Front. Environ. Sci. Eng. 2024, 18(5): 63
https://doi.org/10.1007/s11783-024-1823-4

REVIEW ARTICLE

A systematic review of the inequality of health burdens related to climate change

Xinke Song[1], Shihui Zhang (✉)[2], Hai Huang[1], Qun Ding[2], Fang Guo[1], Yaxin Zhang[1], Jin Li[1], Mingyu Li[1], Wenjia Cai[2], Can Wang[1]

1 State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China
2 Department of Earth System Science, Tsinghua University, Beijing 100084, China

HIGHLIGHTS

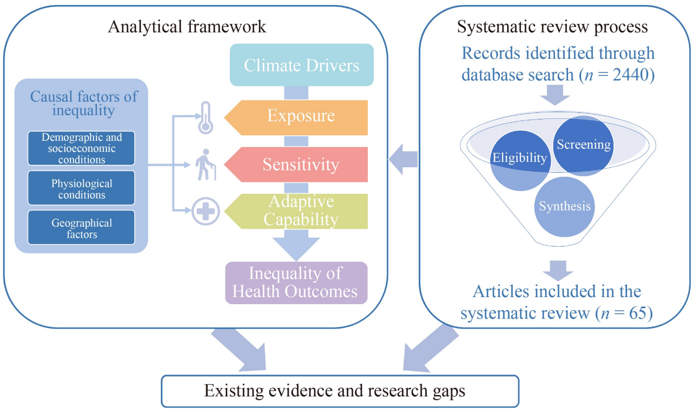
- Varied factors lead to uneven climate health outcomes were revealed.
- Poor people, ethnic minorities, and females are most-studied vulnerable groups.
- Research gaps and methodological challenges were identified.

ARTICLE INFO

Article history:
Received 13 April 2023
Revised 27 January 2024
Accepted 31 January 2024
Available online 11 March 2024

Keywords:
Climate change
Health impact
Human well-being
Inequality
Vulnerability

GRAPHIC ABSTRACT



ABSTRACT

Climate change significantly impacts human health, exacerbating existing health inequalities and creating new ones. This study addresses the lack of systematic review in this area by analyzing 2440 publications, focusing on four key terms: health, disparities, environmental factors, and climate change. Strict inclusion criteria limited the selection to English-language, peer-reviewed articles related to climate health hazards, ensuring the relevance and rigor of the synthesized studies. This process synthesized 65 relevant studies. Our investigation revealed that recent research, predominantly from developed countries, has broadened its scope beyond temperature-related impacts to encompass diverse climate hazards, including droughts, extreme weather, floods, mental health issues, and the intersecting effects of Coronavirus Disease 2019. Research has highlighted exposure as the most studied element in the causal chain of climate change-related health inequalities, followed by adaptive capability and inherent sensitivity. The most significant vulnerabilities were observed among populations with low socioeconomic status, ethnic minorities, and women. The study further reveals research biases and methodological limitations, such as the paucity of attention to underdeveloped regions, a narrow focus on non-temperature-related hazards, challenges in attributing climate change effects, and a deficit of large-scale empirical studies. The findings call for more innovative research approaches and a holistic integration of physical, socio-political, and economic dimensions to enrich climate-health discourse and inform equitable policy-making.

✉ Corresponding author
E-mail: ritazhang9414@gmail.com

Special Issue—Climate Change and Public Health: emerging impacts and responses (Responsible Editors: Can Wang, Shihui Zhang, Derrick Ho & Miriam Marlier)

1 Introduction

The world is currently experiencing profound systemic shocks, including but not limited to the Coronavirus pandemic (COVID-19), the ongoing conflict between Russia and Ukraine, and looming crises in food and energy. Against this backdrop, climate change has further intensified the health impacts faced by humanity (Ebi and Hess, 2020; Romanello et al., 2022). Climate change and pandemics are deemed as the "black elephants" of the Anthropocene—both rare, yet catastrophic "black swan" events and also pressing, but unaddressed "elephants in the room". These "black elephants" reveal profound and pervasive inequalities within human society (Asayama et al., 2021).

In recent years, the impact of climate change on human health has attracted widespread attention from both academia and society. Working Group II of the Sixth Assessment (AR6) of the Intergovernmental Panel on Climate Change (IPCC) has assessed the immense risks that climate change poses to human health and well-being. According to the report (Cissé et al., 2022), there is an increase in climate-related illnesses, premature death, malnutrition in various forms, and the threat posed to mental health and well-being. The report encompasses a range of effects including heat waves, flooding and resultant damages, scarcity of food and water, and the spread of infectious diseases. Moreover, the report assessed the attribution uncertainty of various regions and hazards to climate change, using confidence levels as a measure.

In the IPCC AR6 report of Working Group I (Ranasinghe et al., 2021) and the report of Lancet Countdown (Romanello et al., 2022), there are numerous pathways identified through which climate change affects human health. Based on these foundational reports, our work offers a focused examination, specifically aimed at providing a comprehensive summary of potential hazards and health impacts of climate change related to health burden inequalities. This examination is informed by the "climatic impact-drivers" (CIDs) identified by the IPCC (Chen et al., 2021), as well as the chains of impact made by climate change on human health summarized in the IPCC Working Group II report (Cissé et al., 2022) and the Lancet Countdown report (Romanello et al., 2022). Table 1 is an overview of the various climatic health hazards, their brief descriptions, and the potential impacts on health.

Climate change affects every person on Earth, but the impacts are not equally distributed, and the transmission mechanism of the long chain from climate change drivers to human health is complex and multifaceted (Romanello et al., 2022). The most vulnerable and disadvantaged groups, including women, children, ethnic minorities, poor communities, migrants or displaced people, older populations, and individuals with underlying health conditions, are disproportionately impacted by climate-sensitive health risks (World Health Organization, 2021). These groups face a higher risk of adverse health outcomes due to their multiple vulnerabilities, exposure pathways, and health system capacity and resilience. The IPCC developed an analytical framework applied to examine the relationship between climate change and health outcomes by highlighting the roles of vulnerability, hazard, and exposure (Cissé et al., 2022). The IPCC framework conceptualizes the context in which climate change affects health outcomes and health systems as a function of risk, which is a product of interactions between hazards, exposure, and vulnerability. The resulting impacts can further enhance vulnerability and/or exposure to risks.

The academic community has gained a comprehensive understanding of the health impacts of climate change (Watts et al., 2019b; Romanello et al., 2021; Watts et al., 2021; Cissé et al., 2022; Romanello et al., 2022;

Table 1 Overview of the main climatic health hazards with a short description and related health impacts

Climatic health hazard	Brief description	Examples of potential health impacts
Heat (HT)	Average surface temperature rise and extreme heat events	Dehydration, heat shock, respiratory diseases and cardiovascular diseases
Cold Spell (CS)	Lower average surface temperatures, extreme cold events, heavy snowfall, freeze–thaw events and ice storms	Cold-related illnesses and traffic accidents
Droughts (DR)	Decrease in average rainfall and drought	Lack of freshwater resources
Rising Sea Levels and Extreme Rainfalls (RSL&ER)	Increased average rainfall, rised relative sea level, river and coastal flood and landslide	Drowning, electric shock and freshwater threats
Cyclones and Storms (CY&ST)	Tropical cyclone, severe wind storm, sand and dust storm	Injury, respiratory diseases and cardiovascular diseases
Wildfires (WF)	Wildfire triggered by weather conditions	Direct thermal injuries or death and the exacerbation of respiratory symptoms due to exposure to wildfire smoke
Food-borne Diseases and Malnutrition (FBD&MN)	Food insecurity caused by weather conditions	Hunger. food-borne diseases and malnutrition
Climate-infectious Diseases (CID)	Infectious disease transmission related to climate	Outbreaks of infectious diseases (diarrhea, malaria, cholera, dengue fever, etc.)
Other (OTH)	Air pollution weather, atmospheric carbon dioxide at surface and radiation at surface	Respiratory diseases and cardiovascular diseases

Niu et al., 2023), and there is a growing recognition given to the unequal distribution of these impacts across different populations (Pérez-Peña et al., 2021; Grobusch and Grobusch, 2022; van Daalen et al., 2022; Liu et al., 2023). A range of systematic reviews have explored the intersection of climate change and health inequalities. Khanal et al. highlight the fragmented nature of policy analysis frameworks and the need for a comprehensive approach to understanding health equity in climate change policies (Khanal et al., 2023). Graham et al. emphasize the importance of USA health care's response to climate change, particularly in addressing air pollution, extreme weather events, and infectious diseases (Graham et al., 2019). Khine and Langkulsen underscore the role of climate change in exacerbating inequalities and increasing the risk of diseases among vulnerable populations in South Africa (Khine and Langkulsen, 2023). Scheelbeek et al. provide evidence from low- and middle-income countries, highlighting the need for more evidence on the effects of climate change adaptation responses on public health (Scheelbeek et al., 2021). However, few studies have systematically reviewed the broad range of uneven distribution of climate change-related health impacts on a global level from a comprehensive perspective. To address this gap, it is necessary to identify what evidence exists regarding the unequal impact of climate change on health outcomes, to identify the most significant inequalities, and to advance policies to eliminate these inequalities.

The review was guided by the following questions:

1) To what extent do exposures, sensitivity, adaptive capabilities, and health outcomes related to climate change exhibit uneven global distribution?

2) Which factors, including demographic and socioeconomic conditions, physiologic responses, and geographical elements, contribute to the inequality in health impacts of climate change?

3) How has the literature addressed the equality of health burdens due to climate change, focusing on research trends, geographical emphasis, and methodological approaches?

2 Methods

2.1 Search strategy

In preparation for our systematic literature review, we engaged in a rigorous process of keyword identification, informed by an extensive survey of relevant literature and consultations with experts in the field. This process was pivotal in shaping a search strategy adept at capturing studies intricately addressing the intersection of health disparities and environmental aspects within the broader context of climate change. Our strategy honed in on the titles and abstracts of publications across the Web of Science, Pubmed, and Scopus databases, a decision rooted in the pursuit of precision and relevance. This focus was based on the understanding that titles and abstracts succinctly encapsulate the core themes and findings of research, serving as robust indicators of their relevance to our investigative purview.

Our search encompassed an array of carefully chosen terms related to health (e.g., “health” and “healthy”), disparities (e.g., “disparity”, “inequality”, and “justice”), environmental factors (e.g., “environment”, “environmental”), and the overarching theme of climate change. The search was limited to literature published before January 2023 and was confined to English-language journal articles[1]. This language restriction was a pragmatic decision, aimed at harnessing the extensive body of research predominantly available in English, while maintaining consistency and manageability in our analysis. This approach, while acknowledging certain limitations, was deemed most suitable for fulfilling the objectives of our study within the scope of our resources and time frame. A total of 1813 search results were obtained from Web of Science, 266 from Pubmed, and 361 from Scopus. After removing duplicates, a total of 1766 records were obtained.

2.2 Screening

The screening process is shown in Fig. 1. According to several criteria, the titles and abstracts were screened. For inclusion, documents were restricted to the relevant peer-reviewed English-language journal articles on the climatic health hazards identified in Table 1.

Then, 1649 records were excluded after a review of their titles and abstracts. During the process of eligibility screening, two types of articles were excluded. One included those without primary data, which can be quantitative or qualitative data. These were mainly literature reviews. The other included the methodological or predictive studies that did not analyze existing evidence. Finally, 65 articles were selected out of 2440 search results for subsequent literature review. These articles were fully reviewed to identify their methodology, time and region of study, key findings, and other

[1] In the Web of Science database, we used the search term "TS= ((health OR healthy) AND (disparity OR uneven OR inequality OR equality OR justice OR equity) AND (environment OR environmental) AND (climate change))" to search all literature published before January 2023. In Pubmed, we used the search term "((health[Title/Abstract] OR healthy[Title/Abstract]) AND (disparity[Title/Abstract] OR uneven[Title/Abstract] OR inequality[Title/Abstract] OR justice[Title/Abstract] OR equity[Title/Abstract]) AND (environment[Title/Abstract] OR environmental[Title/Abstract]) AND "climate change"[Title/Abstract]) Filters applied: before 2023/1/1." For Scopus, the search term was "TITLE-ABS ((health OR healthy) AND (disparity OR uneven OR inequality OR equality OR justice OR equity) AND (environment OR environmental) AND "climate change") AND (EXCLUDE (PUBYEAR, 2023)) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar"))".

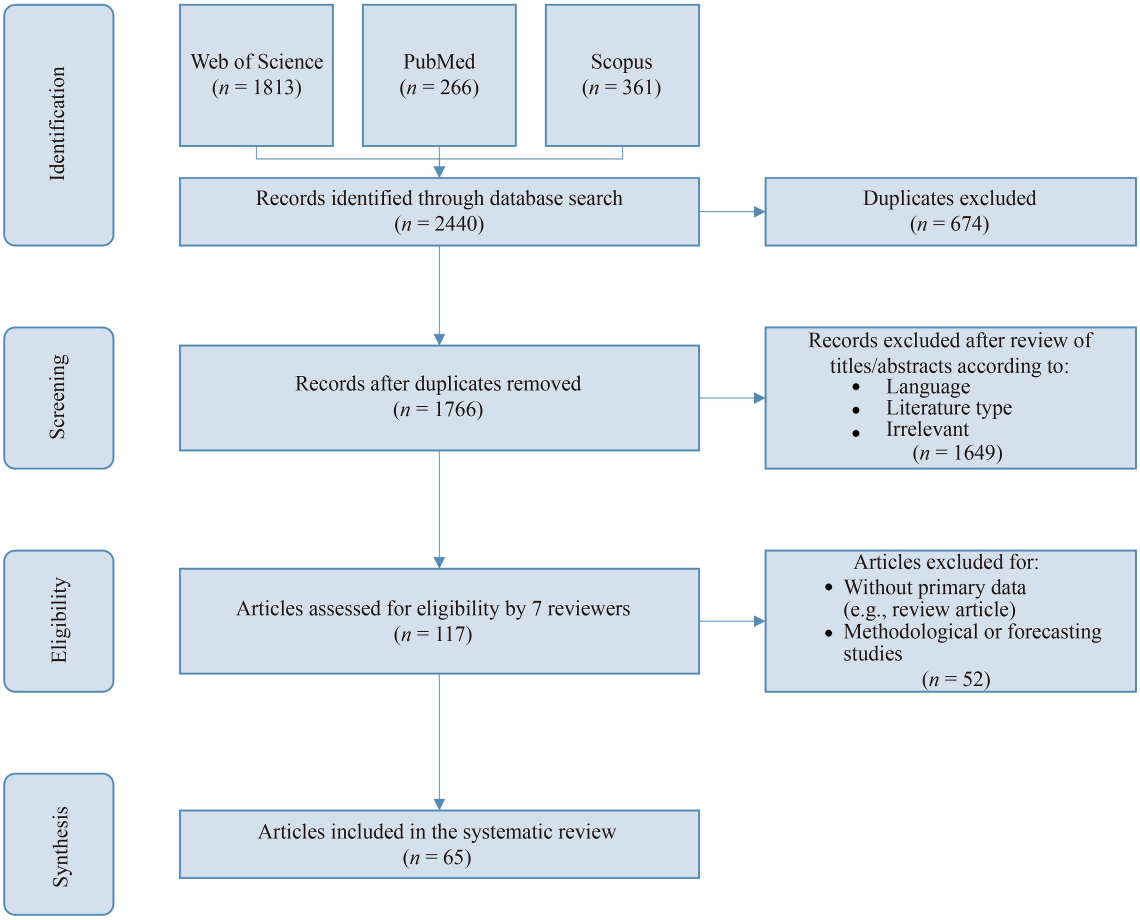


Fig. 1 The literature search and screening process.

relevant details. Supplementary Material A presents the basic information about these articles.

2.3 Keywords mapping

With Vosviewer 1.6.19 (van Eck and Waltman, 2010) software applied to conduct co-occurrence analysis, the keywords of these included articles were visualized, including their frequency of occurrence, correlations, and average publication year. The bibliographic data was counted using the default full counting method, with the strength of each link set to 1. In total, 46 keywords were selected by setting the minimum number of occurrences of a keyword to 3. Represented by the size of the circles in the keyword map, the weights were calculated on the basis of occurrence. Besides, the colors indicated the average year of publication of the literature.

2.4 Analytical framework

Under the frameworks provided by the IPCC (Cissé et al., 2022) and WHO (World Health Organization, 2021), an analytical framework consisting of causal chains and influencing factors was developed, as shown in Fig. 2.

The framework involves three main components in the causal chain from climate drivers to health outcomes: exposure, sensitivity, and adaptive capability. In the left-side box, the causal factors of inequality are identified, including demographic and socioeconomic conditions, physiological conditions, and geographical factors. On the right, there are definitions for exposure, sensitivity, and adaptive capability. Examples are provided for the intersection between causal factors and climate change-related health burdens. Under this analytical framework, the inequality of climate change-related health impacts for individuals and populations was reviewed. Furthermore, the intersection of various factors in the causal chain of health outcomes was examined. In addition, the existing literature was reviewed to identify the research gaps and future research directions in terms of research institutions, topics, regions, and methodologies.

3 Results

3.1 Research trend

Figure 3 illustrates the distribution of the publication year

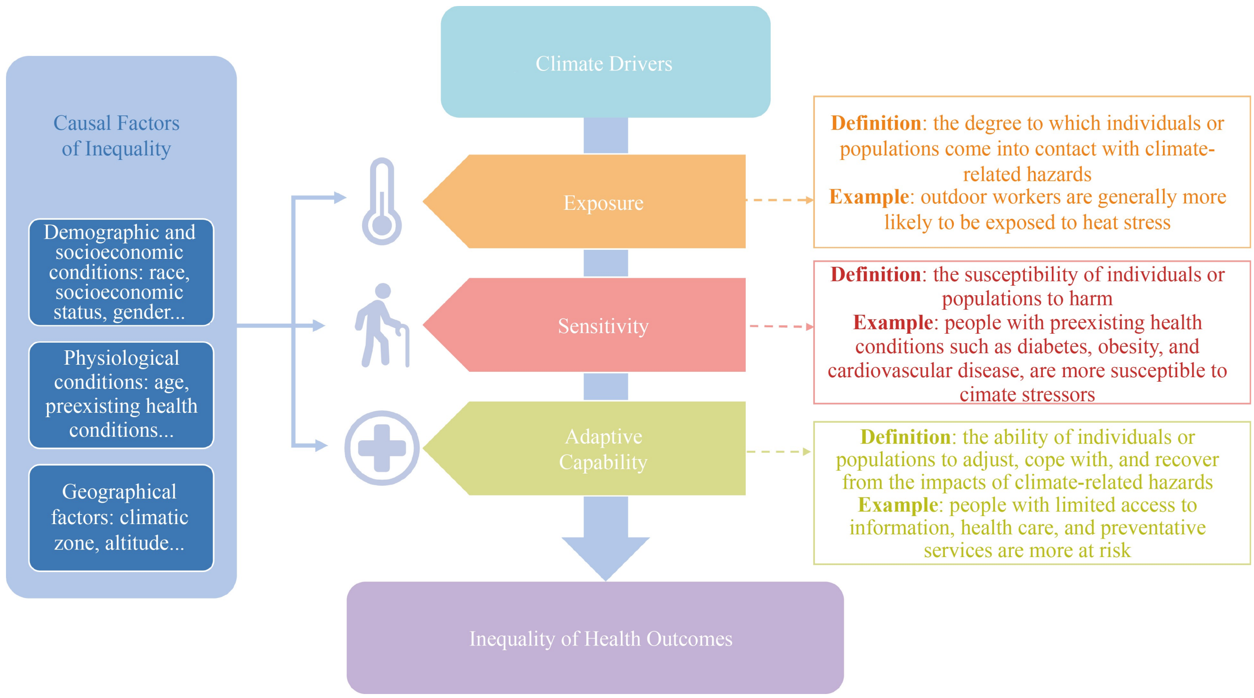


Fig. 2 Analytical framework of the review.

and the country affiliations of all authors' institutions for each article. In cases where the authors of a single article are affiliated with institutions in "n" different countries, each country is attributed a count of 1/n. This approach ensures an equitable representation of multinational collaborations, reflecting the global nature of research contributions and providing a comprehensive understanding of the geographical diversity in the field. The number of studies showed a significant increase after the publication of the 5th IPCC report in 2014, accounting for 89.2% (58 out of 65) of the total. The majority of publications were authored by researchers from the USA (n = 36.1), followed by China (n = 5.8), Australia (n = 3.6), Germany (n = 3.5), and Canada (n = 2.7). Developed countries contributed most to the studies (54.9 studies, 84.5% of the total).

The co-occurrences and average publication time of keywords were mapped to visualize the trend of changes in the research focus (Fig. 4). Initially, the studies (represented in blue) focused mainly on analyzing the health impacts of high and low temperatures through statistical methods, such as regression model. Subsequently, the research paid increasing attention to distinguishing the health effects on susceptible groups, such as the variations in health outcomes based on age, socioeconomic status, and gender/sex (indicated in orange). In recent years, the scope of climate-related hazards has expanded from the initial focus on temperature to the inclusion of drought, extreme weather events, floods, and other hazards. Regarding health impacts, there has been an expansion from traditional indicators such as morbidity and mortality rates to the inclusion of various dimensions such as mental health, vulnerability, and adaptive capacity. Furthermore, COVID-19 has emerged as a new research focus, as researchers have started to explore the overlapping and interactive effects of various health risks faced by humanity.

3.2 Regions in focus

For alignment with the continental regions of the world, the study area was divided into seven regions: North America, Europe, Oceania, Asia, Africa, South America, and the whole world. In this context, the whole world means that the spatial scale of the study is global. Antarctica was excluded from our analysis due to the absence of permanent inhabitants and the limited availability of literature on the health effects of climate change in that region.

Figure 5 illustrates the distribution of publications, with different climatic health hazards covered across various regions. The number of publications related to heat is found to be the highest, with 44 out of the 65 publications involved. Rising sea levels and extreme rainfalls are the second most commonly studied hazards, involving 14 publications. Cold spell ranks third with 11 publications involved. Droughts and wildfires are less frequently studied, each of which involves seven publications. They are followed by food-related and climate-infectious diseases, with six publications each. As for cyclones and storms, the number of publications is the lowest, which is

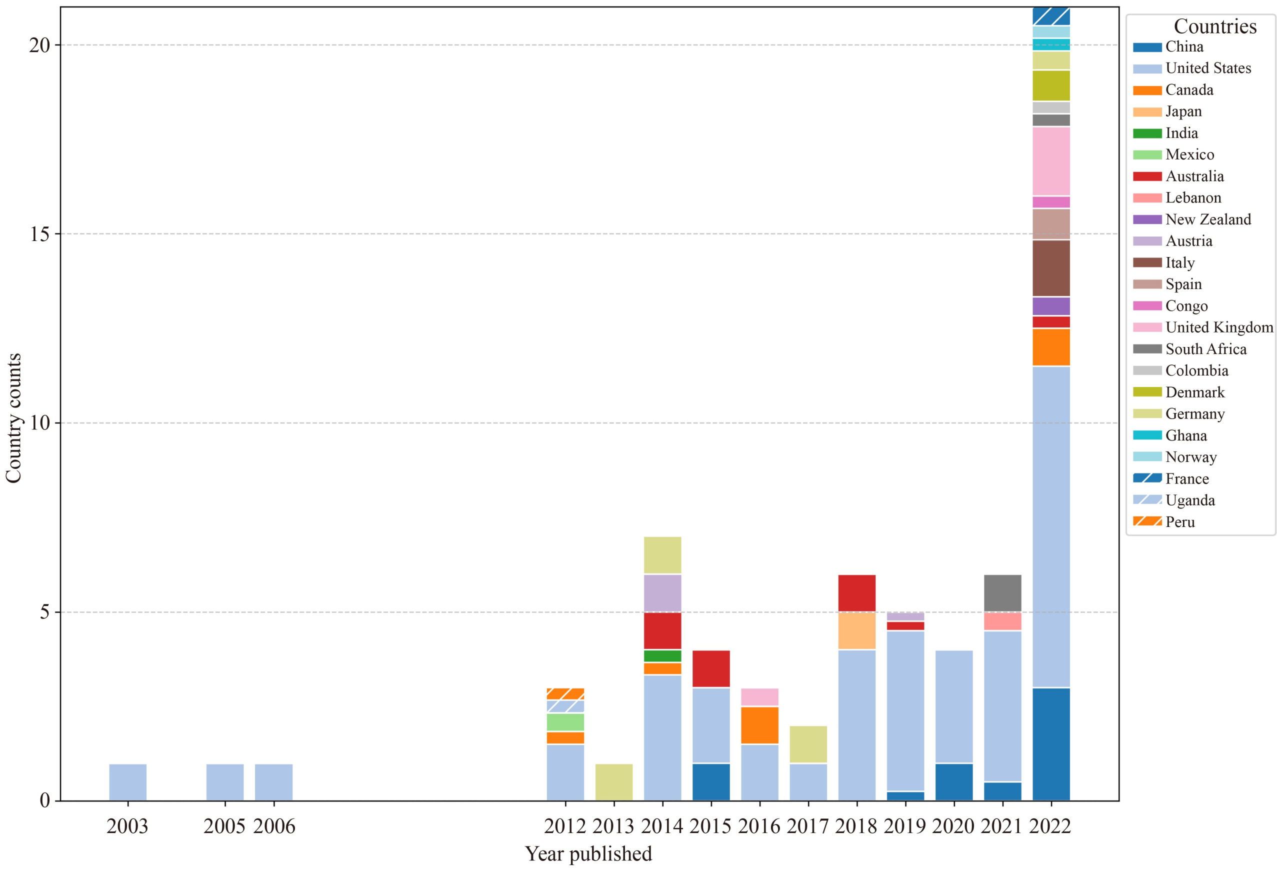


Fig. 3 Global distribution of author affiliations and publication years in climate change and health inequality research (2003–2022). Notes: The initial screening process included all articles in the database that matched the search term up to 2022. After the final evaluation, the temporal distribution of articles ranged from 2003 to 2022. The figure accounts for multinational author collaborations by allocating a fractional count of 1/*n* to each country for articles with authors from "*n*" different countries.

3. Additionally, the four articles classified as "Other" are common in discussing air pollution, including particulate matter, NO_2, and ozone. Notably, each publication in Fig. 5 can be counted multiple times if it covers more than one region or hazard.

By region, the majority of studies were focused on North America ($n = 36$), followed by Europe ($n = 9$), Asia ($n = 8$), Africa ($n = 7$), Oceania ($n = 4$), global analysis (represented as Whole World, $n = 3$), and South America ($n = 2$).

With reference to the IPCC AR6 report by Working Group II (Intergovernmental Panel on Climate Change, 2022), the urgency of regional risks was illustrated. In our review, these key risk categories were corresponded to the hazards of heat, wet and coastal, food, and disease, with the trends in adverse impacts assessed by the IPCC and the confidence degree of attribution to climate change marked on the graph in red and pink for high and medium, respectively. To some extent, this indicates the urgency of the different risks faced in different regions.

As mentioned in the introductory section, the uneven distribution of climate-related health impacts is not only severe but also widespread. Often, a severe crisis of inequality occurs where climate health risks are most urgent. Therefore, the urgency of regional health risks was further investigated as a reference for comparison to the amount of literature on health inequalities in that location. It was discovered that some regions are faced with serious health impact risks. However, there is limited literature on the inequalities in those regions, implying an area for potential progress in future research. For instance, significant health risks are posed in Oceania by wet and coastal hazards, as well as food insecurity. However, there is an absence of literature focusing on the unequal distribution of health impacts in these areas. Similarly, there are health risks faced by Europe due to wet and coastal hazards, food insecurity, and disease. However, most studies revolve around the unequal distribution of health impacts related to high and low temperatures. In contrast, there are few studies exploring the unequal distribution of health impacts caused by other hazards.

It is worth noting that the articles selected for this review are aimed specifically at addressing inequality. They constitute a subset of the broader literature on the

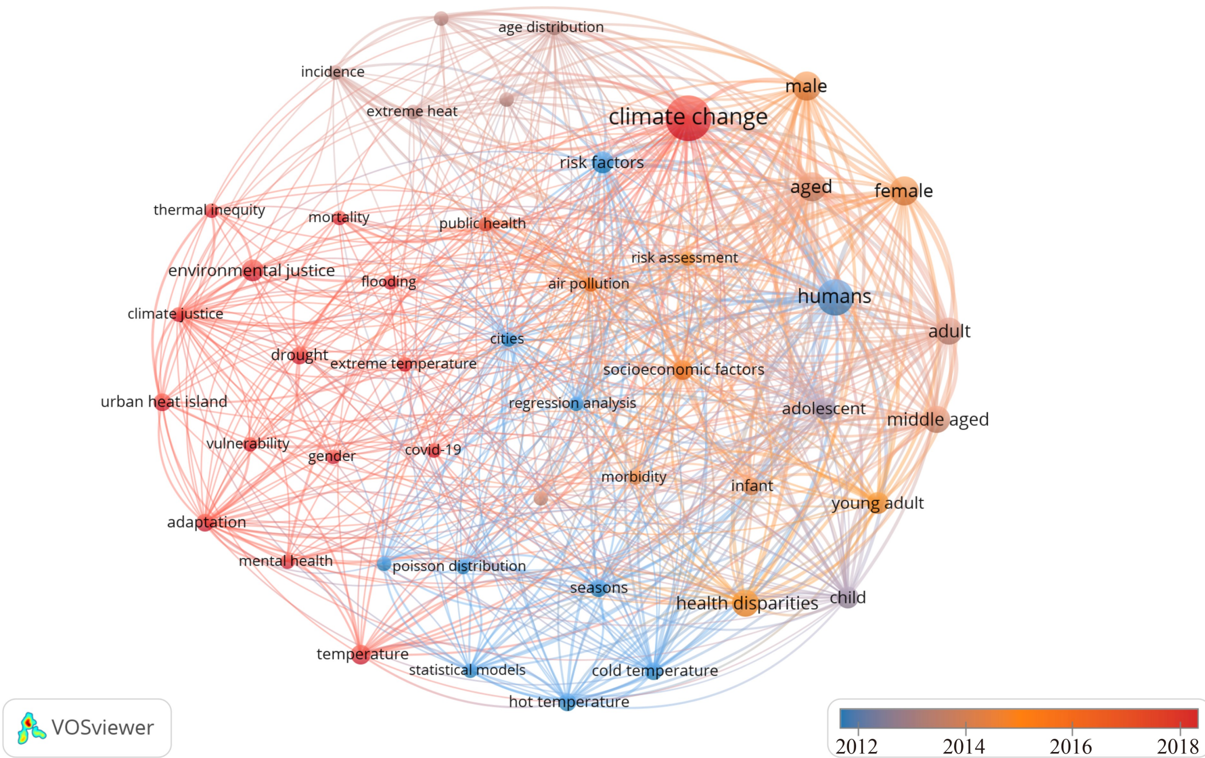


Fig. 4 Visualization of keywords in the selected publications. Notes: Each circle represents a keyword, with the circle's size indicating the keyword's frequency of occurrence across the compiled articles. The color of each circle denotes the average publication time of the articles where the keyword appears, illustrating temporal trends in research focus. Lines between circles represent co-occurrences of keywords within the same articles, indicating thematic connections and common research areas.

Climatic health hazard	North America	Europe	Oceania	Asia	Africa	South America	Whole World
HT	19	9	4	5	3	1	3
CS	2	3	1	3	1	0	1
DR	1	0	0	0	4	2	0
RSL&ER	8	0	0	1	3	1	1
CY&ST	1	0	0	0	1	1	0
WF	5	0	0	0	1	1	0
FBD&MN	2	0	0	0	3	1	0
CID	2	0	0	0	3	1	0
OTH	3	1	0	0	0	0	0

Increasing adverse impacts, high or very high confidence in attribution to climate change

Increasing adverse impacts, medium confidence in attribution to climate change

Length represents number of articles

Fig. 5 The distribution of research regions. Notes: "HT" stands for Heat, indicating extreme heat events or heatwaves; "CS" represents Cold Spell, referring to periods of unusually cold weather; "DR" denotes Droughts, which are prolonged periods of dry weather and water scarcity; "RSL&ER" encompasses Rising Sea Levels and Extreme Rainfalls, highlighting the combination of sea level rise and heavy rainfall events; "CY&ST" signifies Cyclones and Storms, characterized by intense weather systems with strong winds and rain; "WF" pertains to Wildfires, referring to uncontrolled fires in wildland areas; "FBD&MN" covers Food-borne Diseases and Malnutrition, including illnesses transmitted through food and nutritional deficiencies due to climate impacts; "CID" refers to Climate-infectious Diseases, which are illnesses influenced or spread by climatic factors; and "OTH" includes additional climate-related impacts not specifically categorized in the aforementioned terms.

health impacts of climate change. By comparing regional health risks with the amount of literature on inequalities, the possible research gaps in this particular sub-field were identified, which is the only purpose of such comparison.

3.3 Methodologies of existing literature

The selected articles were categorized into three broad types depending on the research methodology applied:

qualitative studies, quantitative studies, and studies utilizing mixed methods, where both qualitative and quantitative research tools are employed. The spatial and temporal scales of research are also indicated in Fig. 6.

Among the 65 articles included in this study, the majority (55 articles) rely on quantitative analysis, while six articles are based on qualitative assessment, and the remaining four articles adopt mixed methods. In terms of research scale, most studies are conducted on a relatively small temporal and spatial scale, which is typically less than ten years (n = 54) and at the city or sub-national level (n = 46).

As a common method used to conduct research on climate change and health, statistical regression is performed in 33 out of 65 articles. The methods of this class encompass a range of statistical techniques, including but not limited to linear regression (Grineski et al., 2012; Wanka et al., 2014; Smith and Hardeman, 2020; Rhubart and Sun, 2021; Ellena et al., 2022; Navas-Martín et al., 2022), Poisson or quasi-Poisson regression (O'Neill et al., 2003, 2005; Anderko et al., 2014; Green et al., 2015; Yang et al., 2015; Riley et al., 2018; Liu et al., 2020; Conte Keivabu, 2022; Ellena et al., 2022; Khatana et al., 2022; Nyadanu et al., 2022), negative binomial regression (Abadi et al., 2022; Lambourg et al., 2022; Lee and Brown, 2022), spatial regression (Grineski et al., 2012; Dialesandro et al., 2021), logistic regression (Mutic et al., 2018; Callender et al., 2022), and others.

Through the regression method, the impact of climate change on people's health outcomes can be described quantitatively and objectively. Besides, the vulnerable populations subjected to climate change inequalities can be identified, along with the variables linked to health outcomes. However, this method is also faced with limitations. One of the most significant drawbacks is that regression models are restricted to showing associations rather than causality. Additionally, it falls short in capturing the complex relationship between climate change and health outcomes, particularly due to challenges in integrating indirect and non-quantitative

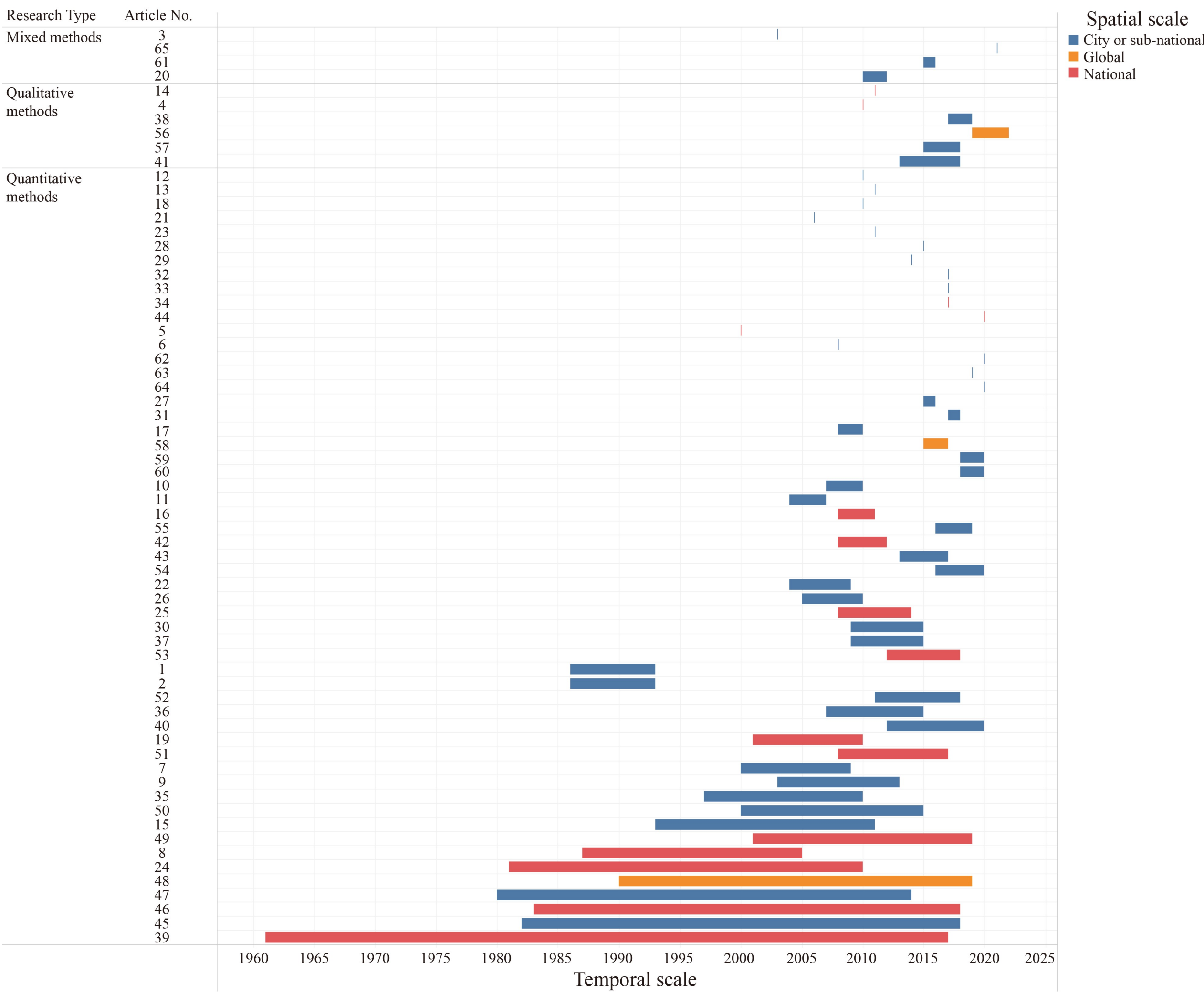


Fig. 6 Research methodologies, spatial and temporal scales of selected articles.

factors. Another challenge lies in data accessibility, especially in the less-developed regions where climate health challenges are more pronounced.

The main qualitative research methods applied in the selected articles include case studies, interviews, and focus group discussions (Berrang-Ford et al., 2012; Hansen et al., 2014; Méndez et al., 2020; Abrams et al., 2021; Ahmed et al., 2022; Engelman et al., 2022). By using qualitative methods, researchers can better understand the experiences and perspectives of individuals or vulnerable groups. Providing a more nuanced and comprehensive view of how social identities intersect and influence vulnerability to the health impacts of climate change, they can help identify the hidden factors that may be overlooked in quantitative data. For instance, the vulnerability of undocumented Latino and Native immigrants during the Thomas Fire in the USA was analyzed through a case study to gain insight into various factors such as racial discrimination, exploitation, economic hardship, limited English and Spanish language skills, and the fear of deportation in their daily lives and in the context of climate change hazards (Méndez et al., 2020).

Undoubtedly, qualitative research is also subject to some limitations worth considering. Firstly, the findings of qualitative research apply only to a particular group of individuals, which means they can not be generalized to a larger population. Secondly, qualitative research shows subjectivity and is susceptible to the influence of the personal bias or interpretation of the researcher. Additionally, qualitative research may fail to fully reveal the complexity of the relationship between climate change and health outcomes as it is focused on individual experiences rather than larger population-level patterns. In spite of this, qualitative research remains crucial to exploring the experiences and perspectives of vulnerable populations as it provides insights into the social and cultural factors affecting their vulnerability to climate change impacts.

In some studies, qualitative and quantitative methods are used in combination to thoroughly examine the inequalities in the health impacts of climate change (Harlan et al., 2006; Wilder et al., 2016; Adepoju et al., 2022; Papworth et al., 2022). This approach can be adopted to better understand the experiences and perceptions of vulnerable populations. Meanwhile, a more objective analysis of the data are enabled. Given the complexity of combining quantitative and qualitative methods, careful planning, data management and analysis, and interpretation of findings are required. Despite these challenges, the use of mixed methods represents an important trend of future research in this area, considering its potential to reveal previously unknown insights and enhance the effectiveness of policy and practice.

3.4 Inequality of exposure, sensitivity, and adaptive capability

The causal factors contributing to inequality in the literature were analyzed, and the elements involved in the causal chain that caused inequality were identified. Figure 7 shows the results. Involving multiple elements or causal factors, some of the literature may have been counted multiple times.

Among these elements, exposure is the most studied (34 out of 65 studies), followed by adaptive capability (31 studies) and inherent sensitivity (8 studies). There are a number of articles restricted to describing the inequality of climate change-related health burdens, with no clear indication of the causal mechanism. For this reason, they were coded as “not clear” in terms of the element in the causal chain.

In terms of causal factors, demographic and socioeconomic conditions are most discussed, with 57 out of 65 in this category. Specifically, socioeconomic status (SES) is most frequently studied in this category, with 45 articles exploring its role in the health inequalities caused by climate change. Race or ethnicity is the second most studied factor, with 38 articles centered on this aspect.

Since both gender and sex play a role in shaping health outcomes, this review distinguishes between them as well. Sex refers to biological and physiologic differences, while gender encompasses socially constructed identities, social roles, and behaviors. For example, there is one study exploring the social and economic factors that contribute to gender inequalities in health impacts, such as the unequal ownership and control of household assets, the gender division of labor, as well as the prevalence of discriminatory legal systems and social practices (Eastin, 2018). This study is classed as a discussion of the “gender” factor. In another study, the differences in heat-related illness symptoms between male and female farmworkers were reported. It was suggested that various biological factors, including high body surface to mass ratio, morphology, and adipose distribution among women, are the contributors to this difference (Mutic et al., 2018). This study falls into the category of a discussion about the “sex” factor.

3.4.1 Exposure

Exposure to climate change-related hazards is widely viewed as a major contributor to climate-related health burdens. The impact of exposure inequality is especially evident among vulnerable groups, which is attributable to various demographic and socioeconomic conditions, physiologic conditions, and geographical factors. There is usually an interrelationship present between these factors, which leads to the complex causal mechanisms.

In the domain of exposure research, a well-established consensus delineates the mechanisms whereby popula-

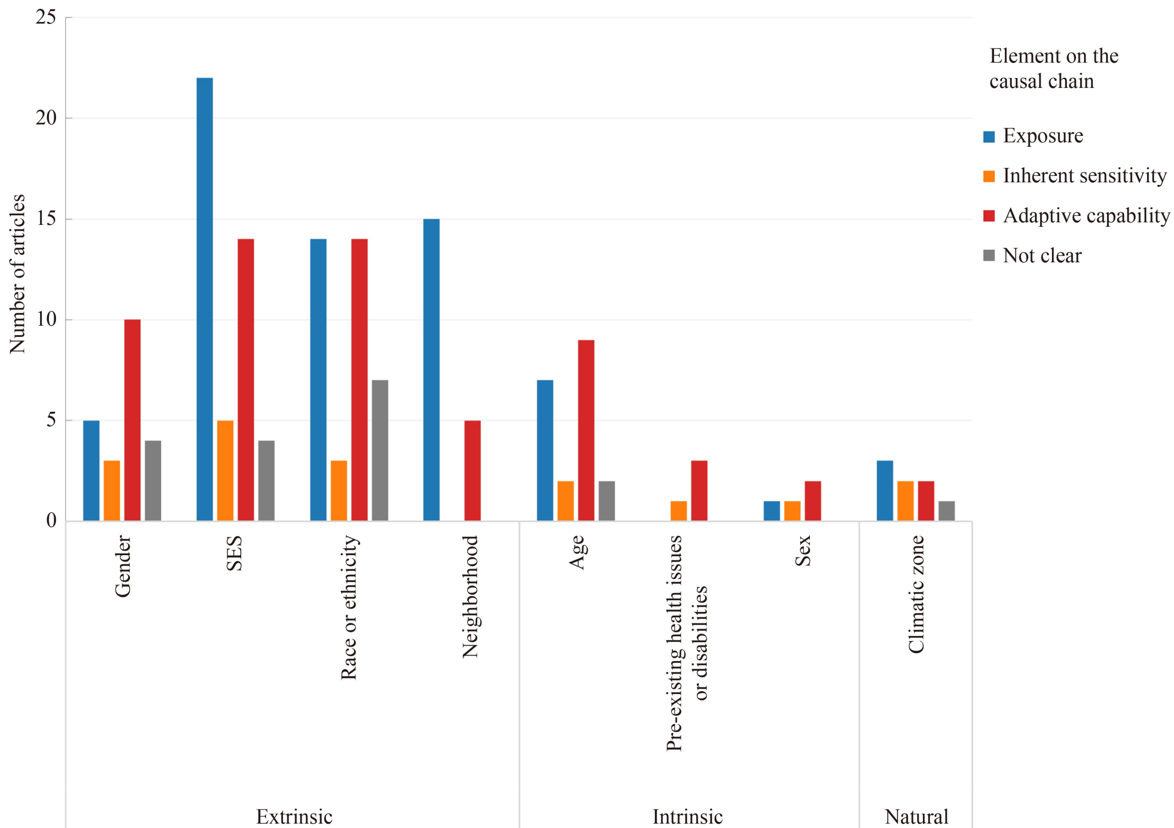


Fig. 7 Number of articles including each causal factor.

tions, particularly those of lower socio-economic status, are disproportionately situated in locales more vulnerable to environmental hazards. This dynamic is aptly demonstrated in the studies (Collins et al., 2019; Qiang, 2019) which illustrate how economically disadvantaged populations are more likely to inhabit flood-prone zones. For example, Qiang's analysis (Qiang, 2019) assessed the socio-economic disparities in population exposure to flood hazards across USA counties. The findings revealed that, at a national scale, economically disadvantaged populations are more prone to reside in flood zones than outside. At a local scale, economically disadvantaged populations tend to occupy flood zones in inland areas, while coastal flood zones are predominantly occupied by wealthier and elderly individuals. Another dimension of socio-economic vulnerability emerges in urban settings, where poorer individuals tend to live in areas characterized by high building density and limited urban green and water spaces. Such urban environmental features exacerbate exposure to heatwaves (Scherber et al., 2013; Mitchell and Chakraborty, 2014).

These studies, therefore, collectively underscore the intersection of socio-economic status and environmental exposure, revealing a pattern in which less affluent communities are disproportionately subjected to diverse environmental hazards, such as floods and heatwaves. This pattern not only poses serious public health challenges but also underscores the urgent issue of environmental justice.

3.4.2 Inherent sensitivity

There is a higher level of sensitivity and vulnerability to climatic hazards among some populations due to their own health status, biological characteristics, etc. The articles included in this review focused mainly on three causal factors: physiologic sex, age, and pre-existing health conditions or disabilities.

In a study conducted in 26 regions across the south and west of China from 2008 to 2011, the effect of temperature on cardiovascular mortality was estimated to reveal that males tend to have a higher risk at cold temperatures, while females tend to have a higher risk at high temperatures (Yang et al., 2015). Despite a lack of clarity on the underlying mechanism for this observation, it is hypothesized that the higher body fat content of females makes them more resistant to coldness but less heat-resistant than their male counterparts. Furthermore, another study on temperatures and sleep suggested that females tend to experience a decrease in their body temperature earlier in the evening than males, which may cause them to experience higher environmental temperatures at bedtime. Additionally, females tend to have more subcutaneous fat, which may increase their difficulty in releasing heat at night. According to the data obtained from this literature, night-time temperature increase has a more significant per-degree negative impact on women than on men ($P < 0.01$) (Minor et al., 2022).

A recent study conducted in Cincinnati, Ohio, analyzed the data on emergency medical service (EMS) incidents over a 5-year period (2016–2020) at the census block group level (Lee and Brown, 2022). In the study, the proportion of the population aged over 65 was identified as a statistically significant predictor of an increased risk of medical incidents. In another article, the environmental injustice implications of three climate change-related hazards were examined in the bi-national context of El Paso, Texas and Ciudad Juárez, Chihuahua, which are extreme heat, peak ozone, and floods. According to this study, the children in El Paso are significantly more burdened by peak ozone (Grineski et al., 2012). Similar conclusions have been drawn from other studies, indicating that vulnerable age groups such as the elderly and children tend to be more sensitive to heat stress (Hansen et al., 2014; Heudorf and Schade, 2014; Liu et al., 2020), air pollution, extreme precipitation (Bush et al., 2014), and other hazards, and are therefore more likely to experience negative health effects.

Focusing on the experiences of people with disabilities during climate disasters, a case study highlights their physiologic vulnerability to the adverse effects of climatic hazards, such as heat and smog (Engelman et al., 2022). For instance, individuals with autoimmune diseases—which affect over 70 million people worldwide—may find it difficult to regulate their body temperature, thus increasing their susceptibility to the harm caused by temperature. As further indicated in the study, it is often the case that disabilities and pre-existing health conditions exacerbate the exposure to climate hazards, reduce adaptive capacity, and increase the overall vulnerability of this population, which is a combined effect.

3.4.3 Adaptive capability

As shown in the selected articles, different populations varied in their adaptive capacity to climate change. In many cases, the poorer adaptive capacity results from a combination of various exogenous factors such as SES, ethnicity, gender and a range of endogenous factors such as age and prior health status.

For example, it is highlighted in the previously mentioned research on disability justice that disability affects whether and how people have access to the information and resources needed to prepare, manage and adapt to disasters and climate health risks promptly. Those with disabilities and low incomes may not be able to afford the costs of adapting to climate risks, such as the use of back-up generators to power ventilators. They may also encounter additional barriers to accessing technological solutions (e.g., mobile phones, computers and internet access). Additionally, they may be daunted by the “digital divide” and illiteracy, which are more prevalent in developing countries. A similar circumstance is found among the immigrant and refugee groups, where various socio-cultural barriers hinder them from adapting to climate hazards, including low socio-economic status, poor housing conditions, language barriers, isolation, health problems, cultural factors, and a lack of adaptation (Hansen et al., 2014).

In some papers, the important role of facilities, such as air conditioning, in climate change adaptation is referred to. As demonstrated by a study exploring disparities by race in heat-related mortality in four USA cities, the prevalence of central air conditioning in black households was lower than half of that in white households in all four cities. Furthermore, black deaths were more significantly correlated with high temperatures, and the prevalence of central air conditioning contributed to the variation in heat effects by race to some extent (O’Neill et al., 2005). In some other studies on heat waves, it has also been highlighted that the poorer, rural populations of racial minorities are less likely to have access to air conditioning, which reduces their capacity to adapt to extreme heat events (Bobb et al., 2014; Hu et al., 2019).

3.5 Vulnerable populations

The selected articles were reviewed to identify 12 categories of vulnerable populations. Table 2 lists the number of papers in which these populations and the corresponding climate hazards are examined. These articles were counted multiple times, given the possibility of them addressing multiple vulnerable populations and climate hazards. The hazards related to temperature are the most discussed topic, of which heat is a particular focus of attention. Those with low SES are the most discussed vulnerable group ($n = 34$), followed by marginalized populations such as people of color, indigenous people and migrants (these populations are counted together, $n = 28$) and females ($n = 14$). Other vulnerable groups include elderly people ($n = 12$), people in the regions with certain geo-climatic features ($n = 7$), people with disadvantaged housing conditions ($n = 7$), people with pre-existing health issues or disabilities ($n = 5$), children ($n = 4$), vulnerable industries ($n = 4$), people in urban areas ($n = 3$), males ($n = 2$), and people in rural areas ($n = 2$).

According to the relevant research, the inequality of climate change-related health burdens is often attributed to various causal factors and mechanisms in combination. Due to a confluence of inequality in multiple dimensions, the uneven distribution of health burdens is perpetuated and reinforced, including but not limited to residential segregation, healthcare, employment, and educational discrimination.

Table 2 Vulnerable populations and number of relative articles

Hazard	Number of articles including each vulnerable group											
	Females	Males	People with low SES	Vulnerable industries	People of color, indigenous people and migrants	People with disadvantaged housing conditions	People in rural areas	People in urban areas	Children	Elderly people	People with pre-existing health issues or disabilities	People in regions with certain geo-climatic features
HT	10	2	21	2	19	6	1	3	2	10	4	3
CS	3	1	7	1	4	1	1	0	1	5	1	2
DR	3	0	1	0	2	0	0	0	0	0	2	1
RSL&ER	2	0	8	1	4	1	1	0	3	1	2	2
CY&ST	1	0	1	0	1	0	0	0	0	1	0	0
WF	2	0	3	0	3	0	0	0	0	0	0	0
FBD&MN	2	0	2	1	1	0	0	0	0	0	0	0
CID	1	0	1	0	2	0	0	0	0	0	0	1
OTH	1	0	2	0	1	0	0	0	1	0	1	0

Notes: The color shade indicates the number of articles. "HT" stands for Heat, indicating extreme heat events or heatwaves; "CS" represents Cold Spell, referring to periods of unusually cold weather; "DR" denotes Droughts, which are prolonged periods of dry weather and water scarcity; "RSL&ER" encompasses Rising Sea Levels and Extreme Rainfalls, highlighting the combination of sea level rise and heavy rainfall events; "CY&ST" signifies Cyclones and Storms, characterized by intense weather systems with strong winds and rain; "WF" pertains to Wildfires, referring to uncontrolled fires in wildland areas; "FBD&MN" covers Food-borne Diseases and Malnutrition, including illnesses transmitted through food and nutritional deficiencies due to climate impacts; "CID" refers to Climate-infectious Diseases, which are illnesses influenced or spread by climatic factors; and "OTH" includes additional climate-related impacts not specifically categorized in the aforementioned terms.

By gender, both females and males have been identified as vulnerable groups, which is largely attributed to the different causal mechanisms of inequality. For example, research has found that males tend to have a higher risk at cold temperatures, while females tend to have a higher risk at high temperatures (Yang et al., 2015). Despite no clear explanation provided by the authors for the different causal mechanisms, this is speculated to result from the gender-based physiologic differences.

However, socially constructed gender differences and corresponding additional vulnerabilities of women in society remain the focus of discussion about gender disparities in the context of climate change vulnerability. It is indicated that the gender inequalities in climate change vulnerability reflect pre-existing gender inequalities while reinforcing them. In the context of climate change, women are faced with inequalities in owning and controlling household assets, increased household burdens due to male outmigration, the reduction in food and water supplies, the extra vulnerability caused by pregnancy and childbirth, and increased disaster risks, among others (Schmeltz et al., 2016; Eastin, 2018; Mutic et al., 2018; Berndt and Austin, 2021; Ahmed et al., 2022; Minor et al., 2022; Navas-Martín et al., 2022; Zeng et al., 2022a). These factors make women less able to gain economic independence, improve human capital, and maintain health and well-being.

Vulnerable groups are comprised of individuals residing in both urban and rural areas, which appears paradoxical. However, there are variations in the cause of unequal health burdens. Rural residents are often considered vulnerable due to their exposure and limited adaptive capacity. For example, a study conducted in Zhejiang, China, revealed a higher mortality risk linked to extreme temperatures in rural areas than in urban areas, regardless of age group, gender, and disease type (Hu et al., 2019). This is possibly attributed to the demographic and socio-economic factors associated with the level of urbanization in China, such as age structure, education, GDP, health services, occupation type, and access to air conditioning (1.21 vs. 1.66 units per household). Similarly, a study carried out in the USA demonstrated that flood risk is higher in rural areas on average, and rural residents are more vulnerable to flood-related events, which exposes them to both public health issues and economic insecurity (Rhubart and Sun, 2021).

The unequal sharing of health burden by urban residents is closely linked to heat-related events. According to the relevant studies, the specific urban environment presents various challenges for urban residents, including higher building densities, greater anthropogenic heat emissions, and less green and water space. Consequently, there is a rise in heat-related risks across urban areas (Scherber et al., 2013; Wu et al., 2021; Zeng et al., 2022b).

4 Discussion

4.1 Addressing regional bias and neglected climate hazards

As revealed by the literature review, there is a regional bias in the existing research, as most studies are focused on developed regions and conducted by authors affiliated with institutions in developed countries. This causes a limitation on the generalizability of findings and a lack of attention paid to some less-developed regions and some areas with high climate risks, as noted in Section 3.2. Furthermore, the existing research is focused mainly on temperature-related hazards, with a particular emphasis on heat, while less attention is brought to other climate hazards with a significant impact on human health. To close these gaps, it is necessary to identify the vulnerable populations facing critical health challenges in future research, where less-developed regions and understudied hazards should be prioritized. This is of particular importance as vulnerable populations may require the mitigation of health impacts caused by climate change through tailored interventions (World Health Organization, 2021; Cissé et al., 2022).

4.2 Advancing interdisciplinary approaches in climate-health research

Allowing for the long and complex causal chain of impacts of climate change on human health (Romanello et al., 2022), innovative and interdisciplinary approaches must be adopted to find multidimensional factors and elements across the climate-health causal chain. During the review, a lack of solid evidence has been identified through an in-depth analysis of the causal mechanisms to account for how natural, biological, and social factors contribute to health inequality. In addition, there is an absence of thorough examination of the correlation between exposure, sensitivity, and adaptive capability, which represent the three concepts in the causal chain from climate drivers to health outcomes. The unequal distribution of health burdens is caused in a complex way, as there are multiple forms of oppression intersecting and interacting with each other. In this context, the impact of climate change on health inequalities must be analyzed from an intersectional perspective (Kaijser and Kronsell, 2014; Versey, 2021; Adepoju et al., 2022; Callender et al., 2022). Regarding methodology, it is highlighted in the review that quantitative and qualitative analyses have their respective strengths and limitations in assessing inequality. It is suggested that future research should be conducted using more innovative tools that integrate multiple methods.

However, it is important to note that the research gaps identified are within the scope of our review, which primarily focuses on empirical data-based studies. Some modeling or theoretical research articles, which are not based on primary empirical data, may have discussed the causal chain and interactions in the literature. However, they are beyond the scope of our analysis.

4.3 Assessing climate-related health inequality at large-scale

To a large extent, the existing research on climate-related health impacts is focused on short-term exposure to regional climate hazards, which leads to a gap in our understanding of how these impacts are distributed across different countries and regions. This is of particular importance given the long-term and global nature of climate change, which can make the existing global health disparities more significant over time. Thus, large-scale studies are required to capture the wide range of temporal and spatial scales related to climate change. This is conducive to gaining insight into the social, political, and economic factors contributing to health inequalities.

However, there are several methodological challenges posed by such studies, including data acquisition and management, resource allocation, and coordination across multiple research teams. To address these challenges, it is essential to establish a more coherent and clear research framework and assessment criteria for better comparability of studies and uniform, robust assessments across regions of the world. Through a regular collection of new findings and evidence in the global field, as done by the Lancet Countdown team (Watts et al., 2019a; Romanello et al., 2021; Watts et al., 2021; Romanello et al., 2022) and the IPCC (Intergovernmental Panel on Climate Change, 2014a, 2014b, 2022), contribution can be made to this large-scale view and the most up-to-date evidence can be gathered for policymakers and the public.

Ultimately, a global perspective that integrates diverse perspectives and disciplines will be key to understanding the complex and multifaceted relationships between climate change and health inequalities. As elucidated in the works of scholars like (Smith et al., 2022) and (Gould and Rudolph, 2015), the role of entrenched structural inequalities in exacerbating health disparities underlines the necessity for an analysis that transcends traditional disciplinary confines. (Morris et al., 2017) and (Rudolph and Gould, 2015) enrich this discourse by dissecting the proximal and distal dimensions of climate impact on health, highlighting the spectrum of direct and indirect effects. The perspectives of (Khanal et al., 2023) and (Pearson et al., 2023) reinforce the need for an integrated framework focusing on health equity to ensure inclusive and equitable responses to climate change. Such a comprehensive, globally-oriented perspective, weaving together insights from environmental science, public health, and social sciences, is quintessential in untangling the complexities at the intersection of climate change and health inequalities, paving the way for informed, holistic, and effective interventions.

4.4 Strengths and limitations

The primary strength of this article lies in its comprehensive review of peer-reviewed literature on health burden inequalities caused by climate change, meticulously examining the exposure, sensitivity, and adaptive capacity dimensions and their interplay with demographic, socio-economic, and geographical factors. Through critical analysis, the paper not only synthesizes key contributing factors to health inequalities induced by climate change but also identifies gaps in current research trends.

However, the study does face notable limitations. The literature review's exclusive reliance on English-language sources may omit essential non-English research, potentially introducing geographic biases. This limitation, while a byproduct of striving for consistency and manageability within our constraints of time and resources, highlights the need for future research to embrace a broader linguistic and geographic scope.

Additionally, in pursuit of focused thematic exploration, the study employed a strict search strategy and inclusion criteria, limiting articles to those with specific keywords in their title or abstract. While this approach ensured a concentrated examination of the most relevant literature, it might have inadvertently excluded significant studies. In future research, expanding the range of considered studies would allow for a more inclusive and comprehensive understanding of this complex issue, capturing the full spectrum of impacts and contributing to a more nuanced discussion in this critical field.

Furthermore, while our screening process implemented stringent quality control measures, it did not extend to quantitative scoring or an exhaustive quality assessment of the selected articles. This was largely attributed to the varied nature of the included studies, rendering the establishment of a standardized quality assessment framework challenging. Future research could consider developing flexible quality assessment models that can adapt to the diversity of studies in this field, thereby enhancing the methodological rigor of literature reviews.

5 Conclusions

In this review, the pressing issue caused by climate change to the inequality of health burdens sharing is highlighted. The growing concern about the impact of climate change on human health is underscored by the severe inequalities in human society. Desirably, there has been an increase in the number of studies and research covering a wider range of topics recently, which further evidences the fact that climate change affects human health unequally. A thorough review of the existing literature is conducted in this study to synthesize the demographic and socioeconomic conditions, physiologic conditions, and geographical factors that cause inequality, with the most affected and vulnerable populations identified.

Meanwhile, this review also highlights the research biases and methodological challenges with the potential to hinder the comprehensive understanding of this complex and multifaceted issue. Specifically, the existing research pays insufficient attention to less-developed regions, with less emphasis placed on non-temperature-related health hazards. Also, climate change is inadequately attributed, and large-scale studies are absent. In future research, the priority should be to address these gaps for a deeper understanding of the unequal impact of climate change on human health.

The pressing requirement to innovate and implement research tools for the detailed assessment and quantification of health impact inequalities deserves reiterated focus. Additionally, it is necessary to better integrate physical evidence and socio-political-economic factors on climate and health through more interdisciplinary approaches and extensive collaboration between research teams. These efforts facilitate decision-making to support the mitigation of adverse impacts on human health, well-being, and social equity caused by current and future climate change. By overcoming these challenges, the unequal distribution of climate change health burdens can be mitigated, and a more equitable and sustainable future can be created for all.

Acknowledgements This research was funded by the National Natural Science Foundation of China (Nos. 71773062, 71525007, 72140002, and 72204137) and the National Social Science Foundation of China (No. 17ZDA077).

Conflict of Interests The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest

Electronic Supplementary Material Supplementary material is available in the online version of this article at https://doi.org/10.1007/s11783-024-1823-4 and is accessible for authorized users.

References

Abadi A M, Gwon Y, Gribble M O, Berman J D, Bilotta R, Hobbins M, Bell J E (2022). Drought and all-cause mortality in Nebraska from 1980 to 2014: time-series analyses by age, sex, race, urbanicity and drought severity. Science of the Total Environment, 840: 156660

Abrams A L, Carden K, Teta C, Wågsæther K (2021). Water, sanitation, and hygiene vulnerability among rural areas and small towns in South Africa: exploring the role of climate change, marginalization, and inequality. Water, 13(20): 2810

Adepoju O E, Han D, Chae M, Smith K L, Gilbert L, Choudhury S, Woodard L (2022). Health disparities and climate change: the intersection of three disaster events on vulnerable communities in Houston, Texas. International Journal of Environmental Research and Public Health, 19(1): 35

Ahmed S, Eklund E, Kiester E (2022). Adaptation outcomes in climate-vulnerable locations: understanding how short-term climate actions exacerbated existing gender inequities in coastal Bangladesh. Journal of Environmental Planning and Management, 66(13): 2691–2712

Anderko L, Davies-Cole J, Strunk A (2014). Identifying populations at risk: interdisciplinary environmental climate change tracking. Public Health Nursing, 31(6): 484–491

Asayama S, Emori S, Sugiyama M, Kasuga F, Watanabe C (2021). Are we ignoring a black elephant in the Anthropocene? Climate change and global pandemic as the crisis in health and equality Sustainability Science, 16(2): 695–701

Berndt V K, Austin K F (2021). Drought and disproportionate disease: an investigation of gendered vulnerabilities to HIV/AIDS in less-developed nations. Population and Environment, 42(3): 379–405

Berrang-Ford L, Dingle K, Ford J D, Lee C, Lwasa S, Namanya D B, Henderson J, Llanos A, Carcamo C, Edge V (2012). Vulnerability of indigenous health to climate change: a case study of Uganda's Batwa Pygmies. Social Science & Medicine, 75(6): 1067–1077

Bobb J F, Peng R D, Bell M L, Dominici F (2014). Heat-related mortality and adaptation to heat in the United States. Environmental Health Perspectives, 122(8): 811–816

Bush K F, O'Neill M S, Li S, Mukherjee B, Hu H, Ghosh S, Balakrishnan K (2014). Associations between extreme precipitation and gastrointestinal-related hospital admissions in Chennai, India. Environmental Health Perspectives, 122(3): 249–254

Callender R, Canales J M, Avendano C, Craft E, Ensor K B, Miranda M L (2022). Economic and mental health impacts of multiple adverse events: Hurricane Harvey, other flooding events, and the COVID-19 pandemic. Environmental Research, 214: 114020

Chen D, Rojas M, Samset B H, Cobb K, Diongue Niang A, Edwards P, Emori S, Faria S H, Hawkins E, Hope P, et al. (2021). Climate Change 2021: the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA: Cambridge University Press, 147–286

Cissé G, Mcleman R, Adams H, Aldunce P, Bowen K, Campbell-Lendrum D, Clayton S, Ebi K L, Hess J, Huang C, et al. (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA: Cambridge University Press, 1041–1170

Collins T W, Grineski S E, Chakraborty J, Flores A B (2019). Environmental injustice and Hurricane Harvey: a household-level study of socially disparate flood exposures in Greater Houston, Texas, USA. Environmental Research, 179: 108772

Conte Keivabu R (2022). Extreme temperature and mortality by educational attainment in Spain, 2012–2018. European Journal of Population, 38(5): 1145–1182

Dialesandro J, Brazil N, Wheeler S, Abunnasr Y (2021). Dimensions of thermal inequity: neighborhood social demographics and urban heat in the southwestern U.S. International Journal of Environmental Research and Public Health, 18(3): 941

Eastin J (2018). Climate change and gender equality in developing states. World Development, 107: 289–305

Ebi K L, Hess J J (2020). Health risks due to climate change: inequity in causes and consequences. Health Affairs, 39(12): 2056–2062

Ellena M, Ballester J, Costa G, Achebak H (2022). Evolution of temperature-attributable mortality trends looking at social inequalities: an observational case study of urban maladaptation to cold and heat. Environmental Research, 214: 114082

Engelman A, Craig L, Iles A (2022). Global disability justice in climate disasters: mobilizing people with disabilities as change agents. Health Affairs, 41(10): 1496–1504

Gould S, Rudolph L (2015). Challenges and opportunities for advancing work on climate change and public health. International Journal of Environmental Research and Public Health, 12(12): 15649–15672

Graham R, Compton J, Meador K (2019). A systematic review of peer-reviewed literature authored by medical professionals regarding US biomedicine's role in responding to climate change. Preventive Medicine Reports, 13: 132–138

Green D, Bambrick H, Tait P, Goldie J, Schultz R, Webb L, Alexander L, Pitman A (2015). Differential effects of temperature extremes on hospital admission rates for respiratory disease between indigenous and non-indigenous Australians in the northern territory. International Journal of Environmental Research and Public Health, 12(12): 15352–15365

Grineski S E, Collins T W, Ford P, Fitzgerald R, Aldouri R, Velázquez-Angulo G, Aguilar M D L R, Lu D (2012). Climate change and environmental injustice in a bi-national context. Applied Geography, 33: 25–35

Grobusch L C, Grobusch M P (2022). A hot topic at the environment–health nexus: investigating the impact of climate change on infectious diseases. International Journal of Infectious Diseases, 116: 7–9

Hansen A, Nitschke M, Saniotis A, Benson J, Tan Y, Smyth V, Wilson L, Han G S, Mwanri L, Bi P (2014). Extreme heat and cultural and linguistic minorities in Australia: perceptions of stakeholders. BMC Public Health, 14(1): 550

Harlan S L, Brazel A J, Prashad L, Stefanov W L, Larsen L (2006). Neighborhood microclimates and vulnerability to heat stress. Social Science & Medicine, 63(11): 2847–2863

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 für Gerontologie und Geriatrie, 47(6): 475–482

Hu K, Guo Y, Hoehrainer-Stigler S, Liu W, See L, Yang X, Zhong J, Fei F, Chen F, Zhang Y, et al. (2019). Evidence for urban-rural disparity in temperature-mortality relationships in Zhejiang Province, China. Environmental Health Perspectives, 127(3): 037001

Intergovernmental Panel on Climate Change (2014a). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate

Change. Cambridge, UK and New York, USA: Cambridge University Press

Intergovernmental Panel on Climate Change (2014b). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA: Cambridge University Press

Intergovernmental Panel on Climate Change (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA: Cambridge University Press

Kaijser A, Kronsell A (2014). Climate change through the lens of intersectionality. Environmental Politics, 23(3): 417–433

Khanal S, Ramadani L, Boeckmann M (2023). Health equity in climate change and health policies: a systematic review. Sustainability, 15(13): 10653

Khatana S A M, Werner R M, Groeneveld P W (2022). Association of extreme heat and cardiovascular mortality in the United States: a county-level longitudinal analysis from 2008 to 2017. Circulation, 146(3): 249–261

Khine M M, Langkulsen U (2023). The implications of climate change on health among vulnerable populations in South Africa: a systematic review. International Journal of Environmental Research and Public Health, 20(4): 3425

Lambourg E, Siani C, De Preux L (2022). Use of a high-volume prescription database to explore health inequalities in England: assessing impacts of social deprivation and temperature on the prescription volume of medicines. Journal of Public Health, 30(9): 2231–2242

Lee K, Brown R D (2022). Effects of urban landscape and sociodemographic characteristics on heat-related health using emergency medical service incidents. International Journal of Environmental Research and Public Health, 19(3): 1287

Liu S, Chan E Y Y, Goggins W B, Huang Z (2020). The mortality risk and socioeconomic vulnerability associated with high and low temperature in Hong Kong. International Journal of Environmental Research and Public Health, 17(19): 7326

Liu Z, Gao S, Cai W, Li Z, Wang C, Chen X, Ma Z, Zhao Z (2023). Projections of heat-related excess mortality in China due to climate change, population and aging. Frontiers of Environmental Science & Engineering, 17(11): 132

Méndez M, Flores-Haro G, Zucker L (2020). The (in)visible victims of disaster: understanding the vulnerability of undocumented Latino/a and indigenous immigrants. Geoforum, 116: 50–62

Minor K, Bjerre-Nielsen A, Jonasdottir S S, Lehmann S, Obradovich N (2022). Rising temperatures erode human sleep globally. One Earth, 5(5): 534–549

Mitchell B C, Chakraborty J (2014). Urban heat and climate justice: a landscape of thermal inequity in Pinellas County, Florida. Geographical Review, 104(4): 459–480

Morris G P, Reis S, Beck S A, Fleming L E, Adger W N, Benton T G, Depledge M H (2017). Scoping the proximal and distal dimensions of climate change on health and wellbeing. Environmental Health, 16(S1): 116

Mutic A D, Mix J M, Elon L, Mutic N J, Economos J, Flocks J, Tovar-Aguilar A J, Mccauley L A (2018). Classification of heat-related illness symptoms among Florida farmworkers. Journal of Nursing Scholarship, 50(1): 74–82

Navas-Martín M Á, López-Bueno J A, Ascaso-Sánchez M S, Sarmiento-Suárez R, Follos F, Vellón J M, Mirón I J, Luna M Y, Sánchez-Martínez G, Culqui D, et al. (2022). Gender differences in adaptation to heat in Spain (1983–2018). Environmental Research, 215: 113986

Niu Y, Yang J, Zhao Q, Gao Y, Xue T, Yin Q, Yin P, Wang J, Zhou M, Liu Q (2023). The main and added effects of heat on mortality in 33 Chinese cities from 2007 to 2013. Frontiers of Environmental Science & Engineering, 17(7): 81

Nyadanu S D, Tessema G A, Mullins B, Pereira G (2022). Maternal acute thermophysiological stress and stillbirth in Western Australia, 2000–2015: a space-time-stratified case-crossover analysis. Science of the Total Environment, 836: 155750

O’Neill M S, Zanobetti A, Schwartz J (2003). Modifiers of the temperature and mortality association in seven US cities. American Journal of Epidemiology, 157(12): 1074–1082

O’Neill M S, Zanobetti A, Schwartz J (2005). Disparities by race in heat-related mortality in four US cities: the role of air conditioning prevalence. Journal of Urban Health, 82(2): 191–197

Papworth A, Maslin M, Randalls S (2022). How food-system resilience is undermined by the weather: the case of the Rama Indigenous group, Nicaragua. Ecology and Society, 27(4): 270401

Pearson A R, White K E, Nogueira L M, Lewis N A, Green D J, Schuldt J P, Edmondson D (2023). Climate change and health equity: a research agenda for psychological science. American Psychologist, 78(2): 244–258

Pérez-Peña M D C, Jiménez-García M, Ruiz-Chico J, Peña-Sánchez A R (2021). Analysis of research on the SDGs: the relationship between climate change, poverty and inequality. Applied Sciences, 11(19): 8947

Qiang Y (2019). Disparities of population exposed to flood hazards in the United States. Journal of Environmental Management, 232: 295–304

Ranasinghe R, Ruane A C, Vautard R, Arnell N, Coppola E, Cruz F A, Dessai S, Islam A S, Rahimi M, Ruiz Carrascal D, et al. (2021). Climate Change 2021: the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press, 1767–1926

Rhubart D, Sun Y (2021). The social correlates of flood risk: variation along the US rural–urban continuum. Population and Environment, 43(2): 232–256

Riley K, Wilhalme H, Delp L, Eisenman D P (2018). Mortality and morbidity during extreme heat events and prevalence of outdoor work: an analysis of community-level data from Los Angeles county, California. International Journal of Environmental Research and Public Health, 15(4): 580

Romanello M, Di Napoli C, Drummond P, Green C, Kennard H, Lampard P, Scamman D, Arnell N, Ayeb-Karlsson S, Ford L B, et al. (2022). The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. Lancet, 400(10363): 1619–1654

Romanello M, Mcgushin A, Napoli C D, Drummond P, Hughes N, Jamart L, Kennard H, Lampard P, Rodriguez B S, Arnell N, et al. (2021). The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future. Lancet, 398(10311): 1619–1662

Rudolph L, Gould S (2015). Climate change and health inequities: a framework for action. Annals of Global Health, 81(3): 432–444

Scheelbeek P F D, Dangour A D, Jarmul S, Turner G, Sietsma A J, Minx J C, Callaghan M, Ajibade I, Austin S E, Biesbroek R, et al. (2021). The effects on public health of climate change adaptation responses: a systematic review of evidence from low- and middle-income countries. Environmental Research Letters, 16(7): 073001

Scherber K, Langner M, Endlicher W (2013). Spatial analysis of hospital admissions for respiratory diseases during summer months in Berlin taking bioclimatic and socio-economic aspects into account. DIE ERDE–Journal of the Geographical Society of Berlin, 144(3–4): 217–237

Schmeltz M, Petkova E, Gamble J (2016). Economic burden of hospitalizations for heat-related illnesses in the United States, 2001–2010. International Journal of Environmental Research and Public Health, 13(9): 894

Smith G S, Anjum E, Francis C, Deanes L, Acey C (2022). Climate change, environmental disasters, and health inequities: the underlying role of structural inequalities. Current Environmental Health Reports, 9(1): 80–89

Smith M L, Hardeman R R (2020). Association of summer heat waves and the probability of preterm birth in Minnesota: an exploration of the intersection of race and education. International Journal of Environmental Research and Public Health, 17(17): 6391

van Daalen K R, Kallesøe S S, Davey F, Dada S, Jung L, Singh L, Issa R, Emilian C A, Kuhn I, Keygnaert I, et al. (2022). Extreme events and gender-based violence: a mixed-methods systematic review. Lancet. Planetary Health, 6(6): e504–e523

van Eck N J, Waltman L (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, 84(2): 523–538

Versey H S (2021). Missing pieces in the discussion on climate change and risk: intersectionality and compounded vulnerability. Policy Insights from the Behavioral and Brain Sciences, 8(1): 67–75

Wanka A, Arnberger A, Allex B, Eder R, Hutter H P, Wallner P (2014). The challenges posed by climate change to successful ageing. Zeitschrift für Gerontologie und Geriatrie, 47(6): 468–474 (in German)

Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Beagley J, Belesova K, Boykoff M, Byass P, Cai W, Campbell-Lendrum D, et al. (2021). The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. Lancet, 397(10269): 129–170

Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Belesova K, Boykoff M, Byass P, Cai W, Campbell-Lendrum D, Capstick S, et al. (2019a). 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

Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Belesova K, Boykoff M, Byass P, Cai W, Campbell-Lendrum D, Capstick S, et al. (2019b). 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

Wilder M, Liverman D, Bellante L, Osborne T (2016). Southwest climate gap: poverty and environmental justice in the US Southwest. Local Environment, 21(11): 1332–1353

World Health Organization (2021). Climate Change and Health: Vulnerability and Adaptation Assessment. Geneva: World Health Organization

Wu S, Wang P, Tong X, Tian H, Zhao Y, Luo M (2021). Urbanization-driven increases in summertime compound heat extremes across China. Science of the Total Environment, 799: 149166

Yang X, Li L, Wang J, Huang J, Lu S (2015). Cardiovascular mortality associated with low and high temperatures: determinants of inter-region vulnerability in China. International Journal of Environmental Research and Public Health, 12(6): 5918–5933

Zeng P, Sun F, Liu Y, Chen C, Tian T, Dong Q, Che Y (2022a). Significant social inequalities exist between hot and cold extremes along urban-rural gradients. Sustainable Cities and Society, 82: 103899

Zeng P, Sun F, Shi D, Liu Y, Zhang R, Tian T, Che Y (2022b). Integrating anthropogenic heat emissions and cooling accessibility to explore environmental justice in heat-related health risks in Shanghai, China. Landscape and Urban Planning, 226: 104490