Narrative Review

When heat becomes a toxin: A narrative review on heatwaves, cardiac vulnerability, and population risk profiles in low- and middle-income countries

Muhammad G. Karsa[1*], Viyola Rahma[1], Radhiah Zakaria[1], Itodo G. Eleojo[2], Eyiuche D. Ezigbo[3] and Iduh M. Unata[4]

[1]Postgraduate Program of Public Health, Universitas Muhammadiyah Aceh, Banda Aceh, Indonesia; [2]Department of Medical Laboratory Science, Federal University Lokoja, Kogi, Nigeria; [3]Department of Medical Laboratory Sciences, Faculty of Health Sciences and Technology, College of Medicine, University of Nigeria, Enugu, Nigeria; [4]Department of Medical Laboratory Science, College of Health Sciences, Usmanu Danfodiyo University Sokoto, Sokoto, Nigeria

*Corresponding Author: m.ghifarikarsa@gmail.com

Abstract

Climate change has intensified global heat exposure, particularly through more frequent and severe heatwaves. These conditions pose substantial risks to cardiovascular health. Low- and middle-income countries (LMICs) are disproportionately affected because of elevated baseline cardiovascular disease (CVD) burdens and limited adaptive capacity. The aim of this study was to synthesize epidemiological evidence linking extreme heat and heatwaves to CVD morbidity and mortality in LMICs, explore biological mechanisms underlying heat-induced cardiac stress, and examines social and environmental factors contributing to population vulnerability. Evidence from studies consistently demonstrates that extreme heat increases CVD events, with effect often emerging within 0–3 days following exposure. Proposed mechanisms include thermoregulatory strain, dehydration-related hemoconcentration, endothelial dysfunction, heightened sympathetic activation, and exacerbation of pre-existing CVD. Older adults, individuals with comorbidities, outdoor workers, and households with poor housing conditions are disproportionately affected. Despite established risks, most LMICs lack a structured heat-health protection system, clinical protocols for managing vulnerable cardiovascular patients during heatwaves, and labor protections for heat-exposed workers. Strengthening climate-resilient health systems and developing targeted preventive strategies are essential to mitigate rising cardiovascular risks associated with extreme heat in LMICs.

Keywords: Heatwaves, cardiovascular disease, climate change, LMICs, mortality

Introduction

Cardiovascular disease (CVD) remains the predominant cause of death globally, with an estimated three-quarters of CVD fatalities occuring in low- and middle-income countries (LMICs) [1]. At the same time, climate change is driving increases in ambient temperature extremes and heatwaves incidents, thereby adding a novel environmental hazard to the already high burden of cardiovascular risk in LMICs [2,3]. Heatwaves, defined variably as prolonged periods of unusually high temperature relative to regional norms, are becoming more frequent, sustained, and intense across many regions, especially those with high vulnerability [4,5]. Heat exposure poses acute stress to the cardiovascular system, particularly in contexts where baseline resilience is compromised by comorbidities, limited healthcares access, and sub-optimal living conditions

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Received: January 11, 2026 - Accepted: March 31, 2026 - Published online: April 1, 2026

Karsa et al. Narra Review 2026; 2 (1): e18 - http://doi.org/10.52225/narrarev.v2i1.18

[6,7]. Despite this, most epidemiological research on heat-related cardiovascular outcomes originates from high-income countries. Studies in LMICs remain comparatively limited, though arguably more urgent given higher exposures and lower adaptive capacity [8,9].

Understanding how extreme heat translates into cardiovascular events in LMICs is essential for clinical and public health communities. Such understanding holds implications not only for the prevention of acute events (myocardial infarction, stroke, heart failure exacerbations) but also for embedding climate risk into cardiovascular care pathways and health-system planning. Thus, the aim of this study was to synthesize recent evidence linking heatwaves and extreme temperatures to cardiovascular outcomes in LMICs, describe biological mechanisms through which heat becomes a cardiovascular "toxin", explore population-level vulnerability and risk profiles in LMIC contexts, and identify research gaps and adaptation strategies pertinent to cardiovascular resilience in a warming world.

Methods

Study design

This study employed a narrative review approach guided by systematic search principles to ensure comprehensive coverage while permitting conceptual synthesis across heterogeneous study designs. The review focused on epidemiological evidence linking heat exposure and heatwaves to cardiovascular outcomes, with particular emphasis on low- and middle-income countries (LMICs).

Search strategy

A literature search was conducted in PubMed, Scopus, Web of Science, and ScienceDirect for articles published between January 2010 and October 2025. Search terms included combinations of keywords related to extreme heat exposure and cardiovascular outcomes, including "extreme heat, "heatwaves", "ambient temperature", "myocardial infarction", "stroke", "heart failure", "hospital admissions", and "mortality", in conjunction with "low- and middle-income countries". The names of individual LMICs (e.g., South Africa, Indonesia, Vietnam, Iran, Brazil, Pakistan, and India) were added to refine searches for context-specific results. Boolean operator (AND/OR) were applied to refine the search.

Eligibility criteria

Studies were included if they: (a) examined associations between high ambient temperature or heatwave conditions and CVD morbidity or mortality; or (b) were multicountry analyses that stratified findings by national income level or reported LMIC-specific estimates. Eligible study designs included time-series, case-crossover, cohort, ecological studies, and systematic reviews or meta-analyses. Studies were excluded if they involved non-human subjects, focused on non-CVD outcomes, or were conducted exclusively in high-income countries without LMIC-relevant subgroup analysis.

Study selection process

All retrieved records were initially screened based on titles and abstracts to identify potentially relevant studies. Full-text articles were then reviewed to confirm eligibility according to predefined inclusion and exclusion criteria. Duplicate records across databases were identified and removed prior to screening. The study selection process was conducted iteratively, with emphasis on relevance to heat exposure and cardiovascular outcomes in LMIC settings.

Screening flow

Given the narrative nature of this review, a formal quantitative screening flow with predefined numerical thresholds was not applied. Instead, studies were selected based on relevance, methodological rigor, and contribution to the understanding of heat-related cardiovascular risk in LMIC settings. Both primary epidemiological studies and secondary evidence (systematic reviews and meta-analyses) were included, with careful consideration to avoid duplication in interpretation. This approach aligns with best practices for narrative review that prioritize conceptual synthesis while maintaining transparency in study identification and selection.

Data extraction process

Data from included studies were extracted using a structured approach focusing on key variables, including study location, study design, population characteristics, definition of heat exposure (e.g., heatwave criteria or temperature metrics), cardiovascular outcomes (e.g., mortality, hospital admissions), effect estimates, and identified vulnerable groups. The extraction process aimed to ensure consistency while allowing flexibility for different study designs and reporting formats.

Data analysis

Given the heterogeneity in study designs, exposure definitions, and outcome measures, a quantitative meta-analysis was not undertaken. Instead, findings were synthesized narratively, with emphasis on: (a) global and LMIC-specific epidemiological patterns, (b) biological mechanisms underlying heat-related cardiovascular stress, and (c) population-level vulnerability and health system factors influencing outcomes [8].

Results

Global evidence from pooled analyses (secondary evidence)

Evidence from systematic reviews and meta-analyses consistently shows that exposure to high ambient temperature and heatwaves is associated with increased cardiovascular morbidity and mortality across diverse settings [1,10,11]. These pooled analyses typically report U- or J-shaped curves, indicating that cardiovascular risk rises once temperature exceed region-specific thresholds [1]. Several multicountry studies further indicate that the magnitude of heat-related cardiovascular mortality is higher in LMICs compared to high-income countries, reflecting differences in exposure, adaptive capacity and health system resilience [2,12,13]. Meta-analytic estimates suggest that heatwave periods are associated with approximately 20% increases in cardiovascular mortality and smaller but significant increases in morbidity outcomes [14]. Findings from pooled analyses are presented here as contextual evidence to avoid duplication in interpretation and are not combined with primary study results in estimating effect magnitude.

Evidence from primary epidemiological studies in LMICs

Primary epidemiological studies conducted in LMIC setting consistently demonstrate short-term associations between extreme heat exposure and cardiovascular outcomes. Time-series analyses from South Africa show that both high and low apparent temperatures are associated with increased cardiovascular hospital admissions, with the strongest effects occurring within the first few days after exposure [6,15]. Similarly, studies in Vietnam report a U-shaped association between temperature and cardiovascular hospitalizations, indicating that both heat and cold extremes contribute to cardiovascular burden [16]. In Iran, heatwave events have been associated with an approximately 8% increase in cardiovascular mortality, highlighting the acute impact of sustained high temperatures [17].

Evidence from rural China further suggests that apparent temperature is strongly associated with cardiovascular admissions, with potentially greater vulnerability in rural populations compared to urban settings, possibly due to differences in infrastructure and healthcare access [18]. Collectively, these primary studies confirm that heat-related cardiovascular risk in LMICs is immediate, geographically widespread, and influenced by local environmental and socioeconomic conditions. Representative studies from LMIC settings are summarized in (**Table 1**).

Synthesis of epidemiological patterns

Several consistent patterns emerge across both pooled and primary evidence. First, heat exposure acts as an acute trigger of cardiovascular events, with effects typically observed within 0–3 days following exposure [6,17]. Second, exposure-response relationships are non-linear, with risk increasing sharply beyond population-specific thresholds [1].

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Table 1. Characteristics and key findings of representative studies examining the association between heat exposure and cardiovascular outcomes in LMICs.

Study	Country	Design	Heat definition	Cardiovascular outcome	Vulnerable groups	Key result
Alahmad *et al.*, 2023 [12]	27 countries	Time-series, DLNM	Ambient temperature relative to Minimum Mortality Temperature (MMT)	CVD mortality (total IHD, stroke, HF, arrhythmia)	Older adults, those with pre-existing CVD, and lower-income populations	Extreme heat significantly increased CVD mortality risk. Hot temperatures contributed to more deaths than cold, with larger effects in socioeconomically deprived regions
Arsad *et al.*, 2022 [4]	Global	Systematic review	Heatwaves, extreme temperatures	Mortality and morbidity due to CVD	Elderly, people with chronic disease, low-income and outdoor workers	Heatwaves consistently worsen CVD morbidity and mortality, with a greater risk in low-resource and hot climate settings
Buhler *et al.*, 2022 [6]	South Africa	Time-series	Apparent temperature	Hospital admissions for CVD	Elderly people and rural poor communities	Higher apparent temperature sharply increased CVD admissions, especially in remote districts with fewer cooling infrastructures
Fritz, 2022 [19]	Indonesia	Retrospective cohort	Ambient temperature	Outpatient visits for NCDs, including CVD	Older age, low socioeconomic groups, rural residents	High temperatures correlated with increased CVD consultations, showing sensitivity even at temperatures below typical “heatwave” thresholds
Giang *et al.*, 2014 [16]	Vietnam	Time-series	Daily mean temperature	Hospital admission for CVD	Elderly (> 60 years)	Both hot and cold temperatures increased CVD admissions, with stronger effects for heat
Gyaase *et al.*, 2025 [8]	Low- and middle-income countries	Systematic review	High temperature and heatwaves	CVD morbidity and mortality	Populations in LMICs with limited cooling access, older adults, and hypertensive patients	Environmental heat and poor air quality interact to amplify CVD burden, with LMICs disproportionately affected due to infrastructural and healthcare gaps
Hadei *et al.*, 2024 [17]	Iran	Systematic review and meta-analysis	Heatwaves and high temperatures	Cause-specific mortality, including CVD	Elderly and those with pre-existing cardiometabolic conditions	Heatwaves increased CVD mortality significantly, especially in urban settings lacking green space and cooling resources
Liu *et al.*, 2024 [1]	Global	Systematic review and meta-analysis	Heat exposure/high temperature	CVD mortality and morbidity	Elderly, outdoor workers, individuals with chronic disease	Each 1°C rise above the threshold increased CVD mortality. Heatwaves produced disproportionately larger effects than single hot days
Ni *et al.*, 2025 [20]	Global	Narrative review	Low and high ambient temperature	CVD events including MI, arrhythmia, HF, stroke	People with prior CVD, diabetes, dyslipidemia, and the elderly	Temperature and CVD relationship is U-shaped. Both heat and cold raise CVD risk. Heat triggers acute cardiac stress and thrombosis
Nukala, 2023 [10]	Global	Systematic review and meta-analysis	Heatwaves/extreme heat	CVD outcomes (mortality and morbidity)	Elderly, people with pre-existing CVD, socioeconomically deprived	Heatwaves significantly raise CVD mortality and morbidity globally. Projected climate change will worsen the effects

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Study	Country	Design	Heat definition	Cardiovascular outcome	Vulnerable groups	Key result
Siddiqui *et al*., 2025 [14]	Global	Systematic review and meta-analysis	Environmental heat exposure	CVD, chronic respiratory disease, and kidney disease outcomes	Elderly, chronic disease patients, and outdoor workers	Heat exposure increases CVD risk and interacts with dehydration and renal/cardiopulmonary strain, amplifying mortality
Singh *et al*., 2024 [2]	Global	Perspective review	Extreme heat and high temperature	CVD mortality	Elderly, people with chronic disease, socioeconomically deprived	Clear evidence that extreme heat increases CVD mortality. Need for early-warning systems and clinical heat-health action plans
Zhai *et al*., 2024 [18]	China	Systematic review and meta-analysis	Extreme heat, extreme cold, high Diurnal Temperature Range (DTR)	CVD mortality	Northern vs southern population, elderly	Heat, cold, and DTR all increased CVD mortality. Southern China is more sensitive to cold, while northern China is more sensitive to heat

CVD: cardiovascular disease; DLNM: distributed lag non-linear model; HF: heart failure; IHD: ischemic heart disease; LMIC: low- and middle-income countries; MI: myocardial infarction; NCD: non-communicable disease

Third, LMIC populations appear to experience higher relative risk compared to high-income settings, likely reflecting differences in baseline vulnerability and adaptive capacity [2,12,21]. However, heterogeneity across studies remains substantial, driven by variation in heatwave definitions, temperature metrics, study design, and population characteristics, which limit direct comparison on effect sizes across regions [14].

Variability in heat exposure definitions

Definitions of heat exposure and heatwaves vary considerably across studies, contributing to heterogeneity in reported effects. Some studies define heatwaves using percentile-based thresholds (e.g., temperature above the 90th or 95th percentile for a given location) [22], while others apply absolute temperature cutoffs (e.g., >35°C) [14,23].

Additionally, temperature metrics differ, with some studies using dry-bulb temperature while others employ apparent temperature or heat index that incorporates humidity, which may better reflect physiological heat stress [6,24]. Duration criteria for defining heatwaves also vary, ranging from two to several consecutive days of extreme temperature [17]. This variability complicates cross-study comparisons and may contribute to inconsistent estimates of cardiovascular risk, particularly in LMIC settings where standardized definitions are lacking.

Geographic distribution of evidence

The geographic distribution of available evidence is uneven across LMIC regions. A substantial proportion of studies originate from China, Iran, South Africa, and Vietnam, with relatively limited data from other regions such as West and Central Africa, large parts of Southeast Asia, and Latin America outside Brazil [1,8]. This imbalance suggests that current estimates of heat-related cardiovascular risk may not fully capture the burden in underrepresented regions, particularly those with high vulnerability and limited surveillance systems.

Discussion

The present review demonstrates that extreme heat and heatwave exposure are consistently associated with increased cardiovascular morbidity and mortality in LMICs. However, interpretation of this relationship requires careful consideration of methodological heterogeneity across studies [1,14,25]. Although the overall direction of association is largely consistent, the magnitude of effect varies substantially due to differences in study design, exposure definitions, and population characteristics [10]. This heterogeneity limits direct comparability across studies and suggests that pooled estimates should be interpreted cautiously, particularly when applied to diverse LMIC settings [2].

A major source of variability arises from differences in how heat exposure and heatwaves are defined. Some studies employ percentile-based thresholds relative to local climate distributions, while others use absolute temperature cutoffs, resulting in inconsistent classification of "extreme heat" across settings [14,26]. Variations in duration criteria for heatwaves further complicate comparisons, as definitions range from two to several consecutive days of elevated temperature [17]. These inconsistencies introduce exposure misclassification that may either attenuate or exaggerate observed associations.

Study design also contributes to uncertainty in the evidence base. The majority of LMIC studies rely on ecological or time-series designs, which are appropriate for detecting short-term associations but are inherently limited in establishing causality and are susceptible to ecological fallacy [16,27]. Individual-level confounders such as comorbidities, medication use, socioeconomic status, and behavioral adaptation are rarely captured in such designs, which may bias effect estimates [12]. Furthermore, air pollution, particularly particulate matter and ozone, often co-varies with temperature and may confound or modify the relationship between heat and cardiovascular outcomes, yet is inconsistently controlled across studies [10,28]. These methodological limitations highlight the need for cautious interpretation and improved study designs incorporating individual-level data and multi-exposure modeling.

Geographic imbalance in the available literature represents another important limitation. A large proportion of LMIC evidence originates from a relatively small number of countries, particularly China, Iran, South Africa, and Vietnam, while substantial regions such as West and

Central Africa, parts of Southeast Asia, and Latin America remain underrepresented [8]. This imbalance limits the generalizability of findings and may underestimate the burden in regions with high vulnerability but limited surveillance systems. Underreporting of cardiovascular events and mortality in LMIC health information systems further compounds this issue, potentially masking the true magnitude of heat-related cardiovascular risk [4,29].

Sex and gender dimensions of heat-related cardiovascular risk remain insufficiently explored in current literature. Although some studies report higher mortality among women or differential vulnerability by sex, the underlying mechanisms are not well elucidated [4,30]. Potential explanations include differences in thermoregulation, hormonal influences, occupational exposure patterns, and gendered access to healthcare, but these factors are rarely examined in LMIC-focused studies [2,31]. Addressing this gap is essential for developing equitable and targeted adaptation strategies. Despite these limitations, the consistency of findings across diverse contexts supports the interpretation that heat exposure acts as an acute trigger of cardiovascular events, particularly among vulnerable populations. Importantly, this risk is not solely biologically determined but is shaped by structural and social determinants, including housing quality, occupational exposure, access to cooling, and health system preparedness [8]. The interaction between environmental exposure and social vulnerability underscores the need for integrated approaches that combine clinical management with public health and policy interventions.

Evidence on adaptation strategies in LMIC settings remains limited but suggests that targeted interventions may reduce heat-related cardiovascular risk. Early warning systems, including mobile-based alerts, have shown potential in improving behavioral responses during heatwaves, although quantitative evidence on cardiovascular outcomes remains scarce [12]. Occupational heat protection measures, such as scheduled rest periods and hydration protocols, are low-cost interventions that may mitigate cardiovascular strain among outdoor workers [8]. Additionally, integrating heat-risk awareness into primary care, particularly for patients with heart failure or hypertension, may provide opportunities for early intervention during high-risk periods [4]. However, robust evaluation of these strategies in LMIC contexts is still lacking.

A conceptual framework summarizing the pathway linking heat exposure to cardiovascular outcomes in LMICs is presented in **Figure 1**. The model integrates environmental exposure, physiological mechanisms, and downstream clinical outcomes, while highlighting the modifying role of biological vulnerability, socioeconomic conditions, occupational exposure, and health system capacity. This framework underscores that heat-related cardiovascular risk is not solely driven by temperature itself but emerges from the interaction between environmental stressors and structural determinants.

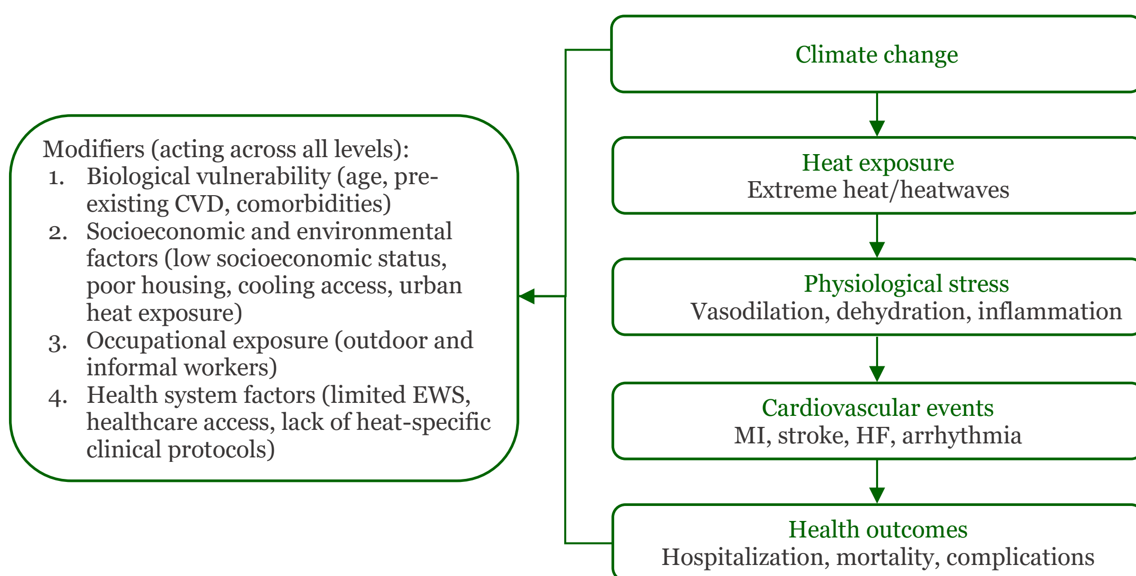

Figure 1. Conceptual pathways linking heat exposure to cardiovascular outcomes in low- and middle-income countries (LMICs). HF: heart failure; MI: myocardial infarction.

Overall, the findings of this review highlight the need for improved methodological rigor, standardized exposure definitions, and expanded geographic representation in future research. Strengthening surveillance systems, incorporating individual-level data, and integrating environmental and social determinants into cardiovascular research will be essential to better understand and mitigate heat-related cardiovascular risk in LMICs.

Conclusion

Extreme heat and heatwaves act as acute triggers of cardiovascular events in LMICs, with consistent increases in myocardial infarction, stroke, arrhythmias, and heart failure occurring within days of exposure. This rapid onset underscore heat as direct physiological stressor rather than a background risk. Mechanistically, thermoregulatory strain, dehydration-induced hemoconcentration, autonomic imbalance, and inflammatory responses collectively precipitate cardiovascular instability in vulnerable individuals.

The disproportionate burden in LMICs is driven by structural inequities that amplify exposure and limit adaptive capacity, particularly among older adults, individuals with chronic disease, outdoor workers, and socioeconomically disadvantaged populations. Given that heat-related cardiovascular risk is largely preventable, extreme heat should be recognized as a modifiable cardiovascular risk factor. Integrating heat adaptation into cardiovascular care, strengthening early warning systems, and enhancing climate-resilient health systems are essential to reducing heat-related cardiovascular mortality in a warming climate.

Acknowledgments

The author would like to acknowledge all individuals and institutions that contributed indirectly to the development of this manuscript, particularly those who provided valuable feedback, language editing, and academic support during the writing process.

Competing interests

All the authors declare that there are no conflicts of interest.

Funding

This study received no external funding.

Underlying data

Derived data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declaration of artificial intelligence use

This study utilized artificial intelligence (AI) tools to support the manuscript preparation process. Specifically, AI-based language models (e.g., ChatGPT) were employed for language refinement, including improving grammar, sentence structure, and overall readability, as well as assisting in the organization and structuring of the scientific content. All AI-assisted outputs were carefully reviewed by the authors to ensure the accuracy, integrity, and reliability of the work. The authors take full responsibility for the final decisions, interpretations, and conclusions presented in this article.

How to cite

Karsa MG, Rahma V, Zakaria R. When heat becomes a toxin: A narrative review on heatwaves, cardiac vulnerability, and population risk profiles in low- and middle-income countries. Narra Rev 2026; 2 (1): e18 - http://doi.org/10.52225/narrarev.v2i1.18.

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