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Research Article

Climate Change and Human Health: Strategies for Building Resilient Healthcare Systems

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Abstract

Climate change has intensified environmental stressors that directly and indirectly threaten human health, including rising temperatures, extreme weather events, vector borne disease expansion, and disruptions to food and water security. Healthcare systems worldwide face increasing pressure as climate-related hazards exacerbate morbidity and mortality, revealing systemic vulnerabilities in infrastructure, workforce capacity, and emergency preparedness. This study aims to identify strategic approaches for strengthening healthcare system resilience in the face of climate change by examining adaptive, organizational, and technological interventions. A mixed methods design was employed, combining systematic literature analysis with case based evaluations of climate adaptation initiatives implemented across multiple regions. The findings show that integrated climate health surveillance, climate resilient infrastructure, workforce training, and digital early-warning systems are among the most effective strategies for enhancing resilience. The results also highlight that governance coordination and equitable resource allocation significantly shape adaptive capacity. The study concludes that building resilient healthcare systems requires a multisectoral approach that embeds climate risk assessment into health planning, expands adaptive technologies, and prioritizes vulnerable populations.

Keywords: Climate Change, Healthcare Resilience, Human Health

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INTRODUCTION

Climate change has emerged as one of the most pervasive global threats to human health, affecting populations through rising temperatures, extreme weather events, deteriorating air quality, shifting disease vectors, and disruptions to food and water systems. Public health data indicate escalating rates of heat-related illness, respiratory conditions, malnutrition, and infectious diseases, demonstrating that climate-driven hazards are no longer distant risks but present realities shaping disease patterns (Ugboko & Jo, 2025; Yu et al., 2025). These expanding health burdens place unprecedented demands on healthcare systems that were not originally designed to address multifactorial climate-related stressors. Understanding the intersection of climate change and human health has therefore become a critical priority for governments, researchers, and health practitioners worldwide.

Healthcare systems play a central role in protecting populations from environmental threats, yet increasing climate volatility exposes their structural weaknesses. Many healthcare facilities face risks such as infrastructural damage during storms, power outages, supply chain disruptions, and surges in patient volume during climate-related emergencies. These challenges highlight the need to conceptualize healthcare systems not merely as service providers but as essential components of climate adaptation strategies. Building resilience within healthcare systems requires a shift in perspective, recognizing health infrastructure as frontline defense against climate hazards (Leung et al., 2025; Zimmermann et al., 2025).

Global health organizations have repeatedly emphasized that climate change amplifies existing inequities, disproportionately affecting socially and economically vulnerable groups. Communities with limited access to healthcare, poor housing quality, and inadequate disaster preparedness face greater risks from climate impacts. This dynamic intensifies the urgency for health systems to develop resilience frameworks that account for social determinants of health while anticipating climate-related disruptions. The background underscores why examining climate resilience within healthcare systems is no longer optional but fundamental to safeguarding population health in the twenty-first century (A Helaly et al., 2025; de Almeida et al., 2026).

Escalating climate-related health threats reveal significant gaps in the capacity of healthcare systems to respond effectively. Many systems lack the infrastructure, technologies, and planning mechanisms needed to handle climate-induced patient surges or maintain continuity of care during environmental emergencies. Insufficient integration between climate science and health system planning limits the ability of health practitioners to anticipate health risks or implement timely interventions. These weaknesses pose a substantial risk of system overload, particularly as climate change increases in intensity (de Almeida et al., 2026; Luo et al., 2025).

Critical challenges arise from inadequate preparedness at institutional and policy levels. Numerous healthcare facilities operate without climate-resilience guidelines, leaving them vulnerable to functional disruptions during extreme events. In many countries, risk assessments rarely incorporate climate projections, resulting in preparedness strategies that lag behind evolving hazards. Workforce capacity is another issue, as health personnel often lack training to manage emerging climate-related conditions such as heatstroke, vector-borne diseases, or mass-casualty events triggered by environmental disasters. These gaps hinder coordinated and effective responses (Ahmadi et al., 2025; Muteeb et al., 2025).

The increasing complexity of climate-related threats underscores the urgent need for healthcare systems to adopt resilience strategies that extend beyond traditional emergency planning. Without systematic adaptation efforts, health systems face growing risks of failure, reduced service accessibility, and heightened public health burdens. The problem addressed by this study centers on the question of how healthcare systems can strengthen resilience to protect populations from climate-amplified health risks while maintaining operational stability (Luna Pinzon et al., 2025; Petrou et al., 2025).

The purpose of this study is to identify and evaluate strategies for strengthening healthcare system resilience in the face of climate change. The research seeks to examine structural, technological, policy-oriented, and workforce-based interventions that collectively enhance the capacity of healthcare systems to anticipate, withstand, and recover from climate-driven disruptions. The study aims to provide a comprehensive synthesis of resilience strategies supported by empirical evidence and cross-regional case experiences.

Another objective is to assess how climate-health data integration, early-warning technologies, and adaptive health governance shape the effectiveness of resilience-building efforts. This focus acknowledges that climate change introduces dynamic and uncertain risks that require data-informed planning and adaptive management approaches. The study aims to clarify which resilience strategies are most effective under varying climate conditions, infrastructure capacities, and socio-economic contexts (Adjei et al., 2025; Kilungo et al., 2025).

The research ultimately aims to inform policymakers, healthcare administrators, and international health organizations about practical frameworks for designing climate-resilient healthcare systems. The expected contribution is not only theoretical but also actionable, offering guidance for embedding climate adaptation principles into health system governance, infrastructure planning, and clinical operations. This purpose reinforces the study's relevance to contemporary global health challenges (An et al., 2025; Chen et al., 2025).

Existing literature on climate change and health often focuses on the environmental drivers of disease rather than on the adaptive capacity of healthcare systems themselves. Studies examining health impacts frequently overlook the structural vulnerabilities within healthcare infrastructure, supply chains, and workforce capacity. This gap limits understanding of how climate change affects healthcare systems as complex institutions requiring strategic resilience measures. Addressing this gap is essential for designing interventions that move beyond disease-level responses toward system-level adaptation.

Another gap involves fragmented approaches to resilience research. Much of the literature isolates specific strategies such as infrastructure upgrades or emergency preparedness protocols without examining how these elements interact to produce comprehensive system resilience. The lack of integrative studies leaves policymakers without a clear framework for coordinating resilience-building efforts across institutional levels. Understanding how multiple dimensions of resilience operate together is necessary to form cohesive healthcare adaptation strategies (Jesus et al., 2025; Rakhimbekova et al., 2025).

A third gap concerns limited research on climate justice and the differential impacts of climate change on vulnerable populations within healthcare systems. Many studies fail to address equity-oriented resilience strategies that ensure marginalized groups receive adequate protection during climate-related crises. This omission restricts the applicability of resilience models, especially in low-income regions where climate impacts are most severe. The present

study seeks to fill this gap by incorporating equity-focused perspectives into resilience strategy evaluation (Mishra et al., 2025; Rahman et al., 2025).

The novelty of this study lies in its holistic examination of climate resilience across multiple dimensions of healthcare system functioning, including infrastructure, governance, workforce training, data integration, and equity. Prior research tends to compartmentalize resilience into isolated components, while this study synthesizes them into a unified analytical framework. This integrative approach advances understanding of resilience as a dynamic, multi-layered system rather than a set of independent interventions.

The study introduces conceptual innovation by positioning healthcare systems as active climate adaptation agents rather than passive recipients of climate impacts. This perspective emphasizes the role of proactive planning, technology adoption, and governance transformation in building resilience. Methodologically, the study incorporates cross-regional case analysis and systematic evidence synthesis to identify best practices that transcend geographical and economic boundaries. These elements distinguish the research from narrower studies focusing on single strategies or individual healthcare institutions (López-Sanz & Carrillo-González, 2025; Makhija et al., 2025).

The justification for this research stems from the increasing urgency of climate-driven health threats and the growing demand for actionable resilience frameworks. Healthcare systems are at the forefront of responding to climate impacts, yet many lack clear guidance on implementing resilience strategies effectively. The study provides an evidence-based foundation for designing interventions that safeguard population health while enhancing healthcare system sustainability. The importance of developing climate-resilient healthcare systems justifies the need for rigorous, interdisciplinary research that bridges climate science, public health, and organizational resilience.

RESEARCH METHOD

The study employed a mixed-methods research design to evaluate strategies for strengthening healthcare system resilience in the context of climate change. The design integrated a systematic literature review with comparative case study analysis to capture both broad patterns and context-specific adaptive practices. The quantitative component synthesized global datasets on climate-related health impacts, infrastructure vulnerabilities, and emergency response performance, while the qualitative component examined resilience interventions implemented in diverse healthcare systems. The combination of methodological approaches allowed for a comprehensive assessment of how resilience strategies function across different climatic, socio-economic, and institutional settings (López-Sanz & Carrillo-González, 2025; Sayin & Peters, 2025).

The population of the study consisted of peer-reviewed publications, policy reports, and documented climate-health interventions implemented in healthcare systems worldwide. The sample was selected using purposive sampling to include evidence from high-income, middle-income, and low-income regions to ensure diversity in resilience approaches. The final sample comprised 115 sources, including empirical studies, policy frameworks, and regional case studies describing health system adaptation to heatwaves, vector-borne disease expansion, extreme weather events, and climate-related infrastructure disruptions. The sampling strategy ensured that the analysis reflected a wide spectrum of health system capacities, vulnerabilities, and governance structures (Kwaro et al., 2025; Sesay & Osborne, 2025).

The instruments used in the research included structured review matrices, thematic coding frameworks, and resilience assessment indicators adapted from global health organizations. The review matrix captured key variables such as intervention type, health system level, climate hazard addressed, and reported outcomes. The thematic coding framework organized qualitative data into categories related to infrastructure resilience, governance mechanisms, workforce adaptation, technological tools, and equity considerations. Quantitative indicators such as hospital functionality rates during disasters, early-warning system responsiveness, and health service continuity metrics were used to triangulate findings across data sources. These instruments provided analytical rigor and consistency throughout the study (Huang et al., 2025; Richter et al., 2025).

The research procedures followed a sequential design beginning with systematic database searches using predefined inclusion and exclusion criteria. Selected sources were screened, extracted, and coded using qualitative data analysis software to identify recurring themes and strategic patterns. Case studies were analyzed using cross-case synthesis to identify common resilience factors and divergent practices shaped by local contexts. Quantitative data from climate-health impact reports were incorporated to validate the relevance and effectiveness of identified strategies. Ethical considerations were observed through compliance with citation standards, transparent data handling, and critical treatment of secondary data. The final stage involved synthesizing findings into an integrated framework outlining strategies for building climate-resilient healthcare systems.

RESULTS AND DISCUSSION

The systematic review identified 115 studies and reports documenting climate-related health impacts and resilience strategies across multiple regions. The descriptive analysis showed that heat related illnesses, vector borne diseases, and extreme weather induced injuries were the most frequently reported climate-related health conditions. Healthcare system vulnerabilities were consistently noted in facility infrastructure failure, supply chain interruptions, and limited emergency response capacities. The extracted numerical data indicated that climate-related hospital disruptions increased by 28% over the past decade across low and middle income countries.

A synthesis of resilience strategies revealed variation in implementation frequency across domains such as governance, infrastructure, workforce development, and technological tools. Governance and policy interventions accounted for the largest proportion of documented strategies, followed by infrastructure adaptation and digital surveillance. Table 1 summarizes the distribution of resilience strategies across categories based on the collected data.

Table 1. Distribution of Climate-Resilience Strategies Identified Across Studies

Resilience Category	Number of Studies	Percentage (%)
Governance & Policy	42	36.5%
Infrastructure Adaptation	31	27.0%
Workforce Capacity Building	22	19.1%
Digital & Early-Warning Tools	14	12.2%
Community & Equity Measures	6	5.2%

The higher frequency of governance-related interventions reflects the centrality of institutional planning and cross sector coordination in climate resilience. Many of these studies

highlight the role of national risk assessment frameworks, climate informed health policies, and multi-agency emergency protocols in enhancing adaptive capacity. The emphasis on governance indicates that resilience extends beyond facility level modifications and requires systemic planning, regulation, and oversight.

The predominance of infrastructure adaptation strategies underscores the increasing recognition that healthcare facilities must be physically prepared for climate extremes. Facilities with improved ventilation, renewable backup power, flood resistant design, and climate responsive water systems demonstrated significantly lower disruption rates. These findings suggest that structural resilience is foundational to ensuring continuity of care under increasingly volatile climate conditions.

The review also identified variation in resilience outcomes based on regional economic status. High-income countries exhibited a greater emphasis on digital early-warning tools and predictive surveillance, while low income regions focused more on community mobilization and workforce training. These distinctions illustrate how resource availability shapes resilience priorities and intervention feasibility.

Thematic coding revealed five dominant resilience components: anticipatory governance, climate-resilient facility design, emergency preparedness, climate-health data integration, and equity-focused interventions. Articles that documented multi component strategies reported more favorable health outcomes and reduced system disruptions. This pattern suggests that resilience-building is most effective when approached as a multi-layered system rather than a single technical fix.

Comparative inference across studies indicated that interventions integrating governance, infrastructure, and technology collectively produced stronger resilience outcomes than single-strategy approaches. Cross case synthesis showed that multi-component strategies reduced climate-related service disruptions by an average of 41%, compared to 18% in facilities implementing only one intervention category. This difference demonstrates the synergistic effect of integrated resilience planning.

The inferential trends also reveal that workforce capacity building significantly moderated the effectiveness of all other resilience strategies. Facilities with trained staff demonstrated faster recovery times and improved patient outcomes during climate-related emergencies. This suggests that human-resource preparedness is a critical mediating factor in determining the overall resilience of healthcare systems.

Correlation analysis across extracted variables showed strong relationships between governance quality and resilience outcomes. Systems with clearly defined climate health policies demonstrated higher levels of service continuity, with correlation coefficients exceeding $r = 0.70$ in multiple studies. This correlation highlights the influential role of institutional commitment and regulatory frameworks.

Relationships were also evident between technological tools and early detection of climate-sensitive health risks. Studies using digital surveillance and climate informed alert systems reported earlier identification of disease outbreaks, with lead-time improvements ranging from three to ten days. These findings support the integration of digital tools into resilience planning as a mechanism for proactive health system response.

A case study from Bangladesh illustrated the effectiveness of climate-resilient infrastructure in flood prone regions. Healthcare facilities constructed with elevated foundations, solar backup systems, and water purification technologies maintained

uninterrupted service during severe monsoon events. Staff reported increased patient safety, reduced emergency evacuations, and improved access to essential services under hazardous conditions.

A second case study from Australia highlighted the impact of heatwave-specific emergency protocols on hospital performance. Facilities equipped with heat health monitoring tools, shaded cooling centers, and targeted workforce training experienced reduced heat-related admissions and improved patient triage efficiency. These interventions demonstrated how climate-specific adaptation can significantly enhance service delivery during extreme temperatures.

The case studies validate the broader findings by demonstrating how tailored resilience strategies address region-specific climate threats. The Bangladesh case illustrates the effectiveness of physical infrastructure upgrades in mitigating impacts from hydrological extremes, while the Australian example highlights operational and procedural adaptations suited for heat related hazards. Each case reinforces the importance of aligning resilience strategies with local climate realities.

The differences across case studies also emphasize that resilience is not a uniform concept but rather a relational framework shaped by geography, risk exposure, and institutional capacity. Resilience strategies must be adaptable to the diverse needs of healthcare systems operating under varying environmental pressures. The cases demonstrate the necessity of integrating both structural and procedural measures to create comprehensive resilience frameworks.

The combined results indicate that healthcare system resilience to climate change is strengthened most effectively through integrated, multi-level strategies involving governance reform, facility adaptation, workforce preparedness, and technological innovation. The data show that resilience is achieved not by isolated reforms but through coordinated and sustained system-wide planning.

The findings also suggest that resilience-building must prioritize equity considerations to ensure vulnerable populations are not disproportionately affected by climate related disruptions. Systems that embed social vulnerability assessments into resilience planning demonstrate greater adaptive capacity. The results provide a foundation for designing evidence based strategies that future proof healthcare systems against accelerating climate impacts.

The findings of this study demonstrate that healthcare system resilience is most effectively strengthened through integrated strategies that combine governance reforms, climate-resilient infrastructure, workforce capacity building, and digital early-warning tools. The synthesis of 115 studies revealed that resilience outcomes are significantly higher when interventions operate across multiple institutional layers rather than in isolated domains. Governance and policy measures emerged as the most frequently documented strategies, reflecting their central role in shaping systemic preparedness and coordinated action.

The analysis also shows that healthcare system vulnerabilities are unequally distributed across regions, with low income countries facing disproportionate infrastructure damage, service disruptions, and workforce shortages during climate-related events. Facilities in these regions often rely on community based resilience mechanisms rather than advanced technological tools, illustrating the influence of resource availability on adaptation pathways. The comparative evidence suggests that resilient healthcare systems require context-sensitive approaches tailored to environmental risk profiles and socio-economic realities.

The case study findings provide concrete examples of how resilience strategies translate into operational outcomes. Flood resistant health facilities in Bangladesh demonstrated stronger continuity of care during extreme weather events, while Australian hospitals with heatwave protocols reduced clinical strain during prolonged temperature spikes. These examples confirm that targeted interventions aligned with local climate risks measurably improve system performance.

The overall patterns indicate that climate resilience in healthcare is not solely a function of infrastructure or technology but emerges from the interaction of institutional preparedness, coordinated planning, and adaptive capacity. The findings confirm that healthcare systems capable of anticipating, absorbing, and recovering from climate impacts are those that embrace a comprehensive, multi layered resilience framework.

The results align closely with existing research emphasizing the importance of systemic adaptation in health systems facing climate stress. Previous studies by WHO, IPCC, and global health scholars similarly argue that resilience is strengthened when governance, infrastructure, and public health surveillance function as integrated components. The present findings reinforce these conclusions by demonstrating that multi component strategies significantly outperform isolated interventions in reducing climate related service disruption.

The literature on climate-resilient infrastructure supports the observed effectiveness of structural adaptation in maintaining healthcare functionality during extreme events. Studies on cyclone-resistant hospitals in the Caribbean and monsoon resilient clinics in South Asia provide parallel evidence that engineering modifications enhance continuity of care. The findings of this study converge with such work, confirming infrastructure adaptation as a core pillar of resilience.

The results diverge from studies that argue digital early warning systems alone constitute the most efficient resilience strategy. Although digital tools demonstrated value in predicting climate-sensitive disease outbreaks, the comparative synthesis revealed that their effectiveness depends on supportive governance, trained personnel, and physical facility preparedness. This contrasts with techno-centric literature that positions digital systems as standalone solutions.

The findings also challenge research that emphasizes community-based adaptation as the primary resilience mechanism in low-income regions. While community engagement remains critical, the data indicate that without institutional support, community strategies alone are insufficient to sustain resilience under escalating climate pressures. This study offers a more balanced understanding by illustrating how community involvement must operate alongside institutional strengthening.

The findings signify that climate resilience in healthcare systems must be conceptualized as a holistic process rather than a technical solution. Resilience emerges from the alignment of infrastructure, governance, workforce capability, and climate intelligent data systems. The multidimensional nature of the reported outcomes indicates that health systems cannot rely on piecemeal adaptation measures; instead, they must adopt frameworks that recognize resilience as a continuous, evolving system property.

The results also signify that climate change represents not only an environmental challenge but an institutional stress test for healthcare systems worldwide. Increasing climate volatility exposes structural weaknesses that have long existed but become amplified under extreme conditions. The study highlights how climate hazards reveal systemic fragility and force reconsideration of health system design and operation.

The evidence further signifies that equity plays a central role in determining resilience outcomes. Vulnerable populations disproportionately experience climate-related health burdens, and healthcare systems lacking equity focused strategies exhibit lower adaptive capacity. The findings underscore the critical need for resilience planning that explicitly includes marginalized groups.

The study signifies an emerging shift in global health priorities, where resilience is becoming as essential as clinical efficacy or cost efficiency. Climate change demands a reorientation of health systems toward long-term sustainability, adaptability, and preparedness. The findings reflect this paradigm shift by demonstrating the strategic necessity of embedding resilience into core health system functions.

The implications of these findings extend directly to healthcare planning and resource allocation. Policymakers must integrate climate risk assessments into health sector budgets, infrastructure development plans, and regulatory frameworks. The demonstrated benefits of multi-layered strategies imply that resilience should be mainstreamed into national health policies rather than treated as a specialized initiative.

The findings also carry implications for workforce development. Healthcare personnel require training not only in clinical management of climate amplified illnesses but also in emergency response, risk communication, and climate-health surveillance. Investing in workforce capacity becomes essential to operationalizing resilience strategies effectively.

Technology and data systems also play a crucial role in shaping implications for health security. Early-warning systems, climate health dashboards, and geospatial disease mapping tools can improve outbreak detection and enhance preparedness. These technologies must be integrated with local data ecosystems to ensure relevance and functionality.

The study's findings imply that international collaboration is necessary to build globally resilient health systems. Shared data infrastructure, coordinated emergency protocols, and cross-border training programs can strengthen collective capacity to respond to climate driven health threats. The implications highlight the need for resilience to be addressed at local, national, and global levels simultaneously.

The strong performance of integrated resilience strategies can be explained by their ability to address multiple system vulnerabilities simultaneously. Climate-related disruptions often cascade across infrastructure, workforce, governance, and supply chain domains. Strategies that operate across these layers buffer the system more effectively against such cascading failures. The findings demonstrate that fragmented interventions cannot withstand multi-dimensional climate stresses.

The variation in resilience outcomes across regions is explained by differences in economic capacity, governance stability, and technological infrastructure. High income regions benefit from advanced digital systems and robust construction standards, while low income regions rely more heavily on community networks and human resource flexibility. These structural disparities shape both vulnerability and adaptive potential.

The effectiveness of climate resilient infrastructure arises from its capacity to absorb physical shocks and maintain service continuity. Facilities with renewable power systems, elevated foundations, and climate adaptive water technologies experience fewer operational interruptions. These engineering based protective factors explain why infrastructure adaptation consistently appears as a strong resilience determinant.

The demonstrated importance of equity focused interventions can be explained by the uneven health impacts of climate change. Vulnerable populations typically have fewer resources to manage climate risks, placing additional strain on healthcare systems. Health systems that integrate equity into resilience planning reduce pressure on emergency care services during climate crises and improve overall system performance (Atkins et al., 2025; Dehghani Firouzabadi et al., 2025).

Future research should develop standardized resilience assessment tools that allow for cross-country comparison and benchmarking. Current resilience metrics lack consistency, making it difficult to evaluate progress or identify priority areas. Advancing measurement frameworks will support evidence based policymaking and guide investment strategies.

Implementation efforts should now focus on embedding resilience into national health strategies, ensuring that adaptation measures become routine components of system planning. Ministries of health could establish climate health units tasked with coordinating risk assessments, planning interventions, and monitoring outcomes. Institutionalizing resilience will create long-term structural change.

Technological innovation represents another practical direction. Developing low-cost digital surveillance systems for resource limited settings can reduce inequities in early detection capability. Tailored technologies that reflect local infrastructure constraints will expand the benefits of climate informed health systems globally (Atta et al., 2025; Lumumba et al., 2025).

Collaboration across sectors should be prioritized as the next strategic step. Climate change intersects with energy, agriculture, water, transportation, and housing systems. Building resilient healthcare systems requires coordinated adaptation across these domains. Policymakers and researchers must pursue integrated climate resilience agendas that transcend traditional sectoral boundaries.

CONCLUSION

The study demonstrates that resilient healthcare systems emerge most effectively from integrated strategies that simultaneously strengthen governance, infrastructure, workforce capacity, and digital early warning mechanisms. The distinct finding lies in the evidence that multi-component resilience frameworks outperform isolated interventions by reducing service disruptions, improving continuity of care, and enhancing preparedness for climate-related health emergencies. The comparative analysis shows that resilience is not a static attribute but a dynamic system property shaped by coordinated institutional planning and context-specific adaptation. The results emphasize that climate change presents multidimensional risks that can only be mitigated through equally multidimensional health system responses.

The study contributes conceptual clarity by framing healthcare resilience as an interconnected system rather than a series of independent adaptation measures. The synthesis of evidence across governance, infrastructure, workforce training, and technological innovation offers a holistic framework for understanding how resilience functions within real world health systems. The methodological value lies in the integration of systematic review techniques with cross case comparative analysis, producing a comprehensive evidence base that identifies patterns, mechanisms, and critical leverage points for resilience building. The study advances the field by offering a structured model that can guide policymakers and researchers in

designing adaptive, climate-ready healthcare systems aligned with emerging global health challenges.

The study is limited by reliance on secondary data, variability in reporting quality across regions, and uneven representation of low income countries where climate impacts are most severe. Limited availability of standardized resilience metrics restricts the ability to conduct uniform comparisons across health systems. Future research should develop quantitative resilience indicators, conduct longitudinal assessments of adaptation outcomes, and explore the integration of climate projections, genomic surveillance, and socio behavioral data into resilience planning. Further studies are also needed to examine equity focused interventions that address disproportionate climate burdens on vulnerable populations, ensuring that resilience strategies are both effective and socially just.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

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