**Saudi Journal of Medicine and Public Health**

https://saudijmph.com/index.php/pub

https://doi.org/10.64483/202522815

# Climate-Related Health Emergencies and Health Security: Developing Integrated Healthcare Preparedness and Resilience Strategies against Extreme Environmental Events.

**Ali Atiah Najmi**

*Samtah General Hospital, Jazan Health Cluster, Ministry of health, Saudi Arabia*

**Abstract**

Climate change is intensifying heatwaves, floods, wildfires, storms, and drought, producing compounding threats to population health and the functioning of health systems. This narrative review synthesises peer-reviewed and institutional literature published between 2017 and 2026 to examine how extreme environmental events generate health emergencies and undermine health security, and to propose an integrated framework for preparedness and resilience. Evidence indicates that mortality, morbidity, mental health burden, and service disruption are unevenly distributed, with older adults, children, outdoor workers, and low-income communities bearing disproportionate risk. Health systems themselves are both vulnerable and contributors to emissions. The review identifies six interlinked strategic domains: surveillance and early warning, climate-resilient infrastructure, workforce and surge capacity, cross-sectoral and One Health governance, equity-centred community engagement, and sustainable financing. Implementation barriers and research priorities are discussed. Integrated, anticipatory, and equity-oriented strategies are essential for protecting health security under accelerating climate risk.

**Keywords:** climate change; health security; extreme weather events; health system resilience; emergency preparedness.

## Introduction

Climate change has moved from a long-term environmental concern to an immediate determinant of population health and a direct challenge to health security. Successive reports of the Lancet Countdown on health and climate change have documented rising exposure to dangerous heat, increasing frequency of extreme precipitation and drought, expanding climatic suitability for infectious disease transmission, and growing strain on health services worldwide (Romanello et al., 2022, 2023, 2024; Watts et al., 2018, 2021). The Intergovernmental Panel on Climate Change has concluded with high confidence that observed warming has already increased human mortality and morbidity, that risks escalate non-linearly with each increment of warming, and that adaptation gaps persist, particularly in low- and middle-income settings (Cissé et al., 2022; Lee et al., 2024). Haines and Ebi (2019) described climate change as among the defining health imperatives of this century, a framing that has since been reinforced by an expanding evidence base linking climatic hazards to cardiovascular, respiratory, infectious, reproductive, and mental health outcomes (Rocque et al., 2021).

Health security, understood as the capacity of societies to anticipate, withstand, and recover from acute public health threats, has traditionally been conceptualised around epidemics, bioterrorism, and chemical or radiological incidents. Extreme environmental events challenge this framing in important ways. They are frequent rather than rare, they affect large populations simultaneously, and they often damage the very infrastructure, such as hospitals, power grids, water systems, and transport networks, on which emergency response depends. They also interact with other crises, including pandemics, conflict, displacement, and economic shocks, generating compound and cascading risks that exceed the planning assumptions of single-hazard emergency systems (Pescaroli & Alexander, 2018; Zscheischler et al., 2018). The experience of recent heatwaves, floods, and hurricanes demonstrates that health systems designed for a stable climate are increasingly misaligned with the hazard environment in which they operate (Ebi et al., 2021a; Weilnhammer et al., 2021).

Despite growing attention, the literature remains fragmented. Studies of heat mortality, flood-related infectious disease, wildfire smoke exposure, and post-disaster mental health are typically published within separate disciplinary silos, while health system preparedness is often addressed through narrow technical guidance. Policy documents increasingly call for climate-resilient and low-carbon health systems (World Health Organization [WHO], 2023), yet the practical integration of surveillance, infrastructure, workforce, governance, equity, and financing remains uneven. A narrative review is well suited to this problem because it permits interpretive synthesis across heterogeneous evidence types,



*Corresponding author e-mail: alibinatya3@gmail.com (Ali Atiah Najmi).

Receive Date: 07 December 2025, Revise Date: 29 December 2025, Accept Date: 31 December 2025

including epidemiological studies, modelling analyses, systematic reviews, case studies, and policy frameworks.

The aim of this review is therefore threefold: (a) to synthesise recent evidence on how extreme environmental events produce health emergencies and threaten health security; (b) to appraise the vulnerabilities of health systems and populations; and (c) to propose an integrated framework of preparedness and resilience strategies, identifying implementation barriers and research priorities. The review is intended to inform health policymakers, emergency planners, clinicians, and researchers working at the interface of climate and health.

## 2. Methods

This article follows a narrative review design, guided by recommendations for transparent reporting of non-systematic reviews. Literature was identified through iterative searching of major bibliographic databases (PubMed/MEDLINE, Scopus, Web of Science) and the websites of key institutions, including the World Health Organization, the Intergovernmental Panel on Climate Change, and the Lancet Countdown. Search terms combined concepts of climate change, extreme weather, heatwave, flood, wildfire, tropical cyclone, health emergency, health security, preparedness, and health system resilience. The temporal scope was 2017 to 2026, reflecting the period in which climate-health evidence has been systematically consolidated and in which major frameworks for climate-resilient health systems have emerged.

Sources were included if they were peer-reviewed articles, major institutional reports, or authoritative framework documents addressing the health effects of extreme environmental events, health system vulnerability, or preparedness and resilience strategies. Priority was given to systematic reviews, multi-country epidemiological analyses, global assessments, and high-quality conceptual papers. Studies focused solely on long-term climate mitigation without health system relevance were excluded. Because the review is narrative, no formal risk-of-bias scoring was applied; instead, the strength and consistency of evidence were considered interpretively, and limitations are discussed in Section 8. Evidence was organised thematically around hazards and health outcomes, population and system vulnerability, and strategic responses.

## 3. Climate Extremes and the Production of Health Emergencies

### 3.1 Conceptual pathway from hazard to health emergency

Climate-related health emergencies arise when a climatic hazard interacts with exposure and vulnerability to produce health outcomes that exceed the capacity of local systems to manage. This risk-based understanding, adopted in the IPCC assessment framework, distinguishes hazard (the physical event), exposure (the presence of people and assets in harm's way), and vulnerability (susceptibility and lack of capacity to cope) (Cissé et al., 2022; Lee et al., 2024). Health consequences may be direct, such as heat stroke, drowning, burns, and trauma; indirect, mediated through ecological and infrastructural disruption such as altered vector ecology, food and water insecurity, or air pollution; and systemic, arising from displacement, economic loss, and degraded health service delivery (Ebi et al., 2018; Ebi et al., 2021a). Figure 1 presents this pathway and the points at which preparedness interventions can intervene.

### 3.2 Extreme heat

Extreme heat is the most consistently documented climate-related health threat. A global analysis of 750 locations estimated substantial excess mortality attributable to non-optimal temperatures, with cold-related deaths still numerically larger than heat-related deaths but with the heat share rising in a warming climate (Zhao et al., 2021). Attribution research indicates that a considerable proportion of warm-season mortality in recent decades can be attributed to human-induced climate change (Vicedo-Cabrera et al., 2021), and projections show that without adaptation, temperature-related excess mortality will increase markedly under higher-emission pathways (Gasparrini et al., 2017). Modelling work has also shown that a growing share of the global population is exposed to climatic conditions that cross deadly heat thresholds for at least part of the year (Mora et al., 2017). The summer of 2022 illustrated the scale of the problem: heat-related mortality across Europe was estimated in the tens of thousands, even in countries with established heat-health action plans (Ballester et al., 2023).

The clinical and system consequences extend beyond heat stroke. Heat exacerbates cardiovascular, respiratory, renal, and mental health conditions, increases emergency department attendance, and affects medication efficacy and safety (Ebi et al., 2021b). Occupational heat strain reduces productivity and increases the risk of kidney injury and accidents among outdoor and indoor workers lacking cooling (Flouris et al., 2018). Heatwaves are also frequently co-occurring with drought, wildfire, and power outages, producing compound events in which cooling infrastructure fails at the moment of greatest need (Zscheischler et al., 2018).

### 3.3 Floods, storms, and cyclones

Flooding and tropical cyclones generate acute injury and mortality but also long-lasting health sequelae. Floods contaminate water supplies, increase the risk of diarrhoeal and respiratory infections, leptospirosis, and vector-borne disease, and displace populations into crowded shelters where outbreaks may occur (Paterson et al., 2018). Evidence from Europe confirms that flood and storm events produce direct injuries, infectious disease, and mental health

effects, with burdens often extending well beyond the immediate impact period (Weilnhammer et al., 2021). The experience of Hurricane Maria in Puerto Rico remains a landmark case: mortality was elevated for months after landfall, and the risk was concentrated among low-income and rural populations, reflecting failures in power, communications, road access, and health service continuity rather than the storm's direct effects alone (Santos-Burgoa et al., 2018).

### 3.4 Wildfires and air pollution

Wildfires affect health through burns and trauma, but the dominant population burden arises from smoke exposure. Fine particulate matter from landscape fires is associated with respiratory and cardiovascular morbidity and mortality, and exposure is expanding with changing fire regimes (Xu et al., 2020). A global assessment estimated that a large proportion of the world's population is exposed to landscape fire air pollution annually, with particularly high exposure in parts of Africa, South America, and Siberia, and with trends differing by region (Xu et al., 2023). Smoke episodes can travel thousands of kilometres, creating transboundary health security challenges and placing demand on health systems in areas not directly threatened by flames.

### 3.5 Climate-sensitive infectious disease

Climate variability alters the geographic range, seasonality, and intensity of transmission of vector-borne, water-borne, and zoonotic diseases. Multi-model projections suggest that mosquito-borne diseases such as dengue and malaria will shift in distribution and expand their population at risk under warming scenarios, though patterns vary by pathogen and region (Colón-González et al., 2021). In Europe, climatic suitability for transmission of Vibrio species, West Nile virus, and Aedes-borne arboviruses has expanded, demonstrating that high-income settings are not exempt (Semenza & Paz, 2021). Wider ecological change may also increase the likelihood of cross-species viral transmission as species shift their ranges and encounter novel hosts, a pathway of relevance to pandemic preparedness (Carlson et al., 2022). These findings underscore that climate-related emergencies and infectious disease threats are not separate agendas but interacting dimensions of health security.

### 3.6 Mental health and psychosocial consequences

Extreme events are associated with post-traumatic stress, depression, anxiety, substance use, and increased suicidality, and chronic stressors such as drought and loss of livelihood contribute to long-term distress (Charlson et al., 2021; Hayes et al., 2018). Children and adolescents are especially vulnerable, given both direct exposure and disruption of education, nutrition, and caregiving, with consequences that may persist across the life course (Helldén et al., 2021). Psychosocial needs are often under-addressed in disaster plans, despite being among the most prevalent and persistent consequences of climate extremes.

Table 1 summarises the principal hazards, mechanisms, health outcomes, and system implications synthesised in this section.

**Table 1. Extreme environmental hazards, health outcomes, and health system implications**

| Hazard | Principal pathways to harm | Representative health outcomes | Key health system implications | Illustrative sources |
|---|---|---|---|---|
| Extreme heat | Physiological heat strain; exacerbation of chronic disease; occupational exposure; infrastructure and power failure | Heat stroke, cardiovascular and renal events, excess mortality, mental health crises | Surges in emergency attendance; cooling failure in facilities; staff heat stress | Ballester et al. (2023); Ebi et al. (2021b); Vicedo-Cabrera et al. (2021); Flouris et al. (2018) |
| Floods and storms | Drowning and trauma; water contamination; displacement; infrastructure damage | Injury, diarrhoeal and respiratory infection, leptospirosis, post-traumatic stress | Facility inundation; supply-chain and access disruption; shelter outbreaks | Paterson et al. (2018); Santos-Burgoa et al. (2018); Weilnhammer et al. (2021) |
| Wildfire and smoke | Burns; inhalation of fine particulates; evacuation | Respiratory and cardiovascular morbidity, mortality, mental health effects | Respiratory surge; air filtration needs; evacuation of facilities | Xu et al. (2020); Xu et al. (2023) |
| Drought and food/water insecurity | Reduced crop yield; water scarcity; livelihood loss | Malnutrition, water-borne disease, psychological distress | Increased nutritional and mental health demand; water supply for facilities | Hayes et al. (2018); Cissé et al. (2022) |
| Changing infectious disease ecology | Range expansion of vectors and pathogens; ecological disruption | Dengue, malaria, Vibrio infection, West Nile virus, zoonotic spillover | Surveillance and laboratory demands; outbreak response | Colón-González et al. (2021); Semenza & Paz (2021); |

Carlson et al. (2022)

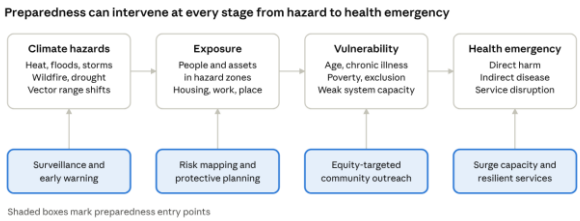



**Figure 1. Conceptual pathway from climatic hazard to health emergency and points of intervention for preparedness.**

## 4. Vulnerability, Inequity, and the Health Security Dimension

### 4.1 Population vulnerability

The distribution of climate-related health risk is shaped by biological susceptibility, social position, and place. Older adults, infants and young children, pregnant women, people with chronic illness or disability, outdoor workers, people experiencing homelessness, and residents of informal settlements consistently face elevated risk (Ebi & Hess, 2020; Romanello et al., 2023). These vulnerabilities are not fixed attributes but outcomes of social and economic processes, including poverty, discrimination, inadequate housing, and political marginalisation. Ebi and Hess (2020) argued that inequity is embedded in both the causes and consequences of climate-related health risk, since populations that contribute least to greenhouse gas emissions often experience the greatest harm and have the fewest resources to adapt.

Global stocktaking of adaptation evidence further shows that much adaptation is fragmented, incremental, and reactive, and that evidence on whether adaptation actually reduces risk for the most vulnerable groups is limited (Berrang-Ford et al., 2021). Without deliberate equity-oriented design, preparedness investments risk reproducing existing disparities, for instance by privileging urban over rural communities or by assuming access to digital warning technologies that marginalised groups may lack.

### 4.2 Health system vulnerability

Health systems are exposed to climate hazards through physical infrastructure, supply chains, workforce, information systems, and financing. Hospitals and clinics may be flooded, lose power or water, or become unsafe for patients and staff during extreme heat; transport disruption may isolate communities from care; and pharmaceuticals and vaccines may be compromised by temperature excursions or supply delays. Salas and Jha (2019) argued that climate change threatens the achievement of effective universal health coverage because it simultaneously increases demand, damages delivery capacity, and diverts resources. A scoping review of strategies for climate-resilient health systems similarly identified vulnerabilities across governance, workforce, infrastructure, service delivery, and information domains, and noted wide variation in implementation capacity (Mosadeghrad et al., 2023).

A further paradox is that health care is itself a significant source of emissions. A global assessment estimated that the health sector accounts for approximately 4.4 per cent of net global greenhouse gas emissions, a share comparable to that of major national economies (Lenzen et al., 2020). Salas et al. (2020) outlined a pathway towards net-zero emissions for health care, emphasising that decarbonisation and resilience can be pursued together, for example through energy efficiency, renewable power, and low-carbon models of care that also reduce exposure to grid failure.

### 4.3 Climate-related emergencies as a health security problem

Framing climate extremes as a health security issue has practical consequences. It elevates them from environmental or sectoral concerns to matters of national and international risk governance, supports integration with emergency management and public health emergency preparedness structures, and justifies sustained investment in anticipatory capacities. Evidence from the COVID-19 pandemic demonstrates both the value and the fragility of health system resilience: a multi-country analysis identified governance, information, adaptive capacity, and equitable service continuity as determinants of how well systems managed shocks (Haldane et al., 2021). Conceptual work on health system resilience emphasises governance and the capacity to absorb, adapt, and transform in response to shocks (Blanchet et al., 2017). These insights apply directly to climate hazards, which increasingly arrive as recurrent, overlapping stressors rather than isolated events.

The WHO's operational framework for building climate-resilient and low-carbon health systems provides a structured approach, organising action around ten components that span leadership and governance, health workforce, vulnerability and adaptation assessment, integrated risk monitoring and early warning, health and climate research, climate-resilient and sustainable technologies and infrastructure, management of environmental determinants of health, climate-informed health programmes, emergency preparedness and management, and climate and health financing (WHO, 2023). Campbell-Lendrum et al. (2023) identified three grand challenges for the field, namely reducing health risks through mitigation and adaptation, leveraging health arguments to accelerate climate action, and ensuring that health systems can both withstand climate impacts and decarbonise, which

converge on the need for integration rather than parallel programmes.

Table 2 compares key characteristics of conventional emergency preparedness with the climate-resilient, integrated approach proposed in this review.

**Table 2. Conventional emergency preparedness versus integrated climate-resilient health security approach**

| Dimension | Conventional preparedness | Integrated climate-resilient approach |
|---|---|---|
| Risk basis | Historical event frequency; single hazard | Forward-looking climate projections; compound and cascading hazards |
| Timing | Reactive response after impact | Anticipatory, forecast-based action before impact |
| Surveillance | Disease-based, delayed reporting | Integrated climate, environmental, and syndromic data with early warning |
| Infrastructure | Built to historical design standards | Climate-proofed, energy- and water-secure, adaptive design |
| Workforce | Event-specific surge staffing | Climate-literate workforce, cross-training, staff protection |
| Governance | Health sector alone | Cross-sectoral and One Health coordination |
| Equity | Implicit or secondary | Explicit targeting of vulnerable populations and community co-design |
| Financing | Post-disaster emergency funds | Sustained, risk-informed, and contingent financing |
| Sustainability | Not considered | Co-benefits with decarbonisation |

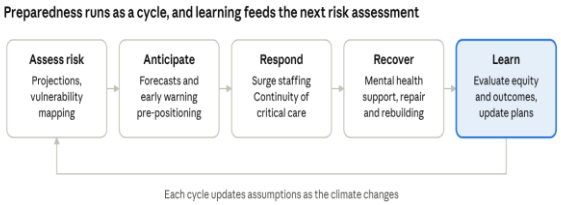



**Figure 2. Climate-informed preparedness cycle for health systems.**

## 5. Surveillance, Risk Assessment, and Early Warning

Anticipatory capacity is the foundation of climate health security. Effective surveillance integrates meteorological, environmental, demographic, and health data to identify emerging risks and trigger timely action. Heat-health warning systems are the most mature example. A European overview found that such systems exist in many countries but vary greatly in thresholds, communication channels, and the specificity of the interventions linked to alerts (Casanueva et al., 2019). The experience of recent summers, in which substantial mortality occurred despite existing plans, suggests that warnings must be coupled to concrete protective actions, targeted outreach to at-risk individuals, and evaluation of effectiveness (Ballester et al., 2023).

Beyond heat, climate-informed forecasting of vector-borne disease, water-borne outbreaks, and smoke exposure can support pre-positioning of resources and public communication. Multi-model projections of mosquito-borne disease risk illustrate the potential of such tools while highlighting uncertainties that require careful communication and local validation (Colón-González et al., 2021). Vulnerability and adaptation assessments, as promoted by WHO, provide the baseline for prioritising interventions, and should incorporate fine-scale demographic data, facility-level exposure mapping, and community knowledge (WHO, 2023). Integration of climate data into routine health information systems remains a persistent gap, particularly in low-resource settings, and investment in data infrastructure, analytic skills, and data governance is therefore a core preparedness priority (Romanello et al., 2024).

## 6. Climate-Resilient Health Infrastructure and Service Continuity

The physical resilience of health facilities determines whether care can continue when communities need it most. Climate-resilient infrastructure involves site selection that avoids flood-prone areas, structural design for wind, heat, and water ingress, redundant power and water supply, passive and active cooling, and protection of cold chains, laboratories, and information systems. The WHO framework treats climate-resilient and sustainable technologies and infrastructure as a core component of health system resilience (WHO, 2023). Experience from Hurricane Maria shows how loss of power and communications can convert a natural hazard into a prolonged health emergency, with deaths occurring long after the storm through interrupted dialysis, oxygen supply, and chronic disease care (Santos-Burgoa et al., 2018).

A key insight from recent scholarship is that resilience and decarbonisation can be mutually reinforcing. On-site renewable generation with storage, efficient building envelopes, and decentralised energy systems reduce emissions while safeguarding facilities against grid failure (Salas et al., 2020). Because the health sector contributes a measurable share of global emissions (Lenzen et al., 2020), infrastructure investment that ignores either dimension is likely to be inefficient. Service continuity also depends on supply chains and on models of care

that reduce dependence on centralised facilities, such as community-based services, home-based care for chronic conditions, and telehealth where connectivity is robust. These approaches can maintain access during transport disruption, although they must be designed so that populations without digital access are not excluded (Salas & Jha, 2019).

Preparedness for compound events requires that infrastructure plans be tested against combined scenarios, for example a heatwave coinciding with a power outage and a wildfire smoke episode, rather than against single hazards in isolation (Pescaroli & Alexander, 2018; Zscheischler et al., 2018). Facility-level vulnerability assessments, regular stress-testing, and clear continuity-of-operations plans for critical services, including emergency departments, maternity care, dialysis, and mental health crisis services, are practical measures that translate this principle into action.

## 7. Workforce, Surge Capacity, and Clinical Preparedness

The health workforce is both the principal resource of emergency response and a population at risk. Clinicians and community health workers may themselves be exposed to heat, smoke, flooding, and psychological strain, and workforce shortages can rapidly become the limiting factor in surge response. Evidence on occupational heat strain indicates that workers in physically demanding or poorly ventilated settings face reduced productivity and elevated health risks (Flouris et al., 2018), a finding that applies equally to health personnel working in facilities without adequate cooling or while wearing protective equipment.

Preparedness therefore requires several linked measures. First, climate and health literacy should be integrated into pre-service and continuing education so that clinicians can recognise heat illness, smoke-related exacerbations, and climate-sensitive infections, and can advise patients on protective behaviours and medication management during extremes (Ebi et al., 2021b; Haines & Ebi, 2019). Second, surge plans should be built on cross-trained and flexible staffing models, mutual-aid agreements across jurisdictions, and mechanisms for deploying volunteers and reserve personnel. Third, occupational health policies should protect staff through heat management protocols, safe rostering, psychological support, and clear guidance during evacuations. The multi-country analysis of health system responses to COVID-19 emphasised workforce protection, communication, and adaptive management as determinants of resilience (Haldane et al., 2021), lessons that are transferable to climate emergencies.

Clinical preparedness also involves the management of vulnerable patients. Registers of individuals at high risk, such as those who are older, living alone, dependent on electrically powered medical equipment, or with severe chronic conditions, can allow proactive outreach during alerts. Pharmacists, primary care teams, and home-care providers are well placed to deliver such targeted interventions, provided that data-sharing arrangements respect privacy and that protocols are tested before the season of highest risk (Casanueva et al., 2019; Ebi et al., 2021a).

## 8. Governance, Intersectoral Coordination, and One Health

Climate-related health emergencies cut across portfolios, including meteorology, water, energy, housing, agriculture, transport, urban planning, and social protection. Consequently, health ministries cannot manage risk alone. Strong governance arrangements establish clear mandates, shared risk assessments, joint exercises, and communication channels among health, disaster management, and environmental agencies. Conceptual work on resilient health systems places governance at the centre, highlighting leadership, accountability, and the capacity to coordinate across levels and sectors (Blanchet et al., 2017). A scoping review of climate-resilient health system strategies reached similar conclusions, noting that leadership, policy integration, and intersectoral collaboration were among the most frequently cited enabling conditions (Mosadeghrad et al., 2023).

The One Health approach, which recognises the interdependence of human, animal, and environmental health, offers a useful organising principle for governance in this field. It supports joint surveillance of zoonoses, vector populations, and environmental conditions, and aligns with evidence that ecological change can alter pathogen transmission dynamics and spillover risk (Carlson et al., 2022; Destoumieux-Garzón et al., 2018). Integrating One Health perspectives into climate emergency planning can improve early detection of emerging threats and avoid duplication between public health, veterinary, and environmental agencies.

Governance also requires alignment across scales. National adaptation plans should be translated into subnational and facility-level action, and international cooperation is essential for transboundary hazards such as smoke plumes, shared river basins, and vector expansion (Xu et al., 2023). Campbell-Lendrum et al. (2023) emphasised that health arguments can accelerate climate action while health systems adapt, which implies that health leaders should participate actively in climate policy fora rather than waiting for adaptation decisions to be made elsewhere. Finally, the evidence of persistent adaptation gaps suggests that monitoring and accountability mechanisms, including indicators of preparedness and outcomes, are required to ensure that commitments are implemented (Berrang-Ford et al., 2021; Romanello et al., 2022).

## 9. Equity, Community Engagement, and Mental Health

Equity is not an optional add-on but a determinant of preparedness effectiveness. Because vulnerability is socially produced, interventions must be designed with and for the populations at greatest risk (Ebi & Hess, 2020). Community engagement can improve the relevance and uptake of warnings, identify local assets and risks that formal assessments overlook, and build trust that is essential during emergencies. Practical approaches include participatory vulnerability mapping, partnerships with community organisations and faith-based groups, multilingual and multi-channel communication, and the use of trusted local messengers. Early warning messages that rely exclusively on smartphone applications or the internet will miss precisely those who are isolated or have limited access, which underscores the need for redundancy in communication channels (Casanueva et al., 2019).

Mental health and psychosocial support should be integrated into emergency preparedness from the outset. Evidence shows that climate extremes and chronic climate stressors are associated with substantial and sometimes long-lasting mental health effects (Charlson et al., 2021; Hayes et al., 2018). Priority actions include training of first responders and primary care providers in psychological first aid, ensuring continuity of care for people with pre-existing mental disorders, and providing child-sensitive services in schools and shelters (Helldén et al., 2021). Longer-term recovery planning should anticipate delayed psychological responses and economic stressors, such as loss of homes and livelihoods.

Gender, age, disability, migration status, and occupation intersect to shape risk. Planning that disaggregates data by these characteristics, anticipates barriers to evacuation and shelter access, and ensures dignified conditions in temporary accommodation is more likely to reduce inequities (Romanello et al., 2023). Importantly, equity-oriented design should be evaluated: the global adaptation stocktake found limited evidence on whether adaptation reduces vulnerability among marginalised groups (Berrang-Ford et al., 2021), which supports routine equity-focused monitoring of preparedness interventions.

## 10. Sustainable Financing and Integration with Mitigation

Preparedness and resilience require predictable investment. Historically, financing has been skewed towards post-disaster response, while prevention, preparedness, and adaptation have remained under-funded. Risk-informed budgeting, contingent financing instruments that release funds on forecast triggers, and dedicated climate-health lines within national budgets can shift the balance towards anticipatory action. The WHO framework identifies climate and health financing as a distinct component and encourages governments to access climate finance streams for health priorities (WHO, 2023). Global monitoring has repeatedly highlighted that health adaptation finance remains limited relative to need, particularly for low-income countries that face the highest risks (Romanello et al., 2022, 2024).

Economic arguments reinforce the case for investment. Climate change threatens universal health coverage by raising costs, reducing productive capacity, and damaging health infrastructure (Salas & Jha, 2019). Conversely, many adaptation measures offer co-benefits; for example, urban greening and building design can reduce heat exposure while improving air quality and mental wellbeing, and cleaner energy can reduce air pollution while reducing emissions (Haines & Ebi, 2019; Watts et al., 2021). Integrating mitigation into health system planning, including pathways towards net-zero emissions, can therefore be framed as part of resilience rather than a competing priority (Lenzen et al., 2020; Salas et al., 2020).

## 11. An Integrated Framework for Preparedness and Resilience

The preceding sections demonstrate that no single intervention is sufficient. Surveillance without response capacity yields warnings that cannot be acted upon; resilient hospitals without equitable access leave vulnerable groups behind; and technical plans without governance and financing remain aspirational. Figure 3 therefore integrates the six strategic domains into a framework in which governance and financing form enabling foundations, surveillance and early warning provide anticipatory intelligence, infrastructure and workforce provide operational capacity, and equity and community engagement ensure that capacity reaches those at greatest risk.

The framework draws on the absorb, adapt, and transform capacities described in resilience scholarship (Blanchet et al., 2017; Haldane et al., 2021) and operationalises the components set out by WHO (2023). Preparedness is conceived as a cycle (Figure 2) of risk assessment, anticipatory action, response, recovery, and learning, with each iteration updating assumptions in light of observed and projected climate change. Three design principles underpin the framework. First, anticipation: decisions should be informed by forward-looking climate and health projections rather than by historical averages alone (Gasparrini et al., 2017; Vicedo-Cabrera et al., 2021). Second, integration: climate, health, emergency, and One Health systems should share data, exercises, and decision-making structures. Third, equity and sustainability: interventions should be evaluated against their distributional impacts and their contribution to emissions reduction.




**Figure 3. Integrated framework for climate-resilient health security.**

Implementation can be staged according to resource availability. In low-resource settings, priorities may include basic vulnerability assessment, simple early warning protocols, protection of critical facilities with reliable water and power, community health worker training, and inclusion of climate risk in existing disaster plans. In higher-resource settings, emphasis may shift to advance forecasting, facility retrofits, integrated data platforms, and decarbonisation. International support, technology transfer, and equitable financing are essential to prevent a widening gap between countries (Campbell-Lendrum et al., 2023; Romanello et al., 2024).

## 12. Implementation Barriers, Limitations, and Research Priorities

Several barriers recur across the literature. Institutional fragmentation, limited mandates, and weak coordination impede integrated action (Mosadeghrad et al., 2023). Data gaps, including limited health data linked to local climate information, hamper risk assessment and evaluation. Financial constraints, competing priorities, and short political cycles reduce investment in preventive measures with long-term benefits (Romanello et al., 2022). Workforce shortages and limited climate-health training constrain delivery, and public communication can be undermined by mistrust or by a lack of locally relevant messaging. The evidence base itself is uneven: a large proportion of high-quality studies originate in high-income settings, even though the greatest burdens fall on low- and middle-income countries (Berrang-Ford et al., 2021; Rocque et al., 2021).

This review has limitations. As a narrative synthesis, it did not follow a systematic protocol or formal quality appraisal, and selection of sources may reflect the authors' judgement. The time window of 2017 to 2026 excludes earlier foundational literature, and the rapid pace of events means that more recent evidence may emerge. The proposed framework is conceptual and has not been empirically validated.

Future research should prioritise: (a) rigorous evaluation of the effectiveness and cost-effectiveness of heat-health action plans and other early warning systems, including their equity impacts; (b) health-system-specific vulnerability metrics and routine monitoring of facility resilience; (c) improved modelling of compound and cascading hazards and their health consequences (Zscheischler et al., 2018; Pescaroli & Alexander, 2018); (d) integration of One Health surveillance and climate data for emerging infectious threats (Carlson et al., 2022; Destoumieux-Garzón et al., 2018); (e) implementation science on how to scale successful interventions in low-resource settings; and (f) evidence on mental health interventions in the context of climate extremes (Charlson et al., 2021).

## 13. Conclusion

Climate-related extreme events are now a persistent feature of the global health landscape and a core component of health security. The evidence reviewed here shows rising burdens from heat, floods, wildfire smoke, and climate-sensitive infectious diseases, compounded by mental health impacts and by the vulnerability of the health systems that society relies upon to respond. Because risks are unequally distributed, the consequences of inaction fall most heavily on those with the least capacity to adapt. An integrated approach that combines anticipatory surveillance, resilient infrastructure, a prepared workforce, cross-sectoral and One Health governance, equity-centred engagement, and sustainable financing offers a coherent route to strengthening preparedness. Realising this agenda requires political commitment, sustained investment, and continuous learning. Given the pace of warming, the window for proactive adaptation is narrowing, and health systems that plan only for the climate of the past will be inadequately prepared for the emergencies of the future.

## References

1. Ballester, J., Quijal-Zamorano, M., Méndez Turrubiates, R. F., Pegenaute, F., Herrmann, F. R., Robine, J. M., ... & Achebak, H. (2023). Heat-related mortality in Europe during the summer of 2022. *Nature medicine*, *29*(7), 1857-1866.
2. Berrang-Ford, L., Siders, A. R., Lesnikowski, A., Fischer, A. P., Callaghan, M. W., Haddaway, N. R., ... & Abu, T. Z. (2021). A systematic global stocktake of evidence on human adaptation to climate change. *Nature climate change*, *11*(11), 989-1000.
3. Blanchet, K., Nam, S. L., Ramalingam, B., & Pozo-Martin, F. (2017). Governance and capacity to manage resilience of health systems: towards a new conceptual framework. *International journal of health policy and management*, *6*(8), 431.
4. Campbell-Lendrum, D., Neville, T., Schweizer, C., & Neira, M. (2023). Climate change and health: three grand challenges. *Nature medicine*, *29*(7), 1631-1638.
5. Carlson, C. J., Albery, G. F., Merow, C., Trisos, C. H., Zipfel, C. M., Eskew, E. A., ...

& Bansal, S. (2022). Climate change increases cross-species viral transmission risk. *Nature*, *607*(7919), 555-562.

6. Casanueva, A., Burgstall, A., Kotlarski, S., Messeri, A., Morabito, M., Flouris, A. D., ... & Schwierz, C. (2019). Overview of existing heat-health warning systems in Europe. *International journal of environmental research and public health*, *16*(15), 2657.
7. Charlson, F., Ali, S., Benmarhnia, T., Pearl, M., Massazza, A., Augustinavicius, J., & Scott, J. G. (2021). Climate change and mental health: a scoping review. *International journal of environmental research and public health*, *18*(9), 4486.
8. Cissé, G., McLeman, R., Adams, H., Aldunce, P., Bowen, K., Campbell-Lendrum, D., ... & Tirado, M. C. (2022). Health, wellbeing, and the changing structure of communities. *Climate change*, *7*, 1041-1170.
9. Colón-González, F. J., Sewe, M. O., Tompkins, A. M., Sjödin, H., Casallas, A., Rocklöv, J., ... & Lowe, R. (2021). Projecting the risk of mosquito-borne diseases in a warmer and more populated world: a multi-model, multi-scenario intercomparison modelling study. *The Lancet Planetary Health*, *5*(7), e404-e414.
10. Destoumieux-Garzón, D., Mavingui, P., Boetsch, G., Boissier, J., Darriet, F., Duboz, P., ... & Voituron, Y. (2018). The one health concept: 10 years old and a long road ahead. *Frontiers in veterinary science*, *5*, 14.
11. Ebi, K. L., & Hess, J. J. (2020). Health risks due to climate change: inequity in causes and consequences: study examines health risks due to climate change. *Health Affairs*, *39*(12), 2056-2062.
12. Ebi, K. L., Hasegawa, T., Hayes, K., Monaghan, A., Paz, S., & Berry, P. (2018). Health risks of warming of 1.5 C, 2 C, and higher, above pre-industrial temperatures. *Environmental Research Letters*, *13*(6), 063007.
13. Ebi, K. L., Vanos, J., Baldwin, J. W., Bell, J. E., Hondula, D. M., Errett, N. A., ... & Berry, P. (2021a). Extreme weather and climate change: population health and health system implications. *Annual review of public health*, *42*(1), 293-315.
14. Ebi, K. L., Capon, A., Berry, P., Broderick, C., de Dear, R., Havenith, G., ... & Jay, O. (2021b). Hot weather and heat extremes: health risks. *The lancet*, *398*(10301), 698-708.
15. Flouris, A. D., Dinas, P. C., Ioannou, L. G., Nybo, L., Havenith, G., Kenny, G. P., & Kjellstrom, T. (2018). Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. *The Lancet Planetary Health*, *2*(12), e521-e531.
16. Gasparrini, A., Guo, Y., Sera, F., Vicedo-Cabrera, A. M., Huber, V., Tong, S., ... & Armstrong, B. (2017). Projections of temperature-related excess mortality under climate change scenarios. *The Lancet Planetary Health*, *1*(9), e360-e367.
17. Haines, A., & Ebi, K. (2019). The imperative for climate action to protect health. *New England journal of medicine*, *380*(3), 263-273.
18. Haldane, V., De Foo, C., Abdalla, S. M., Jung, A. S., Tan, M., Wu, S., ... & Legido-Quigley, H. (2021). Health systems resilience in managing the COVID-19 pandemic: lessons from 28 countries. *Nature medicine*, *27*(6), 964-980.
19. Hayes, K., Blashki, G., Wiseman, J., Burke, S., & Reifels, L. (2018). Climate change and mental health: risks, impacts and priority actions. *International journal of mental health systems*, *12*(1), 28.
20. Helldén, D., Andersson, C., Nilsson, M., Ebi, K. L., Friberg, P., & Alfvén, T. (2021). Climate change and child health: a scoping review and an expanded conceptual framework. *The Lancet Planetary Health*, *5*(3), e164-e175.
21. Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., ... & Ruane, A. C. (2024). Climate change 2023 synthesis report summary for policymakers. *Climate change 2023 synthesis report: Summary for policymakers*.
22. Lenzen, M., Malik, A., Li, M., Fry, J., Weisz, H., Pichler, P. P., ... & Pencheon, D. (2020). The environmental footprint of health care: a global assessment. *The Lancet Planetary Health*, *4*(7), e271-e279.
23. Mora, C., Dousset, B., Caldwell, I. R., Powell, F. E., Geronimo, R. C., Bielecki, C. R., ... & Trauernicht, C. (2017). Global risk of deadly heat. *Nature climate change*, *7*(7), 501-506.
24. Mosadeghrad, A. M., Isfahani, P., Eslambolchi, L., Zahmatkesh, M., & Afshari, M. (2023). Strategies to strengthen a climate-resilient health system: a scoping review. *Globalization and health*, *19*(1), 62.
25. Paterson, D. L., Wright, H., & Harris, P. N. (2018). Health risks of flood disasters. *Clinical Infectious Diseases*, *67*(9), 1450-1454.
26. Pescaroli, G., & Alexander, D. (2018). Understanding compound, interconnected, interacting, and cascading risks: a holistic

framework. *Risk analysis*, *38*(11), 2245-2257.
27. Rocque, R. J., Beaudoin, C., Ndjaboue, R., Cameron, L., Poirier-Bergeron, L., Poulin-Rheault, R. A., ... & Witteman, H. O. (2021). Health effects of climate change: an overview of systematic reviews. *BMJ open*, *11*(6), e046333.
28. Romanello, M., Di Napoli, C., Drummond, P., Green, C., Kennard, H., Lampard, P., ... & Costello, A. (2022). The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. *The Lancet*, *400*(10363), 1619-1654.
29. Romanello, M., Di Napoli, C., Green, C., Kennard, H., Lampard, P., Scamman, D., ... & Costello, A. (2023). The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms. *The Lancet*, *402*(10419), 2346-2394.
30. Romanello, M., Walawender, M., Hsu, S. C., Moskeland, A., Palmeiro-Silva, Y., Scamman, D., ... & Costello, A. (2024). The 2024 report of the Lancet Countdown on health and climate change: facing record-breaking threats from delayed action. *The Lancet*, *404*(10465), 1847-1896.
31. Salas, R. N., & Jha, A. K. (2019). Climate change threatens the achievement of effective universal healthcare. *Bmj*, *366*.
32. Salas, R. N., Maibach, E., Pencheon, D., Watts, N., & Frumkin, H. (2020). A pathway to net zero emissions for healthcare. *Bmj*, *371*.
33. Santos-Burgoa, C., Sandberg, J., Suárez, E., Goldman-Hawes, A., Zeger, S., Garcia-Meza, A., ... & Goldman, L. (2018). Differential and persistent risk of excess mortality from Hurricane Maria in Puerto Rico: a time-series analysis. *The Lancet Planetary Health*, *2*(11), e478-e488.
34. Semenza, J. C., & Paz, S. (2021). Climate change and infectious disease in Europe: Impact, projection and adaptation. *The Lancet Regional Health–Europe*, *9*.
35. Vicedo-Cabrera, A. M., Scovronick, N., Sera, F., Royé, D., Schneider, R., Tobias, A., ... & Gasparrini, A. (2021). The burden of heat-related mortality attributable to recent human-induced climate change. *Nature climate change*, *11*(6), 492-500.
36. Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Berry, H., ... & Costello, A. (2018). The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come. *The Lancet*, *392*(10163), 2479-2514.
37. 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.
38. Weilnhammer, V., Schmid, J., Mittermeier, I., Schreiber, F., Jiang, L., Pastuhovic, V., ... & Heinze, S. (2021). Extreme weather events in europe and their health consequences–A systematic review. *International Journal of Hygiene and Environmental Health*, *233*, 113688.
39. World Health Organization. (2023). *Operational framework for building climate resilient and low carbon health systems*. World Health Organization.
40. Xu, R., Yu, P., Abramson, M. J., Johnston, F. H., Samet, J. M., Bell, M. L., ... & Guo, Y. (2020). Wildfires, global climate change, and human health. *New England Journal of Medicine*, *383*(22), 2173-2181.
41. Xu, R., Ye, T., Yue, X., Yang, Z., Yu, W., Zhang, Y., ... & Li, S. (2023). Global population exposure to landscape fire air pollution from 2000 to 2019. *Nature*, *621*(7979), 521-529.
42. Zhao, Q., Guo, Y., Ye, T., Gasparrini, A., Tong, S., Overcenco, A., ... & Li, S. (2021). Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study. *The Lancet Planetary Health*, *5*(7), e415-e425.

Zscheischler, J., Westra, S., Van Den Hurk, B. J., Seneviratne, S. I., Ward, P. J., Pitman, A., ... & Zhang, X. (2018). Future climate risk from compound events. *Nature climate change*, *8*(6), 469-477.