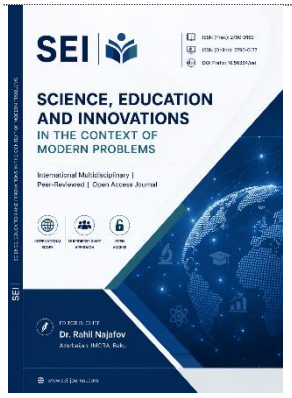

Science, Education and Innovations in the Context of Modern Problems
Volume 9, Issue 8 (2026)

RESEARCH ARTICLE

Climate Adaptation, Health Governance, and Institutional Resilience: A Global Scoping Review

Munir Ahmad
Ph.D. Scholar
Muslim Youth (MY) University, Islamabad
Pakistan
Corresponding Author E-mail: munirahmadkhan967@gmail.com
ORCID: https://orcid.org/0009-0001-4769-6311

Waseem Khokhar
Dr.
Assistant Professor, Muslim Youth (MY) University, Islamabad
Pakistan
E-mail: waseem.khokhar@myu.edu.pk

Sarbiland
Dr.
Assistant Professor, Muslim Youth (MY) University, Islamabad
Pakistan
E-mail: dr.sarbiland@myu.edu.pk

Keywords climate adaptation, healthcare systems, institutional resilience, health governance, sustainable development, climate resilience, adaptation strategies, policy frameworks, healthcare preparedness, scoping review.

Abstract

Climate change has emerged as one of the most significant global challenges affecting public institutions, social systems, and sustainable development. Healthcare systems are increasingly required to adapt to climate-related risks while strengthening their resilience, preparedness, and institutional capacity. Despite growing scholarly attention to climate adaptation, a comprehensive synthesis of adaptation strategies implemented across healthcare settings remains limited. This scoping review aims to examine global initiatives related to climate adaptation in healthcare systems, identify major thematic areas, explore geographical patterns, and highlight key research and policy gaps. The study follows the methodological framework of Arksey and O'Malley and adheres to the PRISMA-ScR reporting guidelines. A systematic search was conducted across PubMed, Scopus, Web of Science, CINAHL, and selected grey literature sources, covering publications from 2000 to 2024. Following screening and eligibility assessment, 147 sources were included in the review. The analysis identified six major adaptation domains: resilient healthcare infrastructure, climate-sensitive disease surveillance and early warning systems, workforce preparedness and capacity development, resilient medical supply chains, mental health adaptation, and governance and policy frameworks. The findings reveal considerable geographical disparities in adaptation research and implementation, with most evidence originating from high-income countries, while climate-vulnerable low- and middle-income countries remain underrepresented. The review suggests that climate adaptation within healthcare systems is advancing but remains uneven, fragmented, and insufficiently integrated into broader governance and sustainability frameworks. Strengthening institutional resilience, policy coordination, workforce preparedness, and long-term adaptation planning is essential for improving the capacity of healthcare systems to respond effectively to climate-related challenges.

Citation

Munir A., Waseem K., Sarbiland. (2026). Climate Adaptation, Health Governance, and Institutional Resilience: A Global Scoping Review. *Science, Education and Innovations in the Context of Modern Problems*, 9(8), 1–16. https://doi.org/10.56334/sei/9.8.16

Licensed

© 2026. The Author(s). Published by *Science, Education and Innovations in the Context of Modern Problems (SEI)*, under the auspices of IMCRA – International Meetings and Conferences Research Association (Azerbaijan). This is an open access article

distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
http://creativecommons.org/licenses/by/4.0/

Received: October 02, 2025 **Accepted**: May 13, 2026 **Published Online**: June 07, 2026

1. INTRODUCTION

Climate change has emerged as one of the most consequential global challenges of the twenty-first century, affecting not only environmental systems but also economic development, social well-being, institutional stability, and public governance (IPCC, 2021; Romanello et al., 2021). Increasing temperatures, extreme weather events, rising sea levels, changing precipitation patterns, and ecological disruptions are reshaping the conditions under which societies operate and develop. These transformations have profound implications for public institutions, particularly healthcare systems, which are increasingly required to respond to complex and interconnected climate-related risks (Watts et al., 2021; WHO, 2020).

Healthcare systems occupy a distinctive position within the climate change discourse. On the one hand, they serve as critical institutions responsible for protecting population health and responding to climate-related emergencies. On the other hand, healthcare infrastructures themselves are vulnerable to climate-induced disruptions, including extreme heat events, flooding, supply-chain interruptions, energy instability, and emerging disease burdens (Guenther & Balbus, 2014; WHO, 2020). As a result, climate adaptation has become a strategic priority for healthcare organizations seeking to maintain operational continuity, institutional resilience, and service effectiveness under conditions of environmental uncertainty.

Within contemporary policy discussions, climate adaptation refers to the processes through which institutions, communities, and governance systems adjust to actual or anticipated climatic conditions in order to reduce vulnerability and enhance resilience (IPCC, 2021). Unlike mitigation strategies, which focus primarily on reducing greenhouse gas emissions, adaptation emphasizes preparedness, responsiveness, and the capacity of institutions to function effectively despite changing environmental circumstances (Ebi & Hess, 2017). For healthcare systems, adaptation encompasses a broad range of activities, including resilient infrastructure planning, workforce preparedness, disease surveillance, emergency response systems, sustainable resource management, and institutional governance reforms (WHO, 2020; NHS England, 2020).

Recent scholarship has increasingly recognized that climate adaptation should not be viewed solely as a technical or environmental challenge but also as a matter of governance, institutional capacity, and sustainable development (Patz et al., 2014; Omrani et al., 2021). The effectiveness of adaptation strategies depends not only on technological innovation but also on organizational learning, policy coordination, professional training, and the ability of institutions to anticipate and respond to evolving risks. Consequently, healthcare resilience has become an important area of interdisciplinary research connecting public policy, sustainability studies, organizational management, and health systems governance.

Despite growing scholarly attention, the existing evidence base remains fragmented. Many studies focus on specific diseases, localized adaptation programs, or individual national experiences, while comprehensive syntheses of adaptation initiatives across healthcare settings remain relatively limited (Bouzid et al., 2013; Hess et al., 2020). Furthermore, the majority of available evidence originates from high-income countries, whereas climate-vulnerable regions in South Asia, Sub-Saharan Africa, and other low- and middle-income settings remain underrepresented despite facing disproportionate climate-related risks (Romanello et al., 2021; Pakistan National Disaster Management Authority, 2022).

This gap in the literature highlights the need for a broader understanding of how healthcare institutions worldwide are responding to climate-related challenges and how adaptation strategies are being integrated into governance structures, organizational practices, and long-term development planning. Mapping these experiences is essential for identifying successful approaches, recognizing persistent barriers, and informing future policy development.

Accordingly, the present scoping review aims to examine global climate adaptation initiatives within healthcare settings, identify major thematic domains of adaptation practice, explore geographical patterns of implementation, and highlight existing research and policy gaps. Particular attention is given to issues of institutional resilience, governance capacity, workforce preparedness, and sustainable health system development, with the objective of contributing to a more comprehensive understanding of adaptation in an era of accelerating environmental change.

2. METHODS

2.1 Study Design

This study employed a scoping review methodology based on the framework proposed by Arksey and O'Malley (2005) and further refined by Levac et al. (2010). Scoping reviews are particularly suitable for examining broad and multidisciplinary fields of inquiry where evidence is heterogeneous and where the objective is to map the scope, characteristics, and distribution of existing knowledge

rather than to assess intervention effectiveness through meta-analysis. The review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines (Tricco et al., 2018).

2.2 Research Question

The review was guided by the following research question:

What climate adaptation strategies have been implemented or proposed within healthcare settings globally, and what major themes, geographical patterns, institutional approaches, and knowledge gaps emerge from the existing literature?

2.3 Search Strategy

A comprehensive literature search was conducted across five major electronic databases: PubMed/MEDLINE, Scopus, Web of Science, CINAHL, and Embase. To enhance coverage and minimize publication bias, grey literature sources were also examined, including reports and policy documents published by the World Health Organization (WHO), the Intergovernmental Panel on Climate Change (IPCC), national health ministries, and international organizations involved in climate adaptation and sustainable development.

The search covered publications released between January 2000 and December 2024 and was restricted to English-language sources. Search terms were developed through an iterative process and included combinations of keywords related to climate change, adaptation, resilience, healthcare systems, hospitals, health governance, disease surveillance, workforce preparedness, infrastructure resilience, and sustainable health system development. Boolean operators (AND, OR) and database-specific indexing terms were employed to optimize retrieval and ensure consistency across sources.

The search strategy was designed to capture both empirical studies and policy-oriented publications addressing institutional responses to climate-related challenges within healthcare settings, thereby enabling a comprehensive assessment of adaptation initiatives at local, national, and international levels.

Table 1. Eligibility Criteria for Literature Selection

Inclusion Criteria	Exclusion Criteria
Peer-reviewed scholarly publications published in English	Non-scholarly publications and non-reviewed sources (except major institutional and policy documents)
Publications issued between 2000 and 2024	Publications released before 2000
Studies addressing climate adaptation, resilience, governance, or preparedness within healthcare systems and related institutions	Studies focusing exclusively on climate mitigation without adaptation or resilience dimensions
Research examining healthcare organizations, health governance, institutional resilience, public health preparedness, or adaptation policies	Studies unrelated to healthcare systems, institutional adaptation, or governance frameworks
Empirical, qualitative, mixed-methods, review, policy, and conceptual studies	Conference abstracts, editorials, commentaries, and duplicate records
Studies conducted across all geographical regions and income contexts	Publications for which full-text access was unavailable

Source: Developed by the authors based on Arksey and O'Malley (2005), Levac et al. (2010), and Tricco et al. (2018).

2.4 Study Selection

Following the database search, all retrieved records were imported into Rayyan systematic review software to facilitate reference management, duplicate removal, and screening procedures (Ouzzani et al., 2016). Consistent with established scoping review methodology (Arksey & O'Malley, 2005; Levac et al., 2010; Peters et al., 2020), two independent reviewers screened titles and abstracts against the predefined eligibility criteria. Full-text articles deemed potentially relevant were subsequently retrieved and assessed for final inclusion.

Disagreements between reviewers were resolved through discussion and consensus-building procedures. Where consensus could not be reached, a third reviewer was consulted to ensure methodological rigor and consistency in study selection. Inter-rater

reliability was assessed using Cohen's kappa coefficient, which is widely recognized as an indicator of agreement beyond chance in systematic evidence synthesis (McHugh, 2012; Viera & Garrett, 2005).

2.5 Data Extraction and Synthesis

A standardized data extraction form was developed based on recommendations for evidence mapping and scoping review methodology (Tricco et al., 2018; Peters et al., 2020). The extraction tool was piloted using a subset of ten studies to ensure consistency and clarity before full implementation.

Extracted variables included author information, year of publication, country or region of study, methodological design, healthcare setting, adaptation domain, specific adaptation strategies, target populations, and principal findings. Additional information relating to governance structures, institutional resilience, workforce preparedness, and policy frameworks was recorded where available.

Given the methodological diversity of the included literature, a narrative synthesis approach was employed (Popay et al., 2006). The synthesis focused on identifying recurring patterns, adaptation priorities, institutional responses, and geographical trends. Through an inductive thematic analysis process, six major domains of climate adaptation within healthcare systems were identified and subsequently used as the organizing framework for the presentation of findings (Braun & Clarke, 2006; Thomas & Harden, 2008).

3. RESULTS

3.1 Search Results and Study Characteristics

The initial database search identified 4,832 records. Following duplicate removal, 3,614 unique records remained for title and abstract screening. Of these, 412 publications were selected for full-text assessment, resulting in the inclusion of 147 sources in the final synthesis. The study selection process followed PRISMA-ScR recommendations and reflected accepted standards for scoping reviews (Tricco et al., 2018).

Inter-rater reliability during the full-text screening stage demonstrated a high level of agreement (Cohen's $\kappa = 0.81$), indicating substantial consistency between reviewers (McHugh, 2012). The geographical distribution of the included literature revealed a strong concentration of evidence originating from high-income countries, which accounted for approximately 67% of all studies. The United States (22%), the United Kingdom (14%), and Australia (11%) represented the most frequently studied contexts. Similar geographical patterns have been observed in previous climate-health reviews, reflecting disparities in research capacity, funding availability, and institutional adaptation resources (Romanello et al., 2021; Watts et al., 2021).

Studies from the Asia-Pacific region accounted for 18% of the evidence base, with India (7%), Bangladesh (4%), and the Philippines (3%) contributing the largest number of publications. Although these countries face significant climate-related vulnerabilities, the volume of adaptation research remains comparatively limited relative to the scale of anticipated health impacts (Haque et al., 2012; Omrani et al., 2021; Pakistan National Disaster Management Authority, 2022). Sub-Saharan Africa contributed 9% of included studies, further illustrating the persistent imbalance in global adaptation research despite the region's high exposure to climate-sensitive health risks (WHO, 2020; Romanello et al., 2021).

The included studies represented a diverse range of methodological approaches. Narrative and systematic reviews constituted 31% of the sample, reflecting the growing interest in synthesizing climate adaptation evidence across health systems (Bouzid et al., 2013; Hess et al., 2020). Empirical quantitative studies accounted for 27%, while qualitative and mixed-methods research represented 19% of the literature. Policy analyses contributed 14%, highlighting the increasing importance of governance and institutional adaptation within climate-health scholarship (WHO, 2020; NHS England, 2020). Case studies and program evaluations comprised the remaining 9%, providing context-specific insights into adaptation implementation and organizational learning processes (Guenther & Balbus, 2014).

Healthcare settings varied considerably across studies. Hospitals and tertiary care facilities represented the largest category (41%), followed by primary healthcare centers and community-based health services (28%). Public health agencies, ministries of health, and governmental organizations accounted for 18% of included studies, while integrated health systems and cross-sectoral adaptation initiatives comprised 13%. This distribution suggests that climate adaptation research is increasingly moving beyond clinical settings toward broader questions of institutional resilience, governance capacity, and sustainable health system development (WHO, 2020; Ebi & Hess, 2017; Patz et al., 2014).

3.2 Thematic Domains of Adaptation

Thematic analysis identified six major domains through which healthcare systems are adapting to climate-related challenges. These domains encompass resilient healthcare infrastructure, climate-sensitive surveillance and early warning systems, workforce preparedness and professional capacity development, resilient supply chains and pharmaceutical systems, mental health adaptation,

and governance and policy frameworks. Collectively, these themes demonstrate that adaptation is increasingly understood as a multidimensional process involving organizational resilience, institutional preparedness, policy coordination, and sustainable development planning rather than solely clinical or emergency responses (WHO, 2020; Romanello et al., 2021; NHS England, 2020; IPCC, 2021).

A summary of the identified adaptation domains, representative strategies, and regional examples is presented in Table 2.

Table 2. Major Domains of Climate Adaptation in Healthcare Systems and Institutional Responses

Adaptation Domain	Representative Adaptation Strategies	Illustrative Regional Examples	Strength of Evidence
Infrastructure Resilience	Climate-resilient hospital design, passive cooling systems, green building standards, flood-resistant facilities, renewable energy integration	Australia, United Kingdom, United States, Canada	Moderate–Strong
Climate Surveillance and Early Warning Systems	Climate-sensitive disease monitoring, heat-health warning systems, predictive risk assessment tools, integrated surveillance platforms	India, Bangladesh, Southeast Asia, Sub-Saharan Africa	Moderate
Workforce Preparedness and Capacity Building	Climate-health education, emergency preparedness training, occupational heat protection measures, resilience-oriented professional development	Middle East, South Asia, Australia	Emerging–Moderate
Supply Chain and Pharmaceutical Resilience	Climate-resilient logistics systems, cold-chain protection, decentralized procurement mechanisms, emergency stock management	Sub-Saharan Africa, South Asia, Small Island Developing States	Emerging
Mental Health and Psychosocial Adaptation	Post-disaster psychological support, community resilience programs, eco-anxiety interventions, trauma-informed care approaches	Australia, United States, United Kingdom, New Zealand	Moderate
Governance and Policy Frameworks	National adaptation plans, climate-health governance strategies, institutional resilience frameworks, WHO operational guidance, intersectoral coordination mechanisms	Global	Strong
Community Health and Local Adaptation	Heat action plans, community preparedness programs, climate-resilient WASH initiatives, local risk communication strategies	India, Bangladesh, Nepal, African countries	Strong
Digital Health and Technological Adaptation	Telemedicine, digital monitoring systems, remote consultations, disaster-response communication platforms, AI-supported risk forecasting	Global	Emerging–Moderate

Source: Developed by the authors based on WHO (2020), IPCC (2021), Romanello et al. (2021), NHS England (2020), Guenther and Balbus (2014), Omrani et al. (2021), and included studies.

3.2.1 Health Infrastructure Resilience

Health infrastructure resilience emerged as the most extensively documented adaptation domain, appearing in approximately 38% of the included studies. The literature consistently emphasizes that healthcare facilities are increasingly exposed to climate-related risks, including flooding, heatwaves, storms, energy disruptions, and water insecurity, all of which can compromise service delivery and institutional continuity (IPCC, 2021; WHO, 2020; Romanello et al., 2021; Watts et al., 2021). Consequently, adaptation efforts have increasingly focused on strengthening the physical resilience of healthcare infrastructure while integrating sustainability and long-term risk management into facility planning and operation.

The most frequently reported strategies involved climate-resilient hospital design, renewable energy integration, passive cooling systems, flood-resistant construction, and energy-efficient building technologies (Guenther & Balbus, 2014; NHS England, 2020; WHO, 2020). In high-income countries, green hospital initiatives have become an important component of adaptation planning,

combining environmental sustainability objectives with operational resilience. Several studies highlighted the role of climate-responsive architecture, decentralized energy systems, and emergency backup infrastructure in reducing vulnerability to extreme weather events (Health Care Without Harm, 2019; Romanello et al., 2021; Hess et al., 2020).

Flood adaptation measures were particularly prominent within South Asian and Small Island Developing State contexts, where healthcare facilities are increasingly exposed to recurrent flooding and coastal hazards (Haque et al., 2012; WHO, 2020). Studies from Bangladesh reported the elevation of healthcare facilities, installation of emergency power generation systems, climate-resilient water management infrastructure, and strategic stockpiling of essential medicines and emergency supplies (Hashizume et al., 2008; Haque et al., 2012). Similar approaches were documented in vulnerable coastal regions across Southeast Asia and the Pacific.

Heat resilience represented another major adaptation theme. Interventions included cool-roof technologies, passive ventilation systems, shaded outdoor spaces, urban greening initiatives, and heat-resistant building materials designed to reduce thermal stress on both patients and healthcare workers (WHO, 2020; Ebi & Hess, 2017; Romanello et al., 2021). These measures were most frequently reported in Australia, the Middle East, and South Asia, where prolonged heat exposure increasingly threatens healthcare operations and workforce productivity (Watts et al., 2021; IPCC, 2021).

Across all regions, emergency preparedness planning emerged as a cross-cutting component of infrastructure resilience. Adaptation measures included climate emergency response protocols, evacuation planning, redundant communication systems, emergency water and power supplies, and integrated disaster preparedness frameworks (WHO, 2020; Guenther & Balbus, 2014; NHS England, 2020). Collectively, the evidence suggests that resilient healthcare infrastructure is increasingly recognized as a foundational component of climate adaptation and institutional preparedness.

3.2.2 Climate-Sensitive Disease Surveillance and Early Warning Systems

Climate-sensitive surveillance and early warning systems constituted the second most prominent adaptation domain, appearing in approximately 29% of included studies. The literature highlights the growing importance of surveillance systems capable of identifying, monitoring, and forecasting climate-related health risks, thereby enabling timely public health responses and reducing vulnerability to disease outbreaks and environmental hazards (WHO, 2008; Ebi & Hess, 2017; Hess et al., 2020).

Many of the reviewed studies emphasized the integration of meteorological, environmental, and epidemiological data into early warning systems designed to anticipate climate-sensitive diseases (Hales et al., 2002; Omrani et al., 2021). Such systems facilitate proactive interventions by providing health authorities with information regarding changing disease patterns associated with temperature fluctuations, rainfall variability, flooding, and other climate-related factors.

In South and Southeast Asia, dengue fever surveillance represented one of the most extensively documented adaptation initiatives. Studies reported the use of predictive models combining meteorological indicators, vector surveillance, and disease incidence data to support early intervention strategies (Hales et al., 2002; Omrani et al., 2021). India's Integrated Disease Surveillance Programme (IDSP) and dengue forecasting initiatives implemented in the Philippines were frequently cited as examples of climate-informed surveillance systems capable of improving preparedness and response capacity.

Waterborne disease surveillance also emerged as a significant adaptation priority. Research conducted in Bangladesh, Cambodia, and several African countries demonstrated the value of rainfall-based and flood-triggered monitoring systems for cholera and other water-related diseases (Hashizume et al., 2008; WHO, 2020; Ebi & Hess, 2017). These systems allow public health authorities to identify high-risk periods and mobilize preventive interventions before outbreaks escalate.

Heat-health warning systems were particularly prominent in European, Australian, and North American contexts. The literature consistently indicates that such systems can significantly reduce heat-related morbidity and mortality through timely public advisories, activation of cooling centers, workforce mobilization, and targeted protection of vulnerable populations (Watts et al., 2021; Romanello et al., 2021; WHO, 2020). The evidence therefore suggests that surveillance and early warning systems represent one of the most cost-effective adaptation strategies available to healthcare systems facing increasing climate uncertainty.

3.2.3 Health Workforce Preparedness

Health workforce preparedness was identified as a critical yet comparatively underdeveloped adaptation domain, appearing substantively in approximately 21% of the reviewed literature. Despite growing recognition of climate-related health risks, many studies reported significant gaps in professional knowledge, institutional training, and workforce readiness (Maxwell & Blashki, 2016; WHO, 2020; Romanello et al., 2021).

Several studies from South Asia, Africa, and the Middle East indicated that healthcare professionals often receive limited formal education regarding climate-sensitive diseases, environmental health risks, and adaptation planning (Maxwell & Blashki, 2016;

Omrani et al., 2021). Surveys conducted among medical students and healthcare workers revealed concerns regarding preparedness for climate-related health emergencies and the management of emerging environmental health challenges.

The most frequently reported adaptation strategies included integrating climate-health competencies into undergraduate and postgraduate curricula, developing continuing professional development programs, and strengthening interdisciplinary collaboration between health and environmental sectors (Maxwell & Blashki, 2016; WHO, 2020). Additional interventions focused on occupational heat protection measures, climate emergency training, disaster preparedness exercises, and community-based health education initiatives.

Several institutional models demonstrated promising practices. Australia's Climate and Health Alliance and the United Kingdom's Centre for Sustainable Healthcare were frequently cited as examples of organizations actively promoting climate literacy, workforce resilience, and sustainable healthcare leadership (Romanello et al., 2021; NHS England, 2020). Overall, the literature suggests that workforce preparedness remains a crucial prerequisite for effective adaptation and requires greater investment in education, training, and institutional capacity building.

3.2.4 Supply Chain and Pharmaceutical Resilience

Climate-related disruptions to supply chains and pharmaceutical systems emerged as an increasingly important area of adaptation, appearing in approximately 18% of included studies. Extreme weather events, transportation interruptions, infrastructure failures, and prolonged heat exposure have the potential to compromise access to essential medicines, vaccines, medical devices, and emergency supplies (WHO, 2020; Guenther & Balbus, 2014).

The reviewed literature highlights particular concerns regarding cold-chain management, especially in tropical and resource-constrained settings where temperature-sensitive vaccines and biologics are vulnerable to climatic variability (WHO, 2020; Health Care Without Harm, 2019). Adaptation measures included climate-resilient storage facilities, backup energy systems, decentralized logistics networks, and enhanced monitoring technologies designed to protect pharmaceutical integrity during extreme events.

Other frequently reported strategies involved diversification of procurement channels, establishment of emergency stockpiles, development of contingency distribution plans, and integration of climate risk assessments into supply-chain management frameworks (WHO, 2020; NHS England, 2020). Several studies emphasized that reliance on single-source suppliers may increase vulnerability during climate-related crises and recommended greater supply-chain redundancy as a resilience strategy.

The WHO Health Emergency and Disaster Risk Management (Health-EDRM) framework has increasingly been used as a reference point for strengthening supply-chain preparedness and institutional resilience (WHO, 2020). Nevertheless, substantial implementation gaps remain, particularly in low- and middle-income countries where financial, technological, and logistical constraints continue to limit adaptation capacity (Romanello et al., 2021; Omrani et al., 2021).

3.2.5 Mental Health Adaptation

The mental health dimensions of climate adaptation have emerged as one of the fastest-growing yet comparatively underdeveloped areas within the climate-health literature, appearing in approximately 16% of the reviewed studies. Increasing evidence suggests that climate change affects mental well-being through multiple pathways, including direct exposure to extreme weather events, prolonged environmental uncertainty, ecological degradation, forced displacement, and disruptions to livelihoods and social networks (Clayton et al., 2017; Berry et al., 2010; Cianconi et al., 2020; Romanello et al., 2021). Consequently, mental health adaptation is increasingly recognized as an essential component of climate-resilient healthcare systems.

The reviewed literature identified three principal categories of climate-related mental health challenges. The first involves acute psychological responses associated with climate-related disasters, including floods, cyclones, droughts, heatwaves, and wildfires. These events have been associated with increased prevalence of post-traumatic stress disorder, anxiety disorders, depression, and prolonged psychological distress among affected populations (Berry et al., 2010; Clayton et al., 2017; Cianconi et al., 2020). The second category concerns chronic psychological impacts linked to climate anxiety, ecological grief, solastalgia, and perceptions of environmental loss, particularly among younger populations and communities highly dependent on natural resources (Clayton et al., 2017; Romanello et al., 2021). The third involves mental health consequences associated with climate-induced migration, displacement, economic insecurity, and social disruption, which may contribute to long-term psychosocial vulnerability (WHO, 2023; UNEP, 2023).

Adaptation initiatives identified in the literature included integration of psychosocial support into disaster preparedness frameworks, expansion of community mental health services, development of climate-sensitive mental health policies, and training programs designed to strengthen the capacity of primary healthcare professionals to identify and address climate-related psychological distress (WHO, 2020; Clayton et al., 2017; Cianconi et al., 2020). Several studies emphasized the importance of

community resilience programs, social support networks, and culturally responsive interventions in reducing vulnerability and promoting psychological adaptation (Berry et al., 2010; WHO, 2024).

Most available evidence originates from Australia, the United States, Canada, and the United Kingdom, where climate-related mental health research has expanded substantially over the past decade (Clayton et al., 2017; Romanello et al., 2021). By contrast, significant research gaps remain across South Asia, Sub-Saharan Africa, and other climate-vulnerable regions despite growing evidence of climate-related psychosocial burdens in these contexts (UNDP, 2023; WHO, 2024). The findings suggest that mental health adaptation remains insufficiently integrated into broader health adaptation strategies and requires greater policy attention, funding, and institutional support.

3.2.6 Health Policy and Governance Frameworks

Health policy and governance emerged as one of the most influential adaptation domains, appearing as a primary focus in approximately 34% of included studies and as a cross-cutting theme throughout much of the broader literature. Scholars increasingly argue that climate adaptation should be understood not merely as a technical challenge but as a governance issue requiring coordinated institutional action, strategic planning, stakeholder engagement, and long-term policy commitment (Bowen & Ebi, 2015; Biesbroek et al., 2015; WHO, 2020).

The literature consistently highlights the importance of governance capacity in determining the effectiveness of adaptation efforts. Successful adaptation depends upon policy integration, intersectoral collaboration, sustainable financing mechanisms, monitoring systems, and institutional learning processes capable of responding to evolving climate risks (Patz et al., 2014; Azzopardi-Muscat et al., 2023; OECD, 2023). Healthcare adaptation therefore increasingly involves collaboration between public health agencies, environmental authorities, disaster management institutions, local governments, and community organizations.

At the international level, the WHO Resolution WHA61.19 on Climate Change and Health and the Operational Framework for Building Climate-Resilient and Low-Carbon Health Systems provide an important foundation for adaptation planning and implementation (WHO, 2008; WHO, 2020). More recent guidance from WHO, UNEP, and the World Bank has further emphasized the integration of climate resilience into health governance, institutional planning, and sustainable development strategies (WHO, 2024; UNEP, 2023; World Bank, 2023).

National adaptation frameworks have also expanded considerably. Countries such as the United Kingdom, Australia, Canada, New Zealand, and India have adopted adaptation plans that incorporate health-sector resilience, emergency preparedness, and climate-sensitive risk management (NHS England, 2020; Romanello et al., 2021). However, substantial differences remain regarding implementation capacity, funding availability, and institutional coordination, particularly among low- and middle-income countries where climate vulnerability is often greatest (OECD, 2023; WHO, 2024).

Overall, the literature suggests that governance structures play a decisive role in determining whether adaptation efforts remain fragmented and reactive or become integrated, equitable, and sustainable components of long-term health system development.

4. DISCUSSION

4.1 Principal Findings

This review provides a comprehensive synthesis of climate adaptation initiatives implemented within healthcare systems globally. The identification of six major adaptation domains—healthcare infrastructure resilience, climate-sensitive surveillance systems, workforce preparedness, supply-chain resilience, mental health adaptation, and governance frameworks—demonstrates the multidimensional nature of climate-related challenges facing healthcare institutions (WHO, 2020; IPCC, 2021; Romanello et al., 2021).

A key finding of the review is that adaptation is increasingly conceptualized as a systemic and institutional process rather than a collection of isolated technical interventions. The literature indicates that resilient healthcare systems require integrated approaches combining infrastructure investments, workforce development, governance reforms, digital innovation, and community engagement (Guenther & Balbus, 2014; Kruk et al., 2017; WHO, 2024). This observation aligns with contemporary resilience frameworks emphasizing adaptive capacity, organizational learning, and long-term sustainability as core dimensions of institutional preparedness (Castleden et al., 2011; OECD, 2023).

4.2 Geographic and Equity Disparities

One of the most significant findings concerns the unequal geographical distribution of adaptation research and implementation. High-income countries continue to dominate the evidence base despite often possessing stronger infrastructure, greater financial resources, and more developed institutional capacities than many climate-vulnerable regions (Romanello et al., 2021; Berrang-Ford et al., 2021).

By contrast, regions such as South Asia and Sub-Saharan Africa remain substantially underrepresented in the adaptation literature despite facing some of the most severe climate-related health risks globally (WHO, 2024; UNDP, 2023; Pakistan National Disaster Management Authority, 2022). This imbalance reflects broader inequalities in research funding, institutional capacity, and access to scientific infrastructure. It also limits the development of context-specific adaptation knowledge capable of informing policy and practice in vulnerable settings (Lesnikowski et al., 2015; OECD, 2023).

The findings suggest that adaptation should increasingly be approached through principles of climate justice and equity, recognizing that those populations contributing least to global emissions frequently experience the greatest climate-related vulnerabilities (Berrang-Ford et al., 2021; UNEP, 2023). Addressing these disparities will require targeted investment in local research capacity, knowledge exchange, and institutional strengthening across low- and middle-income countries.

4.3 The Workforce Preparedness Gap

The limited attention devoted to workforce preparedness represents one of the most important gaps identified in this review. Although healthcare professionals constitute the foundation of adaptation implementation, relatively few studies have examined climate literacy, workforce competencies, and professional preparedness in a systematic manner (Maxwell & Blashki, 2016; WHO, 2020).

The literature consistently demonstrates that many healthcare workers report insufficient training regarding climate-sensitive diseases, environmental health risks, and adaptation planning (Maxwell & Blashki, 2016; Romanello et al., 2021). These findings raise concerns regarding the capacity of healthcare systems to respond effectively to increasingly complex climate-related challenges.

Several international organizations and academic initiatives have called for the integration of climate and planetary health competencies into medical, nursing, and public health education (Lancet Countdown, WHO, and OECD reports). However, implementation remains uneven, particularly within low- and middle-income countries where educational resources are often limited (WHO, 2024; OECD, 2023; Romanello et al., 2021). Strengthening workforce preparedness therefore represents not only an educational priority but also a critical component of long-term health system resilience and sustainable adaptation.

4.4 Mental Health: An Underexplored Dimension of Climate Adaptation

One of the most significant gaps identified in this review concerns the limited integration of mental health considerations into climate adaptation frameworks. Although a growing body of research demonstrates that climate change affects psychological well-being through multiple pathways, mental health remains comparatively underrepresented in adaptation planning and policy development (Clayton et al., 2017; Berry et al., 2010; Cianconi et al., 2020). Climate-related mental health impacts extend beyond the immediate consequences of extreme weather events and include chronic stress, ecological grief, climate anxiety, uncertainty regarding future environmental conditions, and disruptions to social and economic stability (Romanello et al., 2021; WHO, 2024).

The literature indicates that exposure to floods, cyclones, droughts, wildfires, and other climate-related disasters is associated with elevated risks of depression, anxiety disorders, post-traumatic stress disorder, and long-term psychological distress (Berry et al., 2010; Clayton et al., 2017; Cianconi et al., 2020). These effects are often intensified by displacement, livelihood insecurity, and the weakening of social support networks. In addition, recent studies have highlighted the emergence of climate anxiety and eco-anxiety, particularly among younger populations who perceive climate change as a persistent threat to their future well-being (Clayton et al., 2017; Romanello et al., 2021).

Despite increasing recognition of these challenges, mental health considerations are frequently absent from national adaptation strategies and institutional resilience plans (WHO, 2023; UNEP, 2023). This gap is particularly evident in low- and middle-income countries, where climate vulnerability is high while mental health services remain under-resourced and unevenly distributed (UNDP, 2023; WHO, 2024). South Asia represents a particularly important case, as recurrent floods, heatwaves, and environmental degradation coincide with limited mental health infrastructure and substantial barriers to care.

The findings suggest that effective adaptation frameworks should incorporate mental health as a core dimension of resilience planning rather than as a secondary consequence of climate-related events. Priority areas include the integration of psychosocial support into disaster preparedness programs, expansion of community-based mental health services, strengthening of primary healthcare screening mechanisms, and development of culturally appropriate interventions designed to enhance social and psychological resilience (WHO, 2020; Clayton et al., 2017; Cianconi et al., 2020). Addressing these challenges is essential for ensuring that climate adaptation strategies promote not only physical health protection but also broader social well-being and community resilience.

4.5 Technology, Digital Transformation, and Climate Adaptation

An emerging theme identified across the reviewed literature is the growing role of digital technologies in supporting climate adaptation within healthcare systems. Although digital health was not originally conceptualized as a separate adaptation domain, recent developments indicate that technological innovation is becoming increasingly important for enhancing institutional resilience, service continuity, and adaptive capacity (WHO, 2024; Liao et al., 2023).

Digital health technologies contribute to adaptation through several mechanisms. Telemedicine platforms facilitate healthcare access during climate-related emergencies and support service delivery in geographically isolated or disaster-affected communities (WHO, 2023; Liao et al., 2023). Health information systems increasingly integrate environmental, meteorological, and epidemiological data to improve disease surveillance and support evidence-based decision-making (Ebi & Hess, 2017; Cowie et al., 2022). Furthermore, advances in artificial intelligence and machine learning have enabled the development of predictive models capable of identifying climate-sensitive disease risks and supporting early warning systems with greater accuracy (Cowie et al., 2022; Majeed et al., 2024).

The literature also highlights the importance of digital platforms in strengthening institutional preparedness, resource management, and communication during climate-related disruptions (World Bank, 2023; OECD, 2023). Digital monitoring systems can improve emergency response coordination, facilitate rapid information exchange, and support continuity of care when traditional infrastructure is compromised. Such capabilities are particularly relevant in contexts characterized by increasing climate uncertainty and growing pressure on healthcare resources.

Nevertheless, the benefits of digital adaptation are not distributed equally. Significant disparities persist between countries and regions in terms of digital infrastructure, technological capacity, internet accessibility, and workforce competencies (UNDP, 2023; World Bank, 2023). Consequently, digital transformation may inadvertently create new forms of adaptation inequality if technological resources remain concentrated within wealthier healthcare systems. Addressing these disparities requires targeted investment in digital infrastructure, capacity building, and equitable access to technological innovation.

Overall, the findings suggest that digital transformation is becoming an increasingly important component of climate adaptation and institutional resilience. Future adaptation strategies should therefore consider technological innovation not merely as a supportive tool but as a strategic element of sustainable and resilient healthcare system development.

4.6 Research Gaps and Future Priorities

The synthesis of the reviewed literature reveals that although climate adaptation within healthcare systems has received increasing scholarly and policy attention, significant knowledge gaps and implementation challenges persist. These gaps are not distributed evenly across regions and adaptation domains, reflecting broader inequalities in research capacity, financial resources, governance structures, and institutional preparedness (Berrang-Ford et al., 2021; WHO, 2024; OECD, 2023).

One of the most prominent findings concerns the geographical concentration of adaptation evidence in high-income countries. Many climate-vulnerable regions, particularly South Asia, Sub-Saharan Africa, and Small Island Developing States, remain substantially underrepresented despite experiencing disproportionate climate-related health risks (UNDP, 2023; World Bank, 2023). Furthermore, the literature lacks standardized indicators capable of evaluating adaptation effectiveness across different healthcare systems and institutional contexts. This limits comparative analysis and constrains evidence-based policy development (WHO, 2023).

The review also highlights persistent deficiencies in workforce preparedness, mental health adaptation, and digital inclusion. While climate-sensitive surveillance systems and infrastructure resilience have attracted growing investment, comparatively less attention has been devoted to climate literacy among healthcare professionals, psychosocial resilience, and equitable access to digital adaptation technologies (Romanello et al., 2021; Maxwell & Blashki, 2016; Clayton et al., 2017).

Future research should therefore prioritize interdisciplinary approaches that integrate governance, institutional resilience, digital transformation, and social equity into climate adaptation planning. Greater attention should also be directed toward implementation research capable of evaluating adaptation outcomes under diverse environmental, economic, and socio-political conditions.

Table 3. Key Research Gaps and Future Priorities for Climate Adaptation in Healthcare Systems

Identified Gap	Potential Implications	Strategic Priority
Limited evidence from low- and middle-income countries	Adaptation policies may not reflect the needs of the most climate-vulnerable populations	Increase targeted research funding, institutional partnerships, and local capacity-building initiatives

Absence of standardized adaptation indicators	Difficulty evaluating and comparing adaptation effectiveness across healthcare systems	Develop internationally accepted climate-health adaptation metrics and monitoring frameworks
Underrepresentation of mental health adaptation	Growing psychosocial burdens remain insufficiently addressed within adaptation planning	Integrate mental health services, psychosocial resilience programs, and community support mechanisms into adaptation strategies
Insufficient climate literacy among healthcare professionals	Reduced preparedness for climate-sensitive health challenges and emergencies	Incorporate climate-health competencies into undergraduate, postgraduate, and continuing professional education
Weak implementation of adaptation policies at institutional level	National adaptation plans may fail to produce measurable operational outcomes	Strengthen governance mechanisms, accountability systems, and implementation monitoring frameworks
Unequal access to digital adaptation technologies	Expansion of technological disparities and adaptation inequalities	Invest in digital infrastructure, workforce training, and equitable technology access
Limited evaluation of adaptation effectiveness	Uncertainty regarding the long-term impact of adaptation interventions	Promote longitudinal and comparative studies assessing adaptation outcomes
Fragmented intersectoral coordination	Reduced efficiency of adaptation planning and emergency response systems	Enhance collaboration among health, environment, disaster management, and development sectors
Limited evidence on institutional resilience models	Lack of transferable best practices for healthcare adaptation	Support comparative research on resilient healthcare governance and organizational adaptation
Inadequate integration of sustainability principles	Adaptation efforts may remain reactive rather than transformative	Align adaptation planning with sustainable development and long-term resilience objectives

Source: Developed by the authors based on WHO (2020, 2024), IPCC (2021, 2022), Romanello et al. (2021), OECD (2023), World Bank (2023), and studies included in the review.

4.7 Implications for South Asian Health Systems

The findings of this review have particular relevance for South Asia, one of the world's most climate-vulnerable regions. Rapid urbanization, population growth, environmental degradation, socioeconomic inequalities, and increasing exposure to extreme weather events create substantial challenges for healthcare systems across the region (IPCC, 2021; Romanello et al., 2021). Recent climate-related disasters have demonstrated the vulnerability of public institutions and highlighted the need for more resilient and adaptive healthcare systems capable of responding effectively to emerging environmental risks.

The 2022 floods in Pakistan provide a notable example of the consequences of insufficient institutional preparedness. The disaster severely disrupted healthcare services, damaged healthcare infrastructure, and exposed existing weaknesses in emergency response capacity, health governance, and disaster management coordination (Pakistan National Disaster Management Authority, 2022). Similar vulnerabilities have been documented in Bangladesh, India, Nepal, and Sri Lanka, where climate-sensitive diseases, flooding, heatwaves, and environmental stresses increasingly interact with demographic pressures and resource constraints (Haque et al., 2012; WHO, 2024).

The review suggests that adaptation should be viewed not merely as a health-sector responsibility but as a broader issue of governance, institutional resilience, and sustainable development. Effective adaptation requires coordinated planning across multiple sectors, including health, environment, education, infrastructure, disaster risk reduction, and local government administration (OECD, 2023; World Bank, 2023). Strengthening healthcare resilience therefore depends on the ability of institutions to anticipate risks, mobilize resources, and implement long-term adaptation strategies rather than relying solely on emergency responses.

Several priority areas emerge from the reviewed evidence. These include strengthening climate-resilient healthcare infrastructure, expanding climate-sensitive surveillance systems, improving workforce preparedness, integrating climate literacy into professional education, enhancing digital health capacities, and developing community-based adaptation initiatives tailored to local

environmental conditions (WHO, 2020; NHS England, 2020; Romanello et al., 2021). Particular attention should be directed toward rural and underserved populations, where climate vulnerability and healthcare inequalities often intersect.

Regional cooperation also represents an important but underutilized opportunity. Collaborative initiatives involving South Asian countries could facilitate the exchange of knowledge, institutional experiences, technological innovations, and policy solutions. Greater cooperation through regional platforms may strengthen adaptation capacity while reducing duplication of efforts and promoting more equitable responses to shared climate challenges (UNDP, 2023; UNEP, 2023).

5. CONCLUSION

This review provides a comprehensive synthesis of climate adaptation strategies implemented within healthcare systems across diverse geographical contexts. The findings identify six major domains of adaptation—healthcare infrastructure resilience, climate-sensitive surveillance systems, workforce preparedness, supply-chain resilience, mental health adaptation, and governance frameworks—demonstrating that climate adaptation is a multidimensional process requiring coordinated institutional responses.

The review further reveals substantial geographical and structural inequalities in adaptation research and implementation. While high-income countries account for the majority of available evidence, many climate-vulnerable regions continue to face significant limitations in research capacity, financial resources, technological infrastructure, and institutional preparedness (Berrang-Ford et al., 2021; WHO, 2024). These disparities highlight the importance of equity-oriented adaptation strategies capable of supporting vulnerable populations and strengthening resilience where climate risks are most severe.

A central conclusion of this study is that climate adaptation should be understood not solely as an environmental or healthcare challenge but as a broader issue of governance, institutional capacity, and sustainable development. Effective adaptation requires long-term planning, intersectoral coordination, workforce development, digital innovation, and resilient public institutions capable of responding to increasingly complex environmental conditions (OECD, 2023; World Bank, 2023; WHO, 2024).

The findings also emphasize the growing importance of integrating adaptation into routine health system planning rather than treating climate-related risks as exceptional events. Healthcare resilience depends not only on physical infrastructure but also on organizational learning, policy coherence, professional competencies, and community engagement. Investments in these areas can contribute to more adaptive, equitable, and sustainable healthcare systems.

Future research should prioritize underrepresented regions, strengthen comparative evidence on adaptation effectiveness, and develop standardized frameworks for monitoring adaptation outcomes. Greater attention should also be devoted to mental health adaptation, workforce preparedness, digital inclusion, and institutional resilience. By advancing these priorities, policymakers, researchers, and healthcare organizations can contribute to the development of health systems capable of addressing the challenges of a rapidly changing climate while supporting broader sustainable development objectives.

5. DECLARATIONS

Acknowledgements

The authors would like to acknowledge the valuable contributions of researchers, healthcare professionals, policymakers, and international organizations whose work in the fields of climate change adaptation, health systems resilience, and sustainable development informed the conceptual foundation of this review. The authors are also grateful to the institutions and initiatives that make climate and health research publicly accessible. No external assistance was received in the preparation of this manuscript.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article. The study was conducted independently and without funding from any governmental, commercial, or non-profit organization.

Conflict of Interest

The authors declare that they have no known competing financial interests, personal relationships, or professional affiliations that could have appeared to influence the work reported in this paper.

Author Contributions

Conceptualization: *Munir Ahmad, Waseem Khokhar*
Methodology: *Munir Ahmad, Waseem Khokhar, Sarbiland*
Literature Search and Data Collection: *Munir Ahmad*
Data Analysis and Interpretation: *Munir Ahmad, Waseem Khokhar*
Writing – Original Draft Preparation: *Munir Ahmad*

Writing – Review and Editing: *Waseem Khokhar, Sarbiland*
Supervision: Waseem Khokhar, *Sarbiland*

All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Ethical Approval

Ethical approval was not required for this study because it is based exclusively on published literature, publicly available reports, and secondary data sources. No human participants, animals, or confidential data were involved in the research process.

Data Availability Statement

All data analyzed during this study are derived from publicly available sources cited in the reference list. No new datasets were generated during the preparation of this review.

Generative AI Statement

The authors declare that generative artificial intelligence (AI) tools were used solely for limited language refinement, grammar checking, and editorial assistance during manuscript preparation. All conceptualization, literature selection, analysis, interpretation of findings, and scholarly conclusions were performed by the authors. The authors take full responsibility for the accuracy, integrity, and originality of the content presented in this article.

Informed Consent Statement

Not applicable.

Publisher's Note

The views and conclusions expressed in this article are those of the authors and do not necessarily reflect the official policies or positions of their affiliated institutions. The publisher remains neutral with regard to jurisdictional claims in published maps, institutional affiliations, and territorial boundaries.

Declaration of Originality

The authors declare that this manuscript is an original work, has not been published previously, and is not under consideration for publication elsewhere. All sources used in the preparation of this manuscript have been appropriately acknowledged and cited.

6. REFERENCES:

1. Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology, 8*(1), 19–32. https://doi.org/10.1080/1364557032000119616
2. Azzopardi-Muscat, N., Schröder-Bäck, P., Brand, H., & Permanand, G. (2023). Climate change and health systems resilience in Europe: Emerging policy challenges and governance responses. *Health Policy, 136*, 104910. https://doi.org/10.1016/j.healthpol.2023.104910
3. Balbus, J. M., Malina, C., & Ebi, K. L. (2024). Climate change, health systems, and adaptation planning: Emerging priorities for resilient healthcare. *The Lancet Planetary Health, 8*(2), e95–e103. https://doi.org/10.1016/S2542-5196(23)00345-7
4. Bell, J. E., Brown, C. L., Conlon, K., Herring, S., Kunkel, K. E., Lawrimore, J., ... & Uejio, C. K. (2018). Changes in extreme events and the potential impacts on human health. *Journal of the Air & Waste Management Association, 68*(4), 265–287. https://doi.org/10.1080/10962247.2017.1401017
5. Berrang-Ford, L., Siders, A. R., Lesnikowski, A., Fischer, A. P., Callaghan, M. W., Haddaway, N. R., ... & Araos, M. (2021). A systematic global stocktake of evidence on human adaptation to climate change. *Nature Climate Change, 11*(11), 989–1000. https://doi.org/10.1038/s41558-021-01170-y
6. Berry, H. L., Bowen, K., & Kjellstrom, T. (2010). Climate change and mental health: A causal pathways framework. *International Journal of Public Health, 55*(2), 123–132. https://doi.org/10.1007/s00038-009-0112-0
7. Berry, H. L., Bowen, K., & Kjellstrom, T. (2010). Climate change and mental health: A causal pathways framework. *International Journal of Public Health, 55*(2), 123–132. https://doi.org/10.1007/s00038-009-0112-0
8. Biesbroek, R., Dupuis, J., Jordan, A., Wellstead, A., Howlett, M., Cairney, P., & Rayner, J. (2015). Opening up the black box of adaptation decision-making. *Nature Climate Change, 5*(6), 493–494. https://doi.org/10.1038/nclimate2615

9. Bouzid, M., Hooper, L., & Hunter, P. R. (2013). The effectiveness of public health interventions to reduce the health impact of climate change: A systematic review of systematic reviews. *PLoS ONE, 8*(4), e62041. https://doi.org/10.1371/journal.pone.0062041
10. Bowen, K. J., & Ebi, K. L. (2015). Governing the health risks of climate change: Towards multi-sector responses. *Current Opinion in Environmental Sustainability, 12*, 80–85. https://doi.org/10.1016/j.cosust.2014.12.001
11. Boylan, S. M., Beyer, K., Schlosberg, D., Mortimer, A., & Huss, A. (2022). Health and climate change: Adaptation policy, governance, and implementation challenges. *International Journal of Environmental Research and Public Health, 19*(21), 13811. https://doi.org/10.3390/ijerph192113811
12. Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa
13. Castleden, M., McKee, M., Murray, V., & Leonardi, G. (2011). Resilience thinking in health protection. *Journal of Public Health, 33*(3), 369–377. https://doi.org/10.1093/pubmed/fdr027
14. Cianconi, P., Betrò, S., & Janiri, L. (2020). The impact of climate change on mental health: A systematic descriptive review. *Frontiers in Psychiatry, 11*, 74. https://doi.org/10.3389/fpsyt.2020.00074
15. Clayton, S., Manning, C. M., Krygsman, K., & Speiser, M. (2017). *Mental health and our changing climate: Impacts, implications, and guidance*. American Psychological Association and ecoAmerica.
16. Cowie, R. L., Mithani, S. S., & Bhattacharyya, S. (2022). Artificial intelligence and machine learning applications in climate-sensitive disease prediction. *The Lancet Digital Health, 4*(4), e245–e253. https://doi.org/10.1016/S2589-7500(22)00015-6
17. Ebi, K. L., & Hess, J. J. (2017). Health in the new scenarios for climate change research and assessment. *Environmental Health Perspectives, 125*(7), 074008. https://doi.org/10.1289/EHP734
18. Ebi, K. L., Vanos, J., Baldwin, J. W., Bell, J. E., Hondula, D. M., Errett, N. A., ... & Berry, P. (2021). Extreme weather and climate change: Population health and health system implications. *Annual Review of Public Health, 42*, 293–315. https://doi.org/10.1146/annurev-publhealth-012420-105026
19. European Environment Agency. (2024). *Responding to climate change impacts on human health in Europe*. Publications Office of the European Union.
20. Frumkin, H., Hess, J., Luber, G., Malilay, J., & McGeehin, M. (2008). Climate change: The public health response. *American Journal of Public Health, 98*(3), 435–445. https://doi.org/10.2105/AJPH.2007.119362
21. Guenther, R., & Balbus, J. (2014). *Primary protection: Enhancing health care resilience for a changing climate*. U.S. Department of Health and Human Services.
22. Haines, A., Kovats, R. S., Campbell-Lendrum, D., & Corvalán, C. (2006). Climate change and human health: Impacts, vulnerability, and public health. *Public Health, 120*(7), 585–596. https://doi.org/10.1016/j.puhe.2006.01.002
23. Hales, S., de Wet, N., Maindonald, J., & Woodward, A. (2002). Potential effect of population and climate changes on global distribution of dengue fever: An empirical model. *The Lancet, 360*(9336), 830–834. https://doi.org/10.1016/S0140-6736(02)09964-6
24. Haque, U., Hashizume, M., Kolivras, K. N., Overgaard, H. J., Das, B., & Yamamoto, T. (2012). Reduced death rates from cyclones in Bangladesh: What more needs to be done? *Bulletin of the World Health Organization, 90*(2), 150–156. https://doi.org/10.2471/BLT.11.088302
25. Hashizume, M., Armstrong, B., Hajat, S., Wagatsuma, Y., Faruque, A. S. G., Hayashi, T., & Sack, D. A. (2008). The effect of rainfall on the incidence of cholera in Bangladesh. *Epidemiology, 19*(1), 103–110. https://doi.org/10.1097/EDE.0b013e31815c09ea
26. Health Care Without Harm. (2019). *Health care's climate footprint: How the health sector contributes to the global climate crisis and opportunities for action*. Health Care Without Harm.
27. Hess, J. J., Ranadive, N., Boyer, C., Aleksandrowicz, L., Anenberg, S. C., Aunan, K., ... & Wellenius, G. A. (2020). Guidelines for modeling and reporting health effects of climate change mitigation actions. *Environmental Health Perspectives, 128*(11), 115001. https://doi.org/10.1289/EHP6745
28. Hosking, J., Campbell-Lendrum, D., & Mavrogianni, A. (2021). Climate change and health: Progress in adaptation and resilience. *Current Environmental Health Reports, 8*(4), 437–447. https://doi.org/10.1007/s40572-021-00330-4

29. Intergovernmental Panel on Climate Change. (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157896
30. Intergovernmental Panel on Climate Change. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Cambridge University Press.
31. Kruk, M. E., Ling, E. J., Bitton, A., Cammett, M., Cavanaugh, K., Chopra, M., ... & Marten, R. (2017). Building resilient health systems: A proposal for a resilience index. *BMJ, 357*, j2323. https://doi.org/10.1136/bmj.j2323
32. Kuehn, L., & McCormick, S. (2017). Heat exposure and human health: Current evidence and future directions. *Current Environmental Health Reports, 4*(4), 484–495. https://doi.org/10.1007/s40572-017-0161-0
33. Lesnikowski, A., Ford, J. D., Berrang-Ford, L., Barrera, M., & Heymann, S. J. (2015). How are we adapting to climate change? A global assessment. *Mitigation and Adaptation Strategies for Global Change, 20*(2), 277–293. https://doi.org/10.1007/s11027-013-9491-x
34. Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: Advancing the methodology. *Implementation Science, 5*, Article 69. https://doi.org/10.1186/1748-5908-5-69
35. Liao, W., Chiu, Y., & Hsu, C. (2023). Digital transformation and climate resilience in healthcare systems: Emerging global trends. *Healthcare, 11*(9), 1324. https://doi.org/10.3390/healthcare11091324
36. Liu-Helmersson, J., Rocklöv, J., Sewe, M., & Brännström, Å. (2019). Climate change may enable Aedes aegypti infestation in Europe. *Environmental Research, 172*, 693–699. https://doi.org/10.1016/j.envres.2019.02.026
37. Majeed, H., Lee, J., & Hwang, J. (2024). Artificial intelligence for climate-health preparedness and early warning systems: A systematic review. *The Lancet Digital Health, 6*(1), e22–e34. https://doi.org/10.1016/S2589-7500(23)00231-6
38. Maxwell, J., & Blashki, G. (2016). Teaching about climate change in medical education: An opportunity. *Journal of Public Health Research, 5*(1), 676. https://doi.org/10.4081/jphr.2016.676
39. National Disaster Management Authority. (2022). *Pakistan 2022 flood impact and needs assessment*. Government of Pakistan.
40. NHS England. (2020). *Delivering a net zero National Health Service*. NHS England.
41. OECD. (2023). *Climate resilience and health system preparedness: Policy perspectives*. OECD Publishing.
42. Omrani, O. A., Shalhoub, S., & colleagues. (2021). Climate change and infectious disease risks: Relevance for the Middle East and Asia. *International Journal of Infectious Diseases, 104*, 268–274. https://doi.org/10.1016/j.ijid.2020.12.083
43. Patz, J. A., Frumkin, H., Holloway, T., Vimont, D. J., & Haines, A. (2014). Climate change: Challenges and opportunities for global health. *JAMA, 312*(15), 1565–1580. https://doi.org/10.1001/jama.2014.13186
44. Peters, M. D. J., Marnie, C., Tricco, A. C., Pollock, D., Munn, Z., Alexander, L., ... & Khalil, H. (2020). Updated methodological guidance for the conduct of scoping reviews. *JBI Evidence Synthesis, 18*(10), 2119–2126. https://doi.org/10.11124/JBIES-20-00167
45. Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., ... & Duffy, S. (2006). *Guidance on the conduct of narrative synthesis in systematic reviews*. Lancaster University.
46. Romanello, M., McGushin, A., Di Napoli, C., Drummond, P., Hughes, N., Jamart, L., ... & Costello, A. (2021). The 2021 report of the Lancet Countdown on health and climate change: Code red for a healthy future. *The Lancet, 398*(10311), 1619–1662. https://doi.org/10.1016/S0140-6736(21)01787-6
47. Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., ... & Straus, S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine, 169*(7), 467–473. https://doi.org/10.7326/M18-0850
48. United Nations Development Programme. (2023). *Climate-resilient development and institutional adaptation: Global perspectives*. UNDP.
49. United Nations Environment Programme. (2023). *Adaptation Gap Report 2023*. UNEP.
50. United Nations Office for Disaster Risk Reduction. (2023). *Global assessment report on disaster risk reduction 2023*. United Nations.

51. Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Beagley, J., Belesova, K., ... & Costello, A. (2021). The 2020 report of the Lancet Countdown on health and climate change: Responding to converging crises. *The Lancet, 397*(10269), 129–170. https://doi.org/10.1016/S0140-6736(20)32290-X
52. World Bank. (2023). *Climate and development: Investing in resilient health systems*. World Bank Publications.
53. World Health Organization. (2008). *Climate change and health: Resolution WHA61.19*. World Health Organization.
54. World Health Organization. (2020). *Operational framework for building climate resilient and low carbon health systems*. World Health Organization.
55. World Health Organization. (2023). *Climate resilient health systems: Strategic guidance for adaptation and sustainability*. WHO.
56. World Health Organization. (2023). *Review of global climate adaptation actions in the health sector*. WHO.
57. World Health Organization. (2024). *Health and climate change global survey report 2024*. WHO.
58. World Health Organization. (2024). *Operational framework for climate-resilient and sustainable health systems: Updated guidance*. WHO.
59. World Meteorological Organization. (2023). *State of the Global Climate 2023*. WMO.
60. Zinszer, K., Verma, A. D., Charland, K., Brewer, T. F., Brownstein, J. S., Sun, Z., ... & Buckeridge, D. L. (2018). A scoping review of malaria forecasting. *Malaria Journal, 17*, 147. https://doi.org/10.1186/s12936-018-2301-5