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Review

The impact of extreme temperatures on emergency department visits: A systematic review of heatwaves, cold waves, and daily temperature variations

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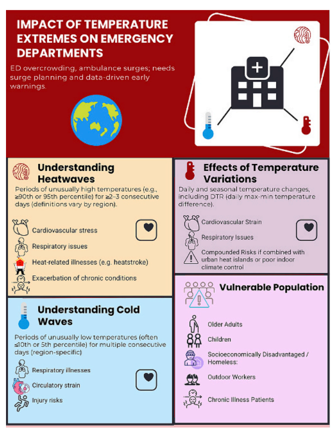
HIGHLIGHTS

- Cold waves raise ED visits for respiratory, cardiovascular, and fall injuries.
- Heat waves increase ED visits and ambulance demand, mainly for trauma cases.
- Air pollution and urban heat worsen temperature-related health risks.
- Vulnerable and disadvantaged groups face higher health risks.
- Strong healthcare planning is vital for extreme weather-related surges.

GRAPHICAL ABSTRACT



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ABSTRACT

Extreme temperature events increasingly challenge global public health systems, affecting both emergency department (ED) presentations and subsequent hospital admissions. Understanding these impacts on emergency healthcare utilization is critical for effective resource planning and public health preparedness. This systematic literature review, conducted following PRISMA guidelines, examines the influence of extreme temperature events on ED admissions. A comprehensive database search from 2012 to 2024 identified 42 relevant studies and two of them considered both heatwaves, coldwaves or temperature variation: 22 on heatwaves, 6 on cold waves, and 16 on temperature variations. Heatwaves are consistently associated with increased ED admissions for various health conditions, including orthopaedic trauma and exacerbations of chronic illnesses. At the same time, cold waves are linked primarily to respiratory and cardiovascular issues, often with delayed effects. Several studies indicate that older adults, those with pre-existing conditions, and socioeconomically disadvantaged populations may face disproportionately severe consequences during these events. Socio-demographic factors, including age, gender, socioeconomic status, and geographic location, significantly influence these outcomes. These findings highlight the differential impacts of extreme temperature events on ED utilization, emphasizing

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the importance of preparing EDs for post-event surges and advocating for coordinated emergency planning and targeted public health interventions to manage these challenges effectively.

Implications for public health: The findings of this study provide actionable insights for clinicians, academics, and policymakers to understand better the impact of extreme temperature events on emergency departments. This knowledge can guide the development of targeted public health strategies, enhance resource allocation, and strengthen healthcare systems to improve outcomes for vulnerable populations.

1. Introduction & background

Climate change increases the frequency and intensity of extreme weather events, such as heat waves, cold waves, and significant temperature fluctuations, posing substantial risks to public health and emergency healthcare systems ([IPCC] IPoCC, 2021; WHO, 2023). Emergency Departments (ED), as the frontline of acute healthcare delivery, are particularly vulnerable to these challenges, facing overcrowding and strained resources during patient surges (Xu et al., 2014; Salway et al., 2017). Understanding how extreme temperatures influence ED utilization is essential for addressing these challenges, especially as climate models project a rise in the severity and frequency of such events in the coming decades (Meehl and Tebaldi, 2004; Watts et al., 2015). The relationship between temperature and health outcomes has been widely studied, particularly regarding temperature-mortality associations (Basu, 2009; Curriero et al., 2002; Huynen et al., 2001). However, comparatively fewer studies have explored temperature-morbidity associations, particularly how extreme temperatures and daily variations affect ED admission patterns (Knowlton et al., 2009; Kovats et al., 2004). Environmental factors such as air pollution further complicate these relationships, with evidence suggesting interactions between temperature and pollutants (Anenberg Susan et al., n.d.; Achakulwisut et al., 2019). This interplay between environmental stressors necessitates a comprehensive understanding of the multifactorial drivers of healthcare demand during extreme temperature events.

Heatwaves represent one of climate change's most critical public health challenges. Studies consistently demonstrate their impact on ED admissions, encompassing direct heat-related illnesses and the exacerbation of chronic conditions (Habeeb et al., 2015; Anderson and Bell, 2009; O'Neill and Ebi, 2009; Basu et al., 2012; Fletcher et al., 2012). However, the extent of these impacts often varies across regions due to differences in acclimatisation, infrastructure, and socioeconomic factors (Anderson and Bell, 2009; O'Neill and Ebi, 2009). Vulnerable populations, such as older persons, individuals with pre-existing conditions, and outdoor workers, face disproportionate risks, raising questions about the adequacy of current public health interventions and resource allocation strategies (Åström et al., 2011; Kenny and Journeay, 2010). While some regions have established temperature thresholds for health warnings, their effectiveness and adaptability across healthcare settings remain areas for further investigation (Tong et al., 2010; Gosling et al., 2007). Additionally, the interaction between air pollution and extreme heat events introduces further complexities that require systematic evaluation, as high temperatures can enhance the formation of ground-level ozone and worsen the health impacts of air pollutants, while stagnant air conditions during heat waves can trap and concentrate pollutants near the surface (Anenberg Susan et al., n.d.).

Cold waves, while less extensively studied than heat waves, also present significant challenges for healthcare systems. Unlike heatwaves, their impacts often include delayed effects, particularly respiratory and cardiovascular health outcomes (Kovats et al., 2004; Bhaskaran et al., 2009). Syndromic surveillance systems and cold weather plans have been implemented in some settings, but their effectiveness in mitigating ED surges and targeting vulnerable populations remains uncertain (Assessment of syndromic surveillance in Europe, 2011; Department of H, 2012). Moreover, questions persist regarding the optimal allocation of resources during cold weather events and the need for tailored interventions based on regional vulnerabilities.

Daily and seasonal temperature variations influence ED utilization patterns beyond extreme heat and cold. Diurnal temperature range (DTR), an emerging indicator of health impacts, highlights the importance of rapid temperature fluctuations in urban areas, where built environment characteristics and urban heat island effects may exacerbate health risks (Makowski et al., 2008; Debbage and Shepherd, 2015). While DTR has shown a decreasing trend globally, any significant changes in DTR - whether increases or decreases - warrant attention given DTR's demonstrated implications for cardiovascular and respiratory health and healthcare system capacity (Zhou et al., 2014; Liang et al., 2009). This is particularly important since some regions, including parts of India, Russia and northern China, have actually experienced increasing DTR. However, understanding the role of urban infrastructure, housing quality, and other modifiers in shaping these health outcomes remains a critical gap in the literature.

This study addresses several significant knowledge gaps in the current understanding of temperature-health relationships. While individual studies have explored temperature extremes in specific contexts, a comprehensive synthesis of evidence on how heat waves, cold waves, and temperature variations impact ED admissions remains lacking (Boyle et al., 2012; Marcilio et al., 2013). This review seeks to examine these impacts across diverse healthcare settings, identify factors contributing to regional variations, and explore the modifying effects of environmental factors such as air pollution and urban infrastructure (Kr et al., 2014). By addressing these gaps, the study aims to inform evidence-based public health responses and resource allocation strategies that are resilient to climate change. The findings of this review have broad implications for healthcare planning and delivery. They can potentially support the development of early warning systems tailored to local conditions and population characteristics, guide targeted interventions for vulnerable groups, and enhance emergency preparedness strategies. Moreover, by identifying critical gaps in existing knowledge, the review aims to set the agenda for future research on climate-health relationships.

The remainder of this review is structured as follows. Section 2 outlines the methods used to conduct the systematic review, including the inclusion and exclusion criteria. Subsequent sections discuss the results and key findings (Section 3), implications for public health, and limitations of the study (Section 4), concluding with recommendations for future research.

2. Methods

2.1. Search strategy

The literature search was led by A.P., assisted by a subject librarian to pinpoint medical subject headings and keywords reflective of the inclusion criteria. This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A comprehensive search strategy was designed to identify studies investigating the association between weather conditions, temperature shifts and ED (Emergency Department), EMS (Emergency medical service) or ER (Emergency room) admissions. Several databases were used: PubMed, Google Scholar, Web of Science, ProQuest, Scopus, Springer, Cochrane Library, and Science Direct. Authors conducted a manual search of abstracts and titles within the specified databases to ensure thorough coverage of relevant literature using combinations of the following terms: “emergency department”, “ED”, “EMS”, “ER”, “hospital admissions”, “patient volume”, “heatwaves”, “temperature”, “heat”, “cold”, “weather”, “climate”, “precipitation”, “rainfall”, “flood*”, “hurricane”, “storm”, “natural event*”, “visit*”, “admission*”, “patient flow”, “crowding”, “predictive”, “prediction”, “forecast*”, “predictive model*”. This Systematic Literature Review (SLR) was registered on PROSPERO under the registration number *CRD42024608772*.[1] Further details about keywords and search strings are available in Supplementary Materials Appendix A.

2.2. Terminology and outcome measures

This review examined studies reporting ED utilization through two primary metrics: ED visits, EMS visits, ER visits and hospital admissions. ED and ER visits generally refer to all presentations to emergency departments both patients discharged directly from the ED and those subsequently admitted (Marcilio et al., 2013; Wang et al., 2012; Hughes et al., 2014; Ghirardi et al., 2015; Sun et al., 2014; Yeung et al., 2020; Murtas et al., 2022; van der Linden et al., 2019; Lippmann et al., 2013; Riley et al., 2018; Ramgopal et al., 2021). Hospital admissions, in contrast, specify inpatient care following ED presentation (Lindstrom et al., 2013; Zhang et al., 2015; Pillai et al., 2014; Oray et al., 2018; Ozturk et al., 2023; Harduar Morano et al., 2015). Given that up to 70 % of hospital inpatients originate from the Emergency Department (ED), and the majority of these admissions arrive via Emergency Medical Services (EMS), we included EMS data to fully capture the spectrum of emergency care demand. Patients transported by EMS have significantly higher odds of hospital admission (Odds ratio [OR] 2.68, 95 % Confidence Interval [CI]: 2.45–2.92), greater severity of illness, increased resource utilization, and substantially higher in-hospital mortality (OR 11.15, 95 % CI: 9.84–12.63) compared to walk-in patients (Ramgopal et al., 2021; Schaffer et al., 2012; Williams et al., 2012a).

Several studies reported both ED visits and subsequent admissions separately, facilitating analyses of how temperature events influence initial ED presentation rates as well as the severity threshold that necessitates inpatient care (Schaffer et al., 2012; Williams et al., 2012a; Novikov et al., 2012; Xu et al., 2019; Robertson et al., 2022; Wilk et al., 2021; Lin et al., 2019; Lin et al., 2021). For instance, Wilk et al. (Wilk et al., 2021) examined extreme heat and pediatric ED visits, while Lin et al. (Lin et al., 2021) evaluated how temperature extremes affected both ED volume and the likelihood of admission among at-risk subgroups.

In addition to these general measures, some studies focused on specific ED presentations: heat-related illness (White et al., 2017; Fuhrmann et al., 2016), fall-related injuries (Yeung et al., 2020), or occupational heat exposures (Harduar Morano et al., 2015). Others analysed pre-hospital data such as EMS dispatches that can provide early indicators of likely ED surges (Ramgopal et al., 2021; Liu et al., 2018). These varied approaches underscore the multifaceted nature of temperature impacts on emergency healthcare utilization, from front-end ED triage to final inpatient admissions. Regarding the definitions for heatwave, cold wave, and extreme temperatures, we have dedicated a column titled ‘TEMPERATURE DEFINITION’ in our detailed study table, which is available in Appendix B.”

2.3. Eligibility criteria

This systematic review included observational studies published between January 2012 and December 2024 that examined the relationship between extreme temperature events and ED admissions. Operational definitions of temperature events varied significantly across studies. Heat waves were predominantly defined using percentile-based approaches, ranging from the 90th to 99th percentile of local temperature distributions (Zhang et al., 2015; Ozturk et al., 2023; Xu et al., 2019). Some regions used absolute temperature thresholds, such as Scotland's definition of $\geq$25 °C for three consecutive days (Robertson et al., 2022). Cold waves were typically defined using lower percentile thresholds (1st-10th percentile) combined with duration criteria (Wang et al., 2012), while some regions incorporated additional factors such as snowfall and ice conditions (Hughes et al., 2014). Temperature variations were most commonly measured through Diurnal Temperature Range (DTR), defined as the difference between daily maximum and minimum temperatures (Kim et al., 2016; Sharafkhani et al., 2019). The search was limited to publications in the English language from 2012 to 2024, as it was believed that older results would no longer apply due to recent developments in medicine and healthcare. Non-peer-reviewed publications, articles not in English, and those addressing conditions outside the scope of this review have been excluded. Eligible studies focused on ED, EMS or ER admissions related to heatwaves, cold waves, or significant temperature variations, spanning diverse geographical regions to provide a comprehensive global perspective on temperature-related ED utilization patterns. Data sources predominantly included medical records, hospital databases, and insurance claims. Most studies employed comparative analyses, assessing ED admission patterns before, during, and after extreme temperature events against designated control periods. This methodology facilitated a robust evaluation of the impact of temperature extremes on ED utilization. The study selection process, guided by inclusion and exclusion criteria (Supplementary Materials Appendix A), involved removing duplicates and screening titles and abstracts. Following a full-text review of 97 articles, 42 studies met the eligibility criteria and were included in the systematic review. A PRISMA flow chart illustrating the selection process is provided in Fig. 1.

2.4. Study selection

This systematic literature review followed PRISMA guidelines to ensure a rigorous and transparent selection process. The review focused on observational studies examining ED admissions concerning heatwaves, cold waves, or extreme temperature variations. The last update for this review was performed in December 2024. Titles and abstracts were screened in the first stage, with non-eligible articles excluded. Full-text papers were subsequently reviewed when insufficient information was available in the title or abstract. Forward citation searches were also conducted for eligible studies.

Three reviewers (A.P., A.I.M, and L.W.) assessed study eligibility. Two reviewers (A.P. and L.W.) independently evaluated the studies retrieved from the literature search, with disagreements resolved by a third reviewer (A.I.M) to reach a consensus. The study selection process prioritised quality and comprehensiveness, employing multiple verification layers to ensure robust inclusion criteria were met. Studies were selected based on verifiable data sources, such as hospital ED records, institutional databases, and health insurance claims. Research employing comparative methodologies was prioritised, focusing on ED admission patterns across temporal periods, specifically before, during, and after extreme temperature events, compared to control periods (if data was available). The initial screening identified 3309 potentially relevant records. A natural language processing (NLP) approach using the Bidirectional Encoder Representations from Transformers (BERT) model was implemented for semantic similarity analysis to enhance efficiency. This screening method evaluated the relevance of articles based on contextual alignment with research objectives, complementing the manual review process (Reimers and Gurevych, 2019; Howard et al., 2016). Full-text screening narrowed the initial selection to 97 articles. Ultimately, 43 unique studies met all eligibility criteria and were included in the final review. Of these, 2 studies (Novikov et al., 2012; Liu

[1] *Ali PoshtMashhadi, Lincoln C. Wood, Abtin Ijad Maghsoodi, “**The Impact of Weather and Temperature on Emergency Department Admission: A Systematic Literature Review**. PROSPERO 2024 CRD42024608772 Available from: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=608772*

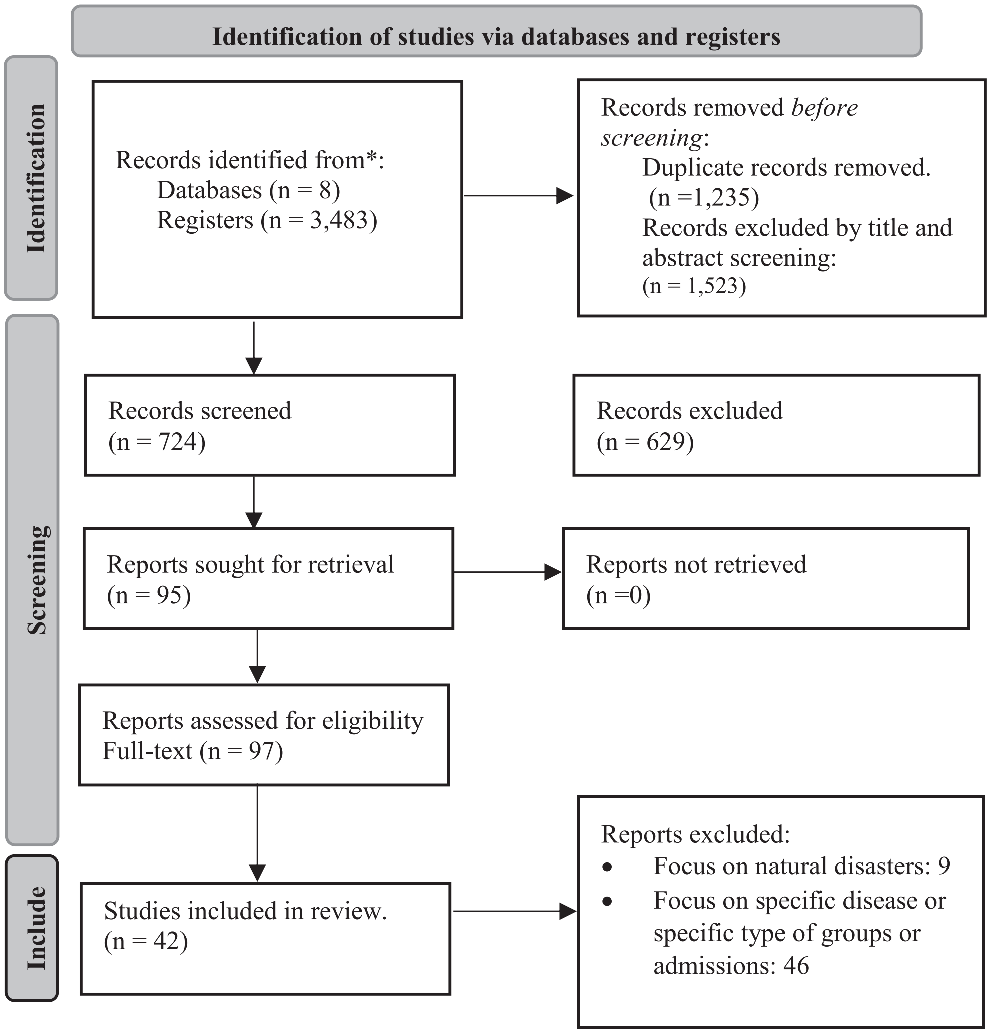

Fig. 1. PRISMA FLOW CHART ON THE ED ADMISSION EFFECTS OF WEATHER.

et al., 2018) analysed multiple weather exposures (for example, both heatwaves and cold waves or general temperature variation), causing them to appear in more than one category.

2.5. Data extraction

Data extracted from the included studies was input into a spreadsheet by one reviewer and verified by another. Extracted data included study details (Authors, Publication Year, Location, Study Design, Types of Weather Conditions Studied, Measurement Methods), event details (Types of Admissions, Number of Admissions, Duration), and outcome details (Statistical Methods Used, Results and Effect Sizes, Confidence Intervals and *P*-values, Age, Gender, Environmental Factors, Limitation, Short Summary, Lesson We Learned). The availability of specific information was noted in the last five columns: Impact on Specific Health Conditions (Yes/No), Vulnerable Populations (Yes/No), Environmental Factors (Yes/No), Health-Related Weather Conditions (Yes/No), and Regional Impact (Yes/No). All Included studies are presented in Supplementary Materials Appendix B Table 1. Study authors were contacted to provide missing data.

2.6. Risk of BIAS assessment

The risk of bias assessment for the included studies was conducted using a modified version of the NIH Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (the latest version published in July 2021) (*National Heart L, and Blood Institute*, 2021). The assessment evaluated vital areas, including study design, participant selection, group comparability, exposure and outcome assessments, follow-up rates, validity of statistical analyses, and control of confounding factors. While alternative tools such as JADAD (Jadad et al., 1996) and EPOC ((EPOC) CEPaOoC, 2023) exist, they are unsuitable for this systematic review, which focuses on cohort and observational studies. Overall, the included studies were determined to have a moderately low risk of bias. Detailed results of the risk of bias assessment are provided in Supplementary Materials Appendix C.

3. Results

3.1. Description and characteristics of studies

The systematic review identified studies examining the relationship between weather conditions and ED admissions, spanning diverse geographical regions and employing various methodologies. Six studies on cold waves were conducted in regions across Asia, Europe, and North America (Wang et al., 2012; Hughes et al., 2014; Yeung et al., 2020; Liu et al., 2018; Gevitz et al., 2017; Richard et al., 2024). These studies primarily examined the impact of cold waves on respiratory and circulatory health outcomes using time-series analyses, distributed lag nonlinear models, observational studies, and retrospective cohort analyses. Sample sizes in the reviewed studies ranged from 2783 ED visits during a heat wave period (Oray et al., 2018) to 7,025,815 EMS

Table 1
SUMMARY OF ADMISSION STATUS IN DIFFERENT WEATHER CONDITIONS.

WEATHER CONDITION	MAIN REASON FOR ADMISSIONS	RANGE OF INCREASE	POPULATION TYPE	IDENTIFIED RISK FACTORS	ADDITIONAL NOTES
Cold Waves	Respiratory diseases (Wang et al., 2012; Liu et al., 2018)	Respiratory: 3.78 % AF[a], 56,928 cases (Liu et al., 2018)	Older Patients ≥75 years (Wang et al., 2012)	PM10[b] and ozone (Wang et al., 2012) Higher urban impact (Wang et al., 2012)	Prolonged low-temperature exposure was particularly linked to circulatory and respiratory admissions (Wang et al., 2012)
	Circulatory diseases (Wang et al., 2012; Liu et al., 2018)	Cardiovascular: 5.2 % AF, 345,358 cases (Liu et al., 2018)	Older adults (Wang et al., 2012)	Lag effects in cardiovascular conditions (Liu et al., 2018)	Both Liu et al. (Liu et al., 2018) and (Wang et al., 2012) indicate significant cold-attributable fractions for CVD.
	Fall injuries (Yeung et al., 2020; Gevitz et al., 2017)	Falls: OR[c] 6.84 (Yeung et al., 2020), OR 22.3 (Gevitz et al., 2017)	Adults 18–64 (70.7 % high-fall days) (Gevitz et al., 2017)	Night freezing (Yeung et al., 2020),Snow/ice hazards (Yeung et al., 2020)	Female patients accounted for a high proportion (57.9 %) of fall-related ED visits (Gevitz et al., 2017).
	Renal diseases (Liu et al., 2018)	Renal: 22.5 % AF, 298,295 cases (Liu et al., 2018)	Not addressed	None specifically mentioned for cold waves in (Liu et al., 2018)	Liu et al. (Liu et al., 2018) found a large cold-attributable fraction for renal diseases, underscoring vulnerability in low temperatures.
Heatwaves	Cardiovascular (Lindstrom et al., 2013; Schaffer et al., 2012)	ED presentations: IRR[d] 1.15 (Lindstrom et al., 2013)	Older Patients (26 % vs 21 % ED visits) (Lindstrom et al., 2013)	High temperatures and humidity (Sun et al., 2014), Urban effects (Zhang et al., 2015; Zhang et al., 2018)	Lindstrom et al. (Lindstrom et al., 2013) noted greater impact among the elderly. Schaffer et al. (Schaffer et al., 2012) observed a short lag for heat effects.
	Respiratory (Lindstrom et al., 2013)	Increased admissions for respiratory disorders	General adult population	Urban heat islands (Zhang et al., 2015) Socioeconomic disparities (Riley et al., 2018)	Lindstrom et al. (Lindstrom et al., 2013) also reported overlaps with circulatory conditions during the 2009 Melbourne heatwave.
	Polytrauma (Robertson et al., 2022)	2.37× increase in polytrauma patient presentations	Adults of varying ages	Possibly dehydration, risk-taking behaviors	High temperatures correlated with more fracture-related polytrauma (Robertson et al., 2022)
	Endocrine/metabolic (Xu et al., 2019)	RR[e] 1.18 (Xu et al., 2019)	Not specifically reported	Air pollution (Sun et al., 2014) 3–7 day lag (Schaffer et al., 2012)	Xu et al. (Xu et al., 2019) found heatwaves significantly affected endocrine and metabolic ED visits in Queensland.
	Mental health (van Loenhout et al., 2018)	ED visits: 1.47 % per °C (Novikov et al., 2012)	Pre-existing conditions (Williams et al., 2012a)	Limited AC[f] access (Riley et al., 2018)	van Loenhout et al. (van Loenhout et al., 2018) found an association between high temperatures and mental health presentations in the Netherlands.
	Renal (Zhang et al., 2015)	Range: 2–37 % increase	Older patients (often more susceptible)	Occupational exposure (Riley et al., 2018)Ethnic minorities (Zhang et al., 2015)	Zhang et al. (Zhang et al., 2015) observed notable heat impacts on renal admissions, especially during peak temperature events.
Temperature Variations	DTR (Kim et al., 2016)	DTR: +0.14 % mortality per 1 °C increment (Kim et al., 2016)	Older adults were more vulnerable (Kim et al., 2016)	Not specifically detailed beyond broad urban/rural differences	Kim et al. (Kim et al., 2016) studied 30 cities in East Asia; though mortality-focused, it informed subsequent ED-based research on temperature variability.
	Cardiovascular ((Kim et al., 2016; Sharafkhani et al., 2019; Sharafkhani et al., 2017)	Elevated CVD risk at high DTR (e.g., 99th percentile)	Older adults (esp. 75+) (Sharafkhani et al., 2019; Sharafkhani et al., 2017)	PM2.5[i] or PM10 synergy in some regions (Zhang et al., 2018)Socioeconomic factors (Lin et al., 2021)	Sharafkhani et al. noted a pronounced effect in older populations for CVD outcomes at extreme DTR levels.
	Respiratory (Sharafkhani et al., 2019)	Significant increased risk at high DTR[h] (≥22 °C)	Individuals over 75 (Sharafkhani et al., 2019)	Urban infrastructure (Murtas et al., 2022) PM2.5 (Zhang et al., 2018)	Greater respiratory vulnerability observed in older patients during large day–night temperature swings.
	All-cause mortality (Lin et al., 2019)	Mortality: IRR[d] 1.71 at low temperatures (Lin et al., 2019)	Older Patients (Lin et al., 2019)	Seasonal variations (Ramgopal et al., 2021) Healthcare capacity (Murtas et al., 2022)	Although Lin et al. (Lin et al., 2019) studied mortality more closely, their findings indicate broader ED impacts at low extremes.
	Mental health (Ghirardi et al., 2015)	Range: 2–10 % increase	Socioeconomically disadvantaged (Lin et al., 2021)	N/A specific to mental health beyond general temperature effects	Ghirardi et al. (Ghirardi et al., 2015) found significant increases in mental health ED visits during periods of sudden temperature fluctuations.
	ED visits (Murtas et al., 2022; Ramgopal et al., 2021)	ED visits rose by ~1–4 per °C (Ghada et al., 2021)	Varies by region, day-of-week, and subpopulation (Ramgopal et al., 2021)	Seasonal patterns (Otsuki et al., 2016) Urban-rural differences not clearly stated for DTR alone	Multi-region data confirm that even moderate daily temperature fluctuations can strain EMS/ED services (Ramgopal et al., 2021)

[a] AF: Attributable Fraction - The proportion of cases that can be attributed to a specific exposure.
[b] PM10: Particulate Matter (10 μm or smaller).
[c] OR: Odds Ratio - The ratio of the odds of an outcome in an exposed group to the odds in an unexposed group.
[d] IRR: Incidence Rate Ratio - The ratio of two incidence rates.
[e] RR: Relative Risk/Risk Ratio - The ratio of the probability of an outcome in an exposed group to the probability in an unexposed group.
[f] AC: Attributable Cases - The number of cases that can be attributed to a specific exposure.
[h] DTR: Diurnal Temperature Range - The difference between daily maximum and minimum temperatures.
[i] PM2.5: Particulate Matter (2.5 μm or smaller).

dispatches (Ramgopal et al., 2021), with several studies analysing large datasets, including Sun et al.'s (Sun et al., 2014) analysis of 4,455,056 ED visits and Liu et al.'s (Liu et al., 2018) examination of 6.64 million ED visits.

Twenty-two studies investigated the effects of heatwaves across multiple continents, including Australia (Xu et al., 2014; Lindstrom et al., 2013; Schaffer et al., 2012; Williams et al., 2012a; Toloo et al., 2014), Europe (Ozturk et al., 2023; Robertson et al., 2022; van Loenhout et al., 2018), North America (Riley et al., 2018; Zhang et al., 2015; Pillai et al., 2014; Harduar Morano et al., 2015; Wilk et al., 2021; White et al., 2017; Fuhrmann et al., 2016; Liu et al., 2018; Gevitz et al., 2017; Zhang et al., 2014; Kearl and Vogel, 2023), and Asia (Sun et al., 2014; Oray et al., 2018; Novikov et al., 2012). These studies explored a wide range of health outcomes, from heat-related illnesses to exacerbations of chronic conditions, utilising various methodologies, including time-series analyses (Zhang et al., 2015), retrospective cohort studies (Lindstrom et al., 2013), and case-crossover designs (Schaffer et al., 2012). Sample sizes varied significantly, with some studies focusing on specific heatwave events (Oray et al., 2018) and others analysing data over extended periods (Williams et al., 2012a). Cross-continental studies (van der Linden et al., 2019) provided insights into global patterns, while region-specific studies highlighted localized impacts (Xu et al., 2019).

Sixteen studies analysed the effects of temperature variations, covering regions in East Asia (Kim et al., 2016; Lim et al., 2012), Europe (Hughes et al., 2014; Murtas et al., 2022; Ghada et al., 2021), North America (Lippmann et al., 2013; Pearson et al., 2020), and multi-regional settings (Ramgopal et al., 2021; Lin et al., 2019; Lin et al., 2021). These studies employed advanced statistical techniques, such as generalized linear models (Marcilio et al., 2013) and distributed lag non-linear models (Sharafkhani et al., 2017), (Sharafkhani et al., 2019) to examine the health impacts of both rapid and gradual temperature changes. Sample sizes ranged from thousands (Otsuki et al., 2016) to millions of cases (Ramgopal et al., 2021) analysing over 7 million EMS dispatches, with study durations spanning from two years to over 15 years. Multi-region studies (Ramgopal et al., 2021; Kim et al., 2016) provided insights into overarching trends, while individual studies highlighted region-specific factors (Ghirardi et al., 2015; Otsuki et al., 2016; Zhang et al., 2018). The studies included in this review demonstrate the global nature of temperature-related health impacts while underscoring the importance of regional variations.

3.2. Impact of cold waves on emergency department admission

Cold waves have been consistently associated with significant increases in ED admissions, posing substantial public health challenges across diverse regions (Wang et al., 2012; Hughes et al., 2014; Yeung et al., 2020; Liu et al., 2018; Gevitz et al., 2017; Richard et al., 2024). Definitions of cold waves show notable regional variation: for instance, Taiwan uses percentile-based thresholds (e.g., 1st, 5th, 10th percentile) lasting multiple consecutive days (Wang et al., 2012), while the UK incorporates additional conditions such as heavy snowfall and widespread ice (Hughes et al., 2014). In Canada, Calgary adopts specialised criteria for “night-freezing” events following Chinook winds, a meteorological phenomenon characterized by warm, dry winds descending from the Rocky Mountains, causing rapid temperature increases, which are often preceded or followed by sudden temperature drops (Yeung et al., 2020). In the United States, adverse winter weather encompasses sub-zero temperatures, ice, and snowfall, with studies in Philadelphia and other urban centres reporting corresponding surges in ED visits (Gevitz et al., 2017).

A large-scale analysis in Taiwan found that, during cold periods, circulatory diseases accounted for a substantial proportion of ED visits cerebrovascular disease comprised 40.2 %, and ischemic heart disease accounted for 29.6 % (Wang et al., 2012). While ozone is more commonly associated with hot weather, Wang et al. (2012) observed that both PM_{10} and ozone exacerbated respiratory admissions during cold spells in Taiwan, highlighting that air pollution can amplify cold-wave impacts as well (Wang et al., 2012).

Recent evidence from Ontario, Canada, (Richard et al., 2024) highlights the disproportionate burden of cold weather on vulnerable populations, with a 27 % increase in non-urgent ED visits among homeless individuals during the 2022/2023 cold season. This increase was especially pronounced in Toronto, where visits surged by 70 %, emphasizing the critical need for accessible warming centers and adequate shelter services (Richard et al., 2024).

In the United States (Minneapolis-St. Paul Metropolitan Area), Liu et al. (Liu et al., 2018) found that cold temperatures were associated with 3.78 % of cardiovascular disease emergency department visits, 22.5 % of respiratory disease visits, and 2.24 % of renal disease visits between 2007 and 2014. Injury rates also climb sharply in cold conditions. In Calgary, post-Chinook weather, which follows warm, dry easterly winds that cause rapid snowmelt and subsequent ice formation (Gevitz et al., 2017) when freezing conditions return, doubled the odds of fall-related injuries (OR 2.19, 95 % CI: 1.84–2.62), while night-freezing events increased these injuries nearly sevenfold (OR 6.84, 95 % CI: 5.88–7.97) (Yeung et al., 2020). Elderly patients had notably longer ED stays (5.61 vs. 3.65 h) compared to younger groups (Yeung et al., 2020). Similarly, adverse winter weather in the United States raised the risk of falls (Gevitz et al., 2017), with adults aged 18–64 making up 70.7 % of fall-related ED visits on high-fall days—versus 54.4 % on normal days—and females accounting for 57.9 % of all such visits (Gevitz et al., 2017). In the UK, syndromic surveillance has proved valuable for real-time monitoring of sub-zero temperatures and fracture-related admissions, particularly among women, supporting the role of continuous data-tracking in public health planning (Hughes et al., 2014).

Collectively, these Six (Wang et al., 2012; Hughes et al., 2014; Yeung et al., 2020; Liu et al., 2018; Gevitz et al., 2017; Richard et al., 2024) studies highlight the consistent and sometimes delayed impact of cold waves on ED presentations, especially for circulatory, respiratory, and injury-related conditions and emphasize the importance of preparedness measures tailored to regional climatic patterns, population demographics, and environmental factors.

3.3. Impact of heatwaves on emergency department admission

Heatwaves pose substantial challenges for emergency departments (EDs) worldwide, influencing both immediate visit patterns and subsequent admissions. Definitions of heatwaves often vary regionally: Australia commonly sets a threshold at or above the 95th percentile of local temperatures for three or more consecutive days (Williams et al., 2012a; Xu et al., 2019), while Turkey applies a 90th percentile definition for a similar duration (Ozturk et al., 2023). More complex indicators, such as an acclimatisation excess heat index, have been used in multi-country comparisons (van der Linden et al., 2019). Some urban areas further incorporate localized metrics; for instance, Munich leverages the Universal Thermal Climate Index (Ghada et al., 2021) to account for humidity and wind effects.

Across diverse regions, heatwave events consistently correlate with increased ED visits and higher mortality. In Australia, Schaffer et al. (Schaffer et al., 2012) reported a 2 % rise in all-cause ED visits (RR 1.02, 95 % CI: 1.01–1.03) alongside a 13 % bump in mortality (RR 1.13, 95 % CI: 1.06–1.22) during an exceptional heatwave, disproportionately affecting those aged 75 years or older. Lindstrom et al. (Lindstrom et al., 2013) also found that older adults made up a larger fraction of admissions during Melbourne's 2009 heat event (26 % vs. 21 %). In Queensland, Toloo et al. (Toloo et al., 2014) identified sharp spikes in acute and chronic ED presentations during peak heat, highlighting especially high risk among vulnerable groups. Williams et al. (Williams et al., 2012a) further quantified ambulance calls in Adelaide, observing a 4.9 % increase per 10 °C above local thresholds, paired with a 6.5-fold surge in heat-related ED visits.

Similar trends emerge internationally. In Turkey, Oray et al. (Oray et al., 2018) documented increased ED visits during heatwaves, particularly among older adults, while Ozturk et al. (Ozturk et al., 2023) found a 19 % rise in hospital admissions during a 9-day heatwave, with the highest increases seen in children (33 % increase), elderly patients (22 %), and women compared to men. Their analysis revealed notable increases in cardiology admissions (36 % rise), particularly for atherosclerotic heart disease (77 % increase), and significant impacts on respiratory and neurological conditions. In Israel, Novikov et al. (Novikov et al., 2012) uncovered a dose-response relationship where in each additional 1 °C was associated with a 1.47 % increase in ED visits (RR 1.0147, 95 % CI: 1.0106–1.0189). China's data similarly illustrated a 2.62 % rise in ED visits and a 4.85 % jump in ambulance dispatches during heatwaves (Sun et al., 2014). Meanwhile, Zhang et al. (Zhang et al., 2015) assessed Houston's 2011 heatwave, revealing a 6.2 % mortality increase and a 3.6 % elevation in ED visits, attributing these effects partly to urban heat island intensification. In multi-country analyses, van der Linden et al. (van der Linden et al., 2019) noted that pediatric populations in the U.S. and the Netherlands were more prone to ED visits, whereas older adults in Pakistan experienced elevated hospitalization risks during hot spells.

Heat-related occupational exposures further compound the problem. Harduar Morano et al. (Harduar Morano et al., 2015) found high rates of heat-related ED visits among Southeastern U.S. workers, while Riley et al. (Riley et al., 2018) showed each 1 % increase in construction workers correlated with an 8.1 % jump in heat-attributed ED presentations in Los Angeles County. In North Carolina, Fuhrmann et al. (Fuhrmann et al., 2016) documented a significant link between extreme heat events and total ED visits, while Pillai et al. (Pillai et al., 2014) found older age strongly predicted heat-illness hospital admissions. White et al. (White et al., 2017) validated a novel syndromic surveillance query to detect heat-related illnesses in Arizona, underscoring the importance of real-time monitoring. Wilk et al. (Wilk et al., 2021) and Lippmann et al. (Lippmann et al., 2013) both examined U.S. heatwaves, identifying heightened risks for pediatric and rural populations, respectively.

Recent extreme events have reinforced these patterns, exacerbating ED congestion and mortality. Wettstein et al. (Wettstein et al., 2024) examined the Pacific Northwest's 2021 “heat dome,” noting 21.7 additional ED visits per day (95 % CI: 14.7–28.6), while Vogel et al. (Kearl and Vogel, 2023) in Washington State reported prolonged overcrowding in EDs during similar historic heat episodes, disproportionately affecting older individuals and those without air-conditioning. Lastly, Ghada et al. (Ghada et al., 2021) highlighted the modifying influence of Munich's urban infrastructure, illustrating how built-environment factors can magnify temperature-related ED pressures.

Taken together, these 19 heatwave-focused studies underscore consistent patterns of elevated ED demand, complex interactions with demographic and urban variables, and significant occupational and pediatric vulnerabilities. They highlight the need for region-specific thresholds, robust syndromic surveillance systems, targeted interventions for high-risk groups, and coordination across public health, clinical, and urban planning sectors to bolster resilience against escalating heatwave events.

3.4. Impact of temperature variation on emergency department admission

Temperature variations beyond discrete heat or cold extremes demonstrate considerable influence on emergency healthcare utilization. While some studies examined both temperature extremes and variability, this section focuses on the specific impacts of daily or seasonal temperature fluctuations—particularly the Diurnal Temperature Range (DTR) on ED presentations.

3.4.1. Diurnal temperature range (DTR) and ED utilization

Multiple studies identified the Diurnal Temperature Range (DTR)—the difference between daily maximum and minimum temperatures—as a key measure of temperature variability. Although Kim et al. (Kim et al., 2016) primarily examined diurnal temperature range (DTR) in relation to all-cause mortality across 30 East Asian cities reporting a 0.14 % increase in mortality for each 1 °C DTR increment this study is not part of our final systematic literature review because it did not report ED-specific outcomes. However, its findings offer valuable context for understanding the broader health impacts of DTR, informing subsequent investigations (Sharafkhani et al., 2019; Sharafkhani et al., 2017) that did link elevated DTR to increased emergency demand, especially among older adults. Similarly, Lim et al. (Lim et al., 2012) in Korea reinforced these findings, underscoring the vulnerability of older populations to cardiovascular admissions when day-to-night temperature fluctuations widen. Supporting these findings, Ramgopal et al. (Ramgopal et al., 2021) analysedx over seven million EMS dispatches, which though pre-hospital predictably translate into ED visits. Their data illustrates that day-to-day temperature swings can strain EMS systems, thereby increasing ED presentations.

3.4.2. Regional and seasonal variations

Research in Taiwan by Lin et al. (Lin et al., 2019; Lin et al., 2021) revealed increased all-cause mortality at low temperatures, with significant modifying effects from socioeconomic factors such as employment rates and access to healthcare. These large-scale analyses also showed higher ED admission rates when temperature deviated sharply from seasonal norms, indicating that short-term fluctuations can be as impactful as sustained extremes. In Germany, Ghada et al. (Ghada et al., 2021) tracked 575,725 admissions, finding that each 1 °C rise in daily temperature during spring and summer yielded an additional 1–4 ED visits, suggesting a dose-response pattern for moderate and variable climate conditions. Complementary evidence from Italy emerged in Murtas et al. (Murtas et al., 2022), who modelled 2,223,479 ED visits in Milan to show that temperature, humidity, and air quality factors collectively shaped daily ED volumes. In North Carolina, Lippmann et al. (Lippmann et al., 2013) identified exponential increases in heat-related illness visits above 15.6 °C (60 °F), particularly among middle-aged males and rural communities, adding to our understanding of regional temperature effects.

3.4.3. Pediatric and vulnerable populations

Several studies examined how temperature variations affect pediatric populations. Xu et al. (Xu et al., 2014) in Australia corroborated these pediatric susceptibilities, noting temperature-driven increases in ED visits for children under 4 years (RR 1.07, 95 % CI: 1.04–1.10). Ghirardi et al. (Ghirardi et al., 2015) found a 3.75 % rise in overall ED attendance per 1 °C temperature increase, with high-acuity pediatric cases being especially affected. In Japan, Otsuki et al. (Otsuki et al., 2016) showed that seasonal temperature shifts influenced ED attendance patterns across different demographic groups, sometimes yielding abrupt surges in older adults and chronic disease patients.

3.4.4. Environmental interactions and forecasting

Urban contexts may compound temperature impacts via heat islands, air pollution, or infrastructure limitations. Hughes et al. (Hughes et al., 2014) established syndromic surveillance in the UK, illustrating how real-time data on temperature and weather hazards correlated with increases in ED visits. Zhang et al. (Zhang et al., 2018) in Beijing specifically investigated PM2.5 and temperature interactions, finding the greatest health burdens when pollution levels spiked amid temperature fluctuations. Marcilio et al. (Marcilio et al., 2013), working in Brazil, demonstrated that generalized linear models (GLM) and generalized estimating equations (GEE) can effectively forecast daily ED volumes by incorporating meteorological variables, a tactic also suggested by Lin et al. (Lin et al., 2021) for improving resource allocation and protecting vulnerable subgroups.

Overall, these 17 studies underscore how temperature variability alone beyond sustained heat or cold waves can drive ED utilization. They collectively point to older adults, children, and populations with fewer socioeconomic resources as particularly susceptible. Interactions with urban infrastructure, air pollution, and pre-existing conditions further compound the risks. Proactive measures such as syndromic surveillance, predictive modeling, and community-based interventions remain crucial for mitigating the healthcare strains induced by fluctuating temperatures.

3.5. Results summary

The evidence indicates distinct patterns of ED utilization for different temperature extremes. Cold waves are predominantly linked to respiratory, circulatory, and injury-related ED admissions, as abrupt drops in temperature increase the risks of respiratory exacerbations, cardiovascular strain, and fall-related injuries. Heatwaves place an additional burden on vulnerable populations, triggering surges in ED visits for chronic illnesses (e.g., cardiovascular, renal, and metabolic conditions) and contributing to higher rates of heat-related morbidity and mortality. Daily and seasonal temperature variations further complicate these relationships, with pronounced impacts on cardiovascular and respiratory health noted even in the absence of defined “extreme” events. Environmental factors such as air pollution and socio-economic disparities amplify these risks across all weather scenarios, underscoring the need for tailored interventions, including infrastructural improvements, real-time warning systems, and public education to bolster healthcare system resilience and reduce temperature-related health burdens.

4. Discussion

This systematic review provides critical insights into the complex relationship between extreme weather events and ED utilization, highlighting key implications for public health and healthcare system preparedness. The findings demonstrate that weather extremes, cold waves, heatwaves, and temperature variations, substantially affect ED admissions through distinct mechanisms, influenced by geographical, environmental, and social contexts. Cold waves primarily increase ED presentations for respiratory and circulatory diseases (Wang et al., 2012; Liu et al., 2018), while heatwaves exert broader systemic effects, impacting endocrine, metabolic, nervous system, and genitourinary functions (Xu et al., 2019). These health outcomes suggest the need for tailored preparedness strategies that address the specific challenges posed by different weather extremes. A significant finding of this review is the identification of vulnerable populations disproportionately affected by weather extremes. Older adults consistently emerge as highly susceptible to both heat and cold extremes due to reduced physiological adaptability and pre-existing conditions (Wang et al., 2012; Lindstrom et al., 2013). Furthermore, socioeconomic disparities significantly modify weather-related health risks. Ethnic minorities and economically disadvantaged groups face heightened vulnerabilities during extreme weather events, attributed to poorer housing conditions, limited access to healthcare, and greater exposure to environmental stressors (Zhang et al., 2015; Fuhrmann et al., 2016). Recent evidence from Ontario further highlights that individuals experiencing homelessness are particularly vulnerable to cold waves, with non-urgent ED visits increasing by 27 % during the 2022/2023 cold season, driven largely by inadequate shelter access and warming services in urban centres like Toronto (Richard et al., 2024).

The heterogeneity in operational definitions of temperature events reflects the need for context-specific approaches in different climatic regions. While percentile-based definitions were common for both heat waves (Zhang et al., 2015; Xu et al., 2019) and cold waves (Wang et al., 2012), the specific thresholds varied based on local climate conditions and population adaptation. This variation in definitions presents both challenges for cross-study comparisons and opportunities for understanding regional adaptation to extreme weather events (van der Linden et al., 2019).

Environmental modifiers further amplify the health impacts of extreme weather events. Air pollution, particularly PM10 and PM2.5, interacts with temperature extremes to exacerbate health risks (Wang et al., 2012; Zhang et al., 2018), while urban heat islands intensify the effects of high temperatures in metropolitan areas (Zhang et al., 2015). The built environment also plays a critical role; regions with better infrastructure and greater access to climate control systems report reduced health impacts during extreme weather (Riley et al., 2018; Novikov et al., 2012). These findings highlight the importance of integrating environmental considerations into public health planning. Moreover, regional variations in weather-related health impacts emphasize the necessity of locally tailored response strategies. Studies from diverse geographical locations demonstrate that similar weather conditions can produce varying health outcomes influenced by local population characteristics, healthcare system capacity, and environmental factors (van der Linden et al., 2019; Ramgopal et al., 2021). For example, urban areas with high levels of air pollution report compounded health risks, while regions with strong healthcare infrastructures can mitigate some impacts. This variation reinforces the need for context-specific public health responses that address local vulnerabilities and healthcare capacities.

The findings regarding vulnerable populations align with recent systematic reviews of temperature impacts on emergency departments. Mason et al. (Mason et al., 2022) identified that low socioeconomic status and limited access to air-conditioning were significant risk factors during heat waves, particularly in Australian healthcare settings. This is consistent with our finding that housing conditions and socioeconomic factors modify temperature-related health risks. Wu et al. (Wu et al., 2023) similarly found that ethnic minorities and economically disadvantaged groups face heightened risks during extreme weather events, especially in urban areas where built environment characteristics can amplify exposure. The Ontario study further highlights the unique challenges those without stable housing face during cold waves, emphasizing the role of accessible public services in mitigating health impacts (Richard et al., 2024).

The social gradient in temperature-related health impacts highlighted in our review is further supported by Lin et al.'s (Lin et al., 2019) detailed analysis of Taiwan's healthcare system, which found that areas with fewer employed persons, medical facilities, and socioeconomic resources had significantly higher mortality risks during temperature extremes. These aligned findings across multiple systematic reviews underscore the critical importance of addressing systemic inequities in climate adaptation planning.

The novelty of this review lies in its comprehensive and integrative approach, addressing gaps in the existing literature. Unlike previous studies that predominantly focused on single weather conditions, this review provides a systematic analysis of the combined impacts of cold waves, heat waves, and temperature variations. By integrating environmental, social, and health system factors, the study offers a holistic understanding of how weather extremes influence ED utilization. Table 2 outlines the key contributions of this systematic review.

By addressing these gaps, this research advances the evidence base for emergency preparedness, contributing to the development of effective public health strategies that account for the multifaceted impacts of extreme weather events. It provides critical insights for policymakers, healthcare planners, and public health officials to enhance system resilience and protect vulnerable populations during periods of weather-induced stress.

4.1. Implications for policy and practice

It is important to note that, our study title references temperature extremes (i.e., heatwaves and coldwaves). None of the studies we

Table 2
NOVELTY OF THIS RESEARCH IN COMPARISON WITH OTHER STUDIES.

ASPECT	OUR FINDINGS	COMPARISON WITH OTHER STUDIES	NOVEL CONTRIBUTIONS
Integration of Weather Types	Combined assessment of cold waves, heatwaves, and temperature variations underscores how multiple temperature extremes simultaneously influence ED[a] visits (Wang et al., 2012; Ozturk et al., 2023; Schaffer et al., 2012)	Prior research often focused on one phenomenon (Hughes et al., 2014) or heatwaves (Oray et al., 2018; Schaffer et al., 2012) limiting cross-event comparison.	Provides a broader perspective by including cold waves, heatwaves, and daily/seasonal fluctuations in one review, emphasizing the need for holistic ED preparedness under different temperature extremes.
Vulnerable Populations	Multidimensional vulnerability analysis accounting for age (e.g., older adults, children), comorbidities, and socioeconomic factors reveals that these groups are more susceptible to extremes (Yeung et al., 2020; Riley et al., 2018; Lindstrom et al., 2013; Lin et al., 2021)	Past studies examined specific at-risk populations, such as the elderly during heat (Schaffer et al., 2012), or children's ED usage under temperature fluctuations (Xu et al., 2014), but typically in isolation.	Offers a multi-factor framework, illustrating how age, comorbidities, and social inequities intersect, thereby guiding more targeted public health interventions (van der Linden et al., 2019).
Environmental Interactions	Shows that PM10[b], PM2.5[c], ozone, humidity, and the urban heat island effect can amplify temperature-related ED surges, especially in dense urban zones (Wang et al., 2012; Sun et al., 2014; Ghada et al., 2021; Zhang et al., 2018).	Earlier work typically focused on a single stressor: e.g., particulate matter alone (Zhang et al., 2018)or humidity alone (Novikov et al., 2012). Many lacked combined analyses of environmental co-factors.	Highlights the importance of integrating air pollution and microclimatic factors (e.g., urban heat islands) when planning ED resources (Murtas et al., 2022).
Healthcare Planning	Predictive models (GLM[d], GEE[e], syndromic surveillance) combining demographic and weather data yield more accurate ED forecasts (Marcilio et al., 2013; Rampgopal et al., 2021; Lin et al., 2019). Encourages resource allocation (staffing, bed capacity) prior to temperature extremes.	Previous approaches often omitted either social/ demographic or meteorological predictors (Marcilio et al., 2013; Ghada et al., 2021). Ramgopal et al. (Ramgopal et al., 2021) used EMS dispatch data but did not address broader health system capacities.	Suggests a multivariable forecasting strategy that combines climate, pollution, and population vulnerabilities for proactive ED management (Hughes et al., 2014; Murtas et al., 2022)
Regional Variations	Highlights location-specific thresholds (e.g., percentile-based vs. absolute cutoffs) and acclimatisation levels. Multinational analyses reveal urban–rural differences and cultural factors (Xu et al., 2014; van der Linden et al., 2019; Lippmann et al., 2013)	Most prior research was region- or city-specific, focusing on a single climate or healthcare system (e.g., Lindstrom et al., (Lindstrom et al., 2013) in Melbourne; Yeung et al., (Yeung et al., 2020) in Calgary).	Demonstrates how varying temperature definitions (Wang et al., 2012; Ozturk et al., 2023) and population adaptation drive differences in ED outcomes across geographies, calling for localized strategies.

[a] ED: Emergency Department.
[b] PM10: Particulate Matter (10 μm or smaller).
[c] PM2.5: Particulate Matter (2.5 μm or smaller).
[d] GLM: Generalized Linear Model.
[e] GEE: Generalized Estimating Equations.

reviewed provided data on floods, storms, or other non-temperature-related weather events, which explains our focus on temperature in this review.

The findings of this systematic review underscore important implications for public health policy and healthcare practice, highlighting the urgent need for integrated approaches to mitigate the health impacts of temperature variations. As temperature patterns become increasingly erratic due to climate change, both immediate and long-term adaptations are essential to ensure healthcare system resilience and population well-being.

Healthcare systems must evolve to meet the growing demands posed by extreme temperature events through the implementation of evidence-based interventions and advanced predictive tools. Integrating real-time temperature data, demographic information, and environmental variables into healthcare planning has shown potential in improving ED demand forecasting (Marcilio et al., 2013; Novikov et al., 2012). Developing predictive models capable of anticipating surges in ED utilization during extreme temperature events is essential. Such models should be complemented by enhanced surge capacity protocols, including specialised care pathways for vulnerable populations such as the elderly, children, and socioeconomically disadvantaged groups. Additionally, training healthcare professionals in climate-adaptive practices and allocating resources to ensure continuity of care during temperature-driven crises are crucial steps toward preparedness.

Effective public health interventions must extend beyond the healthcare setting to address the broader determinants of temperature-related health risks. Early warning systems tailored to local temperature patterns and population characteristics are vital, as demonstrated by successful implementations in various regions (van der Linden et al., 2019; Williams et al., 2012b). These systems should be integrated with community-based monitoring networks, ensuring timely dissemination of information to at-risk populations. Public education campaigns aimed at increasing awareness and resilience can empower communities to adopt preventive behaviors during extreme *heat or cold events*. For example, guidance on heat avoidance, appropriate hydration, and maintaining indoor air quality during pollution spikes can significantly reduce health risks. Specialised outreach programs targeting vulnerable groups, such as elderly individuals living alone or children in poorly insulated housing, are essential to mitigate disparities in exposure and response (Zhang et al., 2015; Lin et al., 2021).

Policy initiatives must prioritize cross-sector collaboration to address the complicated challenges of temperature-related health impacts (van der Linden et al., 2019; Ramgopal et al., 2021). Developing standardised protocols for temperature-related healthcare emergencies (Marcilio et al., 2013), such as guidelines for managing heat stress or cold-induced illnesses, can ensure consistency in care delivery across regions. Urban planning and building codes must incorporate climate adaptation measures, such as enhancing cooling and heating infrastructure, improving housing insulation, and expanding green spaces to reduce urban heat island effects (Zhang et al., 2015). Funding mechanisms should be established to support these infrastructural improvements, particularly in disadvantaged areas where vulnerability to extreme temperature is highest (Riley et al., 2018). Furthermore, policies should incentivise the adoption of renewable energy and sustainable urban designs to mitigate future climate risks.

The complexity of extreme temperature health impacts requires coordination between healthcare providers, public health agencies, urban planners, and social services. Collaboration across these sectors can facilitate the development of holistic approaches that address immediate healthcare needs and longer-term systemic changes. For instance, integrating healthcare data with urban planning tools can identify high-risk areas requiring targeted interventions. Simultaneously, engaging social services can ensure that vulnerable populations receive adequate support during extreme temperatures. Multi-disciplinary partnerships will be key to building resilient systems capable of adapting to evolving climate patterns (Murtas et al., 2022; Novikov et al., 2012). As climate patterns evolve, building resilient healthcare systems capable of protecting vulnerable populations while adapting to temperature variability becomes critical (Williams et al., 2012a; Lin et al., 2021).

Addressing knowledge gaps in *temperature-health* relationships is crucial for refining interventions and policies. Standardised methodologies and integrated databases linking weather, environmental, and health data are needed to enable cross-study comparisons and identify global trends (Sun et al., 2014; Zhang et al., 2018). Longitudinal studies examining the long-term health impacts of temperature variations and extreme weather events are critical, alongside research into the interaction effects of environmental modifiers, such as air pollution and humidity. Evaluating the effectiveness of public health interventions and healthcare system adaptations across different settings will further inform best practices. Additionally, research on the healthcare implications of climate change should explore its cumulative impacts on population health and system resilience, ensuring readiness for emerging challenges.

Building resilient healthcare systems and communities capable of responding to extreme temperature events is no longer optional but imperative. The evidence from this review demonstrates that targeted investments in healthcare infrastructure, public health initiatives, and cross-sector collaboration are essential for reducing the health burdens of temperature extremes. By implementing comprehensive strategies that address environmental, social, and systemic factors, policymakers and practitioners can ensure that populations are protected against the growing threats posed by climate change. As temperature patterns continue to shift, these efforts will not only safeguard public health but also enhance the overall sustainability and equity of healthcare systems.

4.2. Limitations

Significant heterogeneity exists among the included studies, which vary widely in geographic regions, populations, and methodologies. For instance, Wang et al. (Wang et al., 2012) focused on respiratory and circulatory diseases during cold waves in Taiwan, whereas Lippmann et al. (Lippmann et al., 2013) examined heat-related illnesses in rural North Carolina, USA. Such diversity complicates the generalisation of findings across different settings and populations. Additionally, inconsistencies in statistical measures and reported outcomes, further hinder synthesis and comparison. For example, Schaffer et al. (Schaffer et al., 2012) reported an RR of 1.02 for heatwaves affecting all-cause ED visits, while Robertson et al. (Robertson et al., 2022) used an IRR of 2.37 for polytrauma cases during heatwaves. Many studies relied on retrospective data, which introduces potential biases such as incomplete records and misclassification. For example, Marcilio et al. (Marcilio et al., 2013) utilised administrative hospital data that were not explicitly collected for research purposes, potentially affecting the accuracy of associations between extreme temperatures and ED admissions. Retrospective data are also prone to missing or inconsistent information, which can limit the reliability of conclusions. Furthermore, there is a notable underrepresentation of LMIC (low- and middle-income countries) in the reviewed studies, as most were conducted in high-income settings. This geographic bias limits the applicability of findings to LMICs, where healthcare infrastructure, socio-economic conditions, and climate vulnerabilities differ significantly. Environmental and socio-economic confounders were not consistently accounted for across studies. While studies (Sun et al., 2014) adjusted for air pollution levels, others did not adequately consider such variables, potentially confounding the observed relationships between temperature extremes and health outcomes. This inconsistency weakens the ability to establish causal links and identify specific pathways through which extreme weather events impact ED admissions.

Additionally, although several studies examined both cold and heat extremes, the sample size for cold waves was relatively small (7 studies). This limited the ability to draw robust conclusions about the health impacts specifically attributable to cold waves and underscored the need for more focused research on low-temperature events.

Another limitation lies in the lack of focus on evaluating the effectiveness of public health interventions and preparedness strategies in the reviewed studies. Few studies examined measures such as early warning systems, public education campaigns, or infrastructure adaptations, limiting our ability to provide robust evidence-based recommendations for policy and practice. This gap highlights the need for future research to assess the effectiveness of intervention strategies in mitigating the health impacts of extreme weather events. Ultimately, the absence of standardised metrics across studies further complicates comparisons and limits the generalisability of findings. Despite these challenges, this review provides valuable insights into the relationship between extreme weather events and ED admissions while also identifying critical areas for future research. Addressing these limitations in subsequent studies will enable more comprehensive and actionable evidence to guide public health policies and healthcare system adaptations.

5. Conclusion

This systematic review examines the effects of temperature variations—including cold waves, heat waves, and daily fluctuations—on ED admissions. Studies indicate increased ED visits for specific conditions, such as respiratory and circulatory diseases during cold periods and heat-related illnesses during warmer periods. Certain groups, including older adults, children, and those with underlying health conditions, face higher risks, while factors like air pollution and humidity can influence these effects. These findings suggest the value of coordinated public health approaches to address temperature-related challenges. Key considerations include developing warning systems based on local conditions, implementing focused interventions for at-risk groups, and incorporating environmental data into healthcare planning. Improving models to anticipate ED demand and enhancing coordination between healthcare providers, urban planners, and policymakers could help strengthen emergency care systems. As weather patterns change, adapting ED infrastructure and preparedness becomes important for managing temperature-related health impacts. Using research-informed approaches identified in this review, public health officials and decision-makers can work to protect populations and maintain effective emergency care services during future climate-related challenges.

CRediT authorship contribution statement

Ali PoshtMashhadi: Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Abtin Ijadi Maghsoodi:** Writing – review & editing, Validation, Supervision, Resources. **Lincoln C. Wood:** Writing – review & editing, Validation, Supervision, Resources.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ali PoshtMashhadi, Lincoln C. Wood, Abtin Ijadi Maghsoodi report financial support was provided by Health Research Council of New Zealand (ID: 23/931).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2025.178869.

Data availability

The included articles used in the review are specified in the appendix

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