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Review article

Climate Change–Related extreme events and inequities in health outcomes: An umbrella review

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ABSTRACT

This umbrella review synthesises evidence on the unequal health impacts of climate change–related extreme events using an explicit equity-oriented framework. Following PRISMA guidelines, 28 systematic reviews were identified that assessed the health effects of high temperatures, wildfires, floods, droughts, and mixed extreme weather events. Eligibility required reviews to report effect estimates stratified by at least one PROGRESS-Plus dimension, including place of residence, race/ethnicity, occupation, gender, age, religion, education, socio-economic position, social capital, or pre-existing health conditions. Across climate hazards and health outcomes, consistent evidence of differential impacts across PROGRESS-Plus factors was observed. Age and gender were the most frequently examined modifiers, while socio-economic disadvantage, ethnicity, rural residence, and chronic conditions further intensified vulnerability. PROGRESS-Plus not only highlighted vulnerable groups but also provides a framework for guiding policy and intervention design, ensuring that climate-health strategies are equity-sensitive, context-specific, and aimed at addressing structural drivers of disparities rather than only stratifying outcomes.

1. Introduction

Climate change represents a global threat to human health, but its effects are not experienced equally among populations. Extreme events related to climate change affect human health through various direct pathways, including extreme heat events and seasonal rainfall (World Health Organization, 2020, 2024; Bell et al., 2018). Indirectly, climate change can threaten food security, exacerbate malnutrition, and increase mental health challenges, particularly following disasters (World Health Organization, 2018, 2020; Kushal et al., 2023). In recent years, the effects of climate change on human health have sparked discussion in society as well as in the institutional and academic contexts. Working Group II, Intergovernmental Panel on Climate Change (IPCC), in the Sixth Assessment Report (AR6), pointed out serious health and human well-being risks of climate change: according to the report (Cissé et al., 2022), climate-related diseases and overall well-being are increasingly at risk, together with a rise in mental health diseases, premature deaths, and malnutrition.

Globally and within societies, risks of exposure and vulnerability to the adverse health effects of climate change are unequally distributed, with the most at-risk groups being those who are systematically disadvantaged in relation to health and social determinants (Ebi and Hess, 2020), which makes climate change and associated policies an ethical issue (Boeckmann and Zeeb, 2016). Climate change is understood as a "threat multiplier" that can intensify existing health inequities and create conditions for new ones to emerge (Commission De Consolidation De La Paix, 2024). The adverse health impacts of climate change disproportionately affect populations that are socially and structurally disadvantaged, including children, older adults, pregnant individuals, people with pre-existing health conditions, isolated populations, and ethnic minorities (Campbell-Lendrum et al., 2007). In the context of efforts to understand how extreme events related to climate change

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amplifies existing health inequities, an increasing number of studies emphasise three primary mechanisms: differential exposure, differential sensitivity, and differential adaptive capacity, by which structural disadvantage shapes vulnerability (Ebi and Hess, 2020; Cardona et al., 2012; Weis et al., 2016; World Health Organization, 2023). Differential exposure refers to the unequal likelihood of being physically exposed to climate hazards. For instance, men are often overrepresented in outdoor occupations such as construction, agriculture, and transport, which places them at increased risk of heat-related illnesses and dehydration during heatwaves (Fatima et al., 2021; Tord et al., 2019). Similarly, people living in low socio-economic contexts are more likely to live in poorly insulated housing or densely built urban areas with limited green spaces and higher urban heat island effects (Rao et al., 2025; Harlan et al., 2013). Differential sensitivity captures how the level and severity of impacts are modulated by pre-existing health conditions or physiological susceptibilities when exposure occurs, many of which are themselves shaped by broader social and structural determinants. Increased sensitivity is observed among older adults, children, and people living with chronic diseases, such as cardiovascular, respiratory, or metabolic conditions (Kazi et al., 2024; Syed and Basu, 2025). For example, people with asthma, COPD, or cardiovascular conditions experience exacerbation of symptoms in response to wildfire smoke events, while all such conditions are more prevalent in the most socially deprived or minority communities (Gao et al., 2019; Kondo et al., 2019). Differential adaptive capacity exhibits differences in their abilities to prepare for, cope with, and recover from climate-related hazards. Populations with higher income, education, and social capital generally have better access to adaptation resources, such as air conditioning, reliable transport, healthcare, and social support networks, whereas people living in lower income or socially isolated settings face significant barriers to accessing them (Varshney et al., 2023; Adger et al., 2014). Migrants and ethnic minorities also suffer from language and trust barriers that limit their access to early warning systems or emergency assistance (Yari et al., 2020).

Therefore, these mechanisms underscore the importance of incorporating equity considerations into research and policy to understand and transform the structural drivers of risk and to develop adaptation plans and interventions that reduce already existing health inequities. Although numerous umbrella reviews have examined the health impacts of extreme climate events, most have focused on overall effects (Rojas-Rueda et al., 2021; Lo et al., 2024; Bahrami et al., 2026), with limited attention to how these impacts differ across population subgroups defined by characteristics such as gender, ethnicity, place of residence, or other indicators of socio-economic position (SEP). Moreover, several umbrella reviews have provided summaries of evidence restricted to a single extreme event (e.g., heatwaves or wildfires) or focused exclusively on a specific health outcome (Zhu et al., 2025; Basilio et al., 2022). Therefore, this umbrella review aims to summarise the results of systematic reviews (SRs) and meta-analyses available in the literature that assessed the effect of heat (high ambient temperature/heatwaves), wildfires, floods, drought, and mixed extreme weather events (including heatwaves/high ambient temperatures, wildfires, floods, drought, air pollution and hurricanes) on inequities in health outcomes across a broad range of socio-demographic dimensions. Specifically, this review aims to.

1) identify the existing evidence on how key socio-economic and socio-demographic dimensions (place of residence, race/ethnicity/culture/language, occupation, gender, religion, education, SEP, social capital, pre-existing chronic condition, age) influence or modify the effects of extreme weather events on health outcomes;
2) assess the current state of the art, including the availability and quality of evidence;
3) identify which socio-economic and socio-demographic factors are most frequently examined and how they are addressed within existing systematic reviews.

2. Materials and methods

2.1. Design and registration

This umbrella review was conducted by collecting and assessing SRs and meta-analyses that focus on the association between extreme events due to climate change and inequities in health outcomes. It was carried out in accordance with the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The PRISMA 2020 Checklist is provided in Supplementary Table S1. The study protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration number: CRD42024590467). No deviations from the registered protocol were identified in this review.

2.2. Search strategy

A systematic search was conducted in MEDLINE (via OVID), Embase, and Web of Science from database inception up to September, 19, 2025, to identify SRs and meta-analyses, using a combination of terms related to extreme events (heatwaves/high ambient temperatures, wildfires, floods, drought, and mixed extreme weather events) and terms related to equity, inequities and socio-demographic dimensions. Extreme weather events due to climate change were defined in accordance with the classification of the Intergovernmental Panel on Climate Change (IPCC), which defines extreme weather events as the occurrence of a value of a weather variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable (Dokken). In this review, the selection of extreme weather events was based on both scientific relevance and contextual applicability to high-income countries (HIC) settings. Climate-related extreme events that are well-documented in scientific literature and are expected to occur in HICs, based on evidence from authoritative sources, were selected.

To ensure a comprehensive inclusion of equity-related factors, the PROGRESS-Plus framework was applied to the search strategy. This tool, proposed by The Campbell and Cochrane Equity Methods Group, identifies place of residence, race/ethnicity/culture/language, occupation, gender, religion, education, SEP, social capital, and other characteristics ('Plus', such as pre-existing chronic condition and age) as dimensions where health inequities may exist (O'Neill et al., 2014). No restrictions were applied to the search regarding publication date or language. Detailed information on the complete search strategy for each database is provided in the Supplementary Material (Supplementary Table S2, Table S3, Table S4).

2.3. Eligibility criteria and selection of studies

SRs of quantitative or narrative original research, with or without meta-analyses, evaluating the effect of exposures of interest on health outcomes across one or more factors defined by PROGRESS-Plus were included. Population-level studies were included if effect estimates were stratified by any of the following socio-demographic dimensions: place of residence, race/ethnicity/culture/language, occupation, gender, age, religion, education, SEP, social capital/deprivation, and pre-existing chronic conditions. Studies focusing on a particular socio-demographic vulnerable group (e.g., children) were also included when effect estimates were provided for a comparison group (e.g., another age group), or when comparisons were made within the same group based on one of the equity factors mentioned above (e.g., differences in health outcomes between males and females within the population of children). If multiple SRs on the same PROGRESS-Plus factor-exposure-health outcome combination were identified, the most recent and/or the one with the lowest risk of bias according to AMSTAR-2 (A MeaSurement Tool to Assess systematic Reviews) (Shea et al., 2017) evaluation and/or the one including the largest number of studies (taking into account study overlap across SRs) was selected to prevent the overlap of primary

studies. More than one review for the same PROGRESS-Plus factor--exposure-health outcome combination was considered only if no study overlap existed. SRs in which the reported results were based on a single primary study for the PROGRESS-Plus factor-exposure-health outcome combinations of interest, were excluded. Only SRs with at least 60% of included primary studies conducted in high-income countries (HIC), as classified by the World Bank group (World Bank), were considered. Titles and abstracts of all retrieved articles were screened by two independent authors (BS and CD). Any disagreements were resolved by discussion with a third researcher (FR).

Potentially relevant articles were retrieved in full-text and screened by two authors (BS and CD), with any discrepancies resolved through discussion and the involvement of a third author (FR). Reference management, duplicate elimination, and item selection were conducted using Rayyan software (Version 3.0).

2.4. Data extraction and synthesis

Data extraction was independently performed by two investigators (BS and CD), and discrepancies were resolved through consensus. From each study, the authors, year of publication, geographical area, population under investigation, type of exposure, health outcome considered, type of results, PROGRESS-Plus factors assessed in the review, measure of association, and quantitative results (for metanalytic synthesis) were extracted. In this umbrella review, gender is conceptualized as an axis of inequity. In the presentation of results, no distinction was made between sex and gender, as the included studies did not explicitly differentiate between the two concepts, and such a distinction could not be clearly determined. Therefore, in line with the purpose of this review, the term gender was used throughout the analysis.

Health outcomes were grouped into 10 major categories based on clinical and epidemiological characteristics: heat/climate-related outcomes; including dehydration and heat-related illnesses (excessive sweating, headaches, dizziness, muscle and stomach cramps, and skin rashes), cardiovascular outcomes, respiratory outcomes, perinatal disorders, occupational diseases related to climate conditions, mental health outcomes, health service responses, hospitalisations, general mortality, and kidney diseases. The selection of the health outcome categories was guided by the existing literature on the health impacts of extreme weather events. Specifically, the focus was on outcome categories that are most consistently reported and supported by robust evidence in previous reviews. This approach was informed by recent syntheses of the literature (Chu et al., 2025) and reflects the outcome categories most commonly associated with the extreme weather events included in this review. Given the expected high level of heterogeneity across studies in terms of exposure, PROGRESS-Plus factor and health outcome measures, a quantitative synthesis (meta-analysis) was planned only if sufficient homogeneity was observed. In the absence of this condition, the results were synthesised narratively. Accordingly, due to the substantial heterogeneity identified in the results, findings were ultimately summarised using a narrative synthesis approach.

2.5. Risk of bias assessment

Two researchers (BS and CD) conducted risk of bias assessment of the included SRs and meta-analysis using a version of the AMSTAR-2 tool adapted to the research question (Shea et al., 2017).

The AMSTAR-2 tool organizes 16 items into domains covering reporting, study design, risk of bias, meta-analysis, and conflicts of interest of SRs that include randomised or non-randomised studies of healthcare interventions. Seven items are considered critical in the evaluation of systematic reviews: protocol registration (Item 2), literature search (Item 4), study exclusion justification (Item 7), risk of bias assessment (Item 9), meta-analysis methods (Item 11), interpretation of results (Item 13), and publication bias (Item 15). Since to the context of the review is in environmental health, specific domains (study protocol registration - item 2 and justification of study design in inclusion criteria - item 3) were considered a priori not applicable to reflect formal standardized procedures are not in the current practice of systematic reviews in the field (Forastiere et al., 2024; Murtas et al., 2025).

2.6. Assessing equity focus

To systematically assess how equity was addressed in the included reviews, each study was classified as either fully or partially considering equity by two independent authors (BS and CD) based on the following requirements:

A study is classified as fully addressing equity if it meets both of the following criteria.

- Number of PROGRESS-Plus factors: the study considers at least one PROGRESS-Plus factor beyond gender and age (e.g. place of residence, race/ethnicity/culture/language, occupation, religion, education, SEP, pre-existing chronic conditions, and social capital/deprivation).
- Depth of analysis: the study does not merely stratify numerical results but explicitly discusses health inequities in at least one of the following ways in the Results, Discussion, or Conclusion sections: discussion of structural determinants explaining observed differences between social groups (e.g., working conditions, housing policies, access to healthcare); explicit reference to equity implications and the impact on socially vulnerable groups; policy recommendations or mitigation strategies to address the observed inequities.

A study is classified as partially addressing equity if it meets one or more of the following conditions.

- It considers only demographic factors (age and/or gender).
- It reports only numerical results stratified by population groups.
- The Results, Discussion, or Conclusions sections do not explore the causes and implications of inequities nor propose strategies to address them.

3. Results

3.1. Results of the search

A PRISMA flow diagram illustrating the search process and study selection is shown in Fig. 1. A total of 11,721 papers were identified through the database searches described below. Subsequently, 3269 duplicates (i.e., papers identified by more than one database) were excluded. Papers not meeting the inclusion criteria were eliminated by first screening titles and abstracts (8383 papers excluded) and then reviewing the full texts (41 papers excluded). The primary reasons for exclusion after full-text review were (1) overlap of primary studies (n = 10) and (2) less than 60% of included studies conducted in HIC (n = 8). Supplementary Table S5 presents more details on the excluded studies. At the end of the selection process, 28 studies were included in this umbrella review.

3.2. Characteristics of included studies

The studies included in the umbrella review consisted of 11 meta-analyses and 17 SRs. Regarding exposure, 18 articles focused on extreme heat/heatwaves, four articles focused on wildfires, four articles focused on mixed extreme weather events, one article focused on floods, and one article focused on wildfires and drought (Supplementary Material, Table S6). Concerning the health outcomes investigated, the included studies considered different parameters, including heat/climate-related outcomes (n = 6) (Berumen-Flucker et al., 2022; Binazzi et al., 2019; Faurie et al., 2022; Liu et al., 2023; Meadows et al., 2024; Son et al., 2019), mental health outcomes (n = 5) (Varshney et al.,

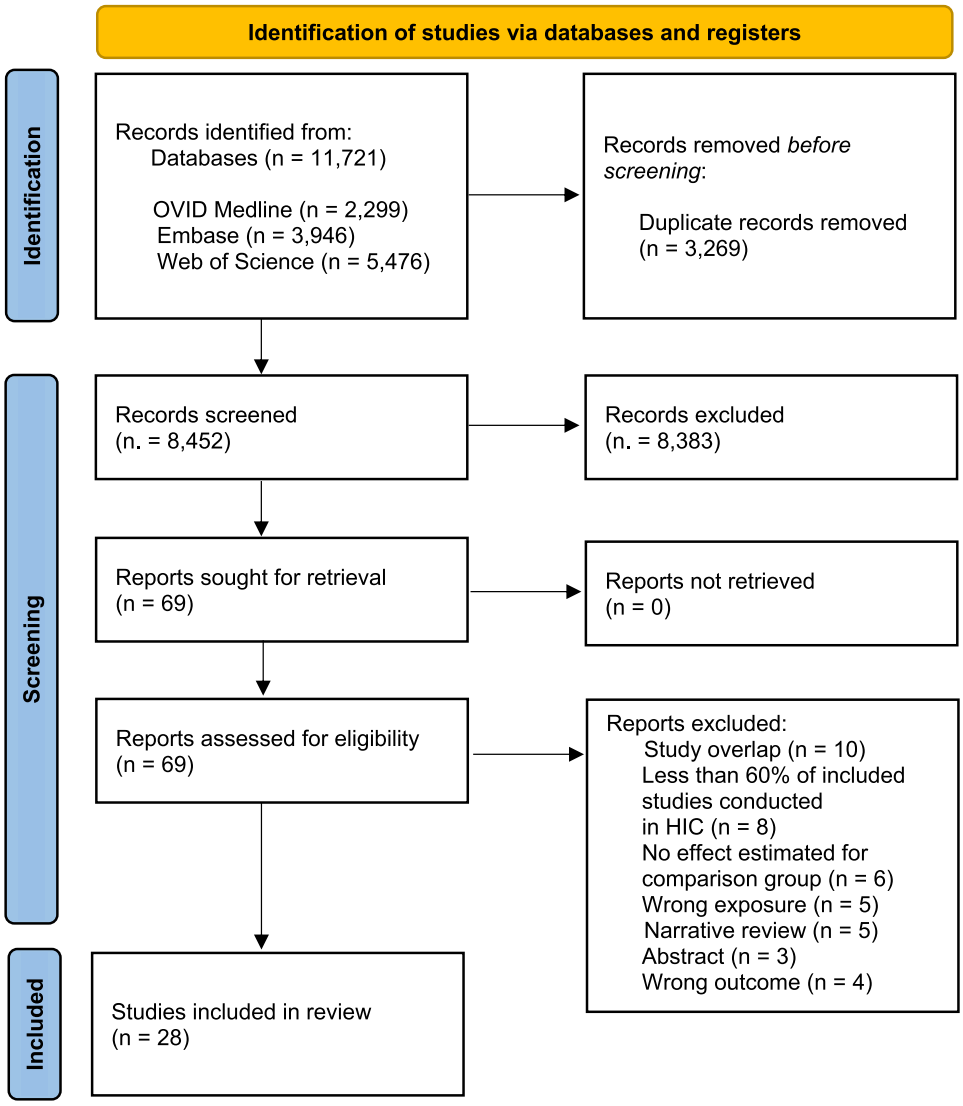


Fig. 1. PRISMA flow diagram representing the entire selection process.

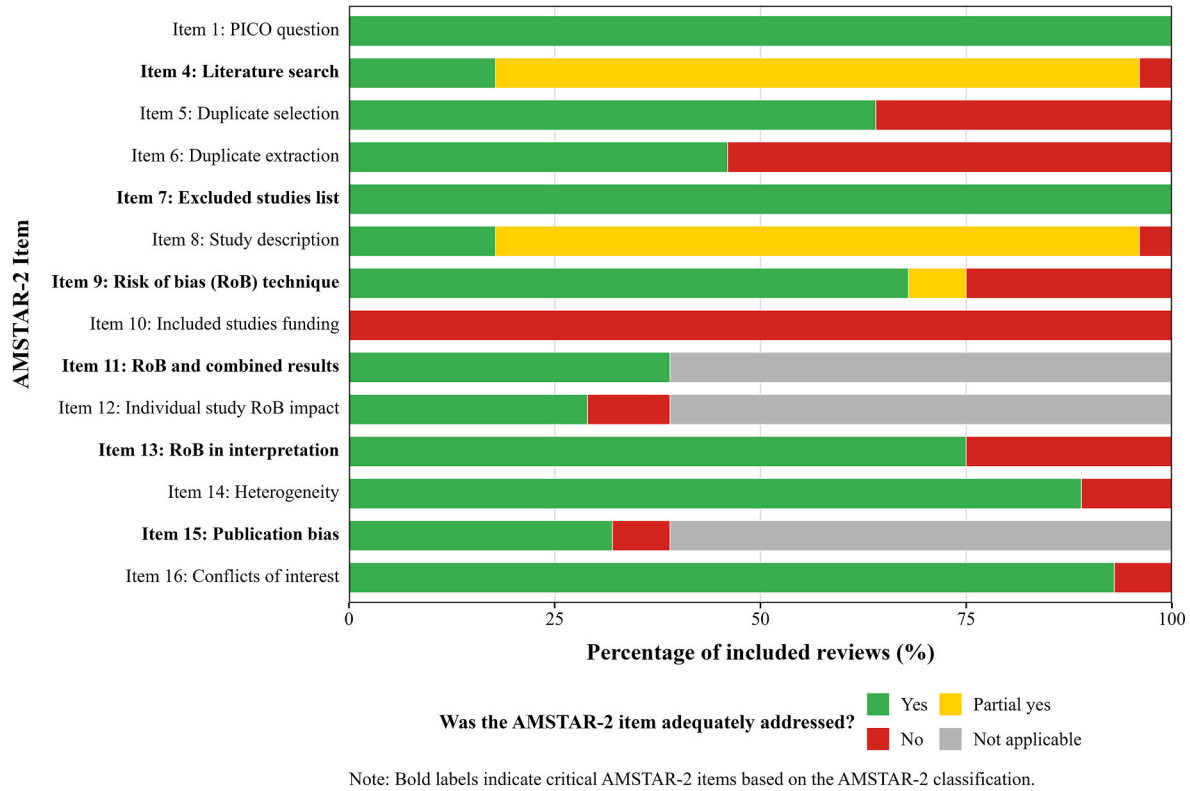
2023; Chen et al., 2024; Tang and Ho, 2025; Rückle et al., 2025; Liu et al., 2021a), cardiovascular outcomes (n = 4) (Kazi et al., 2024; Arsad et al., 2022; Zhou et al., 2025; Wu et al., 2023), respiratory outcomes (n = 4) (Syed and Basu, 2025; Kondo et al., 2019; Jiao et al., 2024; Liu et al., 2015), occupational diseases (n = 3) (Fatima et al., 2021; Berumen-Flucker et al., 2022; Binazzi et al., 2019), hospitalisations (n = 1)(Mason et al., 2022), health service response (n = 2) (Mason et al., 2022; Harvey et al., 2024), general mortality (n = 6) (Yari et al., 2020; Liu et al., 2023; Arsad et al., 2022; Benmarhnia et al., 2015; Rhim et al., 2024; Zafeiratou et al., 2021), perinatal disorders (n = 1) (Chersich et al., 2020), and kidney disease outcomes (n = 1) (Liu et al., 2021b).

Regarding the PROGRESS-Plus socio-demographic determinants of health under investigation, gender and age were considered in the majority of papers (n = 22), followed by pre-existing conditions and race (n = 12), SEP (n = 9), occupation (n = 7), place of residence (n = 6), social capital/deprivation and education (n = 5) and income (n = 4). The complete list of papers included, with detailed information, is provided in Supplementary Table S6 of the Supplementary Material.

3.3. Risk of bias assessment

Twenty-one of the 28 included reviews did not report any flawed critical items, indicating that the literature search strategy was comprehensive, the list of excluded studies was reported, the review authors used a satisfactory technique to assess the risk of bias (RoB) in the individual studies included in the review, appropriate methods were used for the statistical combination of results when meta-analysis was performed, RoB in individual studies was considered when interpreting or discussing the review findings, and publication bias/small-study bias was adequately investigated and discussed when quantitative synthesis was performed (Supplementary Table S7). Conversely, seven reviews reported methodological concerns for at least one of these critical items. Specifically, all seven reviews with flawed critical items failed to use or report a satisfactory technique for assessing the risk of bias in the individual studies included in the review and did not adequately account for risk of bias when interpreting or discussing the review findings. One of these reviews additionally lacked a comprehensive literature search strategy. Moreover, among reviews for which quantitative synthesis was applicable, two did not adequately assess or discuss publication bias/small-study bias. Conversely, the provision of a list of excluded studies with justification was adequately addressed, with no flawed critical item identified for this domain.

The distribution of AMSTAR-2 ratings across individual items is presented in Fig. 2. Items related to the formulation of the research question and reporting of excluded studies were consistently assessed,



Note: Bold labels indicate critical AMSTAR-2 items based on the AMSTAR-2 classification.

Fig. 2. AMSTAR-2 assessment of the included reviews. Stacked bars show the percentage of included reviews rated as "Yes", "Partial yes", "No", or "No meta-analysis conducted" for each AMSTAR-2 item.

with all reviews adequately addressing both the inclusion of the PICO components in the research question and the provision of a list of excluded studies. A high proportion of reviews adequately addressed reporting of conflicts of interest (93%), assessment of heterogeneity in the results of the review (89%), and consideration of risk of bias in the interpretation of results (75%). Conversely, methodological limitations were evident in several domains. Duplicate study selection and duplicate data extraction were not reported in 36% and 54% of reviews, respectively. Literature search and study description were most frequently rated as "Partial yes" (79% each), suggesting incomplete adherence to AMSTAR-2 requirements. Moreover, none of the reviews reported the funding sources of the primary studies included in the review. A summary table of evidence grading is available in Supplementary Material Table S7.

3.4. *Extreme events due to climate change*

3.4.1. *Heat (high temperatures/heatwaves)*

Eighteen studies have examined the association between high temperatures or heatwaves exposure and health outcomes (Fatima et al., 2021; Berumen-Flucker et al., 2022; Binazzi et al., 2019; Faurie et al., 2022; Meadows et al., 2024; Son et al., 2019; Chen et al., 2024; Liu et al., 2021a, 2021b; Arsad et al., 2022; Zhou et al., 2025; Wu et al., 2023; Mason et al., 2022; Harvey et al., 2024; Benmarhnia et al., 2015; Rhim et al., 2024; Zafeiratou et al., 2021; Chersich et al., 2020). A summary of the health effects, stratified by PROGRESS-Plus factors, is presented in Fig. 3 and Supplementary Table S8. Findings across studies regarding gender differences in health outcomes are mixed, suggesting that men and women experience different pathways of vulnerability to heat. Women appear to be at a higher risk of mortality (Arsad et al., 2022), particularly cardiovascular mortality (Zhou et al., 2025), while men appear to be at higher risk of occupational injuries (Fatima et al., 2021), direct heat-illness (excessive sweating, headaches, dizziness, muscle and stomach cramps, and skin rashes), dehydration, heatstroke (Faurie et al., 2022), out of hospital cardiac arrest (OCHA) (Wu et al., 2023), and kidney disease outcomes (Liu et al., 2021b). Regarding mental health outcomes, evidence indicated slightly higher adverse mental health impacts among men (Liu et al., 2021a), while periods of extreme high temperature have been associated with a higher incidence of suicide deaths among men (Chen et al., 2024). Overall, age modifies vulnerability to heat exposure, with older adults generally experiencing higher risks across multiple health outcomes. Evidence shows increased mortality among adults aged ≥65 years compared with younger groups (Arsad et al., 2022; Benmarhnia et al., 2015; Zafeiratou et al., 2021). Older adults also showed higher risks of direct heat-illness or dehydration, heatstroke/heat illness, dehydration/fluid, and electrolyte disturbance (Faurie et al., 2022). Young workers experienced more severe heat-related illness symptoms thanolder workers, and adults <35 years show slightly higher risks of occupational injuries thanolder adults (Fatima et al., 2021; Berumen-Flucker et al., 2022). Heat exposure increased mental health–related mortality and morbidity in all ages, with slightly higher risks among adults ≥65 years compared with younger individuals (Liu et al., 2021a). Exposure to heatwave events or high ambient temperatures has been associated with age-sensitive reproductive outcomes, with greater risks of reduced birth weight and preterm birth among women younger than 25 and older than 35 years compared to other age groups (Chersich et al., 2020). Regarding race and ethnicity, studies suggest higher heat-related mortality among Black populations compared to White populations (Son et al., 2019; Zafeiratou et al., 2021), while regarding adverse pregnancy outcomes, Black and Hispanic women appeared to be particularly vulnerable to preterm birth compared to White women (Chersich et al., 2020). Lower SEP was found to be an increasing risk factor for ED presentations and hospitalisations compared to higher SEP levels (Arsad et al., 2022; Mason et al., 2022), and it was also found to be associated with a higher risk of preterm birth compared to higher SEP groups (Chersich et al., 2020). Lower educational attainment was associated with greater vulnerability to heat-related mortality compared with higher education levels (Son

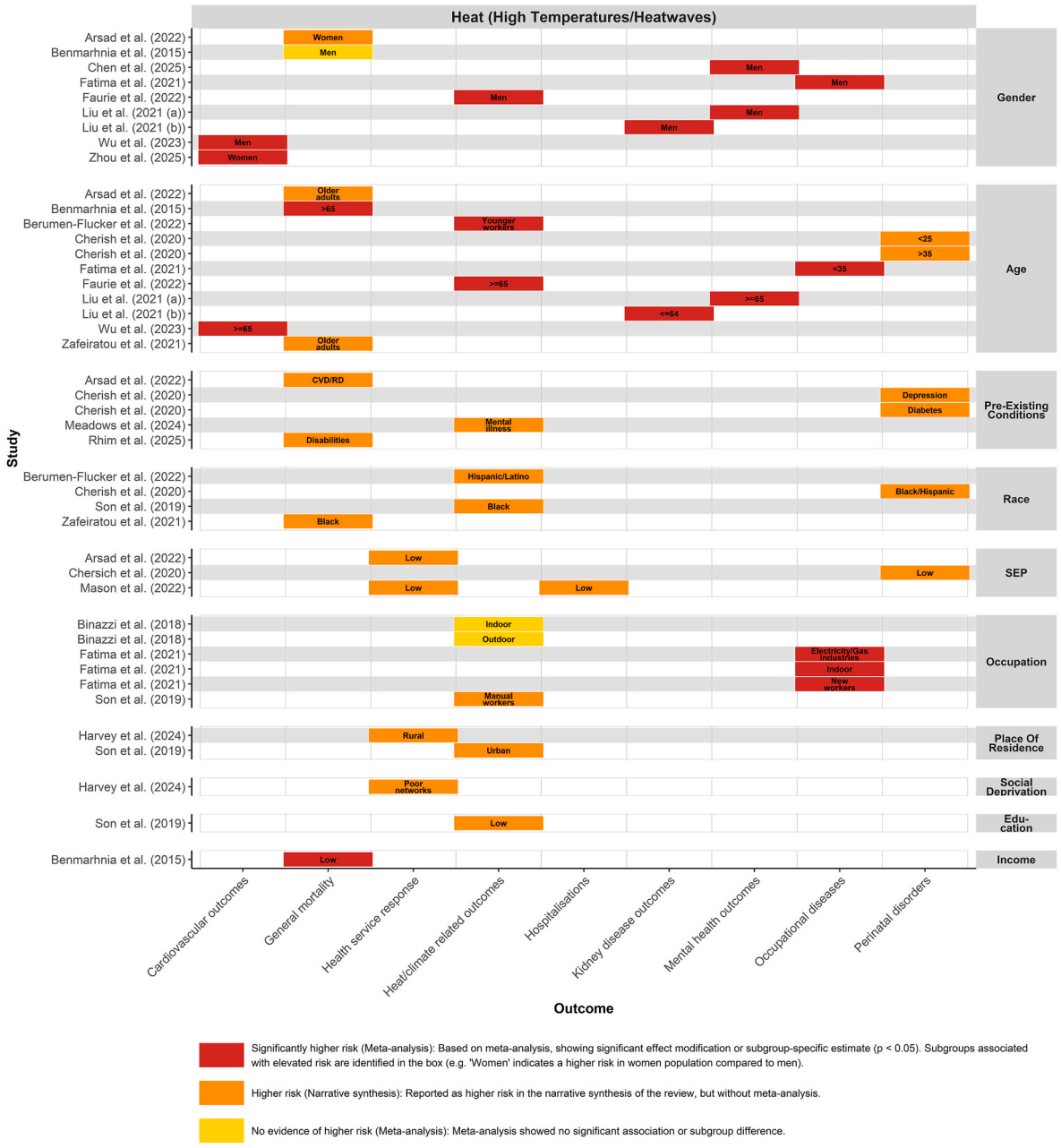


Fig. 3. Mapping of PROGRESS-Plus dimensions and related vulnerable population subgroups across included studies on exposure to heat (high ambient temperatures/heatwaves) and associated health outcomes. CVD = cardiovascular diseases, RD = respiratory diseases.

et al., 2019). Heat exposure was consistently associated with increased occupational injury risk, particularly among indoor workers, new workers, and specific sectors such as gas and electricity industries, utilities, agriculture, construction, manufacturing, and transport, with the highest risks observed in less experienced workers (Fatima et al., 2021). Concerning place of residence, urban areas experienced higher vulnerability to extreme heat due to density and limited green space (Son et al., 2019), while older rural populations were also affected, with distinct exposure patterns and susceptibilities highlighted in studies focusing on remote areas (Harvey et al., 2024).

Individuals with chronic diseases such as cardiovascular, respiratory, renal, disabilities, and mental health conditions showed heightened sensitivity to heat compared with people without those pre-existing conditions (Meadows et al., 2024; Arsad et al., 2022; Chersich et al., 2020). Concerning social deprivation, strong networks were protective, with limited social networks associated with a higher likelihood of emergency service use (Harvey et al., 2024).

3.4.2. *Wildfires*

Five studies have examined the association between wildfire exposure and health outcomes (Syed and Basu, 2025; Kondo et al., 2019; Varshney et al., 2023; Jiao et al., 2024; Liu et al., 2015) summary. A of the health effects, stratified by PROGRESS-Plus factors, is presented in Fig. 4 and Supplementary Table S9. Women showed a higher risk of respiratory outcomes compared with men and slightly increased ED presentations for asthma and COPD, whereas differences for all respiratory causes and pneumonia ED visits were small or not statistically significant (Kondo et al., 2019; Jiao et al., 2024). Older adults experienced higher risks of ED presentations for all respiratory outcomes, whereas younger age groups, especially adolescents and young adults, generally showed lower risks (Kondo et al., 2019). Regarding race/-ethnicity, Aboriginal Australians faced disproportionately higher risks of

Fig. 4. Mapping of PROGRESS-Plus dimensions and related vulnerable population subgroups across included studies on exposure to wildfires and associated health outcomes.

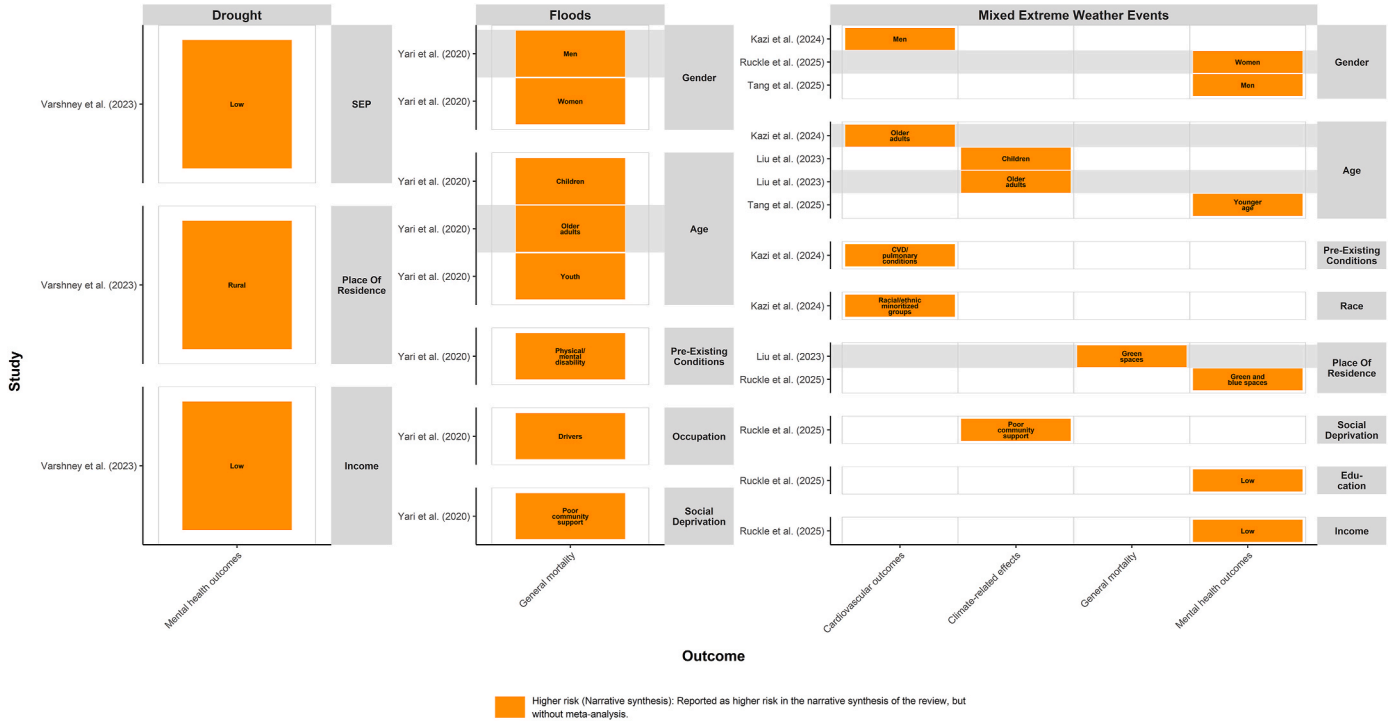


Fig. 5. Mapping of PROGRESS-Plus dimensions and related vulnerable population subgroups across included studies on exposure to drought, floods and mixed extreme weather events and associated health outcomes.

respiratory hospitalisations from PM10 than non-Aboriginal Australians (Liu et al., 2015). Lower educational attainment, SEP, and income were associated with increased vulnerability to depression/PTSD compared with farmers with higher education, SEP, and income level (Varshney et al., 2023). Regarding pre-existing conditions, the risk of respiratory diseases was significantly higher among children with asthma (Varshney et al., 2023), and prior mental health conditions were associated with depression or PTSD following exposure to a wildfire (Varshney et al., 2023). Those residing in rural areas were associated with increased mental and physical health. In one study conducted among farmers, residing in rural areas was associated with increased mental and physical health vulnerability, including higher levels of anger, cynicism, and perceived lack of social support (Varshney et al., 2023).

3.4.3. Floods and droughts

One study has examined the association between floods and health outcomes (Yari et al., 2020), while one study has examined the same relationship with drought (Varshney et al., 2023). A summary of the health effects, stratified by PROGRESS-Plus factors, is presented in Fig. 5 and Supplementary Table S10. Flood-related mortality risk was found to be high for both men and women, with a stronger evidence base for men (Yari et al., 2020). Low SEP and low income were consistently associated with worse mental health outcomes, increased stress, and greater social vulnerability after droughts (Varshney et al., 2023),while certain occupations, particularly regarding people working in the transport sector, were also linked to higher flood mortality risk compared to other occupations (Yari et al., 2020). Physical or mental disabilities were associated with increased vulnerability to mortality following floods (Yari et al., 2020). Finally, factors such as green and blue spaces protected mental health (Yari et al., 2020), whereas rural residence increased vulnerability to drought-related mental health impacts (Varshney et al., 2023).

3.4.4. Mixed extreme weather events

Four studies have examined the association between mixed extreme weather events (including heatwaves/high ambient temperatures, wildfires, floods, drought, air pollution, and hurricanes) and health outcomes (Kazi et al., 2024; Liu et al., 2023; Tang and Ho, 2025; Rückle et al., 2025). A summary of the health effects, stratified by PROGRESS-Plus factors, is presented in Fig. 5 and Supplementary Table S11. Women showed a higher risk of mental health disorders following extreme weather events (flood, wildfire, and temperature extremes) compared to men (Rückle et al., 2025), whereas men experienced increased CVD after exposure to mixed extreme weather events (Kazi et al., 2024) and a higher suicide risk, particularly during droughts, particularly among agricultural workers (Tang and Ho, 2025). Racial or ethnic minoritized populations showed a higher CVD risk following climate events than other ethnic groups (Kazi et al., 2024), whereas pre-existing cardiovascular or pulmonary conditions were associated with increased health risk after extreme weather events (Kazi

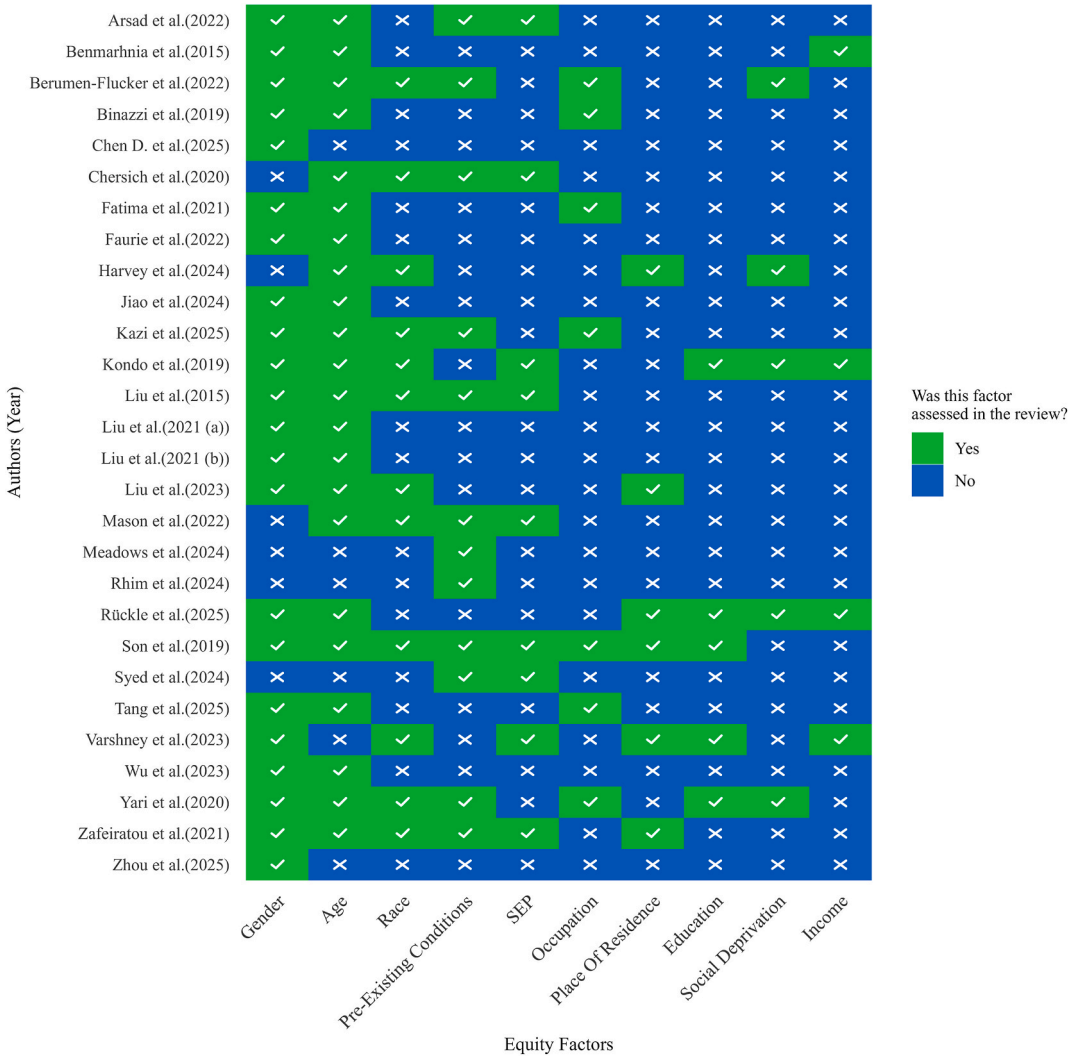


Fig. 6. PROGRESS-Plus Factors assessed in each included SR. SEP = Socio-economic position.

et al., 2024). In contrast, social support and community cohesion were generally protective, while poor community support increased mortality risk (Rückle et al., 2025). Finally, greenness was associated with reduced mortality compared with places with less green areas (Liu et al., 2023).

3.5. Inequities focus assessment

The studies reviewed show clear differences in how they address equity, particularly in the number of PROGRESS-Plus factors they include and the depth of their discussion on inequities. Fig. 6 shows the distribution of the PROGRESS-Plus factors analyzed in each included SR. A total of 17 studies were categorised as fully addressing equity, meaning they went beyond examining differences only by gender and age and explicitly discussed inequities in depth about multiple structural and social dimensions (Fatima et al., 2021; Kazi et al., 2024; Kondo et al., 2019; Varshney et al., 2023; Yari et al., 2020; Liu et al., 2015, 2023; Meadows et al., 2024; Son et al., 2019; Tang and Ho, 2025; Rückle et al., 2025; Arsad et al., 2022; Harvey et al., 2024; Benmarhnia et al., 2015; Rhim et al., 2024; Zafeiratou et al., 2021; Chersich et al., 2020). Studies classified as fully addressing equity systematically examined multiple PROGRESS-Plus dimensions, explicitly linking differential health impacts to broader structural, social, and environmental determinants. They also tended to contextualise inequities within systems and policies, highlighting gaps in adaptation measures and recommending equity-oriented interventions. By contrast, 11 reviews were classified as partially addressing equity, as they either restricted their analyses to demographic factors (primarily age and gender) or mentioned other determinants without engaging with their social or structural implications (Syed and Basu, 2025; Berumen-Flucker et al., 2022; Binazzi et al., 2019; Faurie et al., 2022; Chen et al., 2024; Liu et al., 2021a, 2021b; Zhou et al., 2025; Wu et al., 2023; Jiao et al., 2024; Mason et al., 2022). These studies generally limited their analyses to age and gender differences or mentioned other determinants without elaborating on their social or structural implications. Equity considerations in these reviews were often confined to biological susceptibility or descriptive stratification, with limited discussion of underlying mechanisms, systemic drivers, or policy relevance.

4. Discussion

4.1. Summary of the results

This umbrella review provides a comprehensive overview of the existing evidence on how the health impacts of climate change–related extreme events in high-income countries are shaped by socio-demographic and socio-economic factors, highlighting that these impacts are not evenly distributed across populations but are strongly driven by social, demographic, and structural determinants. Across different types of extreme events, including high temperatures/heatwaves, wildfires, floods, droughts, and mixed hazards, different patterns of inequities emerged, with certain population groups systematically experiencing higher risks of adverse health outcomes.

Age and gender were the most frequently examined modifiers in the existing literature, with older adults showing increased vulnerability across multiple outcomes, particularly mortality, cardiovascular, and respiratory conditions. Gender differences appeared more complex and context-specific, reflecting both biological and socially constructed roles, such as occupational exposure and behavioral factors. Beyond these demographic dimensions, socioeconomic disadvantages, including low income, low educational attainment, and lower social capital, were associated with worse health outcomes. Similarly, racial and ethnic minoritized populations, individuals with pre-existing health conditions, and those living in rural or environmentally disadvantaged areas were disproportionately affected. However, the results show that the majority of primary studies and systematic reviews focus on high temperatures/heatwaves, while much less scientific evidence is reported for extreme events such as droughts and floods in the context of equity. Moreover, important differences emerged in how equity was addressed across the literature: 61% of studies were classified as fully addressing equity, explicitly incorporating multiple PROGRESS-Plus dimensions and discussing structural drivers, whereas 39% only partially addressed equity, typically limiting analyses to descriptive stratification without deeper interpretation of underlying mechanisms. The distinction between fully and partially addressing equity was developed to differentiate studies that simply stratify health outcomes by certain characteristics from those that actively analyse inequities. For example, gender and age are commonly used as stratification variables in health research, but they primarily capture biological and demographic differences rather than structural disadvantages, unless an explicit mention of discrimination dynamics on the ground of gender and age. In addition, in the umbrella review were considered not only the presence of equity-related variables but also how studies engage with the concept of inequity. This aligns with broader public health approaches that emphasise the importance of identifying and addressing the social determinants of health, rather than merely describing disparities (Marmot et al., 2008; Solar et al., 2010).

4.2. Comparison with previous epidemiological studies

Our results are in line with the review literature on climate-related extreme weather events and health outcomes. High ambient temperatures/heatwaves are the most synthesised climate hazards, confirming that the existing evidence is denser for heat than for other extreme events (Rocque et al., 2021; Conti et al., 2022). Within reviews focusing on heat exposure, the epidemiological evidence is consistent with our review: adverse effects are reported for cardiorespiratory mortality and morbidity, with greater vulnerability among women in mortality analyses, older adults, people with lower SEP, and those with pre-existing chronic conditions (Conti et al., 2022). The existing synthesis literature on wildfires is concentrated on respiratory outcomes and less consistent for cardiovascular outcomes, matching our findings. Similarly, flood and drought synthesis evidence remain underrepresented (Stimpson et al., 2025) and mostly narrative.

Moreover, our findings are consistent with broader equity-oriented epidemiological studies. Recent methodological studies show that Progress-Plus has become one of the predominant frameworks to conceptualise equity in epidemiological reviews, but its application is also constrained by incomplete reporting in primary studies (Hollands et al., 2024; Welch et al., 2024). Results from the present umbrella review are consistent with this pattern, indicating that there are dimensions frequently examined, particularly through quantitative analysis, such as age and gender, while other dimensions such as race, education, income, SEP, and social deprivation are less consistently examined. Another study reported the same asymmetries regarding the consideration of equity dimensions in epidemiological studies, indicating that age and gender were the most commonly reported PROGRESS-Plus items, and place of residence, race, SEP, and social deprivation were rarely captured (Karran et al., 2023). Moreover, the PROGRESS-Plus framework has been applied in a systematic review examining social inequalities in exposure to ambient air pollution in the WHO European Region (Fairburn et al., 2019), as well as in a narrative evidence synthesis on urban green space interventions, where it was used to assess equity impacts, consistent with the methodological approach adopted in the present review (Karran et al., 2023).

4.3. Public health implications

Recent policy developments illustrate an increasing recognition of the need to embed equity in climate and health governance, although implementation remains variable. For example, the WHO has advanced an Operational Framework for Building Climate-Resilient Health Systems (World Health Organization, 2023) and promoted a Health in All

Policies (HiAP) approach emphasises addressing the structural determinants of health across sectors. However, a recent SR indicates that there are many gaps in policy analysis frameworks that connect health equity and climate change (Khanal et al., 2023), especially because they mostly focus on problem framing rather than covering the entire policy cycle. To address this gap, the PROGRESS-Plus framework can offer a comprehensive lens through which policymakers can understand and respond to health inequities, as its design allows for equity considerations to be explicitly integrated at every step of the policy cycle. During the agenda-setting phase, PROGRESS-Plus can help identify populations most exposed to climate-related health impacts, ensuring that inequities are recognized early. In the policy formulation stage, it can assist as a guide to the development of interventions aimed at these inequities. During decision-making and implementation, it can ensure that strategies meet the needs of diverse groups and do not inadvertently intensify inequities. Finally, in the monitoring and evaluation phase, PROGRESS-Plus can provide guidance on the identification of relevant population groups and social determinants to be considered when assessing policy impacts. While the framework does not provide direct measurement tools, it helps ensure that data collection and evaluation efforts are structured to capture potential inequities, enabling policymakers to analyse differences across groups and make evidence-informed adjustments where inequities are detected. In this review, PROGRESS-Plus was also operationalised as a methodological tool to systematically explore equity dimensions during the evidence synthesis process. Specifically, it informed both the search strategy, ensuring that relevant socio-demographic and socio-economic dimensions were not overlooked, and the organisation of the results, with extracted evidence explicitly mapped across PROGRESS-Plus categories. This approach is consistent with guidance from the Cochrane Equity Methods Group (Welch et al., 2024), which highlights the importance of incorporating equity considerations throughout the review process and provides methodological tools to support the synthesis of evidence on health inequities.

The use of PROGRESS-Plus in this context represents an added value, particularly within environmental and climate-related research, where standardized tools for integrating equity into evidence synthesis remain limited. By structuring the identification of relevant populations, the framework enhances the reproducibility and transparency of the review process. Moreover, it supports the development of a conceptual pathway linking environmental risk factors to health outcomes through intermediate socio-economic determinants, thereby enabling a more systematic assessment of vulnerability. Importantly, commonly available database filters are often insufficient to capture the full range of equity-relevant dimensions, as these are not consistently indexed across major bibliographic databases. Incorporating PROGRESS-Plus within the search strategy helps avoid the exclusion of relevant population groups and ensures a more comprehensive retrieval of evidence. By systematically identifying key social determinants and their related outcomes, the framework contributes to building a more robust and sensitive search strategy, strengthening the validity of the review.

5. Limitations and strengths

This umbrella review has some limitations. Firstly, it includes studies of which at least 60% were conducted in high-income settings, moreover, among the high-income countries represented, a preponderance of studies were conducted in relatively few settings, notably Australia, the United States, Canada, Italy, the United Kingdom, Korea, France, and Spain, implying that some results may refer to primary research carried out in low- or middle-income countries. Furthermore, the classification of studies as fully or partially incorporating equity dimensions involved a degree of subjective judgment, which may have introduced some variability in the assessment process. Moreover, the assessment of risk of bias in environmental health systematic reviews presents important methodological challenges. Available tools, such as AMSTAR 2, were originally developed for clinical and interventional research and may not be fully appropriate for observational evidence, which constitutes most studies in the environmental epidemiology field. In particular, the absence of randomization and the presence of residual confounding may lead to systematically lower ratings. For this reason, in the present review the original AMSTAR-2 tool was adapted to the environmental health research question and the observational nature of the body of evidence, as suggested by other umbrella reviews' authors (Shea et al., 2017). Furthermore, the limited reporting of risk of bias at the level of individual studies within many reviews represents a critical limitation. Moreover, when included in the review, we relied on the risk-of-bias assessments reported by the authors of the included systematic reviews for the primary studies, which may introduce a certain degree of subjectivity in the overall evaluation due to differences in judgment across review authors. Finally, a quantitative synthesis (meta-analysis) was not possible due to the high heterogeneity across studies in terms of exposures, health outcomes, and PROGRESS-Plus dimensions, as well as the potential overlap of primary studies across included systematic reviews. Therefore, a narrative synthesis was conducted, which may limit the comparability and quantitative interpretation of the findings. However, this umbrella review has several strengths. The first lies in its systematic approach, following protocol registration, and adhering to all typical rules associated with such reviews. The second major strength is that it is the first comprehensive umbrella review of the impact of extreme events due to climate change across a wide range of socio-demographic factors, that drive disparities in health outcomes. It also provides a methodology for classifying studies based on the extent to which they incorporate equity and health inequality analyses in their assessment of outcomes. Finally, the results show high translational and policy relevance, providing empirical evidence and conceptual basis to support the development of public health and climate adaptation policies in an equitable manner.

6. Conclusions

This umbrella review demonstrates that the health impacts of extreme events due to climate change, e.g., heatwaves, wildfires, floods, droughts, and mixed weather extreme events, are not equally distributed among populations, but vary according to social and demographic factors. This comprehensive synthesis highlights that vulnerability to climate-related health impacts is not only a matter of biological susceptibility but is also deeply shaped by social position and structural determinants. This pattern points to the need for future research and policy to move beyond reporting stratified risks and instead interrogate the mechanisms through which inequities are produced and sustained. Importantly, some reviews demonstrated that adopting an explicit equity framework yields richer insights and more applicable recommendations, whereas others risked oversimplifying or individualizing vulnerabilities. This umbrella review underscores that adopting an explicit equity framework, such as PROGRESS-Plus, could help ensure that vulnerability is analyzed across multiple or the full range of structural determinants rather than focusing on individual components of vulnerability.

CRediT authorship contribution statement

Barbara Sodano: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Cinzia Destefanis:** Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – review & editing. **Simona Vecchi:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Writing – review & editing. **Manuela De Sario:** Data curation, Formal analysis, Investigation, Methodology, Resources,

Software, Supervision, Validation, Writing – review & editing. **Chiara Di Girolamo:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – review & editing. **Fulvio Ricceri:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Barbara Sodano reports financial support was provided by Ministry of Health. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2026.125008.

Data availability

No data was used for the research described in the article.

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