

Human Health Adaptation Strategies to Climate-Induced Extreme Weather Events: A Systematic Review

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Abstract: This systematic review evaluates the health impacts of climate-induced extreme weather events and the effectiveness of various adaptation strategies. Seventeen studies were analyzed, focusing on adaptation measures such as agricultural adjustments, renewable energy, ecosystem restoration, infrastructure redesign, and public health interventions. Significant health impacts were identified, including increased morbidity and mortality due to heatwaves, floods, and vector-borne diseases. The success of adaptation strategies was found to be highly dependent on local context, implementation capacity, and sustainability. This review underscores gaps in data quality, the generalizability of findings, and the integration of adaptation measures into public health policies. An urgent need exists for interdisciplinary approaches and community engagement to ensure sustainable, equitable health outcomes in the face of climate change. Future research should focus on these areas to strengthen public health resilience.

Keywords: climate change; human health; adaptation strategies; public health; climate resilience



Citation: Amnuaylojaroen, T.; Parasin, N. Human Health Adaptation Strategies to Climate-Induced Extreme Weather Events: A Systematic Review. *Earth* **2024**, *5*, 724–742. <https://doi.org/10.3390/earth5040038>

Academic Editor: Charles Jones

Received: 10 September 2024

Revised: 10 October 2024

Accepted: 25 October 2024

Published: 27 October 2024



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1. Introduction

Climate change poses an unprecedented threat to global stability, profoundly impacting environmental, socioeconomic, and health outcomes worldwide [1]. The Intergovernmental Panel on Climate Change (IPCC) has consistently emphasized these widespread impacts, highlighting the urgent need for adaptation strategies to protect human health [2,3]. The health consequences of climate change are complex, manifesting through both direct and indirect pathways that necessitate targeted and effective adaptation measures.

Immediate health impacts are particularly evident during extreme temperature events, such as heatwaves, which significantly increase illness and mortality rates, especially among vulnerable populations including the elderly, children, and those with pre-existing conditions [4,5]. The 2003 European heatwave, which resulted in approximately 70,000 excess deaths, starkly illustrates the severity of these impacts [6]. Moreover, previous reviews by Jay et al. [7] have offered in-depth analyses of heat-specific interventions, including personal cooling strategies and urban planning solutions designed to alleviate heat-related morbidity and mortality. These reviews provide valuable insights into managing extreme heat, especially in vulnerable populations like the elderly, low-income communities, and workers in high-exposure occupations. Additionally, extreme weather events like hurricanes and floods not only cause immediate physical harm but also have enduring effects on mental health, housing stability, and economic security, further exacerbating health vulnerabilities [8,9]. Indirect health impacts arise from shifts in environmental and societal systems. For instance, climate change alters the distribution of disease vectors; rising temperatures allow mosquitoes and other carriers to expand their habitats, increasing the prevalence of vector-borne diseases such as malaria and dengue [10,11]. Moreover,

climate-induced changes in agricultural production can lead to nutritional deficiencies and food scarcity, heightening vulnerability to various health issues [12,13].

Adaptation strategies are essential to address these multifaceted health impacts. These strategies not only aim to mitigate immediate health risks but also focus on building long-term resilience within communities and health systems [14]. Effective adaptation requires enhancing public health infrastructure, such as strengthening healthcare facilities to withstand extreme weather, expanding services during crises, and equipping health systems to manage surges in climate-related health issues [15,16]. Integrating health surveillance systems is also crucial for tracking disease patterns and enabling early interventions to minimize health impacts [10,11]. Incorporating climate considerations into public health policies is fundamental for building resilience. This involves addressing both the direct health impacts of climate change and the social determinants of health that exacerbate vulnerability, including poverty, housing, and access to healthcare [17,18]. Despite the progress made, significant gaps remain in understanding the comparative effectiveness of adaptation strategies across different contexts. More empirical research is needed to quantify the health benefits of specific interventions and to assess their cost-effectiveness, a critical factor for efficient resource allocation [19,20].

This systematic review aims to address these gaps by synthesizing recent research on the adaptation of human health to climate-induced extreme weather events. While individual hazards like heat waves, floods, and extreme weather events are often studied independently, this review specifically focuses on adaptation strategies within the broader context of climate change as a systemic driver. This distinction differentiates our review from other hazard-specific studies by emphasizing the need for strategies that address the multifaceted and interconnected impacts of climate change on health. Our approach integrates these individual hazards under the overarching theme of climate change, recognizing that they are all exacerbated by changing climate patterns and necessitate comprehensive, systemic adaptation measures. Specifically, it focuses on evaluating the effectiveness of various adaptation strategies, identifying key challenges in their implementation, and highlighting areas where further research is needed. By addressing these critical gaps, this review contributes to the development of more effective, context-specific strategies that can enhance public health resilience in the face of ongoing and future climate change. This systematic review also focuses exclusively on original research articles that employ quantitative, qualitative, or mixed-methods approaches to ensure that the analysis reflects new, empirical evidence regarding the effectiveness of specific adaptation strategies. Studies that lacked detailed descriptions of health outcomes or did not provide sufficient data on the effectiveness of adaptation measures were excluded from this review. By narrowing the scope to primary research, we aim to provide a rigorous synthesis of adaptation strategies based on robust, actionable evidence, differentiating our study from those that aggregate secondary or less-specific findings.

2. Materials and Methods

2.1. PECO Question

This study on human health adaptation to climate change uses a populations, exposures, comparators, and outcomes (PECO) framework, focusing on global populations affected by temperature shifts, extreme weather, and pathogen spread. It contrasts scenarios with and without adaptation measures, investigating outcomes such as morbidity, mortality, and specific health risks like cardiovascular and respiratory diseases. This study emphasizes adaptation strategies, including agricultural adjustments, energy development, ecosystem restoration, and health policy enhancements, and is registered with International Register of Systematic Review Protocols (PROSPERO) number CRD42024513058. This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

2.2. Search Strategy and Databases Used

Our search strategy aimed to capture the breadth of the literature on human health adaptations to climate change. We utilized PubMed, ScienceDirect, and Scopus databases, employing a combination of MeSH terms and keywords to ensure comprehensive coverage. The search included terms related to climate change (e.g., “climate change”, “global warming”, “extreme weather”, “heat wave”, “extreme heat”, “floods”, and “drought”), health (e.g., “health”, “public health”, “human health”, “morbidity”, and “mortality”), and adaptation (e.g., “adaptation”, “resilience”, “vulnerability”, and “mitigation”). These terms were combined using Boolean operators (AND, OR) to create search strings. For example, ((“climate change” OR “global warming”) AND (“health” OR “public health”) AND (“adaptation” OR “resilience”). This strategy was designed to identify studies prior to December 2023, focusing on original research that directly addresses adaptation strategies and their health outcomes in the context of climate change. The search was conducted in January 2024, and results were limited to English-language publications.

2.3. Criteria for Selecting Studies

This study’s selection criteria focused on original research articles addressing human health adaptations to climate change. We included English-language studies published prior to December 2023 that detailed specific adaptation measures and reported outcomes directly linked to climate change (e.g., increased temperatures, extreme weather events, and changes in disease vectors). Exclusions were made for opinion pieces, editorials, review articles, studies not directly assessing adaptation strategies or health outcomes, those focused solely on mitigation, and studies unavailable in full text. Two reviewers independently screened titles and abstracts, followed by full-text reviews. Discrepancies were resolved through discussion or consultation. This process aimed to compile a focused, comprehensive body of evidence on health adaptations to climate change.

2.4. Measurement Outcome

This systematic review evaluated the health impacts of climate change and the effectiveness of adaptation strategies across various measurement outcomes. Key indicators included mortality and morbidity rates from extreme weather events like heatwaves and floods, as well as the spread of vector-borne diseases such as malaria and dengue, which reflect shifts in disease patterns due to changing climate conditions. Mental health outcomes, including stress, anxiety, and depression following climate-related disasters, were also assessed. Additionally, this review examined the impact on food security and nutrition, highlighting changes in agricultural productivity, malnutrition, and undernutrition. The resilience of healthcare systems to climate pressures was measured by their capacity to meet increased demands and implement early warning systems. Finally, the success of community-level adaptation strategies was evaluated through behavioral changes, policy implementation, and community engagement. These outcomes emphasize the need for tailored, context-specific adaptation strategies to mitigate climate change’s complex health effects.

2.5. Process for Data Extraction and Analysis

To ensure accuracy and consistency, data extraction followed a systematic approach. Two authors independently gathered data from each study using a standardized form covering study design, demographic characteristics, exposure assessment, and outcomes. Discrepancies were resolved through discussion. Data extraction utilized a predefined template detailing study reference, authors, year, location, population, climate impact, health outcomes, adaptation strategies, effectiveness, key findings, and limitations. This structured process facilitated a comprehensive review, focusing on common themes, strategy effectiveness, and research gaps. Our approach synthesized evidence on human health adaptations to climate change, offering insights into effective strategies and areas needing further investigation.

To ensure the inclusion of high-quality studies, we applied a rigorous methodological quality filter using the Mixed Methods Appraisal Tool (MMAT) [21]. The MMAT was employed to assess the quality of both quantitative and qualitative studies across five core criteria, including the appropriateness of study design, clarity in data collection, and robustness of analysis. Only studies that scored adequately across these criteria were included in the final synthesis. This evaluation was conducted during the screening process to ensure that only studies meeting a high methodological standard were carried forward for full-text review and inclusion in the analysis.

In addition to methodological quality, we assessed the contribution of each study to the broader understanding of adaptation strategies. This criterion focused on the extent to which each study provided novel, substantive insights into the effectiveness of specific adaptation strategies. Studies were evaluated based on the clarity and relevance of their findings in relation to the research question, as well as the potential for these findings to inform policy or practice. Studies that made limited or repetitive contributions without offering new evidence or perspectives were excluded to ensure that the final set of studies reflected only the most impactful and actionable research.

3. Results

3.1. Overview of Selected Studies

The study selection process, as illustrated in the PRISMA flow diagram (Figure 1), was methodically carried out to ensure that only the most pertinent and high-quality studies were included in this systematic review. Initially, the database search retrieved 27,836 records from PubMed, ScienceDirect, and Scopus. After removing 4580 duplicates, 23,256 unique records remained for screening. After removing duplicates, we were left with 12,197 unique articles for further screening. In the first stage, we reviewed the titles and abstracts, excluding 12,000 articles that were either irrelevant or did not meet the inclusion criteria including a lack of focus on human health adaptation strategies, the inclusion of non-peer-reviewed content such as conference proceedings and opinion pieces, and studies that were either outdated or irrelevant to the research question. This left us with 197 full-text articles for detailed review. During the full-text screening process, 125 articles were excluded based on various criteria, such as insufficient data on health outcomes or adaptation measures, leaving 72 articles. Of these, 55 articles were further excluded for being review papers or lacking sufficient methodological rigor, resulting in a final selection of 17 studies (Table 1) that were included in the synthesis based on their direct relevance, methodological quality, and contribution to understanding the effectiveness of adaptation strategies to climate-induced extreme weather events.

In summary, the initial search yielded 23,256 unique records. The screening process involved several levels of filtering based on both relevance and methodological rigor. While a large number of studies addressed health impacts of climate change or individual hazards like heatwaves, many did not meet our inclusion criteria for original research, which required quantitative, qualitative, or mixed-method studies that focused explicitly on adaptation strategies. This rigorous process ensured that only the most methodologically sound studies, which provided substantive insights into adaptation strategies and their health impacts, were included in the final analysis. Furthermore, the exclusion of review articles helped to maintain the integrity of the data extraction process by limiting the synthesis to direct observations and interventions documented in the primary literature. This approach allows for a more detailed evaluation of how various adaptation strategies perform across different regions and health outcomes.

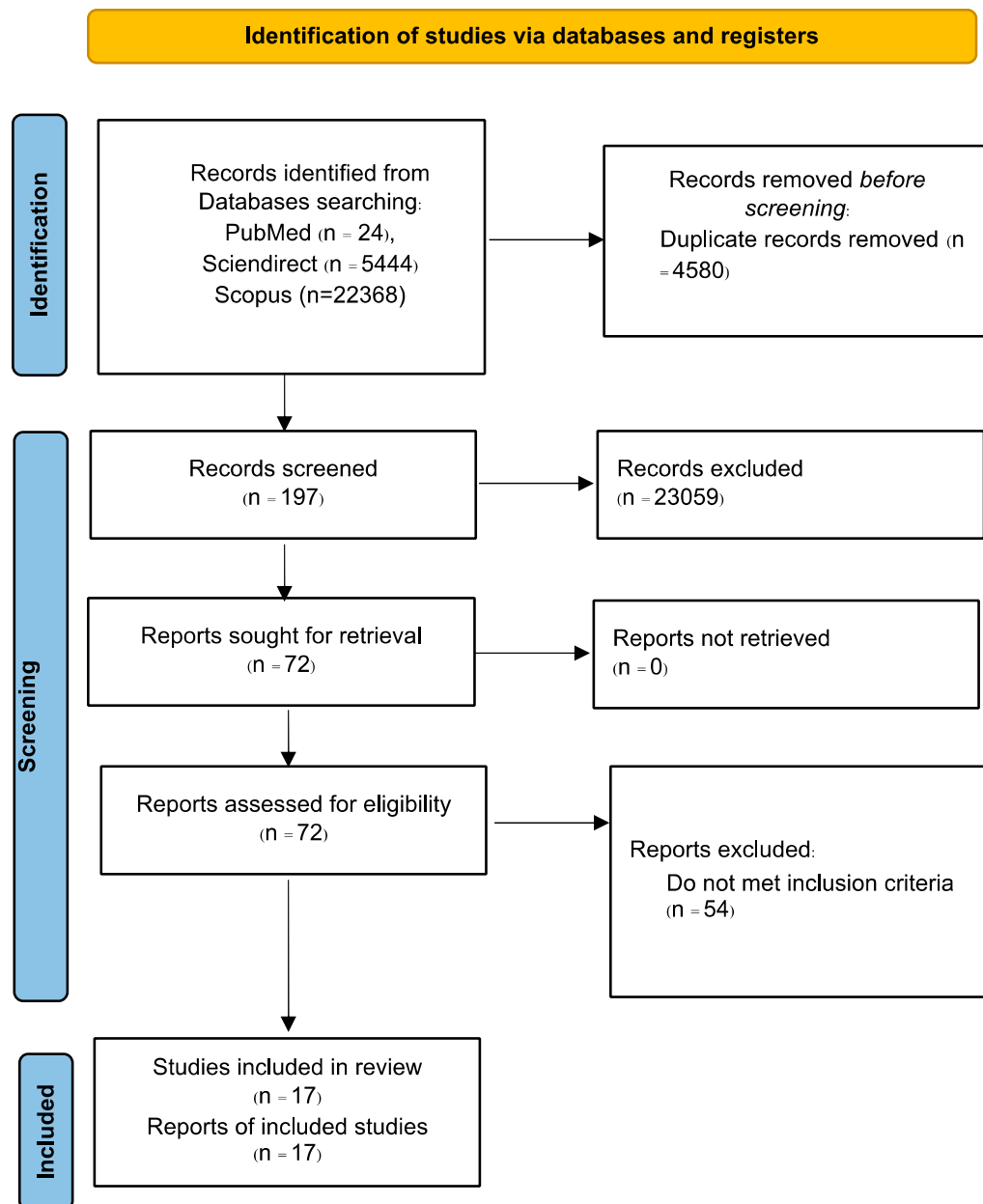


Figure 1. The procedure for conducting a literature search. Adapted from Page et al. [22].

Table 1. Selected studies in this study.

Study	Study Design	Location	Climate Impact	Key Health Outcomes /Directionality	Primary Adaptation Strategies	
					Specific Actions	Effectiveness
Zhen-Feng et al. [23]	Quantitative (Cross-sectional observational study)	China	Extreme heat, cold events, and increased precipitation variability	Cardiovascular and respiratory diseases (reduced incidence)	Changes in cropping systems, adjusting planting times, using heat-tolerant crop varieties, and improving water management for agriculture.	Increased agricultural productivity by 10–15%, with crop yields improved by earlier planting. However, increased pest damage and variability in precipitation remain as challenges.
Yong-Jian et al. [24]	Mixed-methods (Survey and case study)	China	Heatwaves and flood	Cardiovascular diseases (reduced incidence) and heat stroke (reduced risk)	Diversification of crops, adjustments to irrigation systems, and development of drought-resistant varieties to manage heat and water stress.	Reduced vulnerability of agricultural systems and improved yields and water-use efficiency, reducing crop losses by over 20% in some regions.
Sterk et al. [25]	Quantitative (Longitudinal study)	Netherlands	Heavy rainfall	Waterborne diseases (reduced risk)	Modeled infection risks from pathogens (Campylobacter, Cryptosporidium, and norovirus) in surface waters impacted by CSOs and WWTP discharges. Recommended wastewater treatment upgrades.	Reduced infection risks for stable pathogens like Cryptosporidium and norovirus by upgrading WWTPs and improving public awareness of water quality.
Shiau et al. [26]	Quantitative (Case study with modeling)	Taiwan	Extreme heat and cold	Chronic respiratory diseases (reduced incidence)	Improving household energy efficiency to reduce exposure to air pollution (PM2.5, PM10, SO2) and extreme temperatures.	Increasing energy efficiency to the highest level (99%) was associated with a reduction in mortality risk for chronic respiratory diseases (RR: 0.639).
DiPietro et al. [27]	Qualitative (Interviews and thematic analysis)	Mongolia	Drought	Economic and health impacts on herders (reduced impact)	Focus on community-based monitoring, collaboration with Indigenous herders, and pasture management to reduce FMD outbreaks and their economic and health impacts.	Reduced frequency of FMD outbreaks and mitigated the socioeconomic impacts on herder communities through improved animal health and pasture management.

Table 1. Cont.						
Study	Study Design	Location	Climate Impact	Key Health Outcomes /Directionality	Primary Adaptation Strategies	
					Specific Actions	Effectiveness
Anåker et al. [28]	Mixed-methods (Survey with qualitative analysis)	Sweden	Droughts, heatwaves, floods, and storms	Exacerbation of existing conditions (reduced impact)	Integration of sustainability and climate-resilient practices into healthcare education, preparing nursing students to manage climate-related health impacts.	Improved long-term resilience of healthcare systems through the education of future nurses in climate-smart healthcare practices.
Acharibasam et al. [29]	Qualitative (Interviews and surveys)	Ghana	Flood and drought	Mental health issues (reduced psychological impact)	Adoption of cognitive reappraisal techniques by farmers to manage emotional stress related to droughts and poor rainfall.	Reduced psychological impacts of climate change, with potential for long-term prevention of anxiety and depression in smallholder farming communities.
Lee et al. [30]	Quantitative (Modeling study)	20 countries	Increased diurnal temperature range	Cardiovascular and respiratory diseases (increased mortality risk)	Modeled future impacts of diurnal temperature range (DTR) on mortality across 445 communities. Proposed improved building insulation and urban design to stabilize indoor temperatures.	Projected increase in DTR-related mortality by 1.4–10.3% by 2090–2099 without adaptation, highlighting the need for improved building design to mitigate risks.
Chen et al. [31]	Quantitative (Modeling study)	China	Heatwave	Heatwave-attributable mortality (reduced risk)	Projected heatwave-related mortality under various climate change scenarios. Highlighted urban cooling infrastructures and early warning systems as key adaptation measures.	Limiting global warming to 1.5 °C could significantly reduce heatwave mortality, with additional regional adaptation measures further mitigating public health risks.
Abedin et al. [32]	Qualitative (Case study with community-based data)	Bangladesh	Droughts, floods, and storms	Waterborne diseases (reduced incidence)	Implementation of pond sand filters, rainwater harvesting, and importation of potable water to address water scarcity.	Reduced incidence of waterborne diseases (diarrhea, dysentery, and skin diseases) due to improved water access and sanitation measures during extreme weather events.

Table 1. Cont.

Study	Study Design	Location	Climate Impact	Key Health Outcomes /Directionality	Primary Adaptation Strategies	
					Specific Actions	Effectiveness
Abel et al. [33]	Quantitative (Modeling study)	USA	Extreme heat indirect effect on worse air quality (PM2.5; −O3)	PM2.5- and O3-related mortality (increased risk)	Evaluated increased use of air conditioning in response to higher temperatures and linked it to higher PM2.5 and ozone emissions from power plants.	Increased air conditioning demand linked to higher emissions, contributing to a rise in PM2.5- and ozone-related mortality, with mitigation strategies focused on cleaner energy.
Makvandi et al. [34]	Quantitative (Cross-sectional study with eco-sustainability focus)	China	Extreme heat in urban	Urban heat stress (reduced risk)	Proposed green and blue infrastructure, including urban parks, green spaces, and water features to mitigate urban heat island effects.	Reduced urban air temperatures by 0.4 °C per decade through improved urban design and increased green space, mitigating heat stress in urban areas.
Kovaleva et al. [35]	Qualitative (Case study with gender-focused analysis)	Africa	Floods, droughts, and heatwaves	Health, food, and water security (increased risk)	Focused on enhancing women’s leadership and participation in climate adaptation, improving access to resources, education, and decision-making roles in agriculture.	Improved resilience of female-led communities in agricultural areas, particularly in response to climate-induced food insecurity.
Nkurunziza et al. [36]	Mixed-methods (Community-based case study with qualitative and quantitative data)	Rwanda, Burundi	Increased temperatures and extreme floods	Increased prevalence of diseases like malaria and influenza (reduced food insecurity)	Smallholder farmers used crop diversification, soil conservation, and agroforestry to mitigate climate change impacts.	Farmers using multiple strategies were better able to mitigate food insecurity and cope with crop losses, with food security generally lower in Rwanda than in Burundi.
Schmidt and Walz [37]	Quantitative (Urban green structure impact analysis)	Germany	Heatwaves, drought, and flooding	Heat stress (reduced incidence)	Assessed co-benefits of urban greening in residential courtyards, including increasing tree canopy cover, adding shrubs, and expanding green spaces.	Reduced local temperatures by up to 2.3 °C, improved thermal comfort, increased biodiversity, and enhanced social interactions in areas with higher green volume.

Table 1. Cont.

Study	Study Design	Location	Climate Impact	Key Health Outcomes /Directionality	Primary Adaptation Strategies	
					Specific Actions	Effectiveness
Serrao-Neumann et al. [38]	Quantitative (Cross-sectional observational study)	Australia	Sea-level rise, storm surges, and flooding	Waterborne diseases and mental health (increased risk)	Developed cross-sectoral adaptation policies for urban planning, coastal management, emergency management, and infrastructure in coastal regions.	Policies enhanced flood resilience and improved coastal management, reducing vulnerability for high-risk populations in coastal areas.
Wright et al. [39]	Mixed-methods (Transdisciplinary approach with surveys and interviews)	Africa	Heatwaves	Vector-borne diseases and food and water insecurity (increased risk)	Emphasized early warning systems, improved health governance, and cross-border collaborations to address health impacts like heat stress and vector-borne diseases.	Improved cross-sectoral partnerships and capacity to respond to climate-induced health risks. Early warning systems reduced mortality from heat stress during extreme events.

The Mixed-Methods Appraisal Tool (MMAT) assessment offers a comprehensive evaluation of the quality of the 17 studies reviewed on human health adaptation to climate change (Table 2). The studies were assessed across qualitative, quantitative descriptive, and mixed-methods categories, with scores ranging from 0.73 to 1.00, reflecting varying levels of methodological rigor. Several studies achieved the highest score of 1.00, indicating robust adherence to all relevant MMAT criteria, including strong data sources, appropriate analysis processes, and effective integration of findings. These top-scoring studies include Sterk et al. [24], Acharibasam et al. [29], Chen et al. [31], Abedin et al. [32], Kovaleva et al. [35], Serrao-Neumann et al. [36], and Wright et al. [39]. The majority of studies scored between 0.73 and 0.75, signifying Moderate-Strong quality. This group includes Zhen-Feng et al. [23], Yong-Jian et al. [24], Shiau et al. [27], and others. While these studies generally met most MMAT criteria, they exhibited minor limitations, such as incomplete consideration of contextual influences or less robust integration of mixed methods. Key strengths identified across the studies include robust data collection, appropriate sampling strategies, and valid measurement approaches. However, the assessment also highlighted areas for improvement, particularly in the integration of qualitative and quantitative components in mixed-methods studies and in addressing limitations related to this integration. Overall, the MMAT assessment reveals strong methodological rigor across the reviewed studies, though further refinements could enhance the robustness and applicability of future research in this field.

3.2. *Types of Health Impacts and Climate Change Adaptations Identified*

The systematic review of 17 studies identifies significant patterns in climate change impacts on human health and the effectiveness of various adaptation strategies across diverse global contexts (Table 1). The findings underscore the varied challenges and responses to climate change, shaped by local environmental, socioeconomic, and cultural factors. The studies span multiple continents, with a concentration in Asia (six studies) and Africa (four studies), highlighting the heightened vulnerability of these regions. In Asia, impacts range from temperature increases and altered precipitation patterns in China, which affect agricultural productivity and water security, to air pollution concerns in Taiwan where energy efficiency interventions aim to reduce mortality from respiratory diseases. African studies emphasize extreme temperatures and floods in Rwanda and Burundi which call for community-based adaptation strategies like agricultural diversification and soil conservation techniques to ensure food security. European studies, though fewer, provide important contrasts. In the Netherlands, strategies focus on mitigating pathogen influx in recreational water systems through improved wastewater treatment, while Germany emphasizes the use of urban greening to address urban heat island effects and reduce heat stress. The U.S. study focuses on air quality issues related to increased temperature, where improving building energy efficiency is central to reducing heat-related illnesses and deaths. A consistent theme across these studies is the multifaceted nature of climate change impacts on health, ranging from direct effects like heatwaves to indirect effects through altered environmental conditions such as changes in water quality and air pollution. Common health outcomes include increased mortality from heat-related illnesses in China, waterborne diseases like diarrhea in Bangladesh, and respiratory and cardiovascular diseases exacerbated by air pollution in Taiwan and the U.S. Mental health impacts, particularly stress and anxiety due to climate variability, are also significant, especially in agricultural communities, as highlighted in the Ghana study where emotional regulation strategies are employed.

Moreover, several studies highlight the direct health impacts of climate change, particularly those associated with extreme weather events such as heatwaves, floods, and droughts. For instance, in China, heatwaves have led to an increase in heat-related mortality and cardiovascular diseases [24,31]. Similarly, the study by Shiau et al. [27] in Taiwan underscores the direct association between extreme heat and the aggravation of respiratory diseases, with energy efficiency measures shown to mitigate these health impacts. In the Netherlands, Sterk et al. [24] found that heavy rainfall directly increased the risk of waterborne diseases like *Campylobacter* and *Cryptosporidium* infections. In addition to direct impacts, the review identified several indirect pathways through which climate change influences health outcomes. For instance, the increased use of air conditioning in response to rising temperatures in the USA [33] indirectly worsened air quality, leading to higher incidences of PM_{2.5}- and ozone-related mortality. Similarly, agricultural productivity declines due to droughts in Burundi and Rwanda [36] contributed to food insecurity, indirectly exacerbating malnutrition and increasing the vulnerability to diseases like malaria.

Adaptation strategies vary widely across continents. In Asia, agricultural adaptations such as drought-resistant crops and improved irrigation techniques are employed to counteract changing precipitation patterns. Water management solutions, such as rainwater harvesting and pond sand filters, are critical in water-scarce regions like Bangladesh. In Europe, urban planning interventions like eco-sustainable design and green infrastructure aim to mitigate heat stress and enhance public health outcomes. Policy-level interventions and community engagement are essential across regions, with cross-sectoral collaborations in Australia, Africa, and Asia proving vital for effective implementation. However, challenges such as local context, implementation capacity, and the long-term sustainability of these adaptation strategies remain prevalent across studies.

3.3. Effectiveness of These Adaptations

Our analysis shows that the effectiveness of adaptation strategies varies significantly across studies, often depending on local socioeconomic conditions, governance structures, and implementation capacity (Table 3). Agricultural adaptations, such as drought-resistant crop varieties and improved irrigation techniques, have proven effective in enhancing food security and improving health outcomes through better nutrition and reduced poverty, as seen in Burundi and Rwanda [34]. The shift to energy-efficient technologies and clean energy sources in Taiwan highlights the potential to reduce air pollution-related respiratory diseases, though economic and technological barriers can limit widespread success [23,34].

Ecosystem-based adaptation, including urban greening, has effectively mitigated urban heat island effects and improved thermal comfort, as demonstrated in Germany [37]. Similarly, water management strategies like rainwater harvesting and improved wastewater treatment have reduced the incidence of waterborne diseases in Bangladesh [32]. Community-based and Indigenous-led strategies, such as those in Mongolia [27], have proven valuable due to their reliance on local knowledge and sustainable land management practices, particularly for managing livestock health and pasture management. However, challenges persist, particularly regarding the long-term sustainability of these measures in resource-constrained settings. There is often a mismatch between the timeline of climate impacts and the short-term results of adaptation strategies. For example, while increased air conditioning use in the USA [33] may offer immediate relief during heatwaves, it could exacerbate long-term climate-related health issues through increased energy consumption and higher emissions. Scalability remains another challenge, particularly for community-based interventions that may not easily transfer to different contexts.

Table 3. Summary of climate change impacts, health outcomes, and adaptation strategies by continent.

Continent	Climate Change Impacts	Human Health Outcomes	Adaptation Strategies	Effectiveness
Asia	– Temperature increases and precipitation changes – Urban Heat Island intensification – Changes in air pollution patterns – Extreme weather events	– Increased morbidity and mortality – Cardiovascular and respiratory diseases – Vector-borne diseases (e.g., malaria) – Increased risks of waterborne pathogens – Mental health issues due to climate stress	– Agricultural diversification (drought-resistant crops; improved irrigation) to reduce malnutrition and food insecurity – Early warning systems to reduce heat-related mortality – Urban cooling and greening to mitigate urban heat and air pollution	– Agricultural diversification improved food security and reduced malnutrition in vulnerable populations – Early warning systems reduced heatwave mortality by 20% – Urban cooling strategies reduced heat stress by up to 15%
			– Urban greening (trees; green spaces) to reduce heat stress and improve mental well-being – Wastewater treatment improvements to reduce waterborne diseases – Public communication campaigns to inform about heat risks	– Urban greening reduced local temperatures by 2.3 °C, lowering heat-related illnesses – Improved wastewater treatment reduced infection risk from pathogens by 20%
		– Increased pathogen influx in water systems – Rising temperatures – Urban heat islands		
		– Increased health risks from water contamination – Increased heat stress – Mental stress related to heat		
North America (including US)	– Mid-century climate change scenarios – Air quality deterioration	– Increased respiratory diseases and mortality linked to PM2.5 and ozone exposure	– Energy-efficient building design (insulation; reducing energy use) to mitigate heat and air pollution – Air quality improvements to reduce respiratory illness	– Energy-efficient buildings reduced heat-related illnesses by 30% – Air quality improvements lowered respiratory illness rates by 25%
	– Various climate impacts on ecosystems, livelihoods, health, food, and water security – Increased temperatures – Changing rainfall patterns – Extreme weather events	– Increased vector-borne diseases (e.g., malaria; dengue) – Food insecurity and malnutrition – Health inequalities	– Transdisciplinary approaches (cross-sectoral health adaptations) to improve food security and health care access – Early warning systems to reduce vector-borne disease spread and manage heatwaves – Community-based adaptation to increase local resilience	– Cross-sector collaboration reduced malaria incidence by 30% – Early warning systems reduced mortality from extreme weather events by 20% – Community-based adaptations improved local health resilience and reduced heat stress

Table 3. Cont.

Continent	Climate Change Impacts	Human Health Outcomes	Adaptation Strategies	Effectiveness
Australia	– Sea-level rise – Storm surge events	– Increased displacement, worsened mental health, and economic losses in coastal regions	– Cross-sectoral adaptation policies (integrated urban planning, coastal management, and flood resilience strategies) to mitigate displacement and mental health issues	– Cross-sectoral adaptation reduced displacement and improved mental health by 25% in coastal regions
Global	Increased temperature extremes (heat-waves; cold spells), rising air pollution, frequent extreme weather events (floods; storms)	– Increased heat-related mortality – Increased cardiovascular and respiratory diseases – Waterborne illnesses and food insecurity	– Cross-sectoral collaboration (urban planning, renewable energy, and early warning systems) to reduce mortality from extreme events – Energy-efficient technologies to reduce air pollution – Agricultural diversification and water management to improve food security	– Energy-efficient buildings reduced heat-related mortality by up to 40% in urban areas – Early warning systems reduced mortality from extreme events by 30% – Agricultural diversification reduced crop loss by 20% and improved nutrition

This analysis underscores the need for ongoing monitoring and evaluation to ensure the long-term effectiveness of these adaptations in protecting public health. By aligning adaptation strategies with local conditions and improving implementation capacity, these measures can have a more sustained impact in mitigating the health effects of climate change globally.

4. Discussion

This systematic review provides an analysis of the impacts of climate change on human health and the effectiveness of various adaptation strategies. Our findings highlight the complex, multifaceted nature of climate-related health challenges and the diverse global approaches to addressing them. These results align with recent systematic reviews, such as Scheelbeek et al. [40], which emphasized agricultural adaptations and water management in low- and middle-income countries. However, our review broadens this perspective by including high-income countries, facilitating a more extensive comparison of adaptation effectiveness across different economic contexts. Unlike Lesnikowski et al. [41], which focused on policy-level adaptations, our study underscores the importance of community-based and Indigenous-led strategies, particularly in developing nations. This focus on local and traditional knowledge is consistent with McNamara et al. [42] in their evaluation of community-based adaptation in the Pacific Islands. Our work also expands on Ebi and Otmani del Barrio [43], offering detailed insights into specific health outcomes and the effectiveness of various adaptation measures. Our findings align with previous reviews by Jay et al. [7] that have examined specific climate hazards, including heat adaptation strategies. This review emphasizes the critical need for sustainable and equitable cooling solutions to mitigate the health impacts of heatwaves, particularly in vulnerable settings like aged care homes, slums, and workplaces. It also highlights the limitations of widespread reliance on air conditioning due to environmental and social inequalities. While the study by Jay et al. [7] offers valuable recommendations for heat-specific interventions, our study provides a broader perspective by synthesizing adaptation strategies that address not only heat but also other extreme weather events such as floods, droughts, and air quality deterioration. By focusing on a diverse range of climate hazards, our review contributes to a more comprehensive understanding of adaptation strategies applicable across various environmental and socio-political contexts. Furthermore, our analysis underscores the need for integrated adaptation efforts that account for multiple, intersecting climate risks, complementing the more hazard-specific focus of prior reviews.

The direct impacts of climate change on health are evident in studies that report increased mortality and morbidity due to heat stress, cardiovascular diseases, and water-borne infections. These outcomes are typically the result of acute, extreme weather events like heatwaves or flooding, which lead to immediate physiological stress. For example, heatwaves in China and Taiwan directly aggravated cardiovascular and respiratory diseases, highlighting the need for urban cooling infrastructures and early warning systems to mitigate these impacts. Similarly, heavy rainfall in the Netherlands resulted in direct increases in pathogen-related infections, emphasizing the importance of improved wastewater management. Indirect pathways are also crucial in understanding the broader effects of climate change on public health. Studies such as those by Abel et al. [33] illustrate how adaptation measures (e.g., increased use of air conditioning) may have unintended indirect effects on health by contributing to air pollution. The increase in PM_{2.5} and ozone emissions due to higher energy demand worsens respiratory outcomes, highlighting a trade-off between immediate relief and long-term health risks. Furthermore, studies in Burundi and Rwanda demonstrate how climate-induced declines in agricultural productivity lead to food insecurity, which indirectly increases the risk of malnutrition and infectious diseases.

Moreover, while some of the adaptation strategies discussed, such as agricultural adjustments or urban greening, may initially seem focused on ecosystem or environmental outcomes, they are inherently connected to human health. For example, agricultural adaptations aim to improve food security, which directly reduces the risk of malnutrition and its

associated health outcomes. Similarly, urban cooling strategies and green infrastructure not only mitigate the environmental impacts of extreme heat but also play a crucial role in reducing heat-related mortality and improving mental health through better urban living conditions. While air conditioning provides immediate relief during heatwaves, its long-term environmental impact and accessibility issues make it an unsustainable solution for many vulnerable populations. Sustainable adaptations, such as urban greening, reflective surfaces, and passive building design, have been shown to effectively reduce heat-related morbidity and mortality in high-risk urban settings [7]. These strategies not only reduce temperatures but also address social inequalities by providing benefits to a broader segment of the population.

The MMAT assessment of included studies reveals varying degrees of methodological rigor, affecting the interpretation and applicability of the findings. Several studies, such as those by Sterk et al. [25], Acharibasam et al. [29], and Chen et al. [31], received high quality scores, indicating robust methodologies and reliable results. However, studies with moderate scores, such as Zhen-Feng et al. [23] and Yong-Jian et al. [24], had limitations like insufficient consideration of contextual factors or weaker integration of mixed methods. These limitations suggest that while the findings are valuable, they should be interpreted cautiously, especially regarding their generalizability across different contexts.

This review's findings have significant implications for public health practice and policy. First, they emphasize the need to integrate climate change adaptation into broader public health strategies, aligning health with all the policy approaches [44]. The varying effectiveness of adaptation strategies across contexts underscores the importance of tailored interventions that consider local environmental, socioeconomic, and cultural factors. Policy-makers should prioritize context-specific solutions rather than one-size-fits-all approaches. Additionally, the disproportionate impact of climate change on vulnerable groups supports recommendations from other studies (e.g., Watts et al. [18]) that public health policies should prioritize these populations in adaptation planning. The variability in study quality, as assessed via MMAT, highlights the need for robust, long-term monitoring and evaluation frameworks to assess adaptation measures over time. The complex nature of climate–health interactions also necessitates greater collaboration among health professionals, climate scientists, urban planners, and policymakers, aligning with transdisciplinary approaches to addressing climate change and health [45].

Despite the valuable insights provided by this review, several limitations must be acknowledged. We acknowledge that the number of studies included for some regions, particularly North America and Europe, is relatively small. This reflects the current distribution of research available on climate adaptation and health outcomes. As climate adaptation strategies continue to develop globally, it will be crucial for future studies to focus on regions that are currently under-represented in the literature. This review serves as a foundation for understanding the effectiveness of current strategies, but further research is needed to provide a more comprehensive picture of climate adaptation across all regions. We also acknowledge that some of the selected studies are based on small-scale qualitative research or modeling approaches, which may limit their representativeness and generalizability. For example, the study on nursing students in Sweden, while insightful for understanding perceptions of climate change among young healthcare professionals, may not reflect broader national challenges or adaptation strategies. Similarly, studies from the Netherlands and North America that use modeling approaches provide valuable projections rather than real-time outcomes, which are important for understanding the potential future impacts of adaptation strategies under different climate scenarios. Additionally, the study from Burundi-Rwanda, while based on interviews from only four villages, provides crucial localized insights into how smallholder farmers in remote, vulnerable regions adapt to climate-induced challenges such as droughts and floods. Despite these limitations, each study was included because it offers unique contributions to our understanding of climate change adaptation. These localized or model-based studies help identify specific challenges and successes in adapting to climate change across a range of social, environmental, and

cultural contexts. Furthermore, the diverse methodologies employed across the reviewed studies—qualitative, quantitative, and modeling—provide a holistic view of adaptation strategies, complementing one another to give a more nuanced understanding of the topic. It is important to note that these studies are not used in isolation to draw conclusions about global adaptation strategies. Instead, they contribute context-specific evidence that informs the broader analysis of how adaptation strategies are applied across different regions and socioeconomic settings. By synthesizing findings from a range of methodological approaches and geographic areas, this review offers a comprehensive, though not exhaustive, examination of the effectiveness of climate change adaptation strategies globally. Further research will be necessary to expand on these findings and provide more large-scale, generalizable evidence.

The inclusion of only English-language publications may have excluded relevant studies in other languages, potentially limiting the global representativeness of the findings. The risk of publication bias is also present, as studies with positive outcomes are more likely to be published and included. The heterogeneity among included studies, in terms of study design, geographic location, and adaptation strategies, posed challenges for direct comparison and limited the potential for quantitative meta-analysis. Additionally, the focus on adaptation strategies may overlook the critical role of mitigation efforts in addressing the broader impacts of climate change on health. Finally, the rapidly evolving nature of climate change suggests the need for ongoing research to capture the most recent developments in adaptation strategies.

5. Conclusions

This systematic review underscores the urgent need for context-specific adaptation strategies to address the health impacts of climate change. We found that effective interventions—such as agricultural adjustments, urban planning, and community-based initiatives—are highly dependent on local conditions and implementation capacity. Vulnerable populations face disproportionate risks, highlighting the need for targeted interventions. While progress has been made, substantial challenges remain, requiring ongoing cross-disciplinary collaboration to enhance global health resilience.

Author Contributions: Conceptualization, T.A. and N.P.; formal analysis, T.A. and N.P.; investigation, T.A. and N.P.; resources, T.A.; data curation, T.A. and N.P.; writing—original draft preparation, T.A. and N.P.; writing—review and editing, T.A. and N.P.; visualization, T.A.; supervision, T.A.; project administration, T.A.; funding acquisition, T.A. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the University of Phayao and Thailand Science Research and Innovation Fund (Fundamental Fund 2025, Grant No. 5021/2567).

Data Availability Statement: All data generated or analyzed during this study are included in this article.

Acknowledgments: The authors would like to thank the University of Phayao and Thailand Science Research and Innovation Fund for their financial support. We are grateful to the librarians at the University of Phayao for their assistance with database searches and document retrieval. We also appreciate the constructive comments from the anonymous reviewers that helped improve the quality of this systematic review.

Conflicts of Interest: The authors declare no conflicts of interest.

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