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Recording and monitoring deaths during heatwaves: a scoping review of mortality attribution and surveillance systems

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ABSTRACT

Background: Heatwaves are a significant public health concern linked to substantial excess mortality worldwide. Most deaths during heatwaves arise from the exacerbation of underlying chronic conditions rather than direct heat-related causes, making individual attribution challenging. Improving how heatwave-associated deaths are recorded and monitored is essential for enhancing data quality, comparability, and public health response.

Objective: To map and synthesise global practices for recording and monitoring heatwave-related mortality, including attribution methods, ICD coding, and integration of real-time surveillance.

Methods: A scoping review was conducted following Joanna Briggs Institute methodology and the Population–Concept–Context framework. Searches were performed in PubMed, Scopus, CINAHL, Embase, and Web of Science from inception. Two reviewers independently screened and extracted data on mortality attribution, ICD coding, recording systems, managing agencies, surveillance approaches, heatwave definitions, limitations, and recommendations. Findings were synthesized using tables, figures, conceptual maps, and narrative summaries. The protocol was registered in the Open Science Framework (OSF) https://doi.org/10.17605/OSF.IO/5AX4T.

Results: A total of 176 studies from 41 countries were included. Only 8.5% of the included studies used heat-specific ICD codes to identify direct heat-related death; real-time mortality monitoring systems were limited, fragmented, and inconsistent across jurisdictions.

Conclusions: Heatwave-associated deaths are rarely coded as direct heat-related, reflecting the indirect and multifactorial pathways linking heat to mortality. Significant gaps in global mortality recording and surveillance systems highlight the need for improved attribution practices, standardised coding, integrated systems, and stronger institutional coordination to support public health preparedness in a warming climate.

1. Background

Heatwaves are a growing public health concern worldwide (Xu et al., 2016). Extreme heat can cause direct thermal illnesses such as heat exhaustion and heat stroke (Bouchama and Knochel, 2002), but most deaths occurring during heatwaves arise indirectly through the exacerbation of pre-exiting chronic conditions (Thompson et al., 2024a). Elevated temperatures can narrow physiological and therapeutic safety margins, triggering or accelerating events related to respiratory and cardiovascular diseases, acute kidney injury, mental health conditions, and other comorbidities (Åström et al., 2011). As a result, the mortality burden associated with heatwaves is largely population-level and probabilistic and is not individually identifiable through a single direct cause of death (Zhao et al., 2024)

A recent global modelling study estimated that heatwaves contributed to more than 153,000 cases of excess mortality between 1990 and

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2019, with substantial regional and temporal variations (Zhao et al., 2024). In Australia, heatwaves cause more deaths than all other natural disasters combined, including floods, bushfires, storms, and cyclones (Dey and Lewis, 2021). Between 2000 and 2018, 473 deaths were reported as heat-related (Coates et al., 2022). However, this figure reflects only cases explicitly identified as heat-related in coronial records and may not represent the broader mortality patterns observed during heatwave periods (Coates et al., 2014).

Measuring the true mortality burden of heatwaves remains challenging (Coates et al., 2014). Death certificates record the proximate clinical cause of death, typically a cardiovascular, respiratory, or renal event, and heat is rarely certified as a direct cause except in cases of heat stroke (Longden et al., 2020; Longden, 2025). ICD codes mainly capture direct cases of heat illness, and are not designed to quantify for fully measuring population-level excess mortality (Longden, 2025). Most heat-attributable deaths are detectable only through population-level excess mortality analysis, comparing observed against expected deaths during heatwave periods rather than through individual-level coding (Vicedo-Cabrera et al., 2021). This structural gap between clinical death certification and epidemiological surveillance contributes to persistent inconsistency in heatwave mortality data globally (Gasparrini et al., 2015).

Current approaches to monitoring deaths during heatwaves include national mortality datasets, excess mortality estimation, state-based surveillance systems, hospital and emergency department data, and coronial investigation (Coates et al., 2014; Williams et al., 2018a; Hatvani-Kovacs et al., 2016). Effective surveillance systems are essential for timely public health action, resource allocation, and targeted interventions such as early warning alerts, community outreach, and infrastructure support (Michelozzi et al., 2010a; Sheridan et al., 2011; McGregor, 2024a; Nitschke et al., 2016). However, considerable variability exists in data sources, heatwave definitions, and recording practices, complicating both comparison and quantification globally (Coates et al., 2014; Longden, 2025).

To date, no comprehensive synthesis has been conducted to map the various methods and systems used globally to monitor heatwave-related mortality. This scoping review addresses the research question: How are mortality recording and surveillance systems structured and implemented to monitor deaths occurring during heatwaves globally? The findings will highlight inconsistencies and strengths in current approaches and inform the development of more reliable early warning systems, predictive models, and public health policy.

2. Methods

2.1. Scoping review design

This scoping review followed the methodological framework proposed by Arksey and O'Malley (Arksey and O'malley, 2005), incorporating the enhancements of Levac et al. (2010) and the methodological recommendations of Peters et al., 2020, 2022 to ensure rigor and transparency. Reporting adhered to the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) guidelines (Tricco et al., 2018), supplemented by elements of the STORIES statement (Gordon and Gibbs, 2014) and the BEME collaboration guidance (Hammick et al., 2010). The protocol was registered with the Open Science Framework (OSF) to support methodological rigor (https://doi.org/10.17605/OSF.IO/5AX4T).

The review followed the standard five-stage process:

- Stage 1: Identifying the research question (as stated above)
- Stage 2: Identifying relevant studies
- Stage 3: Study selection
- Stage 4: Charting the data
- Stage 5: Collating, summarizing, and reporting the findings

The optional consultation stage was not undertaken, as expertise within the author team (Professor Peng Bi) fulfilled this role.

2.2. Identifying relevant studies

A comprehensive search was conducted on August 18th, 2025, across five major databases: PubMed, Scopus, CINAHL, Embase, and Web of Science (1950 to 2025). The search strategy combined Medical Subject Headings (MeSH) and free-text keywords related to three core concepts: heatwaves and heat exposure, mortality records, and surveillance and monitoring systems. Backward and forward citation tracking was used to identify additional relevant literature. A sample PubMed search strategy is provided in Supplementary File **S1**.

2.3. Study selection

Two reviewers (TYA and YTD) independently screened titles, abstracts, and full texts. Discrepancies were resolved by consensus. Inclusion was informed by the JBI PCC framework (Peters et al., 2015):

- **Population**: Human populations or communities exposed to heatwaves
- **Concept:** Mortality recording, attribution, surveillance systems, or reporting mechanisms
- **Context**: Any geographic setting where heatwave-related mortality monitoring has been implemented or evaluated

2.4. Inclusion and exclusion criteria

The review included studies employing quantitative, qualitative, or mixed-method approaches that examined heatwave-related mortality, data recording practices, or surveillance systems. Eligible studies were those that analysed mortality associated with heatwaves, including investigations of how heatwave related deaths are detected, recorded, and monitored within mortality recording or surveillance systems. Publications in English from 1950 through 2025 were included, without restriction on country or region.

Studies were excluded if they did not examine heatwave-related mortality, data recording, or surveillance systems, or if they did not include mortality or meteorological data to assess heat impacts. Non-English publications, non-empirical publications, conference abstracts lacking full data, duplicate reports, and studies without sufficient methodological detail were excluded.

2.5. Charting the data

The two reviewers independently extracted data using a standardized JBI-aligned form (Aromataris et al., 2022), piloted on a subset of studies to ensure consistency. The extraction form captured the following key variables including study identification, study characteristics, heatwave definition and exposure metrics, mortality variables and attribution methods, data sources (death certificates, health department records, emergency medical services, and coronial data), ICD cause-of-death codes, details of the surveillance system and managing agency (Table 1).

2.6. Collating, summarizing, and reporting findings

Mortality attribution approaches were categorised into three methodological groups (Xu et al., 2016): direct attribution using heat-specific ICD codes recorded on death certificates (Bouchama and Knochel, 2002); population-level excess mortality estimation comparing observed and expected deaths; and (Thompson et al., 2024a) hybrid or descriptive approaches that integrate multiple data sources or classification methods.

Heatwave definitions and exposure metrics were also extracted,

Table 1
Key variables included in the scoping review.

Subcategory	Key variables
Study identification	Author (s) name, publication year, and country
Study characteristics	Study design, data source type (e.g., report, peer-reviewed paper), study period, and geographic scope (local, national, or global)
Heatwave variables	Heatwave definitions used, temperature indices applied, thresholds, and duration of heatwaves.
Mortality variables	Mortality classification (all causes, cause-specific, or excess deaths), data sources (death certificates, health department records, emergency medical services)
Statistical methods used	Attribution methods used (e.g., descriptive analysis, generalized linear model, generalized additive model, or Distributed lag non-linear model).
ICD cause-of death codes	Heat-specific (e.g., X30, T67, E900) and heat-sensitive ICD codes (i.e., codes for cardiovascular, respiratory, renal, mental, neurologic, diabetes mellitus, pre-term birth, and occupational injuries related mortality), integration with meteorological datasets or real-time reporting systems, and population subgroups analysed (age, sex, socioeconomic status, indigenous or minority groups)
System and governance variables	Surveillance system and managing agency (e.g., national health institute, meteorological bureau), limitations, and recommendations
Equity and policy considerations	Inclusion of vulnerable populations and policy relevance and use of data for heat-health warning or response systems.

including advanced indices such as the Excess Heat Factor (Nairn and Fawcett, 2011), Heatwave Magnitude Index (Dosio et al., 2018), Heat Index (Steadman, 1979), Heat-Health Watch Warning System thresholds (McGregor et al., 2015), absolute temperature cut-offs (Anderson and Bell, 2009), and percentile-based temperature definitions (Gasparrini et al., 2015).

Findings were synthesized using both quantitative (descriptive) and qualitative (thematic) approaches. Data were organized and presented through tables, figures, and concept maps, supported by a narrative synthesis. To ensure conceptual coherence particularly regarding different approaches to defining and attributing mortality during heatwaves the synthesis was structured around the following analytical dimensions.

3. Results

A total of 11,498 records were initially identified through database searches. After removing 1748 duplicates, 9750 records remained for screening. Of these, 9349 were excluded based on title and abstract review. Full-text assessment was conducted for 402 articles, with 225 excluded for reasons including being non-heatwave studies (n = 90), wrong exposure or outcome (n = 34), non-English language (Spanish, German, Japanese, Korean, Mandarin, and Portuguese) (n = 11), conference abstracts (n = 8), methodological or policy-focused papers (n = 18), incomplete or unavailable texts (n = 19), and other ineligible study types. Ultimately, 176 studies met the inclusion criteria and were included in the final scoping review ((Aboubakri et al., 2019; Aghababaeian et al., 2023; Ahmadnezhad et al., 2013; Analitis et al., 2014; Anderson and Bell, 2011; Astrom et al., 2020; Azhar et al., 2014; Baker and Sturm, 2024; Basagana et al., 2011; Benmarhnia et al., 2017; Bernal et al., 2022; Błażejczyk et al., 2022; Bobb et al., 2011; Bogdanovic et al., 2013; Bridger et al., 1976; Can et al., 2019; Canoui-Poitrine et al., 2006; Chaston et al., 2022; Cheng et al., 2024; Cheng et al., 2018; Chesini et al., 2022; Chien et al., 2016; Choi et al., 2024; Culqui et al., 2014; D'Ippoliti et al., 2010a; Dang et al., 2019; de Bont et al., 2024; DeCastro et al., 2011; Díaz et al., 2018; Dimitriadou and Zerefos, 2023; Diniz et al., 2020; Dong et al., 2016; Ellis and Nelson, 1978; Ellis et al., 1975; Ellis et al., 1980; Fouillet et al., 2006; Fouillet et al., 2008; Franklin et al., 2023; Gao et al., 2015; Gao et al., 2025; Garssen et al., 2005; Gasparrini and Armstrong, 2011; Geirinhas et al., 2019; Ghumman and Horney, 2016; Gosling et al., 2007; Graczyk et al., 2022; Green et al., 2012; Guo et al., 2017a; Guo et al., 2018; Hagen and Weihs, 2023; Hanzlíková et al., 2015; Heaviside et al., 2016a; Heo et al., 2019; Hertel et al., 2009; Heudorf and Schade, 2014; Hoffmann et al., 2008; Hoshiko et al., 2010; Hu et al., 2025; Hůnová et al., 2017; Hutter et al., 2007; Johnson et al., 2005; Johnson et al., 2016; Kaiser et al., 2007; Kaiser et al., 2001; Kang et al., 2020; Khatana et al., 2022; Kim et al., 2019; Kim et al., 2016), (Kollanus et al., 2021; Kumar and Singh, 2021; Kyselý, 2004; Kyselý and Kim, 2009; Kyselý and Kříž, 2008; Le Tertre et al., 2006; Lee et al., 2018a, 2018b, 2024; Leonardi et al., 2006; Li et al., 2019; Lim et al., 2019; Linares et al., 2015a, 2015b; Liu et al., 2025; Lo et al., 2022; López-Bueno et al., 2020, 2021; Lv et al., 2025; Ma et al., 2015; Madrigano et al., 2015; Martinez-Austria and Bandala, 2017; Mathes et al., 2017; Matte et al., 2016; Mazdiyasni et al., 2017; Michelozzi et al., 2005, 2010b; Miron et al., 2015; Monteiro et al., 2013; Muthers et al., 2010, 2017; Nguyen et al., 2023; Nitschke et al., 2007, 2011; Niu et al., 2023; Nori-Sarma et al., 2019; Oray et al., 2018; Ostro et al., 2009; Ozturk et al., 2023; Paravantis et al., 2017; Paredes-Fortuny et al., 2024; Perkins-Kirkpatrick et al., 2025; Pham et al., 2019; Pyrgou and Santamouris, 2018; Revich and Shaposhnikov, 2008; Rey et al., 2007, 2008; Rezaee et al., 2023; Rooney et al., 1998; Royé et al., 2020), (Ruiz-Páez et al., 2023; Saleem et al., 2017; Schaffer et al., 2012; Schifano et al., 2009; Seposo et al., 2017; Shartova et al., 2018; Sheridan and Lin, 2014; Silveira et al., 2023a, 2023b; Singh et al., 2019; Son et al., 2012, 2014, 2016; Song et al., 2024; Stanojević et al., 2014; Steul et al., 2018; Sun et al., 2014, 2021; Tan et al., 2007; Tao et al., 2025; Thompson et al., 2022, 2024b; Tian et al., 2013; Tong et al., 2010, 2012, 2014; Trigo et al., 2009; Urban et al., 2017, 2019; Vandentorren et al., 2006; Vautard et al., 2020; Vyberci et al., 2015; Wang, 2023; Wang et al., 2012, 2018; Weisskopf et al., 2002; Williams et al., 2012, 2018b; Xi et al., 2024; Xie et al., 2014; Xu et al., 2013, 2023; Xu and Tong, 2017; Yan et al., 2022, 2023; Yang et al., 2013, 2019; Yin and Wang, 2017; Yu et al., 2025a, 2025b; Zaninović and Matzarakis, 2014; Zeng et al., 2014; Zhang et al., 2015a, 2015b, 2016, 2017, 2018, 2021; Zou et al., 2025)) (Fig. 1).

3.1. Characteristics of included studies

The included studies span 41 countries, with the highest representation from China (n = 31), the United States of America (n = 27), and Australia (n = 19). Contributions were also drawn from diverse regions, including Europe, North America, South Asia, and Latin America, reflecting broad international engagement with heat-health research across varied climatic and demographic contexts (Fig. 2).

Over 90% of included studies employed retrospective time-series or case-crossover designs, focusing primarily on all-cause mortality as well as cardiovascular and respiratory mortality outcomes. Across studies, older adults, individuals with chronic conditions, and urban populations emerged as the most frequently studied population groups. There was a progressive rise in research activity, with minimal output (6 studies) from 1950 to 1999, steady growth in the 2000s (62 studies from 2000 to 2014), and a marked surge of 98 studies within the last 10 years **(S3)**.

3.2. Attribution methods

Included studies compared observed deaths with an expected baseline during heatwave periods to identify statistical excess mortality. It operates at the population level and is not constrained by individual-level causal attribution.

A wide range of regression-based frameworks were applied, often in combination rather than as mutually exclusive approaches. Approximately 65% of studies used a generalized linear modelling (GLM) framework, including Poisson, Quasi-Poisson, negative binomial, and logistic regression models for count and binary outcomes. Within this

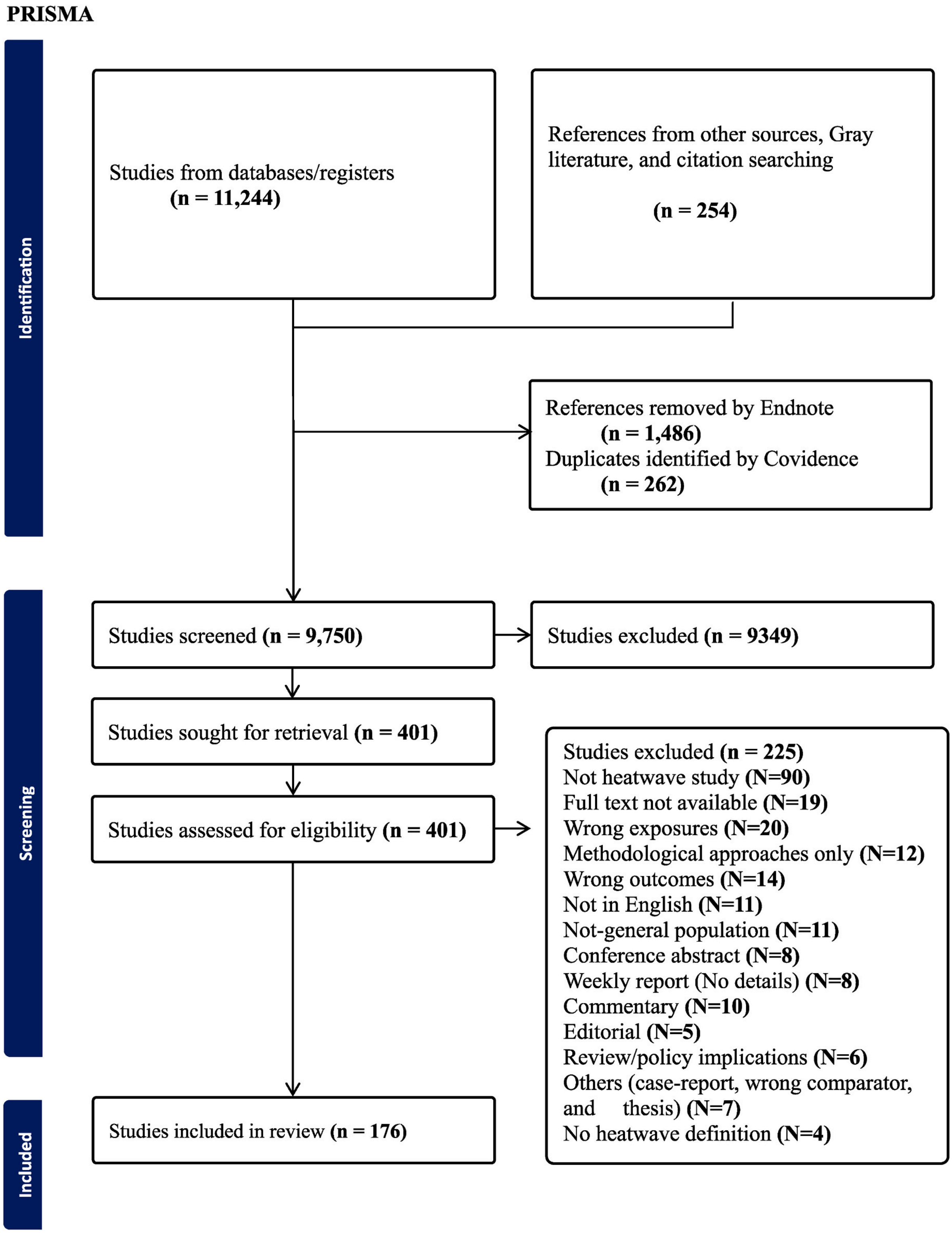

Fig. 1. Study flow chart.

broad framework, distributed lag non-linear models (DLNM) were used in 41 studies (23.3%) to assess delayed and non-linear temperature-mortality relationships, while generalized additive models (GAM) were applied in 21 studies (11.9%) to incorporate smoothing functions for temporal and seasonal variation. Cox proportional hazards models, used mainly in cohort studies, were identified in 5 studies (3%).

Because many studies combined these techniques such as GLM structures with DLNM or GAM elements these categories overlap and should be interpreted as interrelated analytical components within a shared regression framework rather than distinct methodological types. Overall, most studies integrated GLM-based regression structures, frequently incorporating DLNM or GAM extensions to capture non-linear and lagged associations between heat exposure and mortality. Methodological heterogeneity reflected evolution from simple regression (pre-2000) to sophisticated lag-nonlinear modelling (post-2010), with increasing adoption of DLNM and machine learning approaches

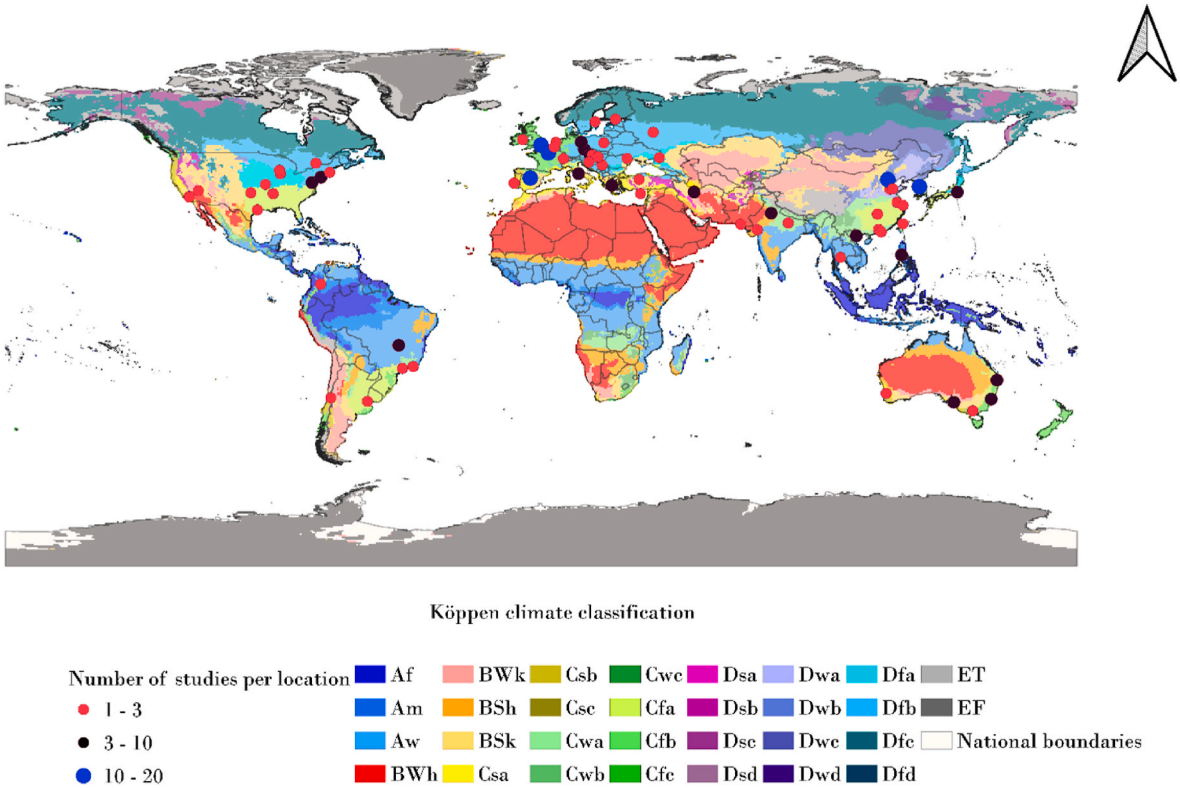

Fig. 2. Geographic spread of included studies based on Köppen-Geiger climate zone classification across continents. Köppen-Geiger climate zone abbreviations are described in the supplementary material (S2).

post-2015 in three studies (Kim et al., 2016, 2019; Heaviside et al., 2016b) **(S3)**.

3.3. *Heatwave definition and measurement approaches*

All 176 studies provided heatwave definitions. Duration criteria appeared in 78.4% studies (n = 138), with minimum consecutive day requirements ranging from 2 to 5 days, followed by percentile-based definitions (e.g., ≥95th percentile for ≥2 days) in 96 studies (54.5%) and absolute temperature thresholds were applied in 65 studies (36.9%).

More sophisticated approaches such as the Excess Heat Factor (EHF) (n = 4) (Franklin et al., 2023; Lee et al., 2018a; Royé et al., 2020; Williams et al., 2018b), the Heat Wave Magnitude Index (HWMI) (n = 1) (Wang, 2023), and the Heat Index (HI) (n = 8) (Hoffmann et al., 2008; Kyselý and Kim, 2009; Kyselý and Kříž, 2008; Madrigano et al., 2015; Mathes et al., 2017; Matte et al., 2016; Monteiro et al., 2013; Weisskopf et al., 2002), as well as operational definitions like the Heat-Health Watch Warning System (HHWWS) (n = 2) (Michelozzi et al., 2005; Schifano et al., 2009) appeared in a small proportion of studies. These indices are summarized in supplementary file **(S4)**.

3.4. *Temperature data reporting and meteorological data sources*

Temperature was reported in 166 studies (94.3% completeness). Average temperature was reported in 58.5% (n = 103), maximum temperature in 46.6% (n = 82), and minimum temperature in 59.1% (n = 104).

Meteorological data sources were reported in 167 studies (94.4%). Ground-based observation systems were most frequently employed (26.7%, n = 47), with national meteorological services contributed data in 25 studies (14.1%), while 17 studies (9.4%) utilized gridded or reanalysis. A further 42 studies (23.5%) integrated multiple sources, and one study (0.5%) reported inadequate meteorological data. Explicit efforts to address spatial heterogeneity through gridded data were limited, appearing in just 17 studies (9.4%) **(S4)**.

3.5. *Surveillance system approach*

Surveillance systems were varied widely among the included studies, with most relying on routine administrative health data rather than dedicated or real-time heat-health surveillance platforms. Public health surveillance systems were used in 30.1% of studies (n = 53). Hospital-based or emergency department syndromic surveillance systems were used in only 8.0% of studies (n = 14). Death surveillance or mortality registration points, and other municipal mortality reporting portals accounted for 18.2% (n = 32). Fewer studies used structured early warning or heat-alert monitoring systems coordinated jointly by meteorological and public health agencies, representing only 6.8% (n = 12). Notably, 39.8% (n = 70) did not describe a specific surveillance system, instead relying on static death certificate registries or retrospective compilations of mortality data **(S4)**.

3.6. *Mortality data sources and institutional coordination*

Across the 176 studies reviewed, mortality data were primarily obtained from routine administrative systems. National public health agencies or registries and related surveillance systems were the dominant source, reported in 67.6% of studies (n = 119). Institutional coordination typically involved data linkages between meteorological agencies, health authorities, and statistical offices. Overall, mortality monitoring depended largely on existing administrative datasets, with coordination achieved through inter-agency data sharing rather than fully integrated operational early-warning systems (Fig. 3 and S4).

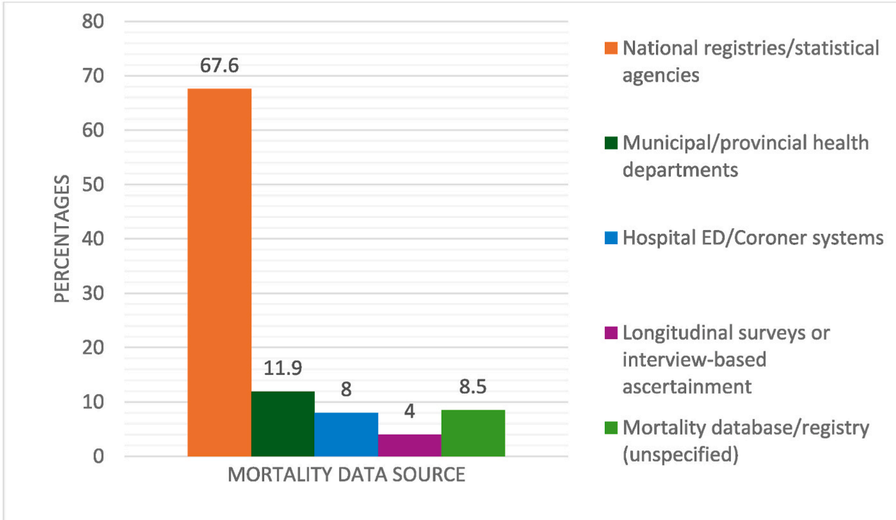

Fig. 3. Sources of mortality data among included studies in the scoping review.

3.7. Mortality assessment and ICD coding practices

All-cause mortality dominated mortality types, at 81.8% (n = 144) of included studies, reflecting easier accessibility and reduced misclassification. Cause-specific mortality appeared in 38.1% (n = 67) of studies. Among those implementing heat codes, ICD-10 was applied in 48.3% (n = 85) of studies and ICD-9 in 15.3% studies (n = 27). Approximately 55.7% (n = 98) of studies did not report specific ICD codes.

Only 8.5% of the 176 studies explicitly used heat-specific ICD codes (X30, T67, E900) to identify deaths directly attributed to heat. Among studies examining all-cause mortality, 36.9% (n = 65) reported cardiovascular disease (CVD) codes (I00–I99), and 23.3% (n = 41) reported respiratory codes (J00–J99) **(S4** and Fig. 4).

Of included studies, 55.7% (n = 98) did not report any ICD codes. Among studies using ICD-10, the most frequently applied heat-specific codes were X30 and T67, while studies using ICD-9 most used E900 to classify heat-specific mortality. A smaller proportion (11.4%, n = 20) reported using both ICD-9 and ICD-10 **(S4)**.

3.8. Reported limitations by published studies

Analysis of the reported limitations across all 176 studies revealed several recurring methodological and data-related challenges. The most frequently cited issue was confounding (30.7%, n = 54), primarily from unmeasured or inadequately controlled variables. Exposure misclassification was also common (17.0%, n = 30), as many studies were unable to capture individual-level heat exposure accurately. An equal proportion of studies also (17.0%, n = 30) identified air pollution confounding. Generalizability concerns were noted in 12.5% (n = 22) of studies and a smaller proportion (6.8%, n = 12) focused on single-city or geographically narrow analyses, reducing external validity. Furthermore, 10.2% (n = 18) of studies mentioned that lag-effect was not considered, limiting the understanding of delayed mortality responses to heat exposure. Finally, sample size limitations (4.5%, n = 8) were reported, particularly where subgroup or stratified analyses were constrained by insufficient data.

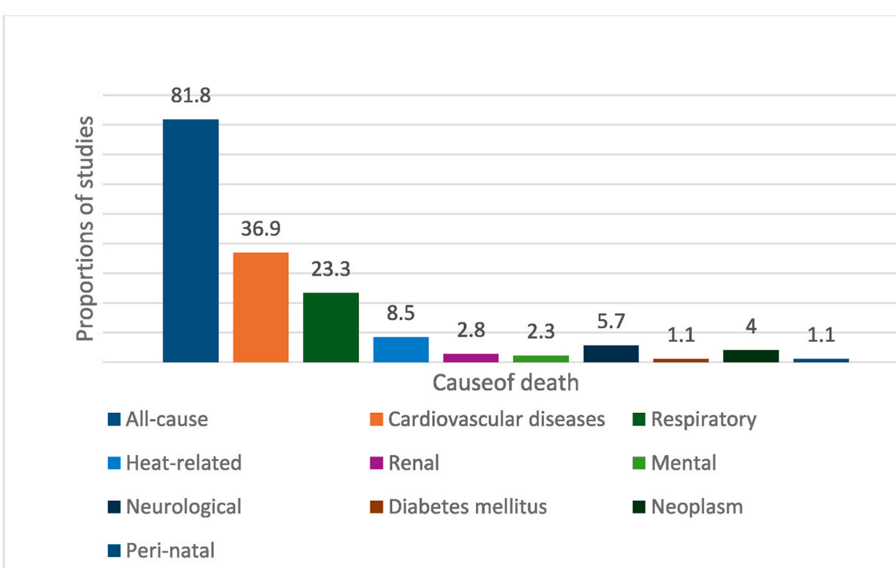

Fig. 4. Proportion of studies reporting each cause-specific mortality category (not the proportion of deaths).

4. Discussion

This global scoping review synthesizes how deaths occurring during heatwave periods are recorded, classified, and monitored across diverse jurisdictions. Analysis of 176 studies from more than 40 countries revealed that most mortality information is derived from passive, retrospective systems, with over 90% of studies relying on routinely collected vital statistics. While these systems provide broad coverage, their retrospective nature limits the timeliness with which exposure-mortality relationships can be identified during extreme heat events. This is consistent with previous assessments noting delays in mortality reporting and limited integration of meteorological and health data (Aromataris et al., 2022).

A fundamental challenge in heatwave mortality recording is the inherently indirect and probabilistic nature of heat as a cause of death (Hajat and Kosatky, 2010). Substantial heterogeneity was observed in how mortality during heatwave periods was defined and reported. All-cause mortality was the most frequently used outcome, while cause-specific mortality appeared less consistently. Only 8.5% of included studies applied heat-specific ICD codes, and more than half did (55.7%) not report any ICD codes. Importantly, the low use of heat-specific ICD codes should not be interpreted solely as systemic underestimation; it also reflects the indirect and multifactorial pathways through which heat contributes to mortality (Basu, 2009a). ICD codes describe individual-level medical causes of death, whereas excess mortality reflects population-level statistical estimates (Hajat and Kosatky, 2010). These represent distinct constructs and are not interchangeable (Organization, 2021). Variability in coding practices therefore reflects differences in reporting conventions, data availability, and institutional procedures rather than providing a direct indication of the extent of heat-attributable mortality (Longden, 2025; Orrall, 2025).

This distinction has direct implications for how surveillance reform should be framed (Vicedo-Cabrera et al., 2021). Systems oriented primarily toward increasing heat-specific ICD code capture are likely to underestimate the broader burden of heat-associated mortality, as mortality does not typically manifest as direct heat illness (Basu, 2009b). Effective surveillance therefore requires integrating ICD coding to flag clinically recognised heat illness with real-time excess mortality modelling to detect the broader population-level signal (Hondula et al., 2015).

Real-time heat-health surveillance remains uncommon globally, with clear regional and temporal disparities. Many surveillance systems developed reactively following catastrophic heat events rather than through proactive public health planning, particularly in the USA (Berko, 2014; Fowler et al., 2013), and in Europe after the 2003 European heatwave (Robine et al., 2008; Pascal et al., 2006). Several Asia-Pacific countries have more recently developed systems, often in response to severe events (Guo et al., 2017b). In contrast, evidence from low-income countries remains limited, with no representation from the Africa region, highlighting major global inequities in heat-health surveillance capacity (Ebi et al., 2021). These patterns suggest that surveillance improvements tend to be reactive, with many low- and middle-income settings lacking the institutional capacity and resources needed for systemic monitoring (Amoatey et al., 2025).

The study has several limitations. A major challenge identified across studies is the absence of a consistent global definition of heatwave (McGregor et al., 2015). Definitions varied widely, ranging from absolute temperature thresholds to percentile-based criteria and composite biometeorological indices (Perkins and Alexander, 2013). While locally adapted definitions improve relevance, the lack of harmonization limits cross-national comparison (Xu and Zhang, 2022; McGregor, 2024b). Future surveillance development should distinguish between locally calibrated operational definitions, which are appropriate and necessary, and cross-national comparative frameworks, which require harmonized standards (Vicedo-Cabrera et al., 2021).

Institutional capacity and professional training emerged as additional constraints (Matthies, 2008). Although targeted education initiatives in Europe after the 2003 heatwave improved recognition and coding of heat-related deaths (Kovats and Kristie, 2006; D'Ippoliti et al., 2010b), such efforts remain limited globally. No standardized international training framework exists for clinicians, medical examiners, or coders to support consistent identification and documentation of deaths occurring during extreme heat (WHO, 2015).

Analytical methods have evolved substantially, with increasing use of DLNMs and machine learning techniques to estimate heat impacts, lag structures, and mortality displacement (Gasparrini et al., 2010). However, most existing surveillance systems have not yet incorporated these tools into real-time operational practice (Pascal et al., 2006). Limited linkage between meteorological and mortality data further restricts the development of predictive models and early warning systems (McGregor et al., 2015).

Many studies report only aggregated temperature metrics, limiting the ability to compare exposure measures or derive variability estimates without access to raw data. Despite these limitations, the findings of this review provide a foundation for developing more coherent and operationally relevant frameworks for recording and monitoring deaths during heatwave periods (Ebi and Bowen, 2016).

Strengthening surveillance will require harmonized definitions, improved data integration, and sustained investment in workforce capacity (Watts et al., 2019, 2021). Standardizing approaches to heatwave classification and ICD coding, linking meteorological and health datasets, and embedding environmental health training within medical and public health curricula would enhance the accuracy and timeliness of mortality monitoring (Hess et al., 2011). Incorporating vulnerability indicators such as age, occupation, and chronic illness into surveillance frameworks may further support targeted public health responses (Åström et al., 2011; Kovats and Hajat, 2008).

The evidence suggests that more effective surveillance is likely where standardized coding practices, integrated data systems, and appropriate professional training are in place (Semenza and Menne, 2009). An effective global framework for heatwave mortality surveillance requires the integration of two methodologically distinct approaches individual-level clinical flagging of heat illness through ICD systems and population-level real-time excess mortality estimation through statistical modelling linked to meteorological data (Mathes et al., 2017; Organization, 2021). Neither approach alone can adequately capture the full spectrum of heat-associated mortality (Lippmann et al., 2013; Gronlund et al., 2014). Achieving these improvements globally will require sustained policy commitment, cross-sector collaboration, and investment in governance and workforce capacity (Organization, 2015). Strengthening coordination among meteorological, forensic, and public health agencies, harmonizing classification systems, and embedding environmental health training within medical and public health education are critical steps toward building a more coherent, responsive, and context-appropriate global heat-health surveillance framework (Organization, 2021; Almohammadi, 2026; Chandra and Lee, 2025).

Future work should explore real-time analytic approaches beyond passive surveillance (May et al., 2009). For example, artificial intelligence applied to emergency department or ambulance records could provide near real-time signals of heat-related health impacts (Reesman, 2022). Comparative assessments across regions may clarify how definitional and methodological differences influence mortality estimates, while modelling studies integrating climatic projections with demographic and health data will be essential for anticipating future heat-related mortality under climate change (Gasparrini et al., 2015).

5. Conclusion

While heat-specific ICD codes capture only a small fraction of deaths occurring during heatwaves, this reflects both the indirect and multifactorial pathways through which heat contributes to mortality and limitations in coding practices. For this reason, low coding rates should be interpreted cautiously and not assumed to represent systematic underestimation on their own. Real-time monitoring capacity also remains limited, and geographic and institutional disparities contribute to inconsistent practices and reduced comparability across jurisdictions. In countries where it exists, it has developed reactively following catastrophic events rather than proactively. Finally, geographic and institutional disparities produce inconsistent practices and systematic underestimation of heat-associated mortality in low- and middle-income settings. These findings advance our understanding of heatwave mortality recording and surveillance systems globally.

Data sharing statement

Data will be available upon request from the corresponding author.

CRediT authorship contribution statement

Temesgen Yihunie Akalu: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Matthew Anthony Borg:** Conceptualization, Data curation, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – review & editing. **Yohannes Tefera Damtew:** Conceptualization, Data curation, Investigation, Methodology, Resources, Validation, Visualization, Writing – review & editing. **Susan L. Heatley:** Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – review & editing. **Matt Beaty:** Methodology, Validation, Visualization, Writing – review & editing. **Vanessa Prescott:** Methodology, Validation, Visualization, Writing – review & editing. **Peng Bi:** Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

Conflict of interest

All authors declare that they have no conflict interests:

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2026.114858.

Abbreviations and acronyms

Numerous abbreviations and acronyms are used in our scoping review, including ABS: Australian Bureau of Statistics, CDC: Center for Disease Control, CINAHL: Cumulative Index to Nursing and Allied Health Literature, DLNM: Distributed Lag Non-Linear Models, ECMWF/ERA5: European Center for Medium Range Weather Forecasts/ECMWF Reanalysis 5th Generation, EHF: Excess Heat Factor, GAM: Generalized Additive Models, GFS: Global Forecast System, GLM: Generalized Linear Modelling, HHWS: Heat Health Warning System in South Australia, ICD: International Classification of Diseases, INE: Instituto Nacional de Estadística, Spain, INSERM: Institut National de la Santé et de la Recherche Médicale, France, JBI: Joanna Briggs Institute, MERRA: Modern-Era Retrospective Analysis for Research and Applications, MeSH: Medical Subject Headings, NGO: Non-Governmental Organization, ONS: Office for National Statistics, OSF: Open Science Framework, PCC: Population–Concept–Context, PET: Physiologically Equivalent Temperature, and PRISMA-ScR: Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews.

References

Aboubakri, O., Khanjani, N., Jahani, Y., Bakhtiari, B., 2019. The impact of heat waves on mortality and years of life lost in a dry region of Iran (Kerman) during 2005–2017. International journal of biometeorology 63 (9), 1139–1149.
Aghababaeian, H., Ostadtaghizadeh, A., Ardalan, A., Asgary, A., Akbary, M., Yekaninejad, M.S., et al., 2023. Mortality risk related to heatwaves in dezful City, Southwest of Iran. Environ. Health Insights 17.
Ahmadnezhad, E., Holakouie Naieni, K., Ardalan, A., Mahmoudi, M., Yunesian, M., Naddafi, K., Mesdaghinia, A.R., 2013. Excess mortality during heat waves, Tehran Iran: an ecological time-series study. J. Res. Health Sci. 13 (1), 24–31.
Almohammadi, A., 2026. Heat-related illnesses in Saudi Arabia: prevention, early recognition, and public health strategies. Journal of Umm Al-Qura University for Medical Science 12 (1), 7.
Amoatey, P., Xu, Z., Odebeatu, C.C., Singh, N., Osborne, N.J., Phung, D., 2025. Impact of extreme heat on health in Australia: a scoping review. BMC Public Health 25 (1), 522.
Analitis, A., Michelozzi, P., D'Ippoliti, D., De'Donato, F., Menne, B., Matthies, F., et al., 2014. Effects of heat waves on mortality: effect modification and confounding by air pollutants. Epidemiology (Cambridge, Mass) 25 (1), 15–22.
Anderson, B.G., Bell, M.L., 2009. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidemiology 20 (2), 205–213.
Anderson, G.B., Bell, M.L., 2011. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. Environ. Health Perspect. 119 (2), 210–218.
Arksey, H., O'malley, L., 2005. Scoping studies: towards a methodological framework. Int. J. Soc. Res. Methodol. 8 (1), 19–32.
Aromataris, E., Stern, C., Lockwood, C., Barker, T.H., Klugar, M., Jadotte, Y., et al., 2022. JBI series paper 2: tailored evidence synthesis approaches are required to answer diverse questions: a pragmatic evidence synthesis toolkit from JBI. Journal of clinical epidemiology 150, 196–202.
Astrom, D.O., Astrom, C., Forsberg, B., Vicedo-Cabrera, A.M., Gasparrini, A., Oudin, A., Sundquist, K., 2020. Heat wave-related mortality in Sweden: a case-crossover study investigating effect modification by neighbourhood deprivation. Scand. J. Publ. Health 48 (4), 428–435.
Azhar, G.S., Mavalankar, D., Nori-Sarma, A., Rajiva, A., Dutta, P., Jaiswal, A., et al., 2014. Heat-Related mortality in India: excess all-cause mortality associated with the 2010 ahmedabad heat wave. PLoS One 9 (3), e91831 organization = on behalf of the Ahmedabad HeatClimate Study Group.
Błażejczyk, K., Twardosz, R., Wałach, P., Czarnecka, K., Błażejczyk, A., 2022. Heat strain and mortality effects of prolonged central European heat wave—an example of June 2019 in Poland. International journal of biometeorology 66 (1), 149–161.
Baker, L., Sturm, R., 2024. Mortality in extreme heat events: an analysis of Los Angeles County Medical Examiner data. Public Health (Lond.) 236, 290–296.
Basagana, X., Sartini, C., Barrera-Gomez, J., Dadvand, P., Cunillera, J., Ostro, B., et al., 2011. Heat waves and cause-specific mortality at all ages. Epidemiology (Cambridge, Mass) 22 (6), 765–772.
Basu, R., 2009a. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. Environ. Health: A Global Access Science Source 8 (1).
Basu, R., 2009b. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. Environ. Health 8 (1), 40.
Benmarhnia, T., Kihal-Talantikite, W., Ragettli, M.S., Deguen, S., 2017. Small-area spatiotemporal analysis of heatwave impacts on elderly mortality in Paris: a cluster analysis approach. Sci. Total Environ. 592, 288–294.
Berko, J., 2014. Deaths Attributed to Heat, Cold, and Other Weather Events in the United States, 2006-2010. US Department of Health and Human Services, Centers for Disease Control and.
Bernal, N., Schwarz, L., Benmarhnia, T., Filho, S.R., 2022. Impact of heat waves on cardiovascular and respiratory morbidity and mortality in municipalities of Northeast Brazil. Sustentabilidade em Debate 13 (2), 96–108.
Bobb, J.F., Dominici, F., Peng, R.D., 2011. A Bayesian model averaging approach for estimating the relative risk of mortality associated with heat waves in 105 U.S. cities. Biometrics 67 (4), 1605–1616.
Bogdanovic, D.C., Milosevic, Z.G., Lazarevic, K.K., Dolicanin, Z.C., Randelovic, D.M., Bogdanovic, S.D., 2013. The impact of the July 2007 heat wave on daily mortality in Belgrade, Serbia. Cent. Eur. J. Publ. Health 21 (3), 140–145.
Bouchama, A., Knochel, J.P., 2002. Heat stroke. N. Engl. J. Med. 346 (25), 1978–1988.
Bridger, C.A., Ellis, F.P., Taylor, H.L., 1976. Mortality in St. Louis, Missouri, during heat waves in 1936, 1953, 1954, 1955, and 1966. Coroner's cases. Environ. Res. 12 (1), 38–48.
Can, G., Sahin, U., Sayili, U., Dube, M., Kara, B., Acar, H.C., et al., 2019. Excess Mortality in Istanbul during Extreme Heat Waves between 2013 and 2017. Int. J. Environ. Res. Publ. Health 16 (22).
Canoui-Poitrine, F., Cadot, E., Spira, A., Groupe Regional, C., 2006. Excess deaths during the August 2003 heat wave in Paris, France. Revue d'epidemiologie et de sante publique 54 (2), 127–135.

Chandra, N.S.V.S., Lee, J.K.W., 2025. A systematic review of heat health warning systems: enhancing the framework towards effective health outcomes. Curr. Environ. Health Rep. 12 (1), 31.
Chaston, T.B., Broome, R.A., Cooper, N., Duck, G., Geromboux, C., Guo, Y., et al., 2022. Mortality burden of heatwaves in Sydney, Australia is exacerbated by the urban heat Island and climate change: can tree cover help mitigate the health impacts? Atmosphere 13 (5).
Cheng, C., Liu, Y., Han, C., Fang, Q., Cui, F., Li, X., 2024. Effects of extreme temperature events on deaths and its interaction with air pollution. Sci. Total Environ. 915.
Cheng, J., Xu, Z., Bambrick, H., Su, H., Tong, S., Hu, W., 2018. Heatwave and elderly mortality: an evaluation of death burden and health costs considering short-term mortality displacement. Environ. Int. 115, 334–342.
Chesini, F., Herrera, N., Skansi, MdLM., Morinigo, C.G., Fontan, S., Savoy, F., Titto, Ed, 2022. Mortality risk during heat waves in the summer 2013-2014 in 18 provinces of Argentina: ecological study. Ciência Saúde Coletiva 27 (5), 2071–2086.
Chien, L.-C., Guo, Y., Zhang, K., 2016. Spatiotemporal analysis of heat and heat wave effects on elderly mortality in Texas, 2006–2011. Sci. Total Environ. 562, 845–851.
Choi, J., Lim, H., Bae, S., Choi, K.-H., Han, X., Ha, M., Kwon, H.-J., 2024. Excess mortality related to high air temperature: comparison of the periods including 1994 and 2018, the worst heat waves in the history of South Korea. PLoS One 19 (11), e0310797.
Coates, L., Haynes, K., O'brien, J., McAneney, J., De Oliveira, F.D., 2014. Exploring 167 years of vulnerability: an examination of extreme heat events in Australia 1844–2010. Environ. Sci. Pol. 42, 33–44.
Coates, L., van Leeuwen, J., Browning, S., Gissing, A., Bratchell, J., Avci, A., 2022. Heatwave fatalities in Australia, 2001–2018: an analysis of coronial records. Int. J. Disaster Risk Reduct. 67, 102671.
Culqui, D.R., Diaz, J., Simón, F., Tobías, A., Linares, C., 2014. Evaluation of the plan for surveillance and controlling of the effects of heat waves in Madrid. International journal of biometeorology 58 (8), 1799–1802.
D'Ippoliti, D., Michelozzi, P., Marino, C., De'Donato, F., Menne, B., Katsouyanni, K., et al., 2010a. The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. Environ. Health: A Global Access Science Source 9 (1).
D'Ippoliti, D., Michelozzi, P., Marino, C., de'Donato, F., Menne, B., Katsouyanni, K., et al., 2010b. The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. Environ. Health 9 (1), 37.
Dang, T.N., Honda, Y., Do, D.V., Pham, A.L.T., Chu, C., Huang, C., Phung, D., 2019. Effects of extreme temperatures on mortality and hospitalization in Ho Chi Minh City, Vietnam. Int. J. Environ. Res. Publ. Health 16 (3).
Díaz, J., Carmona, R., Mirón, I.J., Luna, M.Y., Linares, C., 2018. Time trend in the impact of heat waves on daily mortality in Spain for a period of over thirty years (1983–2013). Environ. Int. 116, 10–17.
de Bont, J., Nori-Sarma, A., Stafoggia, M., Banerjee, T., Ingole, V., Jaganathan, S., et al., 2024. Impact of heatwaves on all-cause mortality in India: a comprehensive multi-city study. Environ. Int. 184.
DeCastro, M., Gomez-Gesteira, M., Ramos, A.M., Álvarez, I., DeCastro, P., 2011. Effects of heat waves on human mortality, Galicia, Spain. Clim. Res. 48 (2–3), 333–341.
Dey, R., Lewis, S.C., 2021. Natural Disasters Linked to Climate Change. the Impacts of Climate Change. Elsevier, pp. 177–193.
Dimitriadou, L., Zerefos, C., 2023. Heatwaves and mortality in Spain and Greece: a comparative analysis. Atmosphere 14 (5).
Diniz, F.R., Gonçalves, F.L.T., Sheridan, S., 2020. Heat wave and elderly mortality: historical analysis and future projection for metropolitan Region of São Paulo, Brazil. Atmosphere 11 (9), 933.
Dong, W., Zeng, Q., Ma, Y., Li, G., Pan, X., 2016. Impact of heatwave definitions on the added effect of heatwaves on cardiovascular mortality in Beijing, China. Int. J. Environ. Res. Publ. Health 13 (9).
Dosio, A., Mentaschi, L., Fischer, E.M., Wyser, K., 2018. Extreme heat waves under 1.5 C and 2 C global warming. Environ. Res. Lett. 13 (5), 054006.
Ebi, K.L., Vanos, J., Baldwin, J.W., Bell, J.E., Hondula, D.M., Errett, N.A., et al., 2021. Extreme weather and climate change: population health and health system implications. Annu. Rev. Publ. Health 42 (1), 293–315.
Ebi, K.L., Bowen, K., 2016. Extreme events as sources of health vulnerability: drought as an example. Weather Clim. Extrem. 11, 95–102.
Ellis, F.P., Nelson, F., Pincus, L., 1975. Mortality during heat waves in New York City July, 1972 and August and September, 1973. Environ. Res. 10 (1), 1–13.
Ellis, F.P., Prince, H.P., Lovatt, G., Whittington, R.M., 1980. Mortality and MORBIDITY IN BIRMINGHAM DURING the 1976 heatwave. Q. J. Med. 49 (193), 1–8.
Ellis, F.P., Nelson, F., 1978. Mortality in the elderly in a heat wave in New York City, August 1975. Environ. Res. 15 (3), 504–512.
Fouillet, A., Rey, G., Laurent, F., Pavillon, G., Bellec, S., Guihenneuc-Jouyaux, C., et al., 2006. Excess mortality related to the August 2003 heat wave in France. Int. Arch. Occup. Environ. Health 80 (1), 16–24.
Fouillet, A., Rey, G., Wagner, V., Laaidi, K., Empereur-Bissonnet, P., Le Tertre, A., et al., 2008. Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003?: a study of the 2006 heat wave. Int. J. Epidemiol. 37 (2), 309–317.
Fowler, D.R., Mitchell, C.S., Brown, A., Pollock, T., Bratka, L.A., Paulson, J., et al., 2013. Heat-related deaths after an extreme heat event—four states, 2012, and United States, 1999–2009. MMWR (Morb. Mortal. Wkly. Rep.) 62 (22), 433.
Franklin, R.C., Mason, H.M., King, J.C., Peden, A.E., Nairn, J., Miller, L., et al., 2023. Heatwaves and mortality in Queensland 2010–2019: implications for a homogenous state-wide approach. International journal of biometeorology 67 (3), 503–515.
Gao, J., Sun, Y., Liu, Q., Zhou, M., Lu, Y., Li, L., 2015. Impact of extreme high temperature on mortality and regional level definition of heat wave: a multi-city study in China. Sci. Total Environ. 505, 535–544.
Gao, J., Wood, D., Katsouyanni, K., Benmarhnia, T., Evangelopoulos, D., 2025. The synergistic and mediating effects of ozone on associations between high temperature, heatwaves and mortality in the Greater London area between 2010 and 2018. Environ. Res. 277.
Garssen, J., Harmsen, C., de Beer, J., 2005. The effect of the summer 2003 heat wave on mortality in the Netherlands. Euro Surveill. : bulletin Europeen sur les maladies transmissibles = European communicable disease bulletin. 10 (7), 165–168.
Gasparrini, A., Armstrong, B., Kenward, M.G., 2010. Distributed lag non-linear models. Stat. Med. 29 (21), 2224–2234.
Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., et al., 2015. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. The lancet 386 (9991), 369–375.
Gasparrini, A., Armstrong, B., 2011. The impact of heat waves on mortality. Epidemiology (Cambridge, Mass) 22 (1), 68–73.
Geirinhas, J.L., Trigo, R.M., Libonati, R., Castro, L.C.O., Sousa, P.M., Coelho, C.A.S., et al., 2019. Characterizing the atmospheric conditions during the 2010 heatwave in Rio de Janeiro marked by excessive mortality rates. Sci. Total Environ. 650, 796–808.
Ghumman, U., Horney, J., 2016. Characterizing the impact of extreme heat on mortality, Karachi, Pakistan, June 2015. Prehospital Disaster Med. 31 (3), 263–266.
Gordon, M., Gibbs, T., 2014. STORIES statement: publication standards for healthcare education evidence synthesis. BMC Med. 12, 1–9.
Gosling, S.N., McGregor, G.R., Páldy, A., 2007. Climate change and heat-related mortality in six cities Part 1: model construction and validation. International journal of biometeorology 51 (6), 525–540.
Graczyk, D., Pińskwar, I., Choryński, A., 2022. Heat-Related mortality in two regions of Poland: focus on urban and rural areas during the Most severe and long-lasting heatwaves. Atmosphere 13 (3).
Green, H.K., Andrews, N.J., Bickler, G., Pebody, R.G., 2012. Rapid estimation of excess mortality: nowcasting during the heatwave alert in England and Wales in June 2011. J. Epidemiol. Community 66 (10), 866–868 (1979).
Gronlund, C.J., Zanobetti, A., Schwartz, J.D., Wellenius, G.A., O'Neill, M.S., 2014. Heat, heat waves, and hospital admissions among the elderly in the United States, 1992–2006. Environ. Health Perspect. 122 (11), 1187.
Guo, Y., Gasparrini, A., Armstrong, B.G., Tawatsupa, B., Tobias, A., Lavigne, E., et al., 2017a. Heat wave and mortality: a multicountry, multicommunity Study. Environ. Health Perspect. 125 (8), 087006.
Guo, Y., Gasparrini, A., Armstrong, B.G., Tawatsupa, B., Tobias, A., Lavigne, E., et al., 2017b. Heat wave and mortality: a multicountry, multicommunity study. Environ. Health Perspect. 125 (8), 087006.
Guo, Y., Gasparrini, A., Li, S., Sera, F., Vicedo-Cabrera, A.M., de Sousa Zanotti Stagliorio Coelho, M., et al., 2018. Quantifying excess deaths related to heatwaves under climate change scenarios: a multicountry time series modelling study. PLoS Med. 15 (7), e1002629.
Hagen, M., Weihs, P., 2023. Mortality during Heatwaves and Tropical Nights in Vienna between 1998 and 2022. Atmosphere 14 (10).
Hajat, S., Kosatky, T., 2010. Heat-related mortality: a review and exploration of heterogeneity. J. Epidemiology & Community Health 64 (9), 753–760.
Hammick, M., Dornan, T., Steinert, Y., 2010. Conducting a best evidence systematic review. Part 1: from idea to data coding. BEME Guide No. 13. Med. Teach. 32 (1), 3–15.
Hanzlíková, H., Plavcová, E., Kynčl, J., Kříž, B., Kyselý, J., 2015. Contrasting patterns of hot spell effects on morbidity and mortality for cardiovascular diseases in the Czech Republic, 1994–2009. International journal of biometeorology 59 (11), 1673–1684.
Hatvani-Kovacs, G., Belusko, M., Skinner, N., Pockett, J., Boland, J., 2016. Heat stress risk and resilience in the urban environment. Sustain. Cities Soc. 26, 278–288.
Heaviside, C., Tsangari, H., Paschalidou, A., Vardoulakis, S., Kassomenos, P., Georgiou, K.E., Yamasaki, E.N., 2016b. Heat-related mortality in Cyprus for current and future climate scenarios. Sci. Total Environ. 569–570, 627–633.
Heaviside, C., Vardoulakis, S., Cai, X.-M., 2016a. Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK. Environ. Health : a global access science source 15 (Suppl. 1), 27.
Heo, S., Nori-Sarma, A., Lee, K., Benmarhnia, T., Dominici, F., Bell, M.L., 2019. The use of a quasi-experimental Study on the mortality effect of a heat wave warning System in Korea. Int. J. Environ. Res. Publ. Health 16 (12), 2245.
Hertel, S., Le Tertre, A., Jöckel, K.-H., Hoffmann, B., 2009. Quantification of the heat wave effect on cause-specific mortality in Essen, Germany. Eur. J. Epidemiol. 24 (8), 407–414.
Hess, J.J., McDowell, J.Z., Luber, G., 2011. Integrating climate change adaptation into public health practice: using adaptive management to increase adaptive capacity and build resilience. Environ. Health Perspect. 120 (2), 171.
Heudorf, U., Schade, M., 2014. Heat waves and mortality in Frankfurt am Main, Germany, 2003-2013: what effect do heat-health action plans and the heat warning system have? Zeitschrift fur Gerontologie und Geriatrie 47 (6), 475–482.
Hůnová, I., Brabec, M., Malý, M., Knobová, V., Braniš, M., 2017. Major heat waves of 2003 and 2006 and health outcomes in Prague. Air Qual. Atmos. Health 10 (2), 183–194.
Hoffmann, B., Hertel, S., Boes, T., Weiland, D., Jockel, K.-H., 2008. Increased cause-specific mortality associated with 2003 heat wave in Essen, Germany. J. Toxicol. Environ. Health, Part A 71 (11–12), 759–765.
Hondula, D.M., Balling, Jr RC., Vanos, J.K., Georgescu, M., 2015. Rising temperatures, human health, and the role of adaptation. Curr. Clim. Change Rep. 1 (3), 144–154.
Hoshiko, S., English, P., Smith, D., Trent, R., 2010. A simple method for estimating excess mortality due to heat waves, as applied to the 2006 California heat wave. Int. J. Publ. Health 55 (2), 133–137.

Hu, J., Zeng, W., Guo, Y., Meng, R., Huang, S., Zhou, C., et al., 2025. Modification and mediation effects of ozone on heatwave-mortality association: a time series study in five provinces of China. Environ. Pollut. 378, 126493 (1987).
Hutter, H.-P., Moshammer, H., Wallner, P., Leitner, B., Kundi, M., 2007. Heatwaves in Vienna: effects on mortality. Wien. Klin. Wochenschr. 119 (7–8), 223–227.
Johnson, H., Kovats, R.S., McGregor, G., Stedman, J., Gibbs, M., Walton, H., et al., 2005. The impact of the 2003 heat wave on mortality and hospital admissions in England. Health Stat. Q. (25), 6–11.
Johnson, M.G., Brown, S., Archer, P., Wendelboe, A., Magzamen, S., Bradley, K.K., 2016. Identifying heat-related deaths by using medical examiner and vital statistics data: surveillance analysis and descriptive epidemiology - oklahoma, 1990-2011. Environ. Res. 150, 30–37.
Kaiser, R., Le Tertre, A., Schwartz, J., Gotway, C.A., Daley, W.R., Rubin, C.H., 2007. The effect of the 1995 heat wave in Chicago on all-cause and cause-specific mortality. Am. J. Publ. Health 97 (Suppl. 1), S158–S162 (1971).
Kaiser, R., Rubin, C.H., Henderson, A.K., Wolfe, M.I., Kieszak, S., Parrott, C.L., Adcock, M., 2001. Heat-Related death and mental illness during the 1999 Cincinnati heat wave. Am. J. Forensic Med. Pathol 22 (3), 303–307.
Kang, C., Park, C., Lee, W., Pehlivan, N., Choi, M., Jang, J., Kim, H., 2020. Heatwave-Related mortality risk and the risk-based definition of heat wave in South Korea: a nationwide time-series Study for 2011–2017. Int. J. Environ. Res. Publ. Health 17 (16), 5720, 12.
Khatana, S.A.M., Werner, R.M., Groeneveld, P.W., 2022. Association of extreme heat with all-cause mortality in the contiguous US, 2008-2017. JAMA Netw. Open 5 (5).
Kim, D.-W., Deo, R.C., Park, S.-J., Lee, J.-S., Lee, W.-S., 2019. Weekly heat wave death prediction model using zero-inflated regression approach. Theor. Appl. Climatol. 137 (1–2), 823–838.
Kim, D.W., Deo, R.C., Chung, J.H., Lee, J.S., 2016. Projection of heat wave mortality related to climate change in Korea. Nat. Hazards 80 (1), 623–637.
Kollanus, V., Tiittanen, P., Lanki, T., 2021. Mortality risk related to heatwaves in Finland – factors affecting vulnerability. Environ. Res. 201.
Kovats, R.S., Hajat, S., 2008. Heat stress and public health: a critical review. Annu. Rev. Publ. Health 29, 41–55, 2008.
Kovats, R.S., Kristie, L.E., 2006. Heatwaves and public health in Europe. Eur. J. Publ. Health 16 (6), 592–599.
Kumar, A., Singh, D.P., 2021. Heat stroke-related deaths in India: an analysis of natural causes of deaths, associated with the regional heatwave. J. Therm. Biol. 95, 102792.
Kyselý, J., 2004. Mortality and displaced mortality during heat waves in the Czech Republic. International journal of biometeorology 49 (2), 91–97.
Kyselý, J., Kříž, B., 2008. Decreased impacts of the 2003 heat waves on mortality in the Czech Republic: an improved response? International journal of biometeorology 52 (8), 733–745.
Kyselý, J., Kim, J., 2009. Mortality during heat waves in South Korea, 1991 to 2005: how exceptional was the 1994 heat wave? Clim. Res. 38 (2), 105–116.
Le Tertre, A., Lefranc, A., Eilstein, D., Declercq, C., Medina, S., Blanchard, M., et al., 2006. Impact of the 2003 heatwave on all-cause mortality in 9 French cities. Epidemiology (Cambridge, Mass) 17 (1), 75–79.
Lee, D.-G., Kim, K.R., Kim, J., Kim, B.-J., Cho, C.-H., Sheridan, S.C., et al., 2018a. Effects of heat waves on daily excess mortality in 14 Korean cities during the past 20 years (1991-2010): an application of the spatial synoptic classification approach. International journal of biometeorology 62 (4), 575–583.
Lee, J., Min, J., Lee, W., Sun, K., Cha, W.C., Park, C., et al., 2024. Timely accessibility to healthcare resources and heatwave-related mortality in 7 major cities of South Korea: a two-stage approach with principal component analysis. Lancet Reg. Health West. Pac. 45, 101022.
Lee, W., Choi, H.M., Lee, J.Y., Kim, D.H., Honda, Y., Kim, H., 2018b. Temporal changes in mortality impacts of heat wave and cold spell in Korea and Japan. Environ. Int. 116, 136–146.
Leonardi, G.S., Hajat, S., Kovats, R.S., Smith, G.E., Cooper, D., Gerard, E., 2006. Syndromic surveillance use to detect the early effects of heat-waves: an analysis of NHS direct data in England. Sozial- Präventivmed. 51 (4), 194–201.
Levac, D., Colquhoun, H., O'brien, K.K., 2010. Scoping studies: advancing the methodology. Implement. Sci. 5, 1–9.
Li, Y., Akkus, C., Yu, X., Joyner, A., Kmet, J., Sweat, D., Jia, C., 2019. Heatwave events and mortality outcomes in Memphis, Tennessee: testing effect modification by socioeconomic status and urbanicity. Int. J. Environ. Res. Publ. Health 16 (22), 4568.
Lim, Y.-H., Lee, K.-S., Bae, H.-J., Kim, D., Yoo, H., Park, S., Hong, Y.-C., 2019. Estimation of heat-related deaths during heat wave episodes in South Korea (2006-2017). International journal of biometeorology 63 (12), 1621–1629.
Linares, C., Diaz, J., Tobías, A., Carmona, R., Mirón, I.J., 2015a. Impact of heat and cold waves on circulatory-cause and respiratory-cause mortality in Spain: 1975–2008. Stoch. Environ. Res. Risk Assess. 29 (8), 2037–2046.
Linares, C., Sánchez, R., Mirón, I.J., Díaz, J., 2015b. Has there been a decrease in mortality due to heat waves in Spain? Findings from a multicity case study. J. Integr. Environ. Sci. 12 (2), 153–163.
Lippmann, S.J., Fuhrmann, C.M., Waller, A.E., Richardson, D.B., 2013. Ambient temperature and emergency department visits for heat-related illness in North Carolina, 2007–2008. Environ. Res. 124, 35–42.
Liu, J., Kim, H., Hashizume, M., Lee, W., Honda, Y., Kim, S.E., et al., 2025. Nonlinear exposure-response associations of daytime, nighttime, and day-night compound heatwaves with mortality amid climate change. Nat. Commun. 16 (1), 635.
Lo, Y.T.E., Mitchell, D.M., Thompson, R., O'Connell, E., Gasparrini, A., 2022. Estimating heat-related mortality in near real time for national heatwave plans. Environ. Res. Lett. 17 (2).
Longden, T., 2025. Underestimating heat-related mortality—a comparison of excess mortality and death record studies for Australia. Lancet Reg. Health West. Pac. 58.
Longden, T., Quilty, S., Haywood, P., Hunter, A., Gruen, R., 2020. Heat-related mortality: an urgent need to recognise and record. Lancet Planet. Health 4 (5), e171.
López-Bueno, J.A., Díaz, J., Sánchez-Guevara, C., Sánchez-Martínez, G., Franco, M., Gullón, P., et al., 2020. The impact of heat waves on daily mortality in districts in Madrid: the effect of sociodemographic factors. Environ. Res. 190.
López-Bueno, J.A., Navas-Martín, M.A., Linares, C., Mirón, I.J., Luna, M.Y., Sánchez-Martínez, G., et al., 2021. Analysis of the impact of heat waves on daily mortality in urban and rural areas in Madrid. Environ. Res. 195.
Lv, L.-S., Yin, L., Liu, Y., Zhou, C.-L., Hu, J., An, N., et al., 2025. The effect of heatwave and cold spell on cardiovascular disease mortality in central China, 2018-2022. International journal of biometeorology 69 (3), 581–589.
Ma, W., Zeng, W., Zhou, M., Wang, L., Rutherford, S., Lin, H., et al., 2015. The short-term effect of heat waves on mortality and its modifiers in China: an analysis from 66 communities. Environ. Int. 75, 103–109.
Madrigano, J., Ito, K., Johnson, S., Kinney, P.L., Matte, T., 2015. A case-only study of vulnerability to heat wave–related mortality in New York City (2000–2011). Environ. Health Perspect. 123 (7), 672–678.
Martinez-Austria, P.F., Bandala, E.R., 2017. Temperature and heat-related mortality trends in the Sonoran and Mojave Desert region. Atmosphere 8 (3).
Mathes, R.W., Ito, K., Lane, K., Matte, T.D., 2017. Real-time surveillance of heat-related morbidity: relation to excess mortality associated with extreme heat. PLoS One 12 (9), e0184364.
Matte, T.D., Lane, K., Ito, K., 2016. Excess mortality attributable to extreme heat in New York City, 1997-2013. Health Security 14 (2), 64–70.
Matthies, F., 2008. Heat-Health Action Plans: Guidance. World Health Organization.
May, L., Chretien, J.-P., Pavlin, J.A., 2009. Beyond traditional surveillance: applying syndromic surveillance to developing settings–opportunities and challenges. BMC Public Health 9 (1), 242.
Mazdiyasni, O., AghaKouchak, A., Davis, S.J., Madadgar, S., Mehran, A., Ragno, E., et al., 2017. Increasing probability of mortality during Indian heat waves. Sci. Adv. 3 (6), e1700066.
McGregor, G., 2024a. Heatwave Responses: Early Warning Systems. Heatwaves: Causes, Consequences and Responses. Springer, pp. 549–599.
McGregor, G., 2024b. Defining heatwaves. Heatwaves: Causes, Consequences and Responses. Springer, pp. 29–79.
McGregor, G.R., Bessemoulin, P., Ebi, K.L., Menne, B., 2015. Heatwaves and Health: Guidance on warning-system Development. World Meteorological Organization Geneva, Switzerland.
Michelozzi, P., de Donato, F., Bisanti, L., Russo, A., Cadum, E., DeMaria, M., et al., 2005. The impact of the summer 2003 heat waves on mortality in four Italian cities. Euro Surveill. : bulletin Europeen sur les maladies transmissibles = European communicable disease bulletin 10 (7), 11–12.
Michelozzi, P., de' Donato, F.K., Bargagli, A.M., D'Ippoliti, D., de Sario, M., Marino, C., et al., 2010b. Surveillance of summer mortality and preparedness to reduce the health impact of heat waves in Italy. Int. J. Environ. Res. Publ. Health 7 (5), 2256–2273.
Michelozzi, P., De'Donato, F.K., Bargagli, A.M., D'Ippoliti, D., De Sario, M., Marino, C., et al., 2010a. Surveillance of summer mortality and preparedness to reduce the health impact of heat waves in Italy. Int. J. Environ. Res. Publ. Health 7 (5), 2256–2273.
Miron, I.J., Linares, C., Montero, J.C., Criado-Alvarez, J.J., Díaz, J., 2015. Changes in cause-specific mortality during heat waves in central Spain, 1975–2008. International journal of biometeorology 59 (9), 1213–1222.
Monteiro, A., Carvalho, V., Oliveira, T., Sousa, C., 2013. Excess mortality and morbidity during the July 2006 heat wave in Porto, Portugal. International journal of biometeorology 57 (1), 155–167.
Muthers, S., Laschewski, G., Matzarakis, A., 2017. The summers 2003 and 2015 in South-West Germany: heat waves and heat-related mortality in the context of climate change. Atmosphere 8 (11).
Muthers, S., Matzarakis, A., Koch, E., 2010. Summer climate and mortality in Vienna - a human-biometeorological approach of heat-related mortality during the heat waves in 2003. Wien. Klin. Wochenschr. 122 (17–18), 525–531.
Nairn, J., Fawcett, R., 2011. Defining heatwaves: heatwave defined as a heat-impact event servicing all. Europe 220, 224.
Nguyen, C.V., Nguyen, M.-H., Nguyen, T.T., 2023. The impact of cold waves and heat waves on mortality: evidence from a lower middle-income country. Health Econ. 32 (6), 1220–1243.
Nitschke, M., Tucker, G., Hansen, A., Williams, S., Zhang, Y., Bi, P., 2016. Evaluation of a heat warning system in Adelaide, South Australia, using case-series analysis. BMJ Open 6 (7), e012125.
Nitschke, M., Tucker, G.R., Bi, P., 2007. Morbidity and mortality during heatwaves in metropolitan Adelaide. Med. J. Aust. 187 (11–12), 662–665.
Nitschke, M., Tucker, G.R., Hansen, A.L., Williams, S., Zhang, Y., Bi, P., 2011. Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis. Environ. Health 10.
Niu, Y., Yang, J., Zhao, Q., Gao, Y., Xue, T., Yin, Q., et al., 2023. The main and added effects of heat on mortality in 33 Chinese cities from 2007 to 2013. Front. Environ. Sci. Eng. 17 (7).
Nori-Sarma, A., Anderson, G.B., Rajiva, A., ShahAzhar, G., Gupta, P., Pednekar, M.S., et al., 2019. The impact of heat waves on mortality in Northwest India. Environ. Res. 176, 108546.
Oray, N.C., Oray, D., Aksay, E., Atilla, R., Bayram, B., 2018. The impact of a heat wave on mortality in the emergency department. Medicine 97 (52).

Organization, W.H., 2015. Operational Framework for Building Climate Resilient Health Systems. World Health Organization.
Organization, W.H., 2021. Heat and Health in the WHO European Region: Updated Evidence for Effective Prevention: World Health Organization. Regional Office for Europe.
Orrall, A., 2025. Why capturing heat-related illness in the medical record matters more than ever. JAMA 334 (7), 557–559.
Ostro, B.D., Roth, L.A., Green, R.S., Basu, R., 2009. Estimating the mortality effect of the July 2006 California heat wave. Environ. Res. 109 (5), 614–619.
Ozturk, Y., Baltaci, H., Akkoyunlu, B.O., 2023. The impacts of heat waves on Hospital admissions and mortality in the Fethiye Province of Turkey. Port. J. Public Health 41 (2), 94–101.
Paravantis, J., Santamouris, M., Cartalis, C., Efthymiou, C., Kontoulis, N., 2017. Mortality associated with high ambient temperatures, heatwaves, and the urban heat island in Athens, Greece. Sustainability 9 (4).
Paredes-Fortuny, L., Salvador, C., Vicedo-Cabrera, A.M., Khodayar, S., 2024. Geographical patterns in mortality impacts due to heatwaves of different characteristics in Spanish cities. GeoHealth 8 (8) e2024GH001092.
Pascal, M., Laaidi, K., Ledrans, M., Baffert, E., Caserio-Schönemann, C., Le Tertre, A., et al., 2006. France's heat health watch warning system. International journal of biometeorology 50 (3), 144–153.
Perkins, S.E., Alexander, L.V., 2013. On the measurement of heat waves. J. Clim. 26 (13), 4500–4517.
Perkins-Kirkpatrick, S.E., Selvey, L., Aglas-Leitner, P., Lansbury, N., Hundessa, S., Stone, D., et al., 2025. Attributing heatwave-related mortality to climate change: a case study of the 2009 Victorian heatwave in Australia. Environmental Research-Climate 4 (1).
Peters, M.D., Godfrey, C., McInerney, P., Khalil, H., Larsen, P., Marnie, C., et al., 2022. Best practice guidance and reporting items for the development of scoping review protocols. JBI Evid. Synth. 20 (4), 953–968.
Peters, M.D., Godfrey, C.M., McInerney, P., Soares, C.B., Khalil, H., Parker, D., 2015. The Joanna Briggs Institute Reviewers' Manual 2015: Methodology for JBI Scoping Reviews.
Peters, M.D., Marnie, C., Tricco, A.C., Pollock, D., Munn, Z., Alexander, L., et al., 2020. Updated methodological guidance for the conduct of scoping reviews. JBI Evid. Synth. 18 (10), 2119–2126.
Pham, T., Young, C., Woodford, N., Ranson, D., Young, C.M.F., Ibrahim, J.E., 2019. Difference in the characteristics of mortality reports during a heatwave period: retrospective analysis comparing deaths during a heatwave in January 2014 with the same period a year earlier. BMJ Open 9 (5), e026118.
Pyrgou, A., Santamouris, M., 2018. Increasing probability of heat-related mortality in a mediterranean city due to urban warming. Int. J. Environ. Res. Publ. Health 15 (8).
Reesman, C., 2022. Changes in Heat Metrics Following a Major Hurricane and Implications on Heat Stress. Louisiana State University and Agricultural & Mechanical College.
Revich, B., Shaposhnikov, D., 2008. Excess mortality during heat waves and cold spells in Moscow, Russia. Occup. Environ. Med. 65 (10), 691–696.
Rey, G., Fouillet, A., Jougla, E., Hémon, D., 2008. Heat exposure and socio-economic vulnerability as synergistic factors in heat-wave-related mortality. Am. J. Epidemiol. 167 (11), S102–S.
Rey, G., Jougla, E., Fouillet, A., Pavillon, G., Bessemoulin, P., Frayssinet, P., et al., 2007. The impact of major heat waves on all-cause and cause-specific mortality in France from 1971 to 2003. Int. Arch. Occup. Environ. Health 80 (7), 615–626.
Rezaee, R., Fathi, S., Maleki, A., Aboubakri, O., Li, G., Safari, M., et al., 2023. Summer heat waves and their mortality risk over a 14-year period in a western region of Iran. International journal of biometeorology 67 (12), 2081–2091.
Robine, J.-M., Cheung, S.L.K., Le Roy, S., Van Oyen, H., Griffiths, C., Michel, J.-P., Herrmann, F.R., 2008. Death toll exceeded 70,000 in Europe during the summer of 2003. C. R. Biol. 331 (2), 171–178.
Rooney, C., McMichael, A.J., Kovats, R.S., Coleman, M.P., 1998. Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. J. Epidemiol. Community 52 (8), 482–486 (1979).
Royé, D., Codesido, R., Tobías, A., Taracido, M., 2020. Heat wave intensity and daily mortality in four of the largest cities of Spain. Environ. Res. 182, 109027.
Ruiz-Páez, R., Díaz, J., López-Bueno, J.A., Navas, M.A., Mirón, I.J., Martínez, G.S., et al., 2023. Does the meteorological origin of heat waves influence their impact on health? A 6-year morbidity and mortality study in Madrid (Spain). Sci. Total Environ. 855.
Saleem, S.G., Ansari, T., Ali, A.S., Fatima, S., Rizvi, M.H., Samad, M.A., 2017. Risk factors for heat related deaths during the June 2015 heat wave in Karachi, Pakistan. J. Ayub Med. Coll. Abbottabad : JAMC (J. Assoc. Med. Can.) 29 (2), 320–324.
Schaffer, A., Muscatello, D., Broome, R., Corbett, S., Smith, W., 2012. Emergency department visits, ambulance calls, and mortality associated with an exceptional heat wave in Sydney, Australia, 2011: a time-series analysis. Environ. Health 11 (1), 3.
Schifano, P., Cappai, G., De Sario, M., Michelozzi, P., Marino, C., Bargagli, A.M., Perucci, C.A., 2009. Susceptibility to heat wave-related mortality: a follow-up study of a cohort of elderly in Rome. Environ. Health 8.
Semenza, J.C., Menne, B., 2009. Climate change and infectious diseases in Europe. Lancet Infect. Dis. 9 (6), 365–375.
Seposo, X.T., Dang, T.N., Honda, Y., 2017. Exploring the effects of high temperature on mortality in four cities in the Philippines using various heat wave definitions in different mortality subgroups. Glob. Health Action 10 (1), 1368969.
Shartova, N., Shaposhnikov, D., Konstantinov, P., Revich, B., 2018. Sardiovascular mortality during heat waves in temperate climate: an association with bioclimatic indices. Int. J. Environ. Health Res. 28 (5), 522–534.
Sheridan, S., Kalkstein, L., Kalkstein, A., Greene, S., 2011. Heat-related mortality and heat watch-warning systems in the United States: recent developments. Epidemiology 22 (1), S13.
Sheridan, S.C., Lin, S., 2014. Assessing variability in the impacts of heat on health outcomes in New York City over time, season, and heat-wave duration. EcoHealth 11 (4), 512–525.
Silveira, I.H., Cortes, T.R., Bell, M.L., Junger, W.L., 2023a. Effects of heat waves on cardiovascular and respiratory mortality in Rio de Janeiro, Brazil. PLoS One 18 (3), e0283899.
Silveira, I.H., Hartwig, S.V., Moura, M.N., Cortes, T.R., Junger, W.L., Cirino, G., et al., 2023b. Heat waves and mortality in the Brazilian Amazon: effect modification by heat wave characteristics, population subgroup, and cause of death. Int. J. Hyg Environ. Health 248, 114109.
Singh, N., Mhawish, A., Ghosh, S., Banerjee, T., Mall, R.K., 2019. Attributing mortality from temperature extremes: a time series analysis in Varanasi, India. Sci. Total Environ. 665, 453–464.
Son, J.-Y., Gouveia, N., Bravo, M.A., de Freitas, C.U., Bell, M.L., 2016. The impact of temperature on mortality in a subtropical city: effects of cold, heat, and heat waves in Sao Paulo, Brazil. International journal of biometeorology 60 (1), 113–121.
Son, J.-Y., Lee, J.-T., Anderson, G.B., Bell, M.L., 2012. The impact of heat waves on mortality in seven major cities in Korea. Environ. Health Perspect. 120 (4), 566–571.
Son, J.Y., Bell, M.L., Lee, J.T., 2014. The impact of heat, cold, and heat waves on hospital admissions in eight cities in Korea. International journal of biometeorology 58 (9), 1893–1903.
Song, J., Lu, Y., Fischer, T., Hu, K., 2024. Effects of the urban landscape on heatwave-mortality associations in Hong Kong: comparison of different heatwave definitions. Front. Environ. Sci. Eng. 18 (1).
Stanojević, G., Stojilković, J., Spalević, A., Kokotović, V., 2014. The impact of heat waves on daily mortality in Belgrade (Serbia) during summer. Environ. Hazards 13 (4), 329–342.
Steadman, R.G., 1979. The assessment of sultriness. Part I: a temperature-humidity index based on human physiology and clothing science. J. Appl. Meteorol. Climatol. 18 (7), 861–873.
Steul, K., Schade, M., Heudorf, U., 2018. Mortality during heatwaves 2003–2015 in Frankfurt-Main – the 2003 heatwave and its implications. Int. J. Hyg Environ. Health 221 (1), 81–86.
Åström, D.O., Bertil, F., Joacim, R., 2011. Heat wave impact on morbidity and mortality in the elderly population: a review of recent studies. Maturitas 69 (2), 99–105.
Sun, X., Sun, Q., Zhou, X., Li, X., Yang, M., Yu, A., Geng, F., 2014. Heat wave impact on mortality in Pudong New Area, China in 2013. Sci. Total Environ. 493, 789–794.
Sun, Z., Chen, C., Yan, M., Shi, W., Wang, J., Ban, J., et al., 2021. Heat wave characteristics, mortality and effect modification by temperature zones: a time-series study in 130 counties of China. Int. J. Epidemiol. 49 (6), 1813–1822.
Tan, J., Zheng, Y., Song, G., Kalkstein, L.S., Kalkstein, A.J., Tang, X., 2007. Heat wave impacts on mortality in Shanghai, 1998 and 2003. International journal of biometeorology 51 (3), 193–200.
Tao, J., Yu, H., Hu, J., Wang, X., Cai, R., Jin, S., et al., 2025. Temporal variation in the association between heatwave and mortality from mental disorders: population-based evidence from a megacity of China. Journal of global health 15, 04231.
Thompson, R., Kovats, S., Hajat, S., Macintyre, H., O'Connell, E., 2024a. Identification of individual-level clinical factors associated with increased risk of death during heatwaves: a time-stratified case-crossover study using national primary care records in England. BMJ Public Health 2 (1).
Thompson, R., Kovats, S., Hajat, S., Macintyre, H., O'Connell, E., 2024b. Identification of individual-level clinical factors associated with increased risk of death during heatwaves: a time-stratified case-crossover study using national primary care records in England. BMJ public health 2 (1), e000927.
Thompson, R., Landeg, O., Kar-Purkayastha, I., Hajat, S., Kovats, S., O'Connell, E., 2022. Heatwave Mortality in Summer 2020 in England: an Observational Study. Int. J. Environ. Res. Publ. Health 19 (10).
Tian, Z.X., Li, S.S., Zhang, J.L., Guo, Y.M., 2013. The characteristic of heat wave effects on coronary heart disease mortality in Beijing, China: a time series Study. PLoS One 8 (9).
Tong, S., Ren, C., Becker, N., 2010. Excess deaths during the 2004 heatwave in Brisbane, Australia. International journal of biometeorology 54 (4), 393–400.
Tong, S., Wang, X.Y., Guo, Y., 2012. Assessing the short-term effects of heatwaves on mortality and morbidity in Brisbane, Australia: comparison of case-crossover and time series analyses. PLoS One 7 (5), e37500.
Tong, S., Wang, X.Y., Yu, W., Chen, D., Wang, X., 2014. The impact of heatwaves on mortality in Australia: a multicity study. BMJ Open 4 (2), e003579.
Tricco, A.C., Lillie, E., Zarin, W., O'Brien, K.K., Colquhoun, H., Levac, D., et al., 2018. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann. Intern. Med. 169 (7), 467–473.
Trigo, R.M., Ramos, A.M., Nogueira, P.J., Santos, F.D., Garcia-Herrera, R., Gouveia, C., Santo, F.E., 2009. Evaluating the impact of extreme temperature based indices in the 2003 heatwave excessive mortality in Portugal. Environ. Sci. Pol. 12 (7), 844–854.
Urban, A., Hanzlíková, H., Kyselý, J., Plavcová, E., 2017. Impacts of the 2015 heat waves on mortality in the Czech Republic-a comparison with previous heat waves. Int. J. Environ. Res. Publ. Health 14 (12).
Urban, A., Hondula, D.M., Hanzlíková, H., Kyselý, J., 2019. The predictability of heat-related mortality in Prague, Czech Republic, during summer 2015—a comparison of selected thermal indices. International journal of biometeorology 63 (4), 535–548.
Vandentorren, S., Bretin, P., Zeghnoun, A., Mandereau-Bruno, L., Croisier, A., Cochet, C., et al., 2006. August 2003 heat wave in France: risk factors for death of elderly people living at home. Eur. J. Publ. Health 16 (6), 583–591.

Vautard, R., Van Aalst, M., Boucher, O., Drouin, A., Haustein, K., Kreienkamp, F., et al., 2020. Human contribution to the record-breaking June and July 2019 heatwaves in Western Europe. Environ. Res. Lett. 15 (9).
Vicedo-Cabrera, A.M., Scovronick, N., Sera, F., Royé, D., Schneider, R., Tobias, A., et al., 2021. The burden of heat-related mortality attributable to recent human-induced climate change. Nat. Clim. Change 11 (6), 492–500.
Vyberci, D., Svec, M., Fasko, P., Savinová, H., Trizna, M., Micietová, E., 2015. The effects of the 1996-2012 summer heat events on human mortality in Slovakia. Morav. Geogr. Rep. 23 (3), 58–70.
Wang, L., 2023. Mediating effect of heat waves between ecosystem services and heat-related mortality of characteristic populations: evidence from Jiangsu Province, China. Int. J. Environ. Res. Publ. Health 20 (3).
Wang, X.Y., Barnett, A.G., Yu, W., FitzGerald, G., Tippett, V., Aitken, P., et al., 2012. The impact of heatwaves on mortality and emergency hospital admissions from non-external causes in Brisbane, Australia. Occup. Environ. Med. 69 (3), 163–169.
Wang, Y., Nordio, F., Nairn, J., Zanobetti, A., Schwartz, J.D., 2018. Accounting for adaptation and intensity in projecting heat wave-related mortality. Environ. Res. 161, 464–471.
Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Beagley, J., Belesova, K., et al., 2021. The 2020 report of the Lancet Countdown on health and climate change: responding to converging crises. The lancet 397 (10269), 129–170.
Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Boykoff, M., et al., 2019. The 2019 report of the Lancet Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. Lancet 394 (10211), 1836–1878.
Weisskopf, M.G., Anderson, H.A., Foldy, S., Hanrahan, L.P., 2002. Heat wave mobidity and mortality, Milwaukee, Wis, 1999 vs 1995: an improved response? Am. J. Publ. Health 92 (5), 830 (1971).
Who, W., 2015. Heatwaves and health: guidance on warning-system development. World Meteorological Organization and World Health Organization. https://wwwwhoint/globalchange/publications/heatwaves-health-guidance/en. (Accessed 5 December 2016).
Williams, S., Nitschke, M., Weinstein, P., Pisaniello, D.L., Parton, K.A., Bi, P., 2012. The impact of summer temperatures and heatwaves on mortality and morbidity in Perth, Australia 1994-2008. Environ. Int. 40 (1), 33–38.
Williams, S., Venugopal, K., Nitschke, M., Nairn, J., Fawcett, R., Beattie, C., et al., 2018a. Regional morbidity and mortality during heatwaves in South Australia. International journal of biometeorology 62, 1911–1926.
Williams, S., Venugopal, K., Nitschke, M., Nairn, J., Fawcett, R., Beattie, C., et al., 2018b. Regional morbidity and mortality during heatwaves in South Australia. International journal of biometeorology 62 (10), 1911–1926.
Xi, D., Liu, L., Zhang, M., Huang, C., Burkart, K.G., Ebi, K., et al., 2024. Risk factors associated with heatwave mortality in Chinese adults over 65 years. Nat. Med. 30 (5), 1489–1498.
Xie, G., Guo, Y., Tong, S., Ma, L., 2014. Calculate excess mortality during heatwaves using Hilbert-Huang transform algorithm. BMC Med. Res. Methodol. 14, 35.
Xu, R.J., Sun, H., Zhong, Z.H., Zheng, Y., Liu, T.T., Li, Y.X., et al., 2023. Ozone, heat wave, and cardiovascular disease mortality: a population-based case-crossover Study. Environ. Sci. Technol. 58 (1), 171–181.
Xu, Y., Dadvand, P., Barrera-Gomez, J., Sartini, C., Mari-Dell'Olmo, M., Borrell, C., et al., 2013. Differences on the effect of heat waves on mortality by sociodemographic and urban landscape characteristics. J. Epidemiol. Community 67 (6), 519–525.
Xu, Z., FitzGerald, G., Guo, Y., Jalaludin, B., Tong, S., 2016. Impact of heatwave on mortality under different heatwave definitions: a systematic review and meta-analysis. Environ. Int. 89, 193–203.
Xu, Z., Tong, S., 2017. Decompose the association between heatwave and mortality: which type of heatwave is more detrimental? Environ. Res. 156, 770–774.
Xu, H., Zhang, G., 2022. Comparison of relative and absolute heatwaves in eastern China: observations, simulations and future projections. Atmosphere 13 (5), 649.
Yan, M., Xie, Y., Zhu, H., Ban, J., Gong, J., Li, T., 2022. The exceptional heatwaves of 2017 and all-cause mortality: an assessment of nationwide health and economic impacts in China. Sci. Total Environ. 812.
Yan, M., Xie, Y., Zhu, H., Ban, J., Gong, J., Li, T., 2023. Cardiovascular mortality risks during the 2017 exceptional heatwaves in China. Environ. Int. 172.
Yang, J., Liu, H.Z., Ou, C.Q., Lin, G.Z., Ding, Y., Zhou, Q., et al., 2013. Impact of heat wave in 2005 on mortality in Guangzhou, China. Biomed. Environ. Sci. 26 (8), 647–654.
Yang, J., Yin, P., Sun, J., Wang, B., Zhou, M., Li, M., et al., 2019. Heatwave and mortality in 31 major Chinese cities: definition, vulnerability and implications. Sci. Total Environ. 649, 695–702.
Yin, Q., Wang, J., 2017. The association between consecutive days' heat wave and cardiovascular disease mortality in Beijing, China. BMC Public Health 17 (1), 223–229.
Yu, K., Jiang, S., Shi, S., Meng, X., Chen, R., Kan, H., et al., 2025a. Association of non-optimum temperature, heatwaves and cold spells with chronic obstructive pulmonary disease mortality: a nationwide time-stratified case-crossover study. EES (Ecotoxicol. Environ. Saf.) 302.
Yu, X., Liu, J., Yin, P., Gao, Y., He, C., Kan, H., et al., 2025b. Nonlinear relation between cardiac mortality and excess temperature in heatwaves: exposure response in 2.39 million patients. J. Am. Coll. Cardiol.
Zaninović, K., Matzarakis, A., 2014. Impact of heat waves on mortality in Croatia. International journal of biometeorology 58 (6), 1135–1145.
Zeng, W., Lao, X., Rutherford, S., Xu, Y., Xu, X., Lin, H., et al., 2014. The effect of heat waves on mortality and effect modifiers in four communities of Guangdong Province, China. Sci. Total Environ. 482–483 (1), 214–221.
Zhang, H., Liu, L., Zeng, Y., Liu, M., Bi, J., Ji, J.S., 2021. Effect of heatwaves and greenness on mortality among Chinese older adults. Environ. Pollut. 290.
Zhang, J., Liu, S., Han, J., Zhou, L., Liu, Y., Yang, L., et al., 2016. Impact of heat waves on nonaccidental deaths in Jinan, China, and associated risk factors. International journal of biometeorology 60 (9), 1367–1375.
Zhang, K., Chen, T.-H., Begley, C.E., 2015a. Impact of the 2011 heat wave on mortality and emergency department visits in Houston, Texas. Environ. Health : a global access science source 14, 11.
Zhang, K., Chen, T.H., Begley, C.E., 2015b. Impact of the 2011 heat wave on mortality and emergency department visits in Houston, Texas -No section. Environ. Health: A Global Access Science Source 14 (1).
Zhang, L., Zhang, Z., Ye, T., Zhou, M., Wang, C., Yin, P., Hou, B., 2018. Mortality effects of heat waves vary by age and area: a multi-area study in China. Environ. Health: A Global Access Science Source 17 (1).
Zhang, Y., Nitschke, M., Krackowizer, A., Dear, K., Pisaniello, D., Weinstein, P., et al., 2017. Risk factors for deaths during the 2009 heat wave in Adelaide, Australia: a matched case-control study. International journal of biometeorology 61 (1), 35–47.
Zhao, Q., Li, S., Ye, T., Wu, Y., Gasparrini, A., Tong, S., et al., 2024. Global, regional, and national burden of heatwave-related mortality from 1990 to 2019: a three-stage modelling study. PLoS Med. 21 (5), e1004364.
Zou, Z., Xu, R., Lv, Z., Zhang, Z., Liu, N., Fang, D., et al., 2025. Heat wave, fine particulate matter, and cardiovascular disease mortality: a time-stratified case-crossover study in Shenzhen, China. EES (Ecotoxicol. Environ. Saf.) 292.