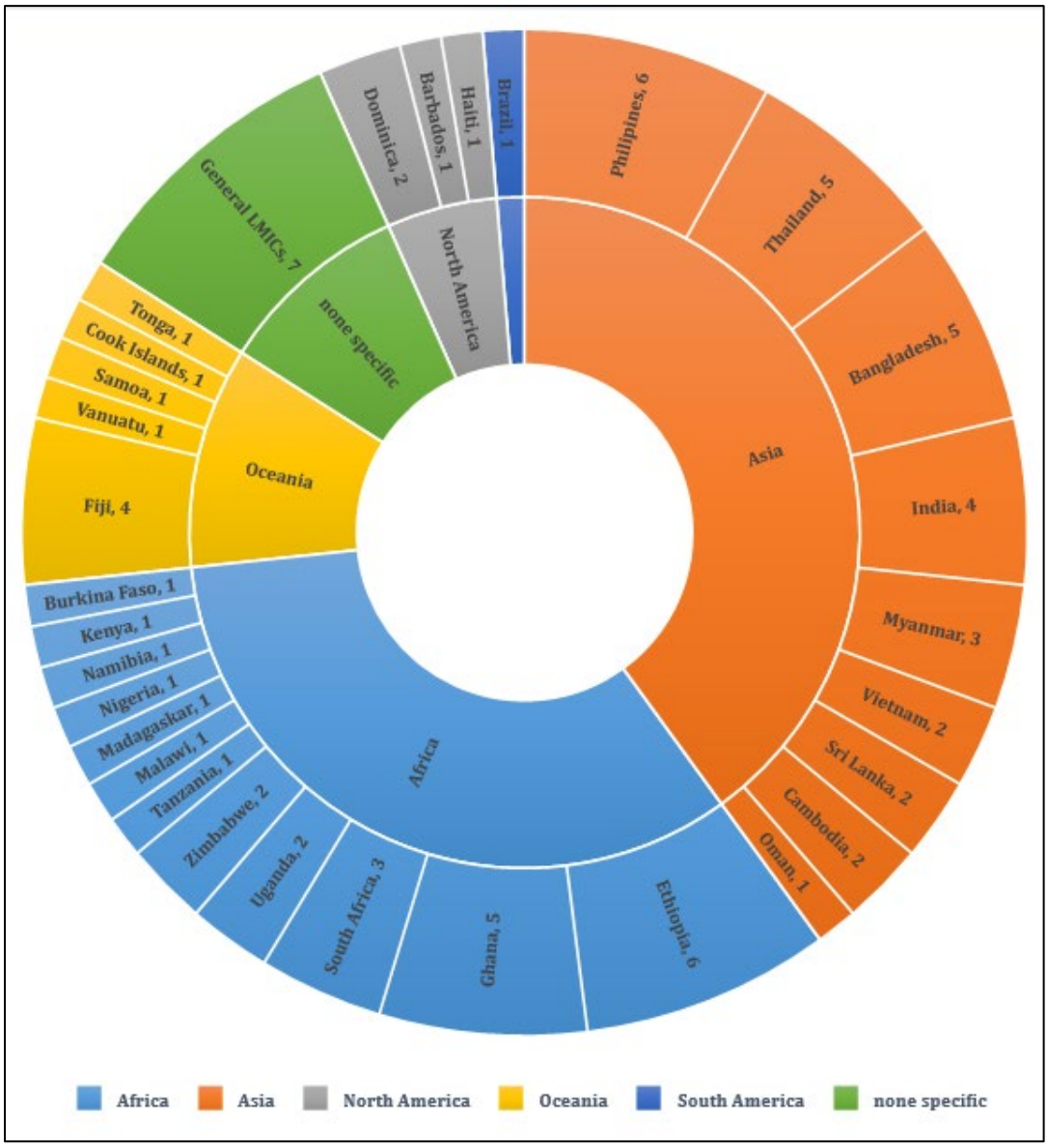

Figure 4 Overview of countries for included studies

Study design

Most of the included studies were primary studies using mixed methods (both qualitative and quantitative) (n=23, Figure 5) and most of them focused on general climate issues (Figure 6). We also identified many primary studies using qualitative methods (n=21, Figure 5) and most of them focused on cyclones/hurricanes, typhoons or flooding (Figure 6). We identified 6 systematic or literature reviews. Fewer of the included studies used quantitative methods.

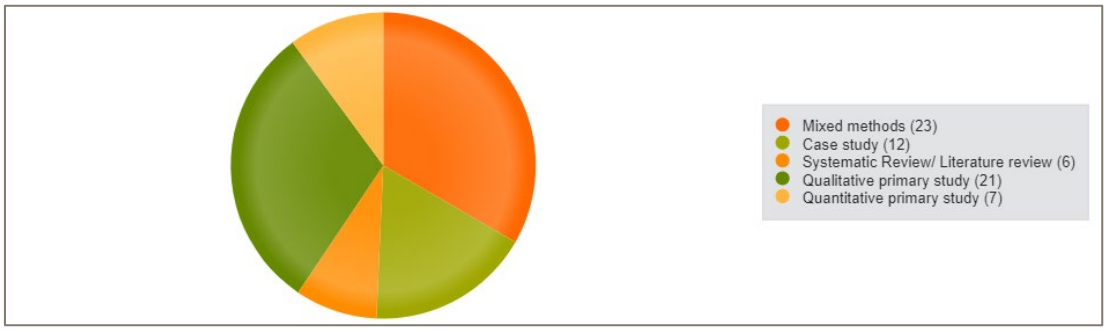

Figure 5 Distribution of included studies by study design

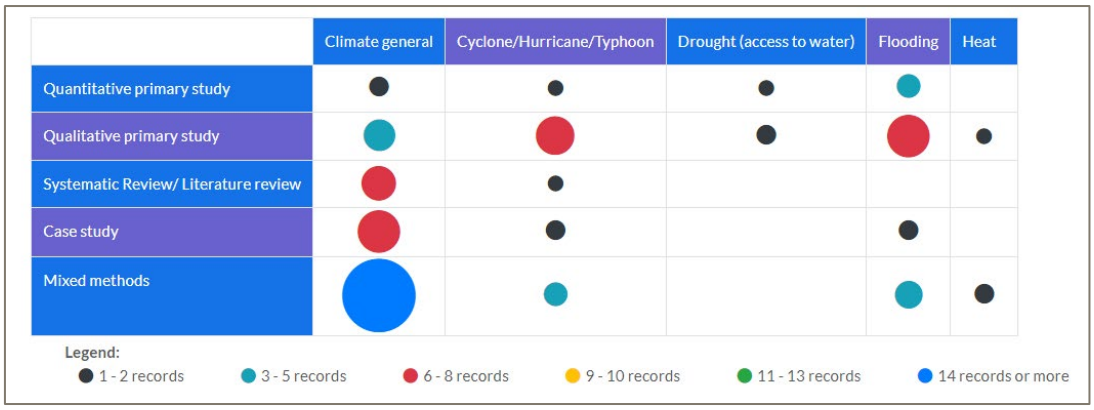

Figure 6 Overview of study designs by climate-related problem

Type of climate related problem

Most of the included studies were focused on general climate issues (Figure 7). Cyclone/Hurricane/Typhoon and flooding were also the focus of many studies.

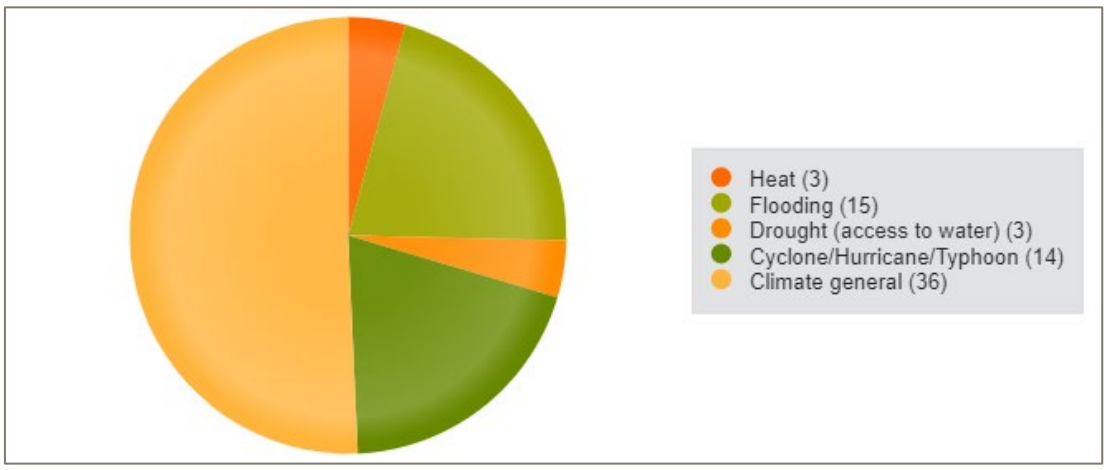

Figure 7 Distribution of included studies by type of climate-related problem studied

Health system pillars

We have described the included studies by one of the six pillars of the health system (Figure 8). One study can be focused on several health system pillars. Most focus was given to the pilar of service delivery and health workforce. Less focus was given to the access to essential medicines and health information systems.

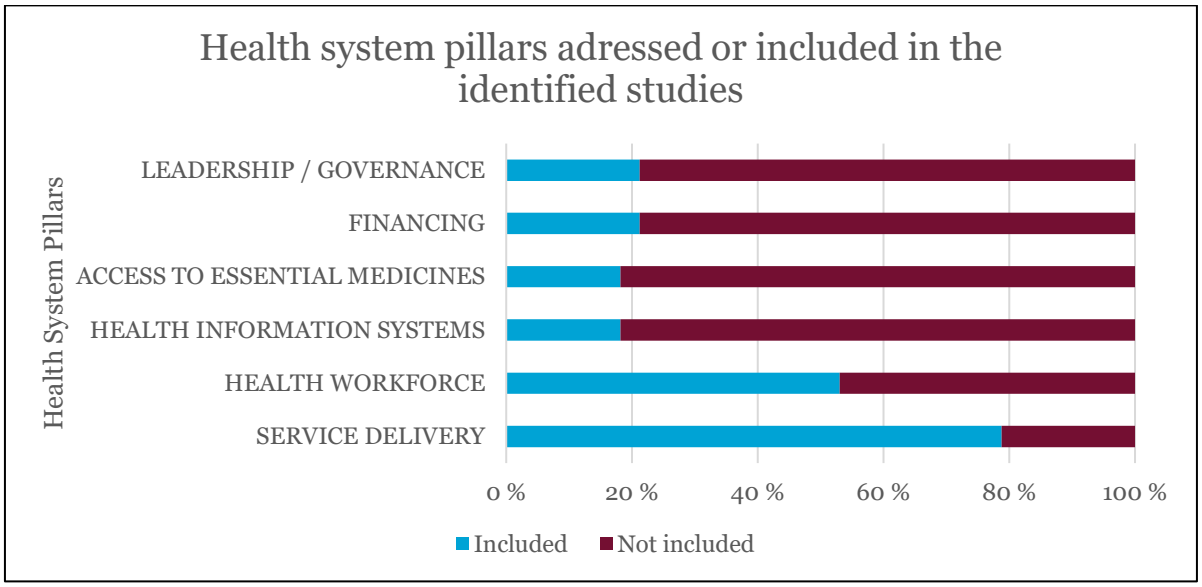

Figure 8 Distribution of included studies by health system pillar

Scoping review questions for climate resilient health systems in LMICs

The following seven chapters describe the findings for each research question. The findings presented in Chapter 1 are organized according to the six WHO health system pillars. Across the chapters, we highlight key concepts that are supported by illustrative examples extracted from individual studies.

Chapter 1: Key strategies

This section addresses the first research question. This question was slightly revised as follows:

What are the key strategies in LMICs to build climate resilient health systems?

In the following section, the findings related to key strategies derived from relevant studies have been categorized according to WHO's six building blocks of health system strengthening, namely: service delivery, workforce, essential medicines and products, health information systems, leadership and governance and finance. Key findings from studies in each of the six dimensions are reported below with accompanying information in tabular form in Tables 1-6.

Service Delivery

Health care service delivery is also considered equally integral to WHO's climate resilient health system framework which further delineates this category into three components:

- Management of environmental health determinants
- Climate-informed health programs
- Emergency preparedness and management.

Overall, strategies focusing on service delivery are important for maintaining effective care in LMICs, particularly in the context of building climate resilient health systems. They emphasize not only the physical readiness and robustness of health facilities and health infrastructure, but also the importance of strong primary health care systems, community participation and integration, decentralized decision-making, mental health support, and technological advancements to ensure comprehensive health service coverage during and after climate-related challenges and/or disasters.

Given the broad nature of this category, nearly all included studies discussed or alluded to some aspect of health care service delivery. Accordingly, we have not listed every relevant study, but specific studies are mentioned in the fourth column of Table 1 Service Delivery.

Table 1 provides a summary of the key strategies, further description, and illustrative examples derived from the study articles. In brief, the key strategies fall into the following main thematic areas:

- Enhance infrastructure resilience and adaptation
- Develop facility preparedness plans
- Ensure baseline standards for health care delivery
- Empower primary health care
- Expand local health services
- Address mental health needs
- Enable rapid response and scalability
- Support community engagement and training
- Ensure adequate human resources
- Strengthen cross-sectoral collaboration
- Integrate emergency preparedness into health culture
- Leveraging digital tools and technology
- Facilitate information sharing and data access
- Establish effective communication platforms

Key takeaways

- The best emergency response is a strong primary health care system.
- Utilize community health systems and extend healthcare services to remote areas to ensure access during emergencies.
- Develop facility preparedness plans that define disaster protocols and operational procedures but remember that plans are meaningless unless put into action.
- Reinforce healthcare facilities and infrastructure against environmental impacts through structural upgrades and backup power systems.
- Implement flexible health service protocols to ensure efficient scalability.
- Health systems under repeated strain may benefit most from basic health system strengthening that address ongoing challenges as this can pay off during emergencies.

Table 1 Service Delivery

Service Delivery	Key strategies	Description	Illustrative examples
Infrastructure and facility preparedness	Enhance infrastructure resilience and adaptation	Strengthening healthcare facilities to withstand environmental impacts, such as floods or earthquakes, by enhancing structural resilience, i.e., retrofitting existing facilities and constructing new ones with climate resilience in mind.	Several studies discuss the importance of ensuring that health facilities (i.e., hospitals) are structurally safe, sound, and accessible which may require building modifications and installation of backup power systems to ensure functional operations (Wijesekara 2020, Nhamo 2019, Rattanakanlaya 2018, McIver 2016).
	Develop facility preparedness plans	Tailor preparedness plans to specific types of disasters, define standard operating procedures, and identify clear lines of command and responsibilities during emergencies	Studies in the Philippines and India both emphasized that having written disaster plans does not necessarily translate to preparedness, also known as the 'paper plan syndrome' (Labarda 2017, Phalkey 2012).
	Ensure baseline standards for healthcare delivery	Public health care standard identified by government being met under no-crisis situation will improve the response during crisis	Ensuring the capacity and capability to maintain routine services while also responding to emergencies is key according to a study on health system resilience (Meyer 2020).
Community-based health services	Empower primary health care	Community health systems and use of community health extension workers, decentralized decision making	Many studies highlight the importance of primary care facilities for climate resilient health systems (Alga 2018, Rawat 2022, Puntub 2022, Van Minh 2014).
	Expand local health services	Expanding health services directly into communities, especially remote areas, ensures that healthcare is accessible during disasters	A study in Bangladesh described how deploying midwives to remote health centers can ensure sexual and reproductive health services for women and girls (Purno 2023).
	Address mental health needs	Develop comprehensive emergency preparedness plans that include mental health and psychosocial support services, recognizing the psychological impact of disasters on affected populations	Several studies explored the psychosocial impacts and mental health needs and the importance of effective mental health programs and policies and of integrating mental health into emergency preparedness (Elshazly 2022, Opoku 2021, Hasan 2020, Htay 2006).
Emergency response and disaster preparedness	Enable rapid response and scalability	Establish protocols that facilitate rapid scalability and flexibility of health services in response to an emergency including action plans for epidemic outbreaks and natural disasters	Several studies discuss the importance of flexibility in health services and having plans in place that address surge capacity to ensure maintain services during emergencies (Saulnier 2022, Meyer 2020, Rattanakanlaya 2018, Al-Shaqsi 2010).

	Support community engagement and training	Mobilize community resources and training local volunteers to support health service delivery during emergencies and recognize the value of the informal sector (i.e., volunteers).	Several studies (e.g., Cambodia, Haiti, Myanmar, Zimbabwe) describe how community health worker resilience is rooted in their trusting relationships, generalized scope of work, intrinsic motivation, self-regulatory capacity and adaptability (Saulnier 2022, Sripad 2021, Grimm 2021, Ray 2022).
	Ensure adequate human resources	Maintain health personnel directories and databases	Several studies noted the value of a health staff databases with community-based health workers, clinical staff, laboratory technicians, pharmacists, logisticians, health managers and key resource persons that can contribute to a disaster assessment (Aung 2013, Rattanakanlaya 2018, Al-Shaqsi 2010). Registering international health personnel during disasters was also considered necessary to ensure timely external assistance, minimizes duplication of scarce resources, provides a transparent process and maximizes effectiveness of health personnel (Rumsey 2014).
Service integration and coordination	Strengthen cross-sectoral collaboration	Facilitating coordination between the health sector and other sectors ensures optimal resource use and a unified response to public health emergencies	Multisector collaboration was considered key to success by many studies and multisectoral approaches have been identified as an international priority (Banwell 2021, Meyer 2020, Ario 2019, Hanefeld 2018, Alhasan 2017, Ebi 2016).
	Integrate emergency preparedness in processes	Embed emergency preparedness into daily processes and structures of health facilities to create a culture of resilience	Several studies mentioned the importance of integrating disaster preparedness into the hospital culture in order to make disaster preparations more effective (Labarda 2017, Al-Shaqsi 2010).
Technology and information utilization	Leverage digital tools and technology	Implement digital tools and technology to maintain care when traditional health services are disrupted.	Several studies discuss the use of digital tools and informatic systems to address climate change and health challenges (Barteit 2023, Merkod 2017)
	Facilitate information sharing and data access	Enhance access of health and climate data to better inform care delivery during emergencies	Several studies highlight the importance of information sharing and data accessibility (Elshazly 2022, Meyer 2020)
Information dissemination and communication	Establish effective communication platforms	Utilize communication platforms to disseminate health information using social media, mobile apps, and other digital communication platforms and tools to enhance reach	Several studies mention that risk communication and social mobilization are key in management of emergencies and development of resilience to prevent and mitigate disasters (Puntub 2022, Meyer 2020, Ario 2019, McIver 2016, Al-Shaqsi 2010)

Health workforce

Health workforce is one of WHO's six pillars of health system strengthening and the second component of WHO's ten components for a climate resilient health system.

Strategies pertaining to the health workforce in LMICs focus on enhanced awareness, knowledge, and skills through training programs as well as ensuring the physical and psychological well-being of health workers which is essential for maintaining a resilient health system.

The strategies are derived from insights described in several different studies reflecting consensus on the effectiveness of strengthening resilience. Findings were derived from the following studies: Abaya 2011, Alga 2018, Alhassan 2017, Al-Shaqsi 2010, Banwell, 2021, Beek 2021, Berhanu 2016, Cuesta 2018, Ebi 2017, Elshazly 2022, Farley 2017, Fil 2018, Grim 2021, Hanefeld 2018, Hussey 2019, Krutphong 2022, Labarda 2017, Lam 2018, Meyer 2020, Naess 2014, Nhamo 2019, Opoku 2021, Phalkey 2012, Purnamita 2016, Purno 2023, Rakotoarison 2018, Rattanakanlaya 2018, Rattanakanalaya 2022, Rawat 2022, Ray 2022, Rumsey 2014, Saulnier 2022, Schnitter 2018, Sripad 2021, Stewart-Ibarra 2019, Varughese 2021, and Van Minh 2014.

Table 2 provides a summary of the key strategies, further description, and illustrative examples derived from the study articles. In brief, the key strategies fall into the following themes:

- Build an agile and adaptable workforce accompanied by task-shifting and teamwork
- Ensure surge capacity and emergency task force teams
- Provide training on climate change and health issues and disaster preparedness training
- Promote interdisciplinary and intersectoral training to address climate change issues
- Leverage community health workers' local knowledge and experience
- Support specialized health professionals to work in rural areas
- Use health provider databases to enhance communication networks
- Create databases of health workers
- Address health workers' mental health needs and provide psychological support for staff
- Ensure health workers' safety

Key takeaways:

- Training of healthcare workers is vital. Continued professional knowledge and skills development with regard to climate-related health impacts warrants investment.
- Community health workers and primary health care teams play a vital role given their local knowledge and experience as well as history working in the community, building trusting relationships and local engagement.
- Interdisciplinary collaboration among healthcare professionals, environmental experts and emergency management professionals fosters a valuable integrated approach. The One Health agenda, for example, offers an opportunity to link animal and human health through the workforce.

Table 2 Health Workforce

Health workforce	Key strategies	Description	Illustrative examples
Human resource management	Build an agile and adaptable workforce accompanied by task-shifting and teamwork	Utilize community health workers to provide health care services to rural and vulnerable communities and offer training as first responders and health educators, particularly in remote areas where access to care is limited.	In Samoa, task-shifting and multi-tasking were encouraged. It was also noted that an agile, competent and properly trained workforce is essential for a functional health system (Rumsey 2014).
	Ensure surge capacity and emergency task force teams	Prepare for increased patient inflow during disasters by pre-arranging additional staffing and mobilizing volunteers. This strategy involves both increasing the number of health workers and improving their distribution based on vulnerability assessments of different regions.	A Thai study of health personnel describes measures for increasing staff size in advance for staff surge capacity by staffing from other departments in the hospital (to join medical mobile units) or support from their healthcare network (Rattanakanlaya 2018). A Cambodia study of maternal/child health workers identified maternal health services as an essential service at risk during floods. Strategies for antenatal and birth services include improving general midwifery skills prior to flooding, providing medical kits with the relevant equipment to mobile outreach teams and ensuring pregnant women can be identified and evacuated during floods (Saulnier 2022).
Develop trained and competent workforce	Provide training on climate change and health issues and disaster preparedness training	Implement ongoing and comprehensive training programs that focus on disaster preparedness, climate change awareness, and health threats associated with climate change including training on handling increased disease prevalence due to climate variability. Health professionals need disaster-specific training including practical drills, theory sessions, and policy analysis activities tailored to local climate hazards.	Several studies stressed the urgent need to strengthen technical and professional capacity of health workers through training and workshops on climate change and health (Hussey 2019, Abaya 2011). A study of a water and sanitation hygiene (WASH) program in Ghana highlights the need to organize training on climate change adaptation for staff and community elders to ensure local engagement (Alhansan 2017).

			Desktop and field simulations and disaster training were available for some health workforce in Fiji and the Cook Islands (Rumsey 2014). An Ethiopian survey of health professionals discussed the importance of community rescue training and knowledge propagation; health worker training on disaster preparedness and response; and regular refresher trainings (Berhanu 2016).
	Promote interdisciplinary and intersectoral training to address climate change issues	Encourage cross-disciplinary training and cooperation among healthcare workers, environmental experts, and emergency management professionals as this approach fosters a versatile workforce capable of managing complex health emergencies.	A Caribbean study focusing on the development of climate services supported the creation of interdisciplinary and intersectoral 'communities of practice.' (Stewart-Ibarra 2019). The One Health agenda offers opportunity to link animal and human health through workforce (Hanefeld 2018).
Community health (extension) workers	Leverage community health workers' local knowledge and experience	CHW's longstanding work in communities builds trust and enhances resilience.	A study in Haiti reported that CHWs have an altruistic love for their work and long history in the community; they are intrinsically motivated and committed to community health. CHWs' resilience is rooted in their scope of work, value as trusted intermediaries, responsiveness to their communities, self-regulatory capacity, and adaptability (Sripad 2021). A study of Myanmar's resilience noted that culture (collective civic duty) and religion (faith/obligation to help others) were important motivating forces. This study emphasized importance of investing in long term infrastructure, i.e., workforce (Grimm 2021). A study of the Pacific Islands found that vast local knowledge and experience of the health workforce could be an asset to wider disaster management process in helping to understand priority needs of affected communities, as well as adequate training (Rumsey 2014).

	Support specialized health professionals to work in rural areas	Deploy specialized health workers (i.e., midwives) to regions prone to climate impacts to ensure essential services, such as maternal and child healthcare, continue during and after disasters. A sustainable and efficient strategy is to include midwives in formal health structure.	A study in Bangladesh demonstrated the successful deployment of midwives in providing uninterrupted sexual and reproductive health services (e.g., ante/postnatal care, deliveries, family planning, etc.) in rural community health facilities increased the resilience of health systems to climate-induced natural disasters (Purno 2023).
Coordination of workforce	Use health provider databases to enhance communication networks	Maintain up-to-date registries of health providers in hospital facilities	A study in Oman suggested that health provider lists in hospitals should be maintained so they can be reached by a mass alert and implement a well-planned warning dissemination to communities (Al-Shaqsi 2010). A Thai study described use of a staff database containing qualifications in order to track progress and assign the right person to the right job (Rattanakanlaya 2018).
	Create databases of health workers	Coordinate and register overseas health personnel	A concern among small island developing states is making use of volunteer staff by registration and coordination to avoid duplication of scarce resources, provide transparent process, ensure timely assistance, and maximize effectiveness of health personnel during disasters (Rumsey 2014).
Health workers' mental health, psychosocial needs, and safety	Address health workers' mental health needs and provide psychological support for staff	Provide mental health support and ensure the overall welfare of health workers, especially those involved in high-stress roles such as disaster response. This includes measures to prevent burnout and ensure the emotional resilience of the workforce	A study of the four Pacific Island countries noted that the limited capacity to manage psychosocial needs resulted in reliance on church groups and NGOs. However, it was also mentioned that mental health capacity was severely lacking even in normal times (Rumsey 2014). A study of refugees in Bangladesh concluded that a mental health emergency preparedness and response plan can mitigate risks associated with monsoons given that prior experience responding to monsoon-related events provides knowledge and skills to plan for future emergency responses (Elshazly 2022).

			Several studies noted the need for mental health for health personnel were often traumatized so mental health support should be provided during or after is needed for health staff during disasters (Lam 2018, Al-Shaqsi 2010).
	Ensure health workers' safety	Climate change imposes many dangers to society and the health sector, so it is necessary to protect the workforce.	A study in the Philippines of health staff after a typhoon found the following to be important: assuring worker safety and housing; improving communication lines, and recognizing the role of faith and rituals in resilience were all reported as important (Cuesta 2018).

Health Information Systems

Information plays a vital role in responding to health challenges and disasters and driving decision making. Health information systems are, therefore, a key building block of a health system. In WHO's climate resilient health system framework, health information systems are expressed as three components, namely:

- Vulnerability, capacity, and adaptation assessment
- Integrated risk monitoring and early warning
- Health and climate research.

Strategies identified in selected studies discuss the importance of a robust, interlinked, and responsive health information system. Accurate data collection, utilization of information technology, and data sharing are essential for a health information system so that data are properly used to inform decision making and response.

These findings are derived from the following studies: Aung 2013, Barteit 2023, Dovie 2017, Ebi 2017, Hanefeld 2018, Merkord 2017, Phalkey 2012, Sheel 2019, Schnitter 2018, Stewart-Ibarra 2019, and Van Minh 2014.

Table 3 provides a summary of the key strategies and interventions, further description, and illustrative examples derived from the study articles. In brief, the key strategies are as follows:

- Integrate data on climate, health, environment, meteorology, and other relevant sources
- Strengthen routine health information systems to support disaster responses
- Encourage information sharing for research and decision-making
- Develop comprehensive surveillance systems with early warning capabilities
- Utilize real-time data monitoring to enhance climate-health response effectiveness
- Encourage data use culture, solicit feedback and support two-way communication among field units and higher levels
- Provide training for health workers on how to use health information systems for decision making
- Strengthen data analysis capabilities
- Leverage digital technology tools for health monitoring
- Enhance data accessibility with data sharing agreements and protocols

Key takeaways:

- The essence of an effective HIS is having the information and the knowledge to make a decision on what needs to be done.
- Linking diverse data sources such as climate, the environment, and health is essential for forecasting purposes.
- Data is a building block of evidence for making public health decisions but relies on good quality data, ongoing feedback between data users and data collectors, and making use of the data to inform decisions and policies.
- Data visualization and innovative ways to convey information to non-experts is vital to clearly communicate information.

Table 3 Health Information Systems

Health information systems	Key strategies	Description	Illustrative examples
Linkages between climate, health and environmental data	Integrate data on climate, health, meteorology, environment, and other relevant data sources	Establish links between environmental, meteorological and health sectors to ensure health planning incorporates relevant data for preparing health systems for climate-sensitive health outcomes	Changes in climate requires that routine health data collection integrate data from other sectors (i.e., weather) to forecast and plan for disease outbreaks. Given intersectoral challenges, establishing data and knowledge sharing 'platforms' enabling different sectors to share information to inform planning, forecasting, and procurement may be better solution (Hanefeld 2018). Data sources for disaster response include health status, mortality, vector control, demographic data, water supply, food security, nutritional status, community vulnerability and resources (Aung 2013). A Dominican study on a national electronic database including health, vector, water, weather, and climate data accessible to stakeholders established mechanisms for routine flow of information between departments (e.g., environment, pest control, meteorological services, agriculture) and offered data collection processes that avoid duplication (Schnitter 2018).
	Strengthen routine health information systems to support disaster responses	Integrate routine health data with emergency health data systems to ensure seamless flow of information during disasters that supports rapid activation of emergency responses and facilitates monitoring and assessment of health needs in real-time.	A study in Orissa, India discussed how a multi-disease surveillance scheme provides opportunities to integrate emergency health information with routine health information systems (RHIS) as a foundation for prediction/warning (Biswas 2009). A study of health information system processes noted that health staff who maintain RHIS should understand information needs and how to prepare RHIS for disaster response (Aung 2013).
	Encourage information sharing for research and decision-making	Utilizing data in research endeavors underscores the importance of using evidence to drive decisions	A study in Dominica and Barbados stressed need to increase local research capabilities. National health sector interviewees had high level of field experience and local knowledge but little knowledge of local empirical studies that could inform decision-making. Researchers were interested in generating local evidence and conducting case studies (Stewart-Ibarra 2019).

Early warning systems, surveillance, and monitoring	Develop comprehensive surveillance systems with early warning capabilities	Implement robust health surveillance systems including early warning capabilities for epidemic-prone diseases. This involves detection of disease outbreaks and monitoring health trends that could be influenced by climate factors	A Fijian study described development of WHO's early warning response toolkit, 'EWARS in a Box,' an automated smartphone-based, early warning surveillance system for rapid deployment during health emergencies. In 2016, EWARS was used during Cyclone Winston. The toolkit included smartphones with pre-installed, open-source EWARS apps, laptops, mobile and locally hosted server, and solar chargers. This demonstrated value of emergency early warning systems incorporated into surveillance systems that strengthen capabilities (Sheel 2019). A study in Ethiopia described a health information data system linking environmental data with malaria surveillance to address malaria outbreaks. The web-based system provides early indications of epidemics and opportunities for proactive interventions, i.e., resource mobilization of services, timely vector-control measures. Data management platforms strengthen surveillance by automating data processing, enabling data access, implementing outbreak alerts, integrating surveillance data with other sources and generating reports (Merkord 2017).
	Utilize real-time data monitoring to enhance climate-health insights and response effectiveness	Utilize digital technologies to enable real-time monitoring of population health and health effects of climate exposures facilitated by mobile health applications and online dashboards that provide access to health data to policymakers and the general public.	An implementation study of a climate and health surveillance and response system (CHEERS) framework in Burkina Faso describes the value of using dashboards that provide data visualizations to illustrate connections between climate change and health (Barteit, 2023). A study in the PhuVang district of Vietnam reported on the lack of a disease early-warning system (DEWS) using epidemic surveillance which made it challenging to provide timely flood warnings to the public that could enable them to take appropriate action (Van Minh 2014).
	Encourage data use culture, solicit feedback, and support two-way communication among field units and higher levels	Engaging feedback in data collection process enhances accuracy of health data collected.	A core component of timely disaster response is two-way communication flow. Feedback from field units should include complexity of reporting, duplication, reporting, logistical issues, workload and training requirements for the HIS in the disaster setting. A culture of data use and feedback established during RHIS will facilitate disaster response (Aung 2013).

			Co-design workshops and regular follow-up workshops to assess system performance ensure prediction accuracy (Merkord 2017).
Data analysis, management capacity building	Provide training for health workers on how to use health information systems for decision making	Training for health workers and data managers can focus on how to use health information systems for decision-making, how to interpret data related to climate impacts on health and how to use data for planning and response	Effective RHIS includes appropriate training but also should involve uses in the system design, avoid complex reporting, adopt user-friendly processes, link data producers with users, and have timely information flows. Most importantly, disaster response will be most effective if integrated into RHIS, rather than parallel information system established when disasters hit (Aung 2013).
	Strengthen data analysis capabilities	Enhance analytic capabilities of health systems to use collected data for prediction and risk assessment to help in forecasting health impacts due to climate variability and planning interventions	A key finding from the implementation of an Ethiopian computer system (EPIDEMIA) that integrates malaria surveillance with climate data was that a critical first step in disease forecasting efforts is to build on a reliable system that provides timely, harmonized data (Merkord 2017). Several studies mention the value of strengthening analytic capabilities and developing data visualization tools for non-experts to enhance communication (Steward-Ibarra 2019, Aung 2013).
Data access and use	Leverage digital technology tools for health monitoring	Introduce electronic health records and other digital tools to maintain continuity of care when traditional health services are disrupted. When possible, incorporate advanced and innovative technologies.	The Climate and Health Surveillance and Response System (CHEERS) framework, implemented in Burkina Faso incorporates advanced technologies such as wearable devices, indoor temperature and humidity sensors, automated weather stations, remote sensing, and interactive dashboards (Barteit, 2023). The development of a health information system, Epidemic Prognosis Incorporating Disease and Environmental Monitoring for Integrated Assessment (EPIDEMIA) links malaria, disease, surveillance with environmental monitoring to enable near real time malaria forecasts in Ethiopia (Merkord 2017, pg. 13).
	Enhance data accessibility with data sharing agreements and protocols	Enhancing the accessibility of health and climate data to better inform health service delivery during emergencies. This includes establishing communication platforms that can quickly disseminate health information to the public and health workers	Data access is an issue in many countries so interagency agreements (i.e., data sharing protocols) are often necessary. Other challenges include sensitivity of health information and extra costs (Ebi, 2017, Stewart-Ibarra, 2019).

	Nhamo (2019) describes how the Government of Lesotho is considering developing monitoring and surveillance systems that include enhancing knowledge management to improve knowledge sharing and communication networks.

Access to essential medical products and technologies

Medicines and medical supplies are essential for a functional health system. While access to essential medical products and technologies is one of the six pillars of a health system, WHO's Operational Framework describes it as 'Climate resilient and sustainable technologies and infrastructure for building climate resilient health systems.'

The findings reveal that strategies highlight planning, management, and climate appropriate approaches to ensure availability of essential medical products in LMICs facing diverse climatic threats.

The findings are derived from the following studies: Alga 2018, Biswas 2009, Farley 2017, Gilfillan 2018, Hussey 2019, ICCDR'B 2013, Lew 2015, Meyer 2020, Miranda 2013, Phalkey 2021, Ray 2022, Salenga 2015, Saulnier 2022, Schnitter 2018, and Van Minh 2014.

Table 4 provides a summary of the key strategies, further description, and illustrative examples derived from the study articles. In brief, the key strategies are as follows:

- Stockpile essential medicines and maintain basic medical supply kits at facility level
- Share medical equipment among facilities to ensure continuous service delivery
- Establish pre-disaster vendor agreements
- Strengthen forecasting, procurement, distribution and donation systems
- Ensure efficient distribution networks for timely delivery
- Utilize climate resilient storage facilities and infrastructure
- Enhance coordination and monitoring to prevent over and understocking
- Manage donations to comply with protocols and maintain quality standards
- Utilize climate resilient medical products and technology
- Adopt electronic registries and reduce reliance on paper records

Key takeaways:

- Maintaining well-stocked emergency kits at health facilities ensures rapid response capabilities when external aid is delayed.
- Effective forecasting and procurement systems, along with preferred vendor agreements, can prevent stockouts and supply chain disruptions.
- Sharing medical equipment among health units and investing in adaptable technologies like solar-powered LED microscopes ensure continuity of care during crises.
- Implementing electronic inventory systems further streamlines supply management, reducing dependency on paper records and improving overall efficiency.
- Procedures for receiving humanitarian aid should be assessed, as processing large quantities of donated medicines can overwhelm storage facilities and create additional burdens to the health system if they are short-dated, near expiry, or unnecessary.
- Identifying vulnerabilities in the medicines supply chain can improve the quality and utility of the health sector.

Table 4 Access to medical products and technologies

Access to medical products	Key strategies	Description	Illustrative examples
Ensure continuity of medical supplies	Stockpile essential medicines and maintain basic medical supply kits at facility level	Maintain reserves of essential medicines, vaccines, and medical supplies to ensure availability during and after climate-related disasters Maintain updated inventories and ensure that stock levels are sufficient to handle increased demand during emergencies	A study in India noted that while facilities maintained emergency supply stockpiles of essential medicines, many experienced stock outs of 6-10 days during floods due to more patients seeking care. Basic medical supply kits should be available at facilities to support quick responses given that emergency assistance often requires 1-4 days (Phalkey 2012). A Sri Lankan study found that 61% of health facilities did not have adequate medical equipment and supplies for service delivery during emergencies including oxygen cylinders, electrocardiogram monitors, and other instruments, and basic items as fridges, beds, and trolleys (Farley 2017).
	Share medical equipment among facilities to ensure continuous service delivery	Share medical equipment among facilities to maintain continuous service delivery, as evidenced by prioritizing coordination in health system resilience checklists and rotating equipment in response to emergencies.	The study focused on developing a health system resilience checklist considered 'plans to coordinate with other facilities' (i.e., to share supplies, etc.) as a top priority (Meyer 2020). A study in the Philippines described how microscopes and medical technologies were rotated among health units to restore TB (DOTS) programming after a typhoon (Lew 2015). Findings from a Sri Lankan study noted that several facilities shared equipment and supplies with other nearby facilities during emergency and non-emergency periods (Farley, 2017).
Enhance procurement and supply chain system	Establish pre-disaster vendor agreements	Develop agreements with suppliers to ensure provision of medical products during emergencies	A study in India noted that alternate mechanisms such as preferred 'vendor agreements' is an effective strategy to avoid stock outs and delays from district headquarters (Phalkey 2012).
	Strengthen forecasting, procurement, distribution and donation systems	Consider impact of disasters on forecasting, procurement, distribution, and donation systems	A study in the Philippines discussed the need for forecasting and procurement systems and procedures for receiving humanitarian aid (Miranda 2013).

Strengthen supply chain management	Ensure efficient distribution networks for timely delivery	Enhancing distribution networks for medical products to ensure they can handle logistical challenges from climate impacts. This involves optimizing routes, using technology for tracking supplies, and ensuring distribution centers are located near vulnerable areas.	A study in Bangladesh assessed infrastructure, emergency supplies and procurement capacity for managing health crises in flood prone districts of Bangladesh (Iccdr,b, 2013). A study in the Philippines reported that a disjointed recording systems for monitoring medicines distribution hampered access to information on stock levels (Salenga 2015).
	Utilize climate resilient storage facilities and infrastructure	Develop storage facilities resistant to climate impacts (i.e., temperature control, backup power) to ensure medical products are stored properly (i.e., temperature sensitive vaccines).	An evaluation of pharmaceutical services preparedness in Brazil noted the importance of good storage practices (GSP) and infrastructure and supporting guidelines on GSP (Miranda 2013).
	Enhance coordination and monitoring to prevent over and understocking	Enhance mechanisms for quality assurance (e.g., regular inspections and monitoring of supply chains)	A study in the Philippines reported challenges with coordination and monitoring that led to over- and understocking medicines. Large volumes of donated medicines often result in storage that was overwhelmed with near expiry dates and unnecessary items (Salenga 2015).
	Manage donations to comply with protocols and maintain quality standards	Inspect and manage supply of medical products, especially during emergencies when risk of substandard or counterfeit products increases.	A study in the Philippines found that national policies for accepting donations were often not followed resulting in the acceptance of large quantities of expired and unnecessary medicines that took up valuable space in warehouses and created a disposal burden (Salenga 2015). An evaluation of pharmaceutical services suggested having a system in place that ensures drug donations are in compliance with donation protocols and medicine regulations and ensures a system of inspecting donations for quality (Miranda 2013).
Innovation and technology utilization	Utilize climate resilient medical products	Encourage development and use of medical products designed to be effective under varying climatic conditions	A study in the Philippines discusses the distribution of LED microscopes that are able to operate on either electric or solar power (Lew 2015).
	Adopt electronic registries and reduce reliance on paper records	Electronic data is much more accessible than paper-based records during emergencies.	The importance of digital records and registries was mentioned by several studies given the difficulties in relying on paper-based records during emergencies (Schnitter 2018, Lew 2015).

Financing

Financing is one of the six pillars of a health system according to WHO, and the last (10th) framework component described as 'Sustainable climate and health financing" in the updated WHO Operational Framework. The component advises that strategies related to financing should have a comprehensive approach to financing within the framework of building climate resilient health systems. Financial resources should not only be available but be strategically distributed to improve health system capabilities in the face of climate challenges.

WHO's Operational Framework underpins the need to mobilize and utilize financial resources to adequately respond to climate threats, assessments of resource requirements, available finance, as well as finance gaps and opportunities to fill them. Indeed, resource requirements can be assessed through budget estimations of selected interventions as identified in the vulnerability assessments or health national adaptation plans and identifying shortfalls in existing budgets and funding sources that need to be addressed through mobilization of new financial resources.

Results are based on findings from Alga 2018, Amis 2014, Banwell 2021, Bowen 2013, Ebi 2017, Hanefeld 2018, Hussey 2019, Krutphong 2022, Naess 2014, Opoku 2019, Phalkey 2012, Saulnier 2022, Schnitter 2018, Van Minh 2014.

Very few articles provide an actual example of having used a finance or budget strategy, nor refer to having used the WHO's Operational Framework in terms financing in a specific setting. However, several papers have emphasized needs related to budgeting and finance. We have therefore chosen to refer to strategies suggested from examples, studies and/or experiences described in the papers.

Table 5 provides a summary of the suggested key strategies, further description, and illustrative examples derived from the study articles. In brief, the key strategies from findings are related to:

- Establishing emergency funds
- Ensuring funds to climate change adaptation interventions in health
- Funding to be catalyst (driver) for supporting climate change adaptation activities
- International aid and securing grants from global health organizations and climate funds
- Co-financing including public-private partnerships
- Financing flows under international organizations
- Multi-lateral and bi-lateral climate change funds
- Own-country financing
- Local health adaptation financing
- Private financing
- Alignment of donor organization funding with national priorities
- Pooled funding
- Climate-inclusive health budgeting
- Sustainability of funding for health adaptation
- Contingency funds for emergency response
- Ensuring fair allocation of funding during crises
- Crop and livestock insurance

Key takeaway:

There is a critical need to integrate climate resilience into national health budgets and financing.

Table 5 Financing

Financing	Key strategies	Description	Examples of strategy suggestions
Financing mobilization for emergency preparedness	Establish emergency funds	Dedicated emergency funds must be quickly mobilized to address immediate needs during a climate-induced health crisis, e.g., funds for response and recovery phases, ensuring that financial resources are available to tackle urgent health system demands	A study describes the experience from India during flood 2018 pinpointing that the suboptimal functioning of the financial structures hampered necessary surge capacity and mounting resources (Phalkey 2012)
	Ensure funds to climate change adaptation interventions in health	Include costs when implementing resilience for climate change health risk to managing the health impact of climate change	Naess et al. states that "Even though the Least Developed Countries Fund (LDCF) has approved the largest volume of adaptation finance for Africa, only a small share of these (4%) have gone to health" (Naess 2014) A health system assessment including interviews of health personnel in Ghana and a report from 14 Southern Africa countries suggest increasing funding to climate programs in the health sector (Hussey 2019, Amis 2014)
	Funding to be catalyst (driver) for supporting climate change adaptation activities	Explore the implication of the donor-driven environment particularly in relation to how this influences project designs, and importantly whether national priorities are maintained despite external funding	A study from Cambodia suggests this strategy and examines to what degree there exists enabling factors to support the development of adaptation policy and activities with relevance to the health sector (Bowen 2013)
Diversifying funding sources	International aid and grants Co-financing including public-private partnerships (PPP)	Leverage international aid and securing grants from global health organizations and climate funds Encourage partnerships between the public sector and private enterprises to fund health initiatives and climate resilience - PPPs can provide alternative funding sources and leverage private sector expertise and resources	Strategy based on study from Myanmar on MoH's coordinating role to improve climate change responses and disaster risk reduction (Gilfillan 2019)
	Financing flows under international organizations	Organize funding schemes though international organizations LMIC can be prioritized for adaptation financing	Approach based on example of the United Nations Framework Convention on Climate Change (UNFCC) provided in the review on climate change adaptation in health in Southern Africa (Amis 2014)
	Multi-lateral and bilateral climate change funds	Need for collaboration between Climate Investment Funds, Multilateral Development Banks, and Countries	From the example of Common Market for Eastern and Southern Africa (COMESA), Southern African Development Community (SADC), and East African Community (EAC) collaboration in tripartite partnership between Norway, EU, and UK (Amis 2014)

	Own-country financing		Suggested among one of the sources for climate finance flows in the Southern African region however challenging due to already stretched resources and inability to raise public funding and need to focus on immediate developmental challenges (Amis 2014)
	Local health adaptation financing	Mobilize community leaders	From an example of a local leader in the Philippines being supportive (more aware) of needs in terms of financing (Banwell 2021)
	Private financing	Hold massive potential for delivering resources for climate change and mitigation, however the private sector is still small in many countries	Example of GEF (Global Environment Facility) suggested in the study reviewing research and policies for climate change adaptation in the health sector in Southern Africa (Amis 2014)
	Alignment of donor organization funding with national priorities	Donor organizations must adjust their funding of programs with national priorities present in the country policies	Strategy drawn from experience from Cambodia on enabling factors to support the development of adaptation policy and activities with relevance to the health sector (Bowen 2013)
	Pooled funding	Achieved through various multilateral and bilateral mechanisms	Pooled funding is available through various multilateral (e.g., United Nations agencies, European Civil Protection and Humanitarian Aid Operations) and bilateral (e.g., Disasters Emergency Committee and START Network (UK), Office of US Foreign Disaster Assistance, Qatar Government (Hanefeld 2018)
Budget allocation and financial planning	Climate-inclusive health budgeting	Integrate climate resilience considerations into national health budgeting processes. This involves allocating a portion of the health budget specifically for climate change adaptation measures, ensuring ongoing financial support for these critical activities	Strategy based on study from Myanmar on MoH's coordinating role to improve climate change responses and disaster risk reduction (Gilfillan 2019)
	Sustainability of funding for health adaptation (long-term financial planning for health resilience)	Develop long-term financial plans that incorporate projections of climate impact on health systems. These plans should include strategies for scaling up investment in infrastructure, workforce, and emergency preparedness over time	Strategy derived from the case study on implementation of national health adaptation in the Philippines including policy principles and implementation barriers (Banwell 2021)
	Contingency funds for emergency response	Develop contingency budgets and funding mechanisms (stocks for emergency response) that are activated during emergencies. These funds are pre-arranged along with local vendor agreements to ensure stock supplies and can be accessed rapidly to ensure that financial delays do not impede response efforts	According to a study from a flood in India in 2008, funding requirements for covering the response should be calculated based on past experiences, and each facility should be granted contingency funds in their annual budget for use during an emergency (Phalkey 2012)

			An example from a flood in Vietnam reports that "the budget for prevention and control of the crisis was limited and had no specific items for healthcare activities. Only a little additional funding was available, but the procedures to get this funding were usually time-consuming and emergency activities was limited" (Van Minh 2014)
	Ensure fair allocation of funding during crises	Consider the whole community/region(s), as these, although not 'directly' affected are often victims, too	The example from the India flood in 2008 reports that: "Due to limited resources to begin with, the flood non-exposed community felt neglected as the flood focus was the flood exposed communities" (Phalkey 2012)
Insurance mechanisms	Crop and livestock insurance	Scale up crop and livestock insurance	A study based on experiences across LMICs, where key LMIC informants suggest of various areas to scale up as adaptation measure among a proposed list of important areas, this being the only one actually dealing with financing strategies (Ebi 2017)

Leadership and governance

Leadership and governance (including policy) is not only one of WHO's six pillars of health system but the very first component of WHO's 10 components for a climate resilient health system.

Strategies for strengthening leadership, policy and governance within health systems are essential for building resilience against the impacts of climate change. They focus on developing adaptive governance structures and policies, enhancing leadership capacity and command, and ensuring that health is integrated in climate change processes, policies, and programs that are adaptable and effectively implemented.

The findings are derived from the following studies: Alhassan 2017, Amis 2014, Banwell 2021, Bowen 2013, Ebi 2017, Farley, 2017, Gilfillan 2018, Gilfillan 2019, Hanefeld 2018, Meyer 2020, Morrow 2014, Nhamo 2019, Phalkey 2012, Rawat 2022, Rumsey 2014, Saulnier 2022, Schnitter 2018, Van Minh 2014.

Most included studies highlighted a number of facets related to this pillar, and more importantly, pinpointed its key role, i.e., that robust governance and leadership is pivotal in building climate resilient health systems. We have described the various strategies as suggested from articles reporting assessments and/or experiences from various settings.

Table 6 provides a summary of the suggested key strategies, further description, and illustrative examples derived from the study articles. In brief, the key strategies from findings are related to:

- Institutionalizing arrangements for adaptation to climate change
- Mainstreaming climate change adaptation
- Enhancing cross-sectoral (multi-sectorial) coordination and collaboration
- Multi-layered (vertical) governance at all levels
- Scaling up
- Promoting cross-country/regional collaboration
- Reducing vulnerabilities
- Taking advantage of existing national, regional, and local facilities and resources
- Managing to absorb external funding
- Well-established communication and command systems
- Dynamic and adaptive governance
- Crisis management and response strategies
- Decentralized decision making
- Awareness among leaders for the need of adaptation to climate change
- Training and capacity development of health leaders on climate change
- Creating platforms for leader collaboration
- Developing comprehensive and contextualized climate health policies
- Ensuring that policies are evidence-based
- Implementing effective policy enforcement mechanisms
- Engaging stakeholders in policymaking at all levels

Key takeaway:

Effective emergency response is achieved through:

- Embedding climate change adaptation at all policy and governance levels,
- Cross-sectoral collaboration and,
- Stakeholder accountability by engaging the affected local communities.

Table 6 Leadership and Governance

Leadership and governance	Key strategies	Description	Examples of strategy suggestions
Robust governance embedding climate change adaptation	Institutionalizing arrangements for adaptation to climate change	Integrate climate change when developing policies and frameworks into the governance structures of health systems is key. This involves creating specific roles, clear mandates, and departments focused on climate health issues, ensuring that adapting to climate chance is a central aspect of health system planning and governance	A study on the policy context for climate change and health adaptation decision-making in Cambodia where the National Climate Change Committee (NCCC) was established suggest this strategy, and to "Have staff exclusively dedicated to climate issues" (Bowen 2013)
	Mainstreaming climate change adaptation - by integrating climate change into all relevant health policies and programs	Mainstreaming climate change adaptation is the process through which the risks of climate change are inherently built into the objectives of development projects Mainstreaming enables adaptation as it avoids the development of parallel structures, ensures the consideration of climate change alongside other drivers of health risks, and assists to overcome funding barriers. Effective mainstreaming ensures that climate risks are incorporated into projects and policies in a way that will support long-term sustainable development	A case study from the Philippines underlines the importance of mainstreaming (Banwell 2021) A study on mainstreaming climate change adaptation in Ghana suggests integrating climate change adaptation into water, sanitation and hygiene (WaSH) policies is through the process of mainstreaming." (Alhassan 2017)
	Enhancing cross-sectoral (multi-sectorial) coordination and collaboration, i.e., across administrative regions and facilities	Facilitating effective coordination between health departments (e.g., MoH), and other sectors such as environment, transport & infrastructure, agriculture & forestry & land ownership, energy & water & sanitation, food security & nutrition, maritime & fisheries & coastal, industry (production and waste), education, trade & finance	In Myanmar it is suggested that MoH takes lead in cross-sectorial and cross scale coordination given that various sectors usually have different agendas, timelines, etc. This ensures unified approach to addressing the health impacts of climate change, leveraging resources/expertise across governmental sectors and platforms (Gilfillan 2019)
	Multi-layered (vertical) governance at all levels	Ensure vertical coordination between the administrative governance levels (MoH, Executive Organs/Institutions, etc.) and between National, State/Regional/Province, and Local levels of health care delivery in terms of decision-making	This strategy is suggested in several articles arguing that vertical coordination ensures coherence between high-level decision-making processes "down to" monitoring and evaluation activities at local levels, as well as experience sharing (Gilfillan 2019, Banwell 2021, Opoku 2021)
	Scaling up	Scale up by expanding coverage of policies and programs to manage climate-sensitive health outcomes, interventions, activities, and tools based on contextual needs as way of	A study based on experiences and lessons learned on health adaptation to climate change, long with another

		adapting. The idea is to increase interventions that have proven effect in previous crises, prioritize interventions that jointly tackle adaptation and mitigation, increase training at appropriate levels	study from on the role of the health sector in the governance of climate change adaption in Myanmar suggest this strategy (Ebi 2017, Gilfillan 2018)
	Promoting cross-country/regional collaboration	Create regional health sector policies and strategies by defining common scopes and contents. This ensures coherent and aligned and collaborative responses in countries in the same region facing the same challenges	A study based on the experience from Malawi, Zimbabwe and South Africa under flooding emphasizes the need for regional governance and policy frameworks (Amis 2014)
	Reducing vulnerabilities	Reduce vulnerability to health impacts of climate change by taking into account when developing policies cultural diversity, geography, demographics and focus on communities and poverty, and how to avoid brain-drain from political unstable places	Two studies suggest this strategy based on experiences from Myanmar and Fiji focusing on the need for policies being in place even under unstable regimes where also food supply may be hampered by embargos. (Morrow 2014, Gilfillan 2019)
	Taking advantage of existing national, regional, and local facilities and resources	Build on pre-existing strengths to enhance the readiness of health system actors to respond to crises, while also maintaining core functions which in turn could help aligning with national plans	Two studies suggest utilizing existing lines of governance as strategy (Bowen 2013, Morrow 2014), and a third study describes an example of existing sub-rural health centers in Myanmar that have established mutual "goodwill" over time between villagers and midwifes (Gilfillan 2019)
	Managing to absorb external funding	Absorption capacity refers to countries' ability to efficiently and effectively spend the financial resources which have been allocated to them.	A study in the context of a policy analysis from Cambodia, examining to what extent there are enabling factors to support the development of adaptation policies and activities relevant to the health sector, suggests this governance strategy (Bowen 2013)
	Well-established communication and command systems	Have pre-determined communication plans and clear lines of command	A study based on the experience of the 2008 flood in India suggests the need for standard operational procedures and pre-determined communication and clear command structures as there was "no understanding on what is happening on the ground and vice-versa: absence of proper feedback to authorities regarding ground realities" (…) and "some facilities did not even have a phone number to whom to contact when there was a crisis" (Phalkey 2012)
Governance adaptability and responsiveness	Dynamic and adaptive governance	Implementing adaptive governance and management frameworks can swiftly respond with suited countermeasures to respond to emerging health crises linked to climate change, which this includes having flexible policies and procedures that can be modified as circumstances change	All included publications on "Leadership and governance" call for the need for integrating adaptive actions towards climate change and highlight the issue of an adaptive governance. One study concludes that "Decision making that is iterative and reflexive when facing uncertainty and

			change ensures continued appropriateness and robustness of health adaptation" (Banwell 2021)
	Crisis management and response strategies	Developing and regularly updating crisis management and emergency response strategies that are specifically designed to handle the health impacts of climate events, thereby ensuring preparedness and a coordinated response during health emergencies	All included publications on "Leadership and governance" underline the need for crisis management and response strategies
	Decentralized decision making	Decentralizing decision making that can swiftly respond with suited countermeasures (on the ground) to meet emerging health crises linked to climate change. This includes having flexible policies and procedures that can be modified as circumstances change	A study from India suggests the strategy referring to rapid and adequate response and actions avoiding clearances from "headquarters" or "higher levels" to avoid delays (Phalkey 2012), and a case study from Ethiopia on the response to the drought 2015-2016 suggests a decentralized decision-making along with implementing adaptive governance and management frameworks and models (Rawat 2022)
Political "will", leadership engagement and capacity building	Awareness among leaders for the need of adaptation to climate change	Create awareness and recognition of the importance of health risks and therefore the need for health adaptation to climate change within policies and processes at national and health sector level	A study from the Philippines supports the advocacy for, and prioritization of health adaptation, capacity building, stakeholder engagement, and health adaptation implementation (Banwell 2021)
	Training and capacity development of health leaders on climate change	Provide targeted training and development programs for health leaders that cover climate change impacts on health, leadership during emergencies, and strategic planning for climate resilience Training and capacity development promotes engagement among policy makers and leaders, and prepare them to effectively manage their organizations/teams when facing climate-related challenges	A policy analysis on decision-making in Cambodia and a case study from the Philippines highlights this strategy (Banwell 2021, Bowen 2013)
	Creating platforms for leader collaboration	Organize workshops (not only including governmental leaders, but health care providers, public health institutes, academia, and donors) where health leaders share experiences, challenges, solutions and best practices related to climate resilience. Forums and networks are also opportunities to promote mutual learning and lay groundwork for innovative solutions	The study from the Philippines suggests the strategy of taking advantage of meetings and discussion fora such as the National Committee for Climate Change (NCCC) as springboard (Bowen 2013)

Policy development / formulation, implementation and adaptation	Developing comprehensive and contextualized climate health policies	Integrate climate change into all relevant health policies and programs, and elaborate these to such detail that they address well enough the specific and contextual challenges posed by climate change to health systems; policies should guide adaptation and mitigation efforts and be based on existing and/or planned infrastructure, and they must be based on knowledge of the effect of climate change adaptation on infrastructures	A study from South Africa identifies this strategy as a key lacking policy strategy (Amis 2014), a second study from the Philippines underscores the need to identify barriers when implementing national health adaptation to climate change policies (Banwell 2021), while a third study suggests that Fiji should include projected health impacts (e.g., dengue, diarrhea, malnutrition) when reviewing their national climate change adaptation strategy and policy their Public Health Act (Morrow 2014)
	Ensuring that policies are evidence-based	Systematically evaluate and integrate robust evidence related to risk, vulnerabilities, and adaptation interventions into decision-making, and use this evidence for developing policies. Strong evidence base is needed to find out if health adaptation strategies are suited (time, scale, coverage) and to support adaptive management	A study from the Philippines underscores the need for evidence-based policy-making when developing climate change adaptation policies (Banwell 2021)
	Implementing effective policy enforcement mechanisms	Ensure vertical coordination and have robust mechanisms in place to monitor and enforce policy implementation	Three studies points at this strategy suggesting regular audits, performance evaluations, and accountability systems to guarantee that policies are accurately and effectively and sustainably translated into practice (Gilfillan 2019, Banwell 2021, Opoku 2021)
Stakeholder engagement	Engaging stakeholders in policymaking at all levels	Involve a broad range of stakeholders such as community leaders, healthcare providers, and private sector representatives, as well as partners/donors in the policy-making process ensures transparency, acceptability and legitimacy. Stakeholder involvement helps ensure inclusive decision-making and that policies are well-rounded and have buy-in from all sectors affected by climate issues	All articles dealing with leadership and governance suggest this strategy

Chapter 2: Opportunities & challenges

This section addresses the second question. The revised version of the question is as follows:

What are the challenges and opportunities for the implementation of strategies for climate resilient health systems?

All included studies have reported several challenges that health systems face in order to respond to the health burden posed by climate change. We have focused our summary on two major challenges: the lack of climate financing and lack of preparedness of health systems. We consider those the underlying challenges for the efficient implementation of strategies for building climate resilient health systems. Other challenges can be seen as linked or caused by the lack of climate financing and health system preparedness.

Challenges for building climate resilient health systems

Health system financing

Key strategies for sustainable health and climate financing are presented in the section "Chapter 1: Key strategies: Financing". It is reported there that the included articles do not adequately articulate challenges nor suggest solutions or refer to having used the WHO's Operational Framework regarding climate and health financing. Hence, this is a major challenge and largely unaddressed. Lack of financial resources is a major barrier to global and national implementations and scaling up of adaptation interventions (Ebi 2017, Banwell 2021, Bowen 2013). In the current section, we do not want to repeat these gaps in implementing specific strategies for overcoming this barrier, rather focus on the interconnections between the challenge of climate financing with other challenges. Overall, the lack of funding, budgets, and financial resources and financing mechanisms are critical barriers to implementing adaptation strategies and strengthening health systems to respond to climate change. This challenge manifests in several ways:

Inadequate resource allocation: Health systems often struggle with insufficient financial resources to effectively prepare and respond to climate-related health challenges. This can have a direct impact, as limited financial resources directly affect the ability to implement necessary health interventions and preparedness measures (i.e., vector control programs, access to safe water and sanitation, and food safety programs). Indirectly, inadequate funding also leads to insufficient training and capacity building for health professionals, which is crucial for effective climate change response. There are often not enough resources to train, retain, and adequately compensate health workers, which limits their ability to respond effectively to climate-related health emergencies. Workforce shortages and high workload without corresponding financial incentives can lead to burnout and reduced effectiveness in emergency response situations. Similarly, inadequate funding will impact the necessary stockpile of medical supplies.

In Ethiopia, Abaya (2011) describes how the health sector is ill-prepared to handle the increasing prevalence and geographical expansion of diseases due to climate change. The local administrative level, or woreda, faces severe funding and human resource shortages, resulting in inadequate coverage of disease prevention activities such as malaria control programs, safe water supply, sanitation facilities, and food safety and quality control. The challenge of resource constraints is further illustrated in Fiji, where Morrow (2014) describes a brain drain of health experts and professionals to high-income countries, exacerbating the resource limitations within the local health sector. In India, Purnamita (2016) emphasizes the limited availability of human and financial resources as a significant hindrance to effective climate adaptation efforts. In Madagascar, Rakotoarison (2018) highlights the lack of readily available resources to adequately

prepare for, respond to, and recover from the damages of climate-related events in the health sector.

Barrier to infrastructure and technology improvements: The lack of sustainable financing affects the ability to invest in surveillance systems, early warning mechanisms, and the necessary technological upgrades for health facilities. Poor health infrastructure exacerbates the effects of climate-related disasters, making it difficult to maintain continuity of care during extreme weather events. Commitment from governments and donors is crucial for addressing these resource constraints. Aung (2013) underscores the importance of such commitment for strengthening routine health information systems, enabling more effective responses to future climate-related disasters.

Inadequate absorption of emergency funds: the lack of necessary infrastructure and planning to quickly absorb and utilize emergency funds results from inadequate predefined protocols and streamlined processes for the rapid allocation and disbursement of funds during emergencies, including external donor funds. Without effective preparedness plans, funds that become available in the wake of an emergency are not used efficiently, leading to delays in response and inadequate service provision.

In Vietnam, Alga (2018) reports that primary health facilities in flood-prone areas lack separate funds for flood preparedness. Even those facilities that had separate funding found it insufficient. This problem is also observed in India, as highlighted by Biswas (2009), where the lack of separate budgets for disaster relief led to inadequate responses at the facility level. Gilfillan (2019) reports similar barriers in Myanmar, noting insufficient resources, including human resources and training, as significant obstacles to effective disaster response. In Pacific Island Countries, Rumsey (2014) identifies healthcare capacity challenges due to limited resource capacity, resulting in dependence on donors. Despite significant funding available for climate change and disaster risk reduction programs, very little is directed towards climate change-related health programs and workforce capacity development for disaster response.

Link to governance and coordination issues: The lack of funding is intricately intertwined with governance and coordination challenges, which manifest in several ways. Poor financial management and inadequate funding mechanisms can lead to fragmented health responses and lack of coordination among different sectors involved in disaster response and health adaptation. For example, in Ghana, external donor funds present an opportunity for strengthening context-based strategies, such as the WASH program, but there is often a lack of coordination and common planning between the implementation bodies dependent on local funds and those dependent on external aid (Alhasan 2017). The fragmented response was reported in the health crisis created by Cyclone Idai in Zimbabwe, where the government response was hindered by fragmented disaster planning, inadequate resource mobilization, inexperienced personnel on the ground and dependence on donor funding (Ray 2022). Similarly, in Southeast Asia, the lack of coordination between regional organizations like the Asian Development Bank (ADB) and the Asia-Pacific Regional Forum (APRF) can lead to a waste of resources and duplication of efforts, while limited funds hinder collaborative efforts (Gilfilian 2018). In Fiji, the "Health in All Policies" approach describes a broad cross-sectoral integration of health within public policy, aiming to improve population health by reforming public policymaking across all sectors, including water and agriculture. Coordinated funding and implementation of such cross-sectoral policies can contribute to better resource absorption (Morrow 2014). Additionally, differing priorities between governments and international donors can hinder effective response to crises, as seen in the drought

response in Ethiopia, where the government's failure to declare an emergency impeded the donors' abilities to respond effectively (Rawat 2022).

By addressing these coordination and governance issues through improved financial management and strategic planning, health systems can better utilize available funds and enhance their resilience to climate-related health threats.

Lack of funding for research: Adequate funding for research is essential for understanding local conditions, cultural contexts, and community needs, which are crucial for designing effective climate adaptation strategies. Without it, significant knowledge gaps persist, hindering the development of targeted interventions and making it difficult for policymakers to make informed decisions. For instance, in Southern Africa, Amis (2014) highlights how the lack of funding for local research impedes the incorporation of climate adaptation measures into policies, as most analyses rely on unsuitable global or regional datasets.

Investing in localized research is crucial for developing effective adaptation strategies and enhancing health system resilience to climate change.

Health system preparedness

Studies assessing the preparedness of health systems at a regional level across multiple African and Pacific Island countries identified severe deficits in all aspects of preparedness, highlighting insufficient healthcare professionals and inadequate training on climate change which hinder the implementation of essential adaptation measures, such as improving water sanitation and hygiene systems and scaling up vector control (Opoku 2021, McIver 2016). These findings underscore a broader systemic issue where low-resource contexts, which are highly susceptible to frequent climate-related disasters, face significant challenges in building resilient health systems. The challenge of health system preparedness in adapting to the burden of climate change is multifaceted, and can be manifested in the following ways:

Limitations in training and capacity building: lack of comprehensive training programs for health professionals on climate change impacts disaster preparedness. This insufficiency results in ineffective disaster response and health system resilience. For example, the health workforce capacity was limited by ineffective disaster training preparations in the Philippines after Typhoon Haiyan (Labarda 2017).

Weak coordination and governance: Weak governance and coordination among various stakeholders, including government agencies and NGOs, pose significant barriers to effective disaster response. In Myanmar, Gilfillan (2019) reported insufficient coordination as a significant barrier, while in Fiji, Morrow (2014) highlighted the need for integrated approaches due to fragmented responses to climate-related health issues. Alhasan (2017) in Ghana noted that external donor funds present opportunities for context-based strategies, but poor coordination and planning between local and external bodies hinder effective implementation. Similarly, in Southeast Asia, Gilfillan (2019) noted that lack of coordination between regional organizations led to resource wastage and duplication of efforts. In Zimbabwe, Ray (2022) examined how the health sector's lack of involvement in decision-making and planning regarding climate change impacts limits effective disaster management and public health protection. In Philippines, Salenga (2015) reported that uncoordinated acceptance of donations results in flux of expired or unnecessary medicines during the post-disaster response of typhoon Haiyan.

Ineffective preparedness plans and resource constraints: health systems lack effective preparedness plans, including clear operating procedures and protocols for disaster response. For example, in South Africa, Naidoo (2022) found that existing disaster plans underestimated the resources needed to deliver essential health services during extreme weather conditions. Hanefeld (2018) described the same issue as "failure to predict", as a common barrier to climate resilience. Similarly, in India, Varughese (2021) addressed flood prevention preparedness and highlighted weak disaster management systems and inadequate disaster preparedness for extreme magnitude floods. Nevertheless, even though national policies might be in place this does not always translate well at local level, as reported in Philippines, by Salenga (2015) where in the post-disaster phase, medicines reached regional facilities and the distribution was considered complete by the ministry but there was a failure to recognize that most regional facilities did not have mechanisms in place to distribute stocks to target recipients.

Health systems often face deficits in human resources, poor access to basic health services, and low availability of health facilities, particularly in rural areas. In Ethiopia, Rawat (2022) highlighted that adaptable human resources can be a strategy for responding to increase burden, cannot be implemented due to suboptimal numbers of health workers, insufficient supplies, and questionable financing sustainability. In India, Phalkey (2012), assessed the preparedness of health facilities in the aftermath of floods, and reported that the health workforce and service capacity was already insufficient, and none of the facilities were able to scale up the number of available patient beds as required during the flood period. Similarly, in Madagascar, Rakotoarison (2018) described the lack of readily available resources to prepare for and respond to climate-related damages. In Bangladesh, Purno (2023) and ICDDRB (2013), reported that the basic emergency perinatal and newborn care, as well as other UHC structures were poorly equipped and not available even before flooding. In Ethiopia, Rawat (2022) describes that health extension workers can play a very important role for community engagement and mobilization, coordination of international partners and donors in responding effectively to health emergencies due to droughts but they are stopped by the challenges of increased workloads, low resources and supplies.

Fragmented response and data weaknesses: in India, Purnamita (2016) emphasized the fragmented response to climate-related health issues and weaknesses in surveillance systems and data availability, hindering effective planning and response. Again, in India, Phalkey (2012), reported that none of the facilities followed the expected data reporting standards during the flood period.

Opportunities for building climate resilient health systems.

Multi-sectoral collaboration and integrated policies

Multi-sectoral collaboration and integrated policies present significant opportunities for building climate resilient health systems, particularly in resource-constrained contexts. Ebi (2017) highlighted that more effective projects focus on the policies and measures needed to facilitate a country's vision of adaptation to climate change, with institutionalizing the management of health risks of climate variability being a cornerstone for resilient health systems.

In Ethiopia, establishing stronger links between meteorological departments and health sectors has been emphasized to ensure that health planning incorporates relevant climate and weather data, as noted by Abaya (2011). Tadesse (2014) described Ethiopia's comprehensive disaster risk management system, particularly for drought, as an exemplary model where all line ministries, including the Ministry of Health, are involved from the federal to the district level. This

multi-sectoral approach is crucial for effective disaster management and long-term resilience. For instance, the integration of emergency programs such as malnutrition guidelines at all levels of health facilities and the community level ensures a coordinated response in drought-prone areas.

Similarly, in Ghana, Alhasan (2017) demonstrated the effectiveness of mainstreaming climate adaptation strategies into WASH programs through cross-sectoral incorporation. This approach included developing and strengthening institutional structures to handle climate change issues, promoting cross-sectoral collaboration, and aligning municipal plans with national budgets. This integration ensures a cohesive response to climate challenges, enhancing the overall resilience of the health system.

Fiji's adoption of a 'Health in All Policies' (HiAP) approach, as assessed by Morrow (2014), illustrates how health considerations can be incorporated into climate adaptation strategies across various sectors such as water and agriculture. This broad cross-sectoral view of health within public policy aims to improve population health by embedding health considerations in all sectoral policies, ensuring a comprehensive and integrated approach to climate resilience. Similarly, in the Philippines, Banwell (2021) highlighted the importance of congruent national climate change and health adaptation policies, emphasizing the need for mainstreaming and integrating climate change into all relevant health policies and programs. A multi-sectoral approach, coupled with vertical integration across scales of government (national, subnational, and local), ensures a coordinated and effective response to climate-related health challenges.

The WHO regional climate change and health vulnerability and adaptation planning project in 13 Pacific Island countries, as reported by McIver (2016), underscores the necessity of incorporating health and safety considerations into adaptation activities across sectors. This initiative highlights the development of new communication pathways between the health sector, meteorology services, and other stakeholders, including trialing and evaluating climate-based early warning systems.

Moreover, Gilfillan (2019) in Myanmar emphasized the importance of health sector governance for better climate change response, noting the Myanmar Action Plan on Disaster Risk Reduction (MAPDRR) which recognizes the significance of cross-sectoral coordination. Proactive planning, as opposed to reactive responses, is crucial for long-term resilience, with sectoral working groups and high-quality health personnel playing vital roles in the National Adaptation Programme of Action (NAPA).

Hanefeld (2018) discussed the need for workable models of inter-sectoral coordination, drawing on experiences from disaster-response approaches like the UNOCHA Cluster system. These models should facilitate continuous systems responses where the health sector can map and act on critical multi-sector links to share forecasting information and coordinate responses effectively.

Finally, building strategic partnerships with NGOs, the private sector, and international organizations, as highlighted by Htay (2006), can mobilize additional resources, expertise, and support for health system strengthening and climate adaptation initiatives. These collaborations are essential for creating resilient health systems capable of addressing the multifaceted challenges posed by climate change.

In summary, multi-sectoral collaboration and integrated policies are pivotal for building climate resilient health systems. By institutionalizing health risk management, improving inter-sectoral

coordination, and integrating climate considerations into all relevant policies, health systems can better prepare for and respond to the impacts of climate change.

Importance of local communities

Local communities play an essential role in supporting climate resilience of health systems through engagement, support, and awareness initiatives, especially in community-based health systems. Although not formally part of the health system, their involvement enhances adaptive capacities, promotes health education, and fosters community-led initiatives.

In Zimbabwe, primary health care teams, trusted by their communities, effectively raised public awareness about climate change. These teams can mediate between government agencies, international organizations, and local populations, using indigenous knowledge to develop protection plans and educate communities about the health impacts of deforestation, air pollution, and the use of alternative cooking fuels (Ray 2022).

In Ghana, training sessions for Municipal Assembly staff, NGOs, and community elders on climate change adaptation was effective in raising awareness and building local capacity to address climate-related health impacts (Alhasan 2017).

In Ethiopia, strong community groups, well-organized and engaged with health facilities, supported surveillance, information exchange, and mobilization efforts during the drought response. These groups played a critical role in identifying problems, implementing solutions, and maintaining effective communication with decision-makers, thereby reducing dependency on government support and improving overall resilience (Rawat 2022).

These examples underscore the importance of local community involvement in climate resilience efforts. By leveraging their communities' engagement and support, health systems can implement more effective and sustainable adaptation strategies.

Innovative technologies

Innovative technologies offer significant opportunities for enhancing the resilience of health systems to climate-related risks. By implementing early warning systems, improving health information systems, and adopting new technologies, health systems can significantly enhance their ability to predict and respond to climate-related health threats.

In Ethiopia, the implementation of the Epidemic Prognosis Incorporating Disease and Environmental Monitoring for Integrated Assessment (EPIDEMIA) system has marked a critical advancement in malaria surveillance (Merkord 2017). In Vietnam, integrating health surveillance with meteorological services and other stakeholders allows for the anticipation and mitigation of climate-related health risks (Van Minh 2014). The Change and Health Evaluation and Response System (CHEERS) facilitates the ongoing monitoring of climate change and health-related data within existing Health and Demographic Surveillance Sites (HDSSs). This system leverages digital technologies for real-time monitoring of population health status and health effects, providing accessible dashboards for policymakers and stakeholders to support data-driven decision-making (Barteit 2023). In the Pacific Island countries, enhancing surveillance systems and establishing new communication pathways between the health sector and meteorological services are essential measures, including trialing and evaluating climate-based early warning systems (McIver 2016).

By adopting and integrating these innovative technologies, health systems can improve their capacity to predict, prepare for, and respond to climate-related health challenges, thus significantly enhancing overall resilience and protecting vulnerable populations.

Key takeaways:

Challenges

Health system financing:

- Health systems in low-resource settings face systemic challenges, with insufficient financial resources being a major barrier to implementing adaptation measures.
- Sustainable financing mechanisms are essential for investing in health infrastructure, workforce training, and technology upgrades to strengthen climate resilience.

Health system preparedness:

- Insufficient training and capacity building for healthcare professionals hampers disaster response and preparedness in climate-vulnerable regions.
- Poor coordination and governance among stakeholders and innefectibe preapradness plans lead to fragmented disaster responses and inefficient resource utilization during climate emergencies.

Opportunities

Multi-sectoral collaboration and integrated policies:

- Collaboration across sectors and programs ensures that health responses are integrated with disaster management, WASH programs, and other critical sectors, enhancing overall system resilience.
- Integrated policies allow for cohesive national responses to climate-related health challenges, reducing fragmentation and promoting a coordinated, efficient approach to health system adaptation.

Importance of local communities:

- Community-led initiatives enhance adaptive capacities by facilitating surveillance, communication, and mobilization efforts during climate crises, reducing dependency on external support.
- Local communities play a pivotal role in health education, awareness, and disaster response at the grassroots level.

Innovative technologies:

- Innovative health technologies, such as early warning systems and digital health monitoring, can dramatically improve a health system's ability to predict and respond to climate-related risks.
- Technological integration, such as linking health surveillance with meteorological data, enables real-time monitoring and data-driven decision-making, strengthening health system preparedness for climate threats.

Chapter 3: Vulnerability of health systems

This section focuses on the third research question. The revised version of the question is as follows:

What are the health systems vulnerabilities associated with climate change in LMICs?

While climate change is a global issue, countries and communities around the world have dramatically different exposures and experiences. Consequently, it is important to understand the unique pressures and threats to respective economies, environments, and populations' health. An essential first step is to assess and understand the range, magnitude and patterns of health risks in the short, medium, and long-term time horizon and potential benefits of policies and programs.

Recognizing the need for assessing country level risk, in 2013 the WHO published the report, 'Protecting health from climate change: vulnerability and adaptation assessment' which provides guidance for countries.[44] An updated version of this tool was published in 2021 to provide lessons learned and more support for countries.[45] WHO also published a checklist that provides a simplified approach to assessing vulnerabilities.[46]

National assessments of the vulnerabilities of health systems to the impacts of climate change are important to assist governments with a more detailed understanding of climate-related health threats, the effectiveness of current adaptation and mitigation policies and future requirements.

The process entails five assessment steps, namely:

1. Frame and scope the assessment.
2. Conduct the vulnerability and adaptation assessment.
3. Understand future impacts on health.
4. Adapt to climate change by prioritizing and implementing health protection.
5. Establish an iterative process for managing and monitoring the health risks of climate change.

Illustrative country examples

An example of a vulnerability and adaptation assessment is well-described in a study conducted in Madagascar. The aim was to increase knowledge on the impact of climate change on population health and the health sector. The study revealed that the health sector is highly vulnerable to current climate variability and is expected to increase risks to health in the future. Furthermore, the study concluded that future climate conditions will exacerbate and increase the incidence of malnutrition, malaria, diarrhea, and acute respiratory diseases (Rakotoarison 2018).

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[44] Protecting health from climate change: vulnerability and adaptation assessment. Geneva: World Health Organization; 2013. https://www.who.int/publications/i/item/9789241564687. Accessed: 31 May 2024.

[45] Climate change and health vulnerability and adaptation assessment. Geneva: World Health Organization; 2021. Licence: CC BY-NC-SA 3.0 IGO.

[46] Checklists to assess vulnerabilities in health care facilities in the context of climate change. Geneva: World Health Organization, 2021 (https://www.who.int/publications/i/item/checklists-vulnerabilities-health-care-facilities-climate-change)

Similarly, a climate change and health vulnerability and adaptation assessment was conducted in Dominica, a small island developing state, that found concerns related to the re-emergence of malaria and other outbreaks of vector-borne diseases such as chikungunya, zika, dengue (Schnitter 2018). Food insecurity (i.e., threats to food production systems), as well as food-borne and waterborne diseases will also be exacerbated by climate change. Several measures to reduce the health risks related to food security, vector-borne, food-borne, and waterborne diseases have been implemented despite challenges such as a lack of knowledge, training, data, and human and financial resources.

A third example describes the experience of research conducted in the Somali region of Ethiopia by Abaya (2011) that identified ten health problems associated with climate variability (i.e., malnutrition, malaria, diarrheal diseases, mental health problems, parasitic infections, tuberculosis, skin infections, eye infection, acute respiratory infections and injuries). Yet, despite an observed increase in the magnitude and severity of these health problems during the past twenty years, their survey revealed a deficit of health professionals, inadequate healthcare infrastructure, and no training on climate variability and change for health care workers.

Illustrative regional example

Small Island developing states are among the most vulnerable to the health impacts of climate change due to socioeconomic, geographic, and demographic factors coupled with exposure to intense climate weather events. From 2010-12, the WHO led a regional health and climate change vulnerability assessment and adaptation planning project that included 13 Pacific Island countries (McIver 2016). Many Pacific Island countries have profoundly under-resourced health systems so improving water, sanitation, and hygiene systems and scaling up vector control have broad and long-term benefits can be challenging without avenues of technical support and resources.

The co-benefits of addressing climate change and health are promising opportunity in that health gains from action on climate change strategies, such as decreased fossil fuel use, increased active transport (e.g., walking and cycling), and greater consumption of fresh, local foods rather than imported products, will bring health benefits and reduce effects of climate change. Other lessons include a "Health in All Policies" approach, improving safety and security of food and water, sanitation and hygiene facilities, and health emergency risk management.

Key takeaways:

- Identifying and assessing health system vulnerabilities to climate change in low resource settings requires detailed evaluations of current and future health risks and the effectiveness of existing adaptation policies.
- Assessment tools such as the WHO's vulnerability and adaptation assessment reports and checklists provide guidance for countries in evaluating and addressing climate-related health threats.
- Addressing climate change leads to significant co-benefits such as improved air quality , physical exercise, and nutrition, when integrated into broader health and climate policies.

Chapter 4: Stakeholders

This section focuses on the fourth research question. The revised version of the question is as follows:

What is the role of different stakeholders in building and strengthening climate resilient health systems in LMICs?

It is important for climate resilient health systems to consider the diversity of stakeholders that are necessary to ensure a comprehensive and effective response. Climate change is inherently complex and requires participation and input from many different actors and sectors, particularly in addressing climate-related disasters. Diverse stakeholders bring valuable perspectives, resources, and expertise, that are necessary to effectively solve these challenges.

A more thorough examination of this question is beyond the scope of this review given that the search strategy and exclusion criteria excluded studies that focused specifically on response strategies delivered by humanitarian agencies and/or involving multi-sectoral, non-health systems.

Illustrative examples

A stakeholder analysis of organizations in Barbados and Dominica (Stewart-Ibarra 2019) related to vector control and climate services for health delineates a broad range of local, regional and national climate and weather partners. The expansive list noted below underscores the vast number of stakeholders and partnerships involved in the nexus of climate-related vector control and health.

- Ministry of Education, Ministry of Environmental Health, Ministry of Education
- Caribbean Institute for Meteorology and Hydrology
- Barbados/Dominca Meteorological Services
- Government information service
- National housing corporations
- Non-governmental organizations such as Red Cross
- Village councils, constituency councils
- Town planning department
- Donors, i.e., DFID (UK), Health Canada
- Private vector control
- Media and communications
- National Petroleum Corporation
- Water authorities
- Utility companies
- Solid Waste management
- Regional health sector, such as CARPHA and PAHO
- Faith-based organizations
- Land surveyors/planning
- Disaster management
- Academia, universities
- Tourism (e.g., hotels)
- Other community organizations

Similarly, an analysis of flood prevention preparedness in the southern Indian state of Kerala in 2018 describes how various government departments and different ministries came together to address the needs of flood-stricken communities (Varughese 2021).

The success of the state of Kerala's flood relief efforts relied on using a chain of command approach that enabled the state and district levels to assume authority and coordinate many different sectors including the following:

- Agriculture
- Animal husbandry
- Environment
- Finance
- Fisheries
- Forestry
- Home
- Health
- Land
- Livelihoods
- Roads and bridges
- Revenue
- Social welfare
- Transportation
- Urban services and infrastructure
- Water resources management
- Water supply and sanitation.

In sum, the wide-ranging impact of climate change on society necessitates engagement from many different sectors.

Finally, a study of Dominica's adaptive capacity (Schnitter 2018) revealed involvement of many different partners, programs and initiatives that included the following:

- International partners (e.g., German Agency for International Cooperation (GIZ), Dominica Medical Information System project, (World Bank), and Japan International Coordinating Agency (JICA))
- Regional partners (e.g., Caribbean Disaster Emergency Management Agency, The Caribbean Public Health Agency, Caribbean Regional Fisheries Mechanism)
- National programs and initiatives (e.g., Water quality monitoring, Solid waste collection and management)

These examples highlight the complexity of climate change, emphasizing that effective preventive efforts, responses and disaster relief in LMICs necessitates the involvement of numerous actors from diverse fields and disciplines. Broad collaboration and coordination ensure that different expertise is contributing to the solution and enhancing the overall effectiveness and resilience of health systems.

Key takeaways:

- Building climate-resilient health systems in low resource settings requires the involvement of a broad range of stakeholders from various sectors to address the complexity of climate change effectively.
- Local, regional, and national partners need to work together to address climate-related health challenges.
- Coordination among multiple government departments and sectors is critical.
- Partnerships with international, regional, and national organizations underscores the need for broad-based cooperation.
- Effective climate change prevention, response, and disaster relief in low resource settings depend on the integration of diverse expertise and coordinated efforts across multiple disciplines and sectors.

Chapter 5: Data sources

This section addresses the fifth question. The revised question is as follows:

What data is required for climate resilient health systems and what are the current strategies for improved measurement and evaluation?

High-quality data on population health status (e.g., mortality, morbidity, well-being), health systems (e.g., human resources, management, service coverage), and health determinants, including climate-related factors (e.g., socio-economic, demographic, environmental, behavioral), are crucial for countries and decision-makers. These data inform risk and capacity assessments, enabling evidence-based planning, enhanced preparedness, and more effective responses to disasters and emergencies. By integrating climate information with routinely collected health status and health system indicators, decision-makers can assess vulnerability, risk, and preparedness at local (Pasquini 2020, Labarda 2017, Alga 2018), national (Rakotoarison 2018, Schnitter 2018), and regional levels (McIver 2016). This approach helps countries plan and prepare for the increasing burden of climate-related risks on public health and health systems.

When health systems face the challenge of responding to frequent and large-scale disasters, adapting and strengthening the established routine Health Information Systems (HIS) is crucial. Aung et al. (2013) emphasize the need for HIS to effectively collect health status and health systems indicators pre- and post-disaster data. Already burdened health systems cannot optimally support the collection of such data even at baseline, pre-disaster conditions, jeopardizing the response and planning for large scale disasters. As climate-related disasters increase, strengthening HIS is essential not only for disaster response but for overall health system capacity.

The complex impact of climate change on health systems is calling for innovative solutions in terms of data collection systems, data integrations and data use and the following studies have specifically focused on supporting data-driven strategies for building climate resilience of public health systems, either by exploring specific health indicators (Dovie 2017, Miranda 2013, Puntub 2022, Meyer 2020), or by implementing and evaluating innovative data collection, analysis and communication methods build-on existing infrastructure (i.e. early warning systems) (Barteit 2023, Merkord 2017, Scheel 2016).

Illustrative country examples

We have presented illustrative selected examples in detail by Barteit 2023, Dovie 2017 and Merkord 2017. In summary these examples provide the following take home messages: to build efficient data collection systems for climate resilient health systems it requires strengthening the routine data, indicators, sources of already well-established and functioning collection, processing, analysis and dissemination infrastructure, the inclusion of multiple stakeholders and a multi-dimensional approach.

Barteit (2023) and colleagues describe the development and implementation of the Change and Health Evaluation and Response System (CHEERS) as a methodological framework, designed to facilitate the generation and ongoing monitoring of climate change and health-related data within existing Health and Demographic Surveillance Sites (HDSSs).

Routine data collection infrastructure
Health and demographic surveillance systems (HDSS) - *"long-term, dynamic, whole-population cohorts with up to 62 years of continuous data, covering an average of 75,000 people residing in a defined geographic region, implemented in 56 low-and middle-income countries (LMICs)"* Routine data: Demographic events: deaths, births, migrations (denominator and numerator data for the targeted population); age, socioeconomic status, occupation, and access to resources and infra-structure. Limitations: Lack of detailed individual-level morbidity data and by weather data from satellites or proximate weather stations, which lack the necessary granularity to accurately capture spatial and temporal weather variations, leading to potentially biased risk estimations.
Innovation
Climate and health surveillance and response system (CHEERS) system - for rigorous examination of climate change and health interrelations, providing crucial insights for researchers and policymakers with seamless integration with HDSS. Additional climate-data: • Indoor (household) temperature and humidity by installed devices in the household. • Outdoor temperature, precipitation wind speed, wind direction, solar radiation by weather stations. • Remote sensing for land use/cover data, surface water occurrence maps Additional health data: • Daily activity measured in steps, sleep with regards to sleep length and sleep quality, heart rate by individual wearable devices. • Physical examination: height, weight, body temperature, blood pressure Innovation: • Broaden the scope of existing health and demographic surveillance systems (HDSSs) on the topic of climate change and its impact on health. • Used to identify the most pressing climate change and health-related priorities, particularly for vulnerable populations by effective utilization of surveillance data (i.e., calculation of climate-associated DALYs (cDALYs) and QALYs (cQALYs). • Develop better models for prediction of crop yields and other environmental factors with integration with other health risk factors (i.e., socio-economic status) and health status (i.e., child nutrition and family health status). • Use of graph database for faster analysis, broader data type management, and structural flexibility, as compared to relational databases.

- Use of dashboards for data visualizations of complex data that can effectively illustrate the connections between climate change and health to enable a wider audience, including non-experts, policymakers, and the general public, to access and understand the information.

Key implementation opportunities (case countries: Burkina Faso, Kenya, Malaysia)

- **Transformative Potential:** CHEERS can upgrade HDSSs and similar research infrastructures into climate-and health-ready systems, generating data to inform public health policy and practice.
- **Versatility and Adaptability:** Designed for seamless integration into existing HDSSs and similar infrastructures in any country, regardless of income level, demonstrating its wide applicability.
- **Data Governance**: Establish governance processes to protect privacy while promoting data access. Implement guidelines to facilitate data sharing, though further research is needed for optimal strategies.
- **Wearable Devices:** Enable continuous, non-invasive monitoring of physiological parameters, providing real-time data to identify health risks and the impacts of climate change, especially in underrepresented populations.
- **Capacity Building:** Train healthcare workers, including community health workers, to perform physical examinations and use point-of-care testing devices, enhancing data collection in remote and resource-limited settings.
- **Contextual Adaptation:** Revise components to fit local environmental, socio-cultural, and infrastructural contexts for effective implementation.
- **Cost Efficiency:** Anticipated lower operating costs compared to annual HDSS data collection; a detailed cost assessment is needed for accurate comparison.
- **Community Involvement**: Establish guidelines for regular community feedback to help define research programs and identify priority areas.

Dovie (2017) and colleagues identified new indicators for building resilience against three climate sensitive diseases (cerebrospinal meningitis, malaria and diarrhea) to complement existing health indicators. These new climate-sensitive indices enhance health planning and contribute to the climate resilience of public health infrastructure. They capture biophysical, social changes, and policy decisions outside the health sector that impact health and system resilience. This study emphasizes a multi-dimensional approach in data collection to build resilience within the health sector against climate change.

Routine data collection infrastructure

Routinely collected Environmental Public Health Indicators:
Health indicators are measurable quantitative and qualitative parameters that measure determinants of health (socioeconomic, environmental, behavioural, demographic and genetic determinants or risk factors), health system inputs and related processes (i.e. policy, organization, human resources, financial resources, health infrastructure, equipment and supplies) and outputs (service coverage and utilization, health service availability and quality, information availability and quality) and health status (levels of mortality, morbidity, disability and wellbeing) used by agencies and practitioners to support and monitor health policies at all levels, from local to international.

Limitations: Lack coverage of climate risk factors, and the integration of broader climate-sensitive indicators, as well as external indicators outside the health sector, is progressing slowly, limiting the ability to address the added burden of climate change on health systems.

Innovation

A total of forty-five individual climate-related indicators, grouped under 11 categories, from both health and non-health sectors relevant of the impact of climate change on the health sector (example indicators are only those with high and very high relevance):

- Adaptation: well trained workforce, health facility accessibility, linked surveillance and climate data
- Biological: shellfish bumper harvest, algal blooms
- Demographic: population structure, population health, migration/displacement
- Environmental: pollution, sanitation, stagnated water, environmental temperature
- Epidemiological: History of disease occurrence
- Meteorological: rainfall, atmospheric temperature, humidity, sunshine/heat, extreme weather
- Mitigation: Increased health facilities
- Physical: shorter response/confirmation time, ventilation, buffer stock, resident reference laboratories, logistics/human resource, increased ambulance service
- Policy: decentralization, boundary partnership, sector-wide data monitoring
- Sustainability: diminished cases of diseases, system wide early warning
- Vulnerability: sea level rise, flooding, stagnated water (pockets)/pools, dams and ponds, elderly living alone, children, people with disabilities, previous exposures

Key implementation opportunities (country case: Ghana)

- **Comprehensive approach needed:** Demographic and environmental health indicators must incorporate meteorological, mitigation, biophysical, policy, vulnerability, and biological factors to support sector resilience.
- **Impact of social-ecological settings:** Different social-ecological settings outside the health sector influence the challenges of climate change, including exposure levels and health outcomes.
- **Multidimensional resilience building:** Building resilience requires cross-sector and cross-scale harmonization of climate-sensitive indicators for effective health planning.
- **Flexible planning horizons:** Capturing relevant climate-sensitive indicators requires flexible planning and prioritization to refine public health management tasks.
- **Overlapping indicators:** there is overlap between health and non-health indicators. This highlights their importance in public health planning to reduce climate change vulnerability.
- **Policy and strategy alignment:** Public health policies should reflect interventions that match impact scales, engage external resilience sources, and address social-ecological linkages, including ecosystem services.

Merkord (2017) and colleagues addressed a strong need for innovative malaria information systems that facilitate data sharing among stakeholders and enable the use of this information to direct public health response, by developing the Epidemic Prognosis Incorporating Disease and Environmental Monitoring for Integrated Assessment (EPIDEMIA) computer system.

Routine data collection infrastructure

For health data: Routine health information systems for tracking the temporal trends and spatial patterns of malaria cases and deaths. Standard technique for early detection involves computing a threshold value for a malaria indicator within a given geographic region based on the expected distribution under "normal" conditions as inferred from historical data. If observations exceed the threshold it is interpreted as signs of a rising epidemic curve.

Routine data: Weekly counts of total patient visits in primary health care facilities on all patients who seek treatment, numbers of malaria screening tests, confirmed malaria cases, estimated total population at risk, morbidity and mortality.

Limitations: Standard early detection techniques only identify epidemics once they are underway. Scarcity of in-situ monitoring networks, such as meteorological stations, poses extra barriers. Challenges in integrating environmental data with malaria surveillance systems hinder the effectiveness of such early warning systems.

Innovation

Epidemic Prognosis Incorporating Disease and Environmental Monitoring for Integrated Assessment (EPIDEMIA) computer system - *integrating malaria surveillance with environmental monitoring data in a malaria information system, collected via remotely sensed earth observation data and meteorological station data.*

Additional climate data:

- Rainfall
- Temperature
- Various spectral indices of vegetation greenness and surface moisture

Innovation:

- Easy uploading and error screening of epidemiological data.
- Automatic acquirement, processing, and harmonization of the latest remotely sensed environmental data with epidemiological data, for forecast modelling of future levels of malaria transmission.
- Access through a simple menu-driven interface (public health interface).
- Generation of early detection alerts and epidemic forecasts when new data are uploaded and summary of the information into standardized reports.

Key implementation opportunities (country case: Amhara region, Ethiopia)

- **Priority on timely, high-quality data:** Recognize the critical importance of timely and high-quality data in developing malaria early warning systems.
- **Continuous evaluation and improvement:** Emphasize the continuous evaluation of predictions using new, independent observations to ensure transparency and accuracy. Avoid reliance on single validated models and prioritize the development of dynamic malaria information systems to support data access, prediction, and continuous evaluation.
- **Incorporate stakeholder input:** Involve stakeholders in the co-design and updating of the system to ensure alignment with end-user needs. Formal requirements analysis helps identify and prioritize system components tailored to user requirements.
- **Shared informatics framework:** Establish a shared informatics framework for research scientists and public health professionals, facilitating near-real-time data updates to support early detection and warning systems for malaria.

- **Adaptation to changing data:** Prepare for changes in earth observation data products by anticipating updates in algorithms, file specifications, or access protocols. Expect variations in data availability over time due to sensor decommissioning and replacement.

Key takeaways:

- Strengthening routine HIS is essential for effective disaster response and long-term health system resilience.
- Innovative data collection systems offer significant opportunities to integrate climate and health data, improving early warning, surveillance, and response for climate-sensitive diseases. They can provide real-time data on health and environmental factors, enabling more accurate monitoring of climate-related health risks
- Cross-sector data integration—combining health, demographic, environmental, and meteorological data—enhances the capacity to assess risks and develop climate-resilient health strategies.
- Contextual adaptation and capacity building are key to implementing these systems effectively, requiring training for healthcare workers and tailoring systems to fit local socio-cultural and environmental contexts.
- Collaborative data governance frameworks are necessary to ensure data privacy while promoting data sharing and accessibility for real-time monitoring and prediction, supporting evidence-based public health policies.

Chapter 6: Equity and vulnerability

This section addresses the sixth research question. This revised question is as follows:

What are the equity implications for vulnerable populations from climate-related health challenges and how can these be addressed?

The climate crisis disproportionately affects segments of society, particularly vulnerable populations such as the poor, marginalized, and disenfranchised.[47] A broad range of factors influence the health impacts of climate change including biological, demographic, geographic, socioeconomic, and sociopolitical. Factors linked to vulnerability may be due to physiological and/or psychological sensitivity (e.g., poor health status), poor housing conditions, food insecurity, reduced access to clean water and adequate sanitation, reduced capacity to adapt (e.g., poverty), and/or lower education levels.

Such groups face challenges in coping with, and recovering from, climate disasters due to increased exposure to risks and reduced access to support and services. In sum, climate change tends to exacerbate existing inequities and disparities, amplifying health and economic impacts of already disadvantaged populations. Ray and colleagues (2022), for example, note that:

> *"the poor, disadvantaged, and marginalized are 50% more likely to bear the impact of climate change than non-poor people" (pg. 1, Ray 2022)*

Among the 65 studies, approximately half discuss or mention the vulnerability of certain groups to the impacts of climate change on health. While many articles briefly touch on this topic, few address this as the singular focal topic (Pasquini 2020, Codjoe 2020, Berrang-Ford 2012). Thus, while some has focused on this issue, there is a gap in understanding the unique needs of groups most affected by climate change.

Vulnerable Groups

These studies identified several groups that were particularly vulnerable to the impacts of climate change. These include the following:

- **The elderly:** The very old are particularly susceptible often due to weak, compromised immune systems, isolation, and/or dependence on others for care (Tasdik 2020).
- **Newborns and children under 5 years of age:** The very young, whether healthy or sick, are inherently susceptible due to developing immune systems and dependence on others for their care (Schnitter 2018).
- **Pregnant and single women:** Facing greater risks from climate-related health issues due to socio-economic disadvantages and additional caregiving responsibilities (Purno 2023, Saulnier 2020, Codjoe 2020, McIver 2016).
- **Economically disadvantaged:** The poor are more vulnerable due to limited access to healthcare, safe housing, and other necessary resources (Ray 2022).
- **Persons with disabilities:** Struggling with mobility and access challenges, making them more susceptible to climate change impacts (Varughese 2021).
- **Indigenous and marginalized communities:** Disruption of traditional ways of life and facing barriers to accessing resources and support (Amis 2014, Berrang-Ford 2012).

[47] Climate change and health: vulnerability and adaptation assessment. Geneva: World Health Organization, 2021. Licence CC BY-NC-SA 3.0 IGO.

- **Refugees (e.g., Rohingya refugees in Bangladesh and other internally displaced populations):** Displacement leads to overcrowding, poor living conditions, and limited access to healthcare (Elshazly 2022, Berhanu 2016).
- **Rural and remote populations:** Poor infrastructure, inadequate transport services, and limited access to health care increases vulnerability of these populations (Rawat 2022, Ebi 2017, Ray 2022).
- **Urban informal settlement residents:** Informal settlement residents in cities (i.e, Dar es Salaam, Tanzania) have high exposure, high sensitivity and low adaptive capacity to heat. (Pasquini 2020).
- **Low literacy:** An assessment in Madagascar reported significant correlations between climate-sensitive health outcomes and low literacy rates (Rakotoarison 2018).
- **Immunocompromised individuals and those with chronic conditions, including mental illness:** Individuals with diabetes, asthma, hypertension, and HIV, for example, face significant challenges when climate-related disasters disrupt access to medications and treatments (Ray 2022 and Schnitter 2018). Vulnerability among those with mental health issues is also exacerbated by climate disasters due to challenges in accessing services, medicine, and support (Elshazly 2022).
- **Climate-dependent livelihoods:** Farmers, fishers, and pastoralists whose income and well-being rely on climate conditions are particularly vulnerable to climate change impacts (Ray 2022).
- **Outdoor workers and some occupational groups:** Employment sectors such as agriculture, tourism, and construction are vulnerable due to the potential of working conditions in extreme heat even among healthy workers (Schnitter 2018).
- **LGBTQI individuals:** These groups are potentially at risk due to societal marginalization and challenges in accessing necessary resources and support due to discrimination (Beek 2021).

These groups face heightened risks due to factors such as living in high-risk areas, poor infrastructure, and limited access to healthcare and resources. Schnitter (2018) and colleagues also noted that many populations face *multiple health risks* thus increasing challenges for adequate preparedness.

Strategies addressing inequities and vulnerable groups

The studies discussed various strategies to address inequities and groups that are vulnerable to the health impacts of climate change, such as:

- **Sensitive data collection strategies:** Gathering data on the needs of vulnerable groups during climate change events may help tailor effective interventions and support systems (Aung, 2013). Data collection could include housing, transportation, gender, disability, and migrant status.
- **Early warning and response systems:** In several countries, early warning systems were designed with vulnerable groups in mind that guide the issuing of warnings and take into account the needs of the most vulnerable populations (Ebi, 2017).
- **Vertical governance:** Integrating health risk assessments and vulnerability analyses into several governance layers is important in addressing vulnerable populations' needs (Banwell 2021).
- **Community-focused interventions:** Involving local community perspectives in planning and implementing responses ensures that marginalized groups needs are met (Rattanakanlaya 2018, 2022).

- **Cross-sectoral approaches:** Encouraging engagement from sectors such as transport, education, environment, and emergency management support resilience planning (Codjoe 2020).
- **Appropriate communication channels:** Identifying appropriate communication channels is essential as traditional methods such as TV, Facebook, and YouTube, may not reach hard-to-reach groups (Pasquini 2020).
- **Gender and vulnerable groups in planning documents:** Government plans often fail to mention the needs of vulnerable groups or include gender considerations, highlighting the need for more inclusive planning (Van Minh 2014).
- **Reduce household vulnerability:** Elevate overall standard of living, diversify income sources, and improve living conditions to ensure adequate housing, sanitation, safe water, and food security (Rakotoarison 2018).

The strategies mentioned above illustrate focal topics addressed in several of the studies included in this review. However, further work is needed to ensure that the needs of vulnerable groups are adequately addressed in climate change mitigation and adaptation efforts.

Illustrative examples

Several studies provide useful examples showcasing how selected countries have addressed inequities and vulnerable groups at the national, district, or community level.

A study by **Codjoe and colleagues (2020)** reviews how extreme heat impacts pregnant women and newborn infants in crowded healthcare facilities. Overcrowded wards exacerbate heat exposure, causing increased discomfort and health risks. For example, having more than one patient in a bed on the children's ward or placing mattresses on the floor between beds reduces air flow and increases temperatures among patients struggling to sleep. Some patients sleep outside during extreme heat which increases risk of diseases such as malaria. In sum, climate change may compound existing health issues and infrastructure challenges, particularly for pregnant women, newborns, and families.

The **Pasquini et al study (2020)** examines the heat vulnerability of urban informal settlements residents in Dar es Salaam, Tanzania concluding that these residents have high exposure, high sensitivity and low adaptive capacity to heat which has serious implications for vulnerable groups living in urban environments in Africa and around the world.

The **Berrang-Ford (2012)** study focuses on the vulnerabilities of Batwa Pygmy populations in Uganda providing yet another example. The Batwa Pygmies are faced with the disruption of traditional livelihoods and increased risk of health issues (i.e., malnutrition, stomach disorders) due to their dependence on natural resources. Moreover, they often encounter challenges in accessing health care and other essential services due to their marginalized status.

In summary, these findings reveal the broad impact of climate change on vulnerable populations underscoring the need to address health disparities and promote equity to achieve climate resilient health systems. Moreover, the findings suggest that a large number of populations can be impacted by climate change which has significant implications for managing different needs and challenges.

Key takeaways:

- Climate change disproportionately affects the poor, marginalized, and disenfranchised, exacerbating existing inequities and health disparities due to factors such as poor housing, food insecurity, and limited access to resources.
- Specific groups, including the elderly, children, pregnant women, economically disadvantaged, and those with disabilities or marginalized status, face heightened risks from climate-related health challenges.
- There is increasing recognition that some groups in societies traditionally considered less vulnerable to climate-related health effects, such as healthy young men, are also at risk, particularly those employed in occupations like agriculture, construction, manufacturing, and transportation. These groups may experience challenging working conditions, including prolonged exposure to extreme weather and poor indoor environments, that heighten their vulnerability to the health impacts of climate change.
- Effective approaches include sensitive data collection, early warning systems tailored to vulnerable groups, vertical governance integration, community-focused interventions, cross-sectoral collaboration, and improving communication channels and planning documents that address gender and vulnerable groups.
- There is a critical need for inclusive planning and adaptive strategies that address the unique needs of vulnerable populations to enhance climate resilience and equity in health systems.

Chapter 7: Future investigation

This section addresses on the seventh question:

What is the current state of research on climate resilient health systems, and what are areas requiring future investigation?

A broad overview of the current state of research on climate resilient health systems in LMICs has been presented in the preceding six research questions. Based on these findings, this section focuses on what was not found or discussed that may reflect the need for future investigation.

A common thread running through many different articles is the lack of ***sustainable financing***, adequate resources, or emergency funds in times of crisis. Throughout the majority of articles, there was universal agreement that this is a critical issue but little discussion on how it has been successfully addressed. Thus, climate change and health financing is an arena ripe for future investigation. Future research should focus on identifying effective strategies for securing and managing funds during climate-related crises. This includes exploring innovative financing mechanisms such as public-private partnerships, international aid, and climate funds. It's important to understand how to create financial safety nets and emergency funds that can be quickly mobilized during disasters. Additionally, research should investigate how to integrate climate resilience into national health budgets to ensure continuous support for these critical activities.

In a similar vein, while some studies remarked on the impact of climate change on health for ***vulnerable populations***, few offer effective strategies for communicating with and addressing the needs of these diverse groups. The scope of vulnerable populations is likely to expand, including more individuals who become at risk due to factors like housing conditions and livelihood activities. Research should focus on targeted interventions designed to protect the most vulnerable groups, such as low-income families, elderly individuals, and marginalized communities. This includes finding ways to make health services more accessible and ensuring that climate adaptation strategies are fair and inclusive. Future research should also focus on creating assessment tools to pinpoint which populations are most at risk and why, helping tailor interventions to different communities' needs. We have identified studies that conducted vulnerability assessments at both national and regional levels using WHO's tools, but not including specific tools for vulnerable populations. By focusing on equity, we can help ensure that everyone can stay healthy despite the challenges posed by climate change.

Additionally, we need more research on how climate resilience strategies are being implemented in ***real-world settings***. This involves examining how health systems adapt to climate change in various contexts. By studying these real-world applications, we can understand the practical challenges and successes, developing solutions that are practical and effective in specific environments. Research should prioritize developing and testing interventions tailored to local contexts, considering each region's unique environmental, social, and economic conditions, and without excluding vulnerable population groups. By doing so, health systems can implement more effective and with sustainable resilience measures.

Another aspect lacking in the identified literature is the ***long-term impact studies***. This research can evaluate the effectiveness of adaptation strategies and interventions, by looking at the long-term outcomes. Hence, we can learn how to improve and sustain health system resilience in the face of ongoing climate challenges.

Regarding the geographical representation of the included studies, we have identified and included studies from the most affected LMICs, from Africa, South Asia and island nations that face severe impacts due, for example, frequent and extreme weather events. Nevertheless, research on climate-resilient health systems is ***not spread out evenly***. Some countries, like Ethiopia, the Philippines, and Bangladesh, have many studies. But other vulnerable areas, like small island developing states, were under-represented in research.

Finally, ***effective communication*** is key to protecting communities from the health impacts of climate change. Even though we did not include studies that are focused on empowering community climate resilience, we report a lack of research on how to develop and implement communication strategies that reach diverse and vulnerable populations, led by the health system. This includes finding the best ways to educate people about climate-related health risks and ensure they have the information they need to protect themselves. Research should also look at how the health sector can use technology, to disseminate health information quickly and effectively.

Concluding remarks

These brief concluding remarks are intended to acknowledge methodological limitations, reflect on the scoping review process, and highlight the potential contribution of this work to the growing field of building climate-resilient health systems. These remarks are not intended to summarize findings or identify research gaps as those aspects have been covered in preceding chapters.

It is important to mention several methodological limitations that must be transparently shared with readers as these may impact the interpretation of findings. First, search strategies focused primarily on the health sector which may have resulted in missing relevant literature from other fields such as the development, disaster, humanitarian, and other non-health sectors such as energy and agriculture. Second, gray literature searches were not conducted so it is possible that informal country reports and other documentation (e.g., guidance papers and tools found in the ATACH resource repository) could have enriched the findings. Third, as mentioned in the methods section, quality assessment of included studies was not conducted as this is not within the purview of scoping review methods. Finally, the broad scope of the review made it challenging to fully capture all relevant perspectives so exclusions, such as studies aiming to build resilience of community and not led by the health sector, further narrowed the scope.

The yearlong process of designing and conducting a scoping review exploring the landscape of research dedicated to climate change and health systems in low and middle-income countries has been demanding and informative. The review yielded a substantial number of studies offering valuable information on strategies, approaches, or initiatives aimed at enhancing the climate resilience of health systems. Extracting this large volume of information and organizing it into meaningful categories and responses was challenging yet resulted in a compendium that now provides valuable insights on many different aspects of climate-resilient health systems.

It is our hope that this report will be widely shared and disseminated contributing to ongoing efforts to strengthen health systems against the challenges posed by climate change. Despite the limitations, this scoping review captured a broad range of studies providing a comprehensive snapshot of global research and initiatives dedicated to this topic. This report makes in important contribution to the growing body of research focused on enhancing the climate resilience of health systems and can serve as a resource for researchers, policymakers, and practitioners.

Appendix 1: Search strategy

Epistemonikos, Epistemonikos Foundation: www.epistemonikos.org/en/ (searched 01 September 2023)

- Searched Advances search in Title/Abstract.
- 12 individual strategies combining the 'climate line' with each of the 'health system lines' below.
- Limit to **Publication type: Systematic review (SR), Broad synthesis (BS), Structured summary (SS)**

1.	climate* OR climatic* OR sea-level OR "sea level" OR "global warming" OR "greenhouse effect" OR "greenhouse effects" OR natural-disaster OR "natural disaster" OR natural-disasters OR "natural disasters" OR natural-hazard OR "natural hazard" OR natural-hazards OR "natural hazards" OR cyclonic OR cyclone OR cyclones OR hurricane OR hurricanes OR storm OR storms OR typhoon OR typhoons OR tornado OR tornados OR drought OR droughts OR flood OR floods OR flooding OR landslide OR lands-slide OR "land slide" OR landslides OR lands-slides OR "land slides" OR rockslide OR rock-slide OR "rock slide" OR rockslides OR rock-slides OR "rock slides" OR mudslide OR mud-slide OR "mud slide" OR mudslides OR mud-slides OR "mud slides" OR tidal-wave OR "tidal wave" OR tidal-waves OR "tidal waves" OR wildfire OR wild-fire OR "wild fire" OR wildfires OR wild-fires OR "wild fires" OR wildland-fire OR "wildland fire" OR wildland-fires OR "wildland fires" OR forest-fire OR "forest fire" OR forest-fires OR "forest fires" OR bush-fire OR "bush fire" OR bush-fires OR "bush fires" OR "extreme weather" OR "extreme cold weather" OR "extreme hot weather" OR heatwave* OR heat-wave OR "heat wave" OR heat-waves OR "heat waves" OR "extreme heat" OR "extreme temperature" OR "extreme temperatures" OR "extreme rain" OR "extreme rains" OR "extreme wind" OR "extreme winds" OR "crop failure" OR "crop loss" OR "crop losses" OR "crop destruction" OR "crop destructions" OR "farmland destruction" OR "farmland destructions" OR "farm land destruction" OR "farm land destructions"
	AND
1.	"delivery of health care" OR "delivery of health-care" OR "delivery of healthcare" OR "delivery of health" OR "delivery of care"
2.	health-system OR "health system" OR health-systems OR "health systems" OR "healthcare system" OR "healthcare systems" OR "health care system" OR "health care systems" OR "health-care system" OR "health-care systems"
3.	health-service OR "health service" OR health-services OR "health services" OR "healthcare service" OR "healthcare services" OR "health care service" OR "health care services" OR "health-care service" OR "health-care services"
4.	health-facility OR "health facility" OR health-facilities OR "health facilities" OR "healthcare facility" OR "healthcare facilities" OR "health care facility" OR "health care facilities" OR "health-care facility" OR "health-care facilities"
5.	"health workforce" OR health-workforce OR "health manpower" OR health-manpower
6.	health-sector OR "health sector" OR health-sectors OR "health sectors" OR "healthcare sector" OR "healthcare sectors" OR "health care sector" OR "health care sectors" OR "health-care sector" OR "health-care sectors"
7.	health-plan OR "health plan" OR health-plans OR "health plans" OR "healthcare plan" OR "healthcare plans" OR "health care plan" OR "health care plans" OR "health-care plan" OR "health-care plans" OR "health planning" OR "healthcare planning" OR "health care planning" OR "health-care planning"
8.	health-policy OR "health policy" OR health-policies OR "health policies" OR "healthcare policy" OR "healthcare policies" OR "health care policy" OR "health care policies" OR "health-care policy" OR "health-care policies"
9.	"healthcare financing" OR "health care financing"
10.	health-priority OR "health priority" OR health-priorities OR "health priorities" OR "healthcare priority" OR "healthcare priorities" OR "health care priority" OR "health care priorities" OR "health-care priority" OR "health-care priorities"

11.	"early warning" OR early-warning OR "warning system" OR "warning systems" OR warning-system OR warning-systems OR "health information system" OR "health information systems" OR "healthcare information system" OR "healthcare information systems" OR "health care information system" OR "health care information systems"
12.	"response strategy" OR "response strategies" OR "strategic management" OR preparedness OR resilience OR resilient OR mitigation

Ovid MEDLINE(R) ALL 1946 to August 04, 2023 (searched 05 August 2023)

#	Searches	Results
1	Global Warming/pc [Prevention & Control]	638
2	Climate Change/	26448
3	Global Warming/	4397
4	Sea Level Rise/	137
5	Natural Disasters/	542
6	Cyclonic Storms/	3013
7	Droughts/	12052
8	Floods/	3974
9	Landslides/	275
10	Tidal Waves/	382
11	Tornadoes/	235
12	Wildfires/	1154
13	Extreme Weather/	139
14	Extreme Hot Weather/	31
15	Extreme Cold Weather/	137
16	Extreme Heat/	564
17	Greenhouse Effect/	6150
18	Anthropogenic Effects/	470
19	(climate* or climatic* or sea level rise or sea level rising or rising sea level or global warming or greenhouse effect* or greenhouse gas or greenhouse gasses or carbon footprint* or natural disaster* or natural hazard* or cyclon* or storm* or hurricane* or typhoon* or tornado* or drought* or flood* or landslide* or land slide* or rockslide* or rock slide* or mudslide* or mud slide* or tidal wave* or wildfire* or wild fire* or wildland fire* or forest fire* or bush fire* or extreme* weather or extreme* cold weather or extreme* hot weather or heat wave* or heatwave* or extreme* heat or extreme* temperature* or extreme rain or extreme rains or extreme wind or extreme winds or crop failure or crop loss* or crop destruction* or farmland destruction* or farm land destruction*).ti,ab,kf.	248359
20	or/2-19 [CLIMATE CHANGE]	255215
21	"Delivery of Health Care"/	117354
22	"Delivery of Health Care, Integrated"/	14298
23	Health Services Accessibility/	85593
24	"Health Services Needs and Demand"/	55187
25	Needs Assessment/	32444
26	Health Workforce/	14470
27	Health Care Sector/	6728
28	Disaster Planning/	15774
29	Health Planning/	21978
30	Regional Health Planning/	5459
31	Community Health Planning/	5242
32	Health Facility Planning/	1881

33	Health Systems Plans/	195
34	Health Care Rationing/	12096
35	Health Policy/	72235
36	Government Programs/	6425
37	Forecasting/	91672
38	Healthcare Financing/	1255
39	Health Information Systems/	1635
40	(delivery of health* or health* system* or health care system* or health* sector* or health care sector* or health* plan* or health care plan* or health* polic* or health care polic* or health* priorit* or health care priorit* or health* financing or health care financing or disaster plan* or ((health* service* or health care service* or health* facility or health facilities or health care facility or health care facilities or health* workforce or health care workforce or health* manpower or health care manpower) adj6 (plan or plans or planning)) or response strateg* or strategic management or preparedness or health* information system* or health care information system* or early warning or warning system*).ti,ab,kf.	301375
41	or/21-40 [HEALTH SYSTEMS]	711552
42	(afghan* or africa* or albania* or algeria* or angola* or antigua* or barbuda* or argentin* or armenia* or aruba* or azerbaijan* or bahrain* or bangladesh* or bengal* or bangal* or barbados* or barbadian* or bajan or bajans or belarus* or belorus* or byelarus* or byelorus* or belize* or benin* or dahomey or bhutan* or bolivia* or bosnia* or herzegovin* or botswan* or batswan* or bechuanaland* or brazil* or brasil* or bulgaria* or burkina* or burkinese* or upper volta* or burundi* or urundi* or cabo verde* or cape verde* or cambodia* or kampuchea* or khmer* or cameroon* or cameroun* or ubangi shari* or chad* or chile* or china* or chinese or colombia* or comoro* or comore* or comorian* or mayotte* or congo* or zaire* or costa rica* or "cote d'ivoir*" or "cote d' ivoir*" or cote divoir* or cote d ivoir* or ivory coast* or ivorian* or croatia* or cuba or cuban or cubans or "cuba's" or cyprus* or cypriot* or czech* or djibouti* or french somaliland* or dominica* or ecuador* or egypt* or united arab republic* or el salvador* or salvadoran* or guinea* or equatoguinea* or eritrea* or estonia* or eswatini* or swaziland* or swazi* or swati* or ethiopia* or fiji* or gabon* or gabonese* or gabonaise* or gambia* or ((georgia or georgian or georgians) not (atlanta or california or florida)) or ghana* or gibraltar* or greece* or greek* or grecian* or grenada* or grenadian* or guam* or guatemala* or guyana* or guiana* or guyanese* or haiti* or hispaniola* or hondura* or hungary* or hungarian* or india* or indonesia* or iran* or iraq* or isle of man* or jamaica* or jordan* or kazakh* or kenya* or karabati* or korea* or kosovo* or kosova* or kyrgyz* or kirgiz* or kirghiz* or laos or lao or laotian* or latvia* or lebanon* or lebanese* or lesotho* or lesothan* or lesothonian* or basutoland* or mosotho* or basotho* or liberia* or libya* or jamahiriya* or lithuania* or macedonia* or madagasca* or malagasy* or malawi* or nyasaland* or malaysia* or malay* federation or maldives* or maldivian* or indian ocean or mali or malian* or "mali's" or malta or maltese* or "malta's" or micronesia* or marshallese* or kiribati* or marshall island* or nauru or nauran or nauruans or "naurian's" or mariana or marianas or palau or paluan* or tuvalu* or mauritania* or mauritan* or mauritius* or mexico* or mexican* or moldova* or moldovia* or mongol* or montenegr* or morocco* or moroccan* or ifni or mozambique* or mozambican* or myanmar* or burma* or burmese or namibia* or nepal* or new caledonia* or netherlands antill* or nicaragua* or niger* or oman or omani or omanis or "oman's" or pakistan* or palestin* or gaza* or west bank* or panama* or paraguay* or peru or peruvian* or "peru's" or philippine* or philipine* or phillipine* or phillippine* or filipino* or filipina* or poland* or polish or pole or poles or portugal* or portuguese or puerto ric* or romania* or russia* or ussr* or soviet* or rwanda* or rwandese or ruanda* or ruandese or samoa* or navigator island* or pacific island* or polynesia* or sao tome* or santomean* or saudi arabia* or saudi or saudis or senegal* or serbia* or seychell* or sierra leone* or slovak* or sloven* or melanesia* or solomon island* or norfolk island* or somali* or sri lanka* or ceylon* or saint kitts or st kitts or kittian* or nevisian* or saint lucia* or st lucia* or saint vincent* or st vincent* or vincentian* or grenadine* or sudan* or surinam* or syria* or tajik* or tadjik* or tadzhik* or tanzania* or tanganyika* or thai* or timor leste* or east timor* or timorese* or togo or togoles* or "togo's" or tonga* or trinidad* or tobago* or tunisia* or turkiy* or turkey* or turk or turks or turkish or turkmen* or uganda* or ukrain* or uruguay* or uzbek* or vanuatu* or new hebrides* or venezuela* or vietnam* or viet nam* or yemen* or yugoslav* or zambia* or zimbabwe* or rhodesia* or arab* countr* or middle east* or global south or sahara* or subsahara* or magreb* or maghrib* or west indies* or caribbean* or central america* or latin america* or south america* or asia central or central asia* or asia northern or north asia* or northern asia* or asia southeastern or southeastern asia* or south eastern asia* or southeast asia* or south east asia* or asia western or west asia* or western asia* or europe eastern or east europe* or eastern europe* or developing countr* or developing nation* or develop-	3202533

	ing population* or developing world or less developed countr* or less developed nation* or less developed world or lesser developed countr* or lesser developed nation* or lesser developed world or under developed countr* or under developed nation* or under developed world or underdeveloped countr* or underdeveloped nation* or underdeveloped world or middle income countr* or middle income nation* or middle income population* or low income countr* or low income nation* or low income population* or lower income countr* or lower income nation* or lower income population* or underserved countr* or underserved nation* or underserved population* or under served population* or under served nation* or under served population* or deprived countr* or deprived population* or high burden countr* or high burden nation* or countdown countr* or countdown nation* or poor countr* or poor nation* or poor population* or poor world or poorer countr* or poorer nation* or poorer population* or poorer world or developing econom* or less developed econom* or underdeveloped econom* or under developed econom* or middle income econom* or low income econom* or lower income econom* or low gdp or low gnp or low gross domestic or low gross national or lower gdp or lower gnp or lower gross domestic or lower gross national or lmic or lmics or third world or lami countr* or transitional countr* or emerging econom* or emerging nation*).ti,ab,hw,kf. [EPOC LMIC FILTER - FEB 2023]	
43	1 and 42	131
44	20 and 41 and 42	4402
45	43 or 44	4525

Global Health 1973 to 2023 Week 30, Ovid (searched 05 August 2023)

#	Searches	Results
1	((climate* or climatic* or sea level rise or sea level rising or rising sea level or global warming or greenhouse effect* or greenhouse gas or greenhouse gasses or carbon footprint* or natural disaster* or natural hazard* or cyclon* or storm* or hurricane* or typhoon* or tornado* or drought* or flood* or landslide* or land slide* or rockslide* or rock slide* or mudslide* or mud slide* or tidal wave* or wildfire* or wild fire* or wildland fire* or forest fire* or bush fire* or extreme* weather or extreme* cold weather or extreme* hot weather or heat wave* or heatwave* or extreme* heat or extreme* temperature* or extreme rain or extreme rains or extreme wind or extreme winds or crop failure or crop loss* or crop destruction* or farmland destruction* or farm land destruction*) and (delivery of health* or health* system* or health care system* or health* sector* or health care sector* or health* plan* or health care plan* or health* polic* or health care polic* or health* priorit* or health care priorit* or health* financing or health care financing or disaster plan* or ((health* service* or health care service* or health* facility or health facilities or health care facility or health care facilities or health* workforce or health care workforce or health* manpower or health care manpower) and (plan or plans or planning)) or response strateg* or strategic management or preparedness or health* information system* or health care information system* or early warning or warning system*)).ti,hw.	1207
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4	(afghan* or africa* or albania* or algeria* or angola* or antigua* or barbuda* or argentin* or armenia* or aruba* or azerbaijan* or bahrain* or bangladesh* or bengal* or bangal* or barbados* or barbadian* or bajan or bajans or belarus* or belorus* or byelarus* or byelorus* or belize* or benin* or dahomey or bhutan* or bolivia* or bosnia* or herzegovin* or botswan* or batswan* or bechuanaland* or brazil* or brasil* or bulgaria* or burkina* or burkinese* or upper volta* or burundi* or urundi* or cabo verde* or cape verde* or cambodia* or kampuchea* or khmer* or cameroon* or cameroun* or ubangi shari* or chad* or chile* or china* or chinese or colombia* or comoro* or comore* or comorian* or mayotte* or congo* or zaire* or costa rica* or "cote d'ivoir*" or "cote d' ivoir*" or cote divoir* or cote d	1556499

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Global Index Medicus, WHO: www.globalindexmedicus.net/ (searched 06 August 2023)

- Searched Advances search in Title, Abstract, Subject.
- Limit to the following databases: LILACS (Americas), WPRIM (Western Pacific), IMSEAR (South-East Asia), IMEMR (Eastern Mediterranean), AIM (Africa)

"climate change" OR "climate changes" OR "climate hazard" OR "climate hazards" OR "climate mitigation" OR "climate resilience" OR "climate resilient" OR "climate related" OR "climate induced" OR "climate event" OR "climate events" OR "climatic change" OR "climatic changes" OR "climatic hazard" OR "climatic hazards" OR "climatic mitigation" OR "climatic resilience" OR "climatic induced" OR "climatic event" OR "climatic events" OR "sea level" OR "global warming" OR "greenhouse effect" OR "greenhouse effects" OR "natural disaster" OR "natural disasters" OR "natural hazard"

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VHL Regional Portal, Bireme: bvsalud.org (searched 06 August 2023)

- Searched Advances search in Title, Abstract, Subject.
- Limit to following databases/sources included in VHL, except Medline, Lilacs, WPRIM, AIM (duplicates with Global Index Medicus)

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Appendix 2: List of included studies

1. Preparedness of primary healthcare facilities to respond to infectious disease outbreaks in flood-prone sub-districts of Bangladesh. Hsb. 2013;11(2):8-16.

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Appendix 3: List of excluded studies

Excluded based on study design (n=17)

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Exclude based on lack of methods description / commentary (n=76)

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