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Mapping social vulnerability indicators to understand the health impacts of climate change: a scoping review

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The need to assess and measure how social vulnerability influences the health impacts of climate change has resulted in a rapidly growing body of research literature. To date, there has been no overarching, systematic examination of where this evidence is concentrated and what inferences can be made. This scoping review provides an overview of studies published between 2012 and 2022 on social vulnerability to the negative health effects of climate change. Of the 2115 studies identified from four bibliographic databases (Scopus, Web of Science, PubMed, and CAB Direct), 230 that considered indicators of social vulnerability to climate change impacts on health outcomes were selected for review. Frequency and thematic analyses were conducted to establish the scope of the social vulnerability indicators, climate change impacts, and health conditions studied, and the substantive themes and findings of this research. 113 indicators of social vulnerability covering 15 themes were identified, with a small set of indicators receiving most of the research attention, including age, sex, ethnicity, education, income, poverty, unemployment, access to green and blue spaces, access to health services, social isolation, and population density. The results reveal an undertheorisation and few indicators that conceptualise and operationalise social vulnerability beyond individual sociodemographic characteristics by identifying structural and institutional dimensions of vulnerability, and a preponderance of social vulnerability research in high-income countries. This Review highlights the need for future research, data infrastructure, and policy attention to address structural, institutional, and sociopolitical conditions, which will better support climate resilience and adaptation planning.

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Introduction

Understanding indicators of social vulnerability to the health impacts of climate change is recognised as essential to protecting population health.[1] Through changes in the climate system and our failure to enact sufficient climate adaptations, anthropogenic climate change is having a detrimental impact on human health to such an extent that the 2022 report of the *Lancet* Countdown[2] concluded that climate change is affecting all monitored dimensions of global health.[2] Contrary to the notion that environmental risks represent a "universalization of hazard", which is not hierarchical in effect but rather "democratic",[3] research finds that susceptibility to the health impacts of climate change reflects broader social structures and inequalities.[4–8] For individuals exposed to climate-related hazards, vulnerability or the potential to be harmed is greater when there are insufficient resources or adaptive capacities to minimalise the resulting health impacts.[5,9] Indicators of vulnerability are needed for early community screening and rapid assessment to facilitate climate adaptation and health protection.

There are several pathways that link climate change and human health.[2] Direct effects of climate change on physical health have been documented (including cardiovascular, respiratory, and renal health conditions; injury and death; and poor mental health and wellbeing) from non-optimal temperatures, shifting weather patterns, and climate-related disasters.[1] Indirect effects from climate change altering ecological and human systems that cascade to affect human health have also been described.[10,11] Changing climatic and environmental conditions are more favourable to some vector-borne and water-borne diseases,[10] endanger crop yields and food security,[11] put strain on inadequately adapted health-care systems,[2] and might increase societal conflicts,[1] all of which constitute negative feedbacks that aggravate health losses.

Adaptations in response to climate change need to take social vulnerabilities into consideration. The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as "the propensity or predisposition to be adversely affected" that "encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" when exposed to hazards.[1] Social vulnerability encompasses all social practices, structures, or positions within the sets of relations and hierarchies that render individuals, groups, or societies unable to respond or adapt to harms.[5,6,12] These vulnerabilities can be operationalised in terms of

Key messages

- Literature on how social vulnerability influences the health impact of climate change is unevenly distributed across the globe; research is centered on high-income countries and more research is needed on social vulnerability in low-income countries
- Sociodemographic indicators are the most used indicators; a broader range of indicators that capture structural and institutional domains of vulnerability and capacity are needed to identify actionable leverage points and pathways for adaptation
- Domains of social vulnerability and capacity, such as housing, access to community facilities beyond health services, governance, and social development, are less researched; explanatory frameworks from the social sciences could enrich this work

individual characteristics (including age, gender, ethnicity, income, and education) and how these factors influence the set of resources and capacities available to individuals and social groups.[4] Broader operationalisations include institutional (including governance and service systems), structural (including sociodemographic and socioeconomic inequalities, power hierarchies, and discrimination), and place-based (including urbanisation, green spaces, and urban heat refuges) features of social systems that afford or constrain adaptive capacity and therefore moderate susceptibility.[1,5,6]

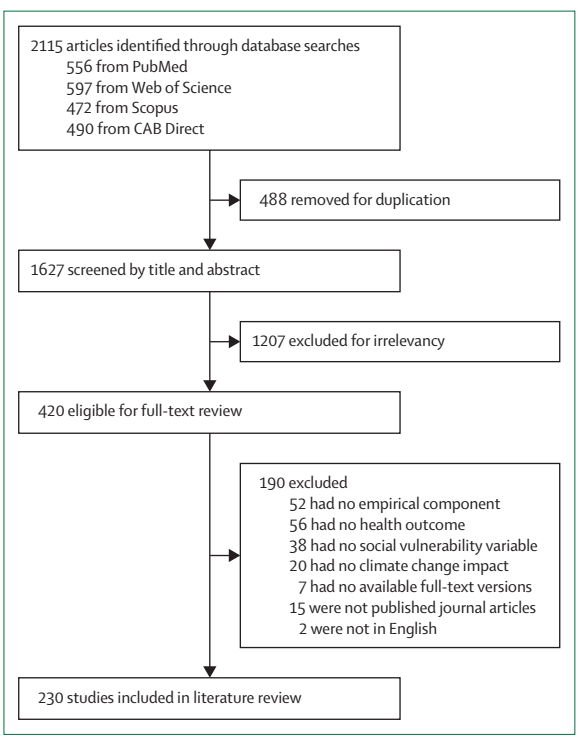

Figure 1: **Flow diagram of study selection**

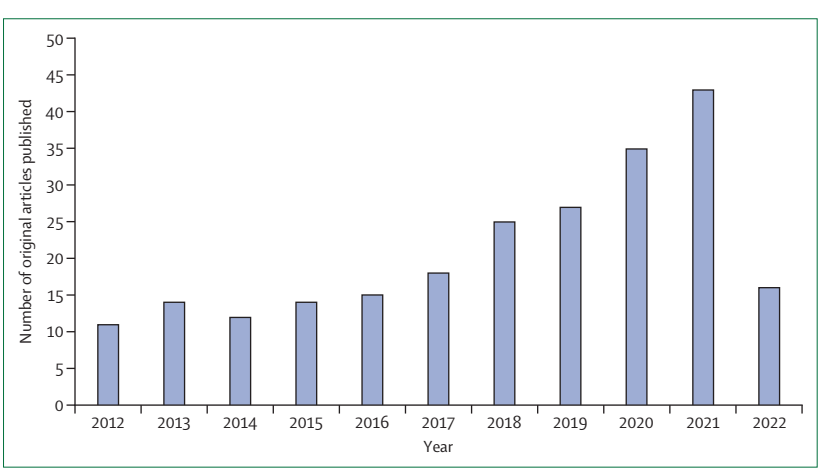

Figure 2: **Number of relevant articles published between 2012 and 2022**
Social vulnerability studies published and indexed in bibliographic databases before May 7, 2022, were included. Articles published in 2022 are therefore under-represented.

IPCC assessment reports have increasingly emphasised the importance of understanding and reducing social vulnerability to improve resilience to climate hazards, and the sixth (and most recent) assessment report in 2022 noted that, at an urban and community level, a crucial barrier to the implementation of climate adaptation plans includes a "limited ability to identify social vulnerability and community strengths".[1] Research on social indicators went through a period of abeyance throughout much of the 1980s and 1990s, but, since the early 2000s, there have been calls for the development of indicators and indices of vulnerability that have led to an exponential growth in indicator-based research.[6]

This scoping review of research literature on social indicators of vulnerability to the health impacts of climate change seeks to provide an overview of the state of empirical literature on social vulnerability to the health impacts of climate change from 2012 to 2022, summarise the substantive scope and themes of current evidence and research methods, identify the social indicators used for the analysis of climate change impacts on health or the development of social vulnerability indices, and detect areas of social vulnerability that are under-researched or undertheorised in the current literature.

Methods

Overview

This scoping review followed the methodology outlined in the JBI (formerly known as the Joanna Briggs Institute) guide.[13] This method was selected to provide an overview of the large and diverse body of work and identify research gaps, considering the range of relevant studies from varied disciplines. The five main steps of this method were: the formulation of a research question; the collection of relevant studies from literature databases; the screening of search results to identify articles that fit the eligibility criteria; the extraction of data to identify the frequency of topics and themes within the literature; and the collating, summarising, and reporting of results.

Data extraction and charting

Data charting followed the established approach for scoping reviews.[14] Data were extracted independently by two reviewers (AL and MT) with a standardised spreadsheet based on predetermined extraction codes. These extraction codes consisted of the date of publication, study setting, study aim, data source, study design, climate change exposure, social vulnerability or capacity factors, health outcomes, and key findings. Charting of the data elements into categories for frequency analysis and thematic construction was arranged first by the conceptual framework employed by the studies and second by inductive thematic analysis to establish the main domains of social vulnerability. This was done iteratively by AL and MT until consensus was

	Frequency (n; N=230)	Percentage (%)
Data source		
Primary data	35	15·2%
Secondary data	195	84·8%
Study area		
North America	71	30·9%
South America	13	5·7%
Europe	32	13·9%
Oceania	8	3·5%
East Asia	59	25·7%
South Asia	21	9·1%
Western Asia	2	0·9%
Africa	10	4·3%
Cross-regional	14	6·1%
Climate change impact		
Temperature	90	39·1%
Extreme heat	100	43·5%
Precipitation	23	10·0%
Air pollution	10	4·3%
Floods	17	7·4%
Landslides	2	0·9%
Storms, cyclones, or hurricanes	23	10·0%
Wildfires	10	4·3%
Extreme cold	9	3·9%
Humidity	15	6·5%
Drought	11	4·8%
Riverbank erosion	2	0·9%
Climate change or general natural disasters	3	1·3%
Dry spells	2	0·9%
Dust events	2	0·9%
Health outcome		
Cardiovascular disease	37	16·1%
Respiratory disease	27	11·7%
Diabetes and other endocrine diseases	6	2·6%
Genitourinary system disease	13	5·7%
Infectious disease	20	8·7%
Heat-related conditions	41	17·8%
Neonatal conditions	3	1·3%
Mental disorders	19	8·3%
Nutritional diseases	6	2·6%
Nervous system disease	2	0·9%
Years of life lost	1	0·4%
Emergency department presentation	17	7·4%
Hospital admission	19	8·3%
Medication use	2	0·9%
Injury	2	0·9%
Hypertension	7	3·0%
Neoplasms	2	0·9%
Sleep disturbance	1	0·4%
Gastrointestinal disease	7	3·0%
General health	42	18·3%
Mortality	76	33·0%

(Table 1 continues on next column)

(Continued from previous column)

Table 1: **Characteristics of the reviewed social vulnerability studies**

reached. Inconsistencies with regards to data extraction fields and charting were discussed and resolved by all three reviewers. The results of the charting process were reported in descriptive statistics and narrative overviews of the prominent domains of social vulnerability.

Results

The database searches returned 597 articles from Web of Science, 472 articles from Scopus, 556 articles from PubMed, and 490 articles from CAB Direct (a total of 2115 studies). Duplicates were removed in EndNote (n=488), producing a total of 1627 studies for abstract and title screening. 1207 articles were excluded during the screening due to an absence of empirical components, missing climate change, health, or social indicators, or non-English texts. Full-text screening was conducted on the remaining 420 articles. 190 articles did not meet the criteria for inclusion, leaving a total of 230 articles for data extraction and charting (figure 1). The number of relevant articles increased yearly during the last decade (figure 2).

Of 230 articles included in this Review, 216 report analyses of data from 46 individual countries and 14 report comparative analyses of data from multiple countries (table 1). Most studies are from the USA, China, the UK, Brazil, Canada, and Australia. The most represented regions are North America and East Asia, followed by Europe, South Asia, South America, Africa, Oceania, and western Asia. Secondary data analyses were more common than primary data analyses. Studies often addressed more than one climate-related factor and the most common primary climate impact addressed was extreme heat. Health outcomes were mostly measured by mortality, followed by heat-related health conditions, cardiovascular disease, respiratory disease, infectious disease, hospital admission, mental disorders, emergency department presentation, genitourinary system disease, gastrointestinal disease, nutritional disease, hypertension, diabetes and endocrine disease, medication use, injury, neonatal conditions, nervous system disease, sleep disturbance, and years of life lost.

A total of 113 factors associated with social vulnerability, covering 15 themes, were reported in the literature. The most reported factors were age (174 articles); sex (92); education (81); income and economic status (65); poverty (51); ethnicity and race (49); poor access to green and blue spaces (43); population density (41); employment (41); access to health services or the health

workforce (38); living alone (37); urban or rural areas (32); social capital; isolation and connectedness (27); individual physical conditions (27); and occupation, livelihood, and industry (25). These factors were all mentioned at least 25 times across the 230 studies. The frequency of social vulnerability factors and selected indicators are shown in table 2. A full list of the studies and indicators is included in the appendix (pp 1–25).

See Online for appendix

Age

Age was the most common indicator of social vulnerability, affecting morbidity, mortality, prescription volumes of medication, hospital admission, and emergency department visits that are related to heat stress, cardiovascular disease, respiratory disease, infectious disease, and psychological disorders. Age has been found to have a U-shaped relationship with the negative health effects of climate change, with younger (eg, individuals aged ≤5, ≤7, ≤14, ≤17, or ≤19 years) and older (eg, individuals aged ≥50, ≥55, ≥60, ≥65, or ≥75 years) age groups being most reported as susceptible to the health effects of extreme temperatures.[15,16] Older individuals were also found to be susceptible to cold snaps[17] and other climate impacts such as wildfires[18] and floods.[19] Occasional studies found that other age groups (eg, middle-aged individuals) were susceptible to high temperatures and heatwaves depending on the setting.[20] Living alone and social isolation are compounding factors of this vulnerability.[21]

Sex or gender

Sex or gender was used as an indicator of social vulnerability in relation to cardiovascular disease, kidney disease, respiratory disease, mental disorders, emergency department visits, and mortality across multiple settings. However, the relationship between sex or gender variables and impact susceptibility is contextual and differs according to the climate change impact, health effect, and setting. Although extreme temperatures are correlated with increased hypertension, ambulance dispatches, and mortality for men,[22] this gender gap has narrowed over time.[23] Alternatively, women were found to be more vulnerable to temperature variation,[24] heatwaves,[24] cold spells,[20] hurricanes,[25] and floods.[26] Variables that measure gender as a social structure, such as the proportion of female-headed households, were also used as indicators of vulnerability in several studies.[27,28]

Race, ethnicity, minority, and migration

Multiple indices include race or ethnicity-based indicators for social vulnerability, which have been found to be associated with susceptibility to extreme heat, extreme precipitation, hurricanes, and wildfires. Associated health conditions include cardio-respiratory, infant, and heat mortality; renal, heat, and respiratory hospitalisation and emergency department presentations; asthma morbidity; myocardial infarction; post-traumatic stress; mental health disorders; suicidal ideation; pregnancy complications; poor fetal growth; malaria; and mumps. These associations are attributed to the history of structural disadvantage and discrimination faced by minority communities.[29,30] Minority groups experience higher incidences of poverty, low educational attainment, and limited English proficiency than non-minority groups in English-speaking settings, increasing the vulnerability of minority residents to heatwave-related mortality.[31] Studies also included migration status, country of birth, and Indigenous status as vulnerability factors.[32]

Language, language proficiency, and literacy

Language barriers were identified as a source of social vulnerability to climate change, with studies addressing poor fluency in the primary local language, linguistic isolation, or illiteracy. Linguistic barriers and linguistic isolation thwart adaptive behaviours during extreme weather events as warning and emergency directives are not fully understood,[33,34] with a higher level of vulnerability observed in linguistically heterogenous areas than in homogenous ones.[32] Illiteracy is often used as a social vulnerability indicator in settings where educational attainment is low.[35]

Economics and socioeconomics

There were several indicators that measured socioeconomic status at both the individual and area level,[21,33,36–42] including household income, neighbourhood deprivation, labour force participation, poverty, gross domestic product, unemployment, asset ownership, welfare payments, health insurance, sources of income, and economic development. The relationship between income or socioeconomic status, either on an individual-level or area-level scale, and susceptibility to the health impacts of climate change was consistently negative. Higher income and socioeconomic levels suggest more resources for resilience. Individuals with lower incomes and socioeconomic status spend more time outdoors during heatwaves[43] and are more likely to reside in poorly built urban areas that are subject to higher temperatures,[31] compounding their vulnerability to extreme temperatures.

Education

Lower educational attainment at an individual or area level is correlated with poorer health outcomes after climate change exposures across all settings in high-income, middle-income, and low-income countries. Similarly to socioeconomic status, the generally observed relationship between low educational attainment and high climate-related health impacts is attributed to people with lower education having access to fewer resources and therefore less adaptive capacity,[33] although health-related education interventions can reduce this vulnerability.[44] Findings are less consistent when considering the interaction of education with demographic variables, such as sex, or when other socioeconomic variables are controlled for.[45,46]

Livelihood and occupation

Livelihood strategies were frequently included as a main driver of socioeconomic vulnerability for households supported by resource-based livelihoods in low-income countries such as Bangladesh,[47] Uganda,[48] and Ethiopia.[49] These hazard-prone households are vulnerable due to their dependance on rain-fed agricultural livelihoods[50] and their existing livelihood status aggravates a vicious cycle of vulnerability.[47] Households with access to diverse agricultural activities or alternative means of livelihood (measured with the livelihood diversification index,[49] crop diversity index,[27] and livestock diversity index)[27] are less vulnerable to extreme weather events. Across income settings, occupational groups that require outdoor work, such as council workers, construction workers, and farmers, had their health put at risk during periods of extreme heat.[50]

Living and built environments

Under this theme, studies have identified poor access to green or blue space (measured with the normalised difference vegetation index, normalised difference water index, distance to green space, the percentage of tree canopy coverage, the percentage of non-green space, etc), impervious surfaces (measured with the normalised difference impervious surface index, the percentage of impervious cover, etc), building density (measured with

	Frequency (n; N=230)	Selected indicators
Age and sex or gender		
Age	174	Children, adolescents, or young people (eg, aged ≤5, ≤7, ≤14, ≤17, or ≤19 years) and older individuals (eg, aged ≥50, ≥55, ≥60, ≥65, or ≥75 years)
Age structure	6	Dependency ratio
Sex or gender	92	Percentage of the female population; percentage of female householders with low levels of education; and ratio of women to men
Language and literacy		
Language	20	Primary language; limited English proficiency; and linguistic isolation
Literacy	24	Percentage of illiterate individuals and percentage of literate individuals aged 15–49 years
Ethnicity and migration		
Ethnicity or race	49	Native American people; Black people; Hispanic people; Bakiga people; Batwa people; Asian people; Māori people; and Pacific peoples
Country of birth	6	Country of birth; foreigners as a proportion of the population; and non-citizen population proportion per km^2
Indigenous people	6	Indigenous children; proportion of people who self-identify as Indigenous; and tribal affiliations
Redlining	2	Historical redlining
Migration	18	Refugee population proportion; recent immigrants; households with a migrant member; and immigrant population percentage
Minority	12	Social caste and percentage of ethnic or racial minority populations
Socioeconomics		
Income and economic status	65	Proportion of ouseholds with low incomes and population per km^2 in the bottom 40% of household incomes
Labour force participation	6	Proportion of people not in the labour force and labour force participation rate
Wealth or assets	7	Number of durable assets per household and asset ownership
Poverty	51	Percentage of people living below the poverty line and percentage of people living in extreme poverty
Welfare payments	12	Number of people receiving minimum living allowances and percentage of households receiving any form of social benefits
GDP or GNI	14	GDP per capita and GNI per capita
House value or rent	4	Median housing value and median gross rent
Debt, borrowing, or lending	2	Borrowing and lending ratio and percentage of households with loans
Source of income	4	Families depending on agriculture as their primary source of income and percentage of households with more than one source of income
Economic development	7	Financial independence; livelihoods dependent on natural resources; and Shannon index of economic diversity
Unemployment	41	Unemployment rate; working hours per day; percentage of female unemployment; and percentage of people with low-skilled jobs
Insurance	7	Percentage of people without health insurance coverage
Area socioeconomics	21	Socioeconomic index for areas; area neighbourhood deprivation index; and economic power index
Education	81	Low level of education (less than a high school diploma or university degree or the out-of-school population older than 15 years)
Living and built environment		
Green or blue space	43	No tree canopy coverage (%); green space per capita; and distance to the nearest ocean
Building density	14	Housing density; normalised difference built-up index; and land types (%)
Built conditions	9	Number of informal settlements; presence of poorly built and managed areas; and sky view factor or obstructed sky factor
Access to cooling spaces	5	Poor access to cool public spaces; access to cooling centres; and access to publicly available air-conditioned space
Impervious surface	4	Normalised difference impervious surface index
Pollution	4	Air pollution; land-based pollution; outdoor pollutants; and distance from dust emission sources
Community safety	6	Community or neighbourhood safety; crime prevention; and proportion of people affected by local crimes

(Table 2 continues on next page)

	Frequency (n; N=230)	Selected indicators
(Continued from previous page)		
Access to and quality of service and infrastructure		
Health service or health workforce	38	Access to medical care; number of hospitals per capita; and number of public health workers per unit of population
Clean water or irrigation	22	Percentage of people without a daily source of water; groundwater availability; and investment benefits
Transportation	15	Density of roads and railways; adequacy of public transportation; and distance to the nearest major roadway
Sanitation	13	Percentage of households with sanitary installation; the rate of accessibility to water; and sanitation and hygiene infrastructure
Communication	13	Percentage of the population with access to communication facilities (television, radio, phones, computers)
Vehicles	11	Percentage of households without a vehicle; car ownership; and number of housing units with no automobile
Electricity or utilities	8	Access to electricity and rural electrification
Sewage facilities	5	Percentage of households with drainage connection and average age of sewer pipes
Fuel	4	Access to clean fuels for cooking and percentage of households connected to efficient cooking fuel
Food or nutrition	12	Access to food; access to nutritional services; and food security index
Waste disposal	3	Percentage of households with solid waste collection and waste disposal practices
Education or childcare	6	Access to school, education services, and childcare facilities
NGO assistance	1	Access to NGOs and percentage of people receiving government or NGO assistance during disasters
Community and social services	8	Distance from city facilities (ie, shopping centres); little government assistance; and access to safe shelters
Legal service	1	Access to legal services
Banking or loans	2	Percentage of households with access to banking facilities and proportion of households with access to credit facilities provided by the government or NGOs
Health and health behaviour		
Disability	21	People with a disability; people receiving disability pensions; and older people with a disability
Area-level mortality rate	12	Mortality rate; mortality rate for individuals younger than 5 years; age at death; and number of premature deaths from all causes
Area-level health or disease rates	18	Prevalence of undernourishment and prevalence of HIV, tuberculosis, anaemia, diabetes, and cholera
Individual, pre-existing general health	15	Chronic health conditions (yes or no); self-related health in general; pre-existing health conditions (yes or no)
Health behaviours	9	Smoking; tobacco use; drug use; alcohol consumption; unhealthy diet; physical exercise; and unsafe sex
Individual, pre-existing mental health condition	9	Percentage of people suffering from psychiatric disorders
Individual, pre-existing cognitive disorders	3	Cognitive impairment and previous admission for Alzheimer's disease and dementia
Individual, pre-existing nervous system disorders	3	Diseases of the nervous system
Individual, pre-existing physical condition	27	Obesity; asthma; cardiovascular disease; diabetes; undernourishment; lung infection; and COPD
Pregnancy or births	4	Pregnant women; babies younger than 1 year; and the ratio of the number of births domiciled at the mother's home
Physical independence	3	Loss of ability for labour and loss of autonomy
Mobility limitations	2	People with mobility limitations
Vaccination	3	Inoculation rates and percentage of children aged 12–23 months immunised against major diseases
Medicine storage	1	Percentage of households not able to store medicine during floods
Domestic care needs	1	Number of people receiving domestic care
Nursing home	4	Population living in nursing homes
Social connection		
Social capital, isolation, and connectedness	27	Local connection; social ties; family and social support; and emotional social support
Local familiarity or attachment	3	Sense of place or place attachment; years spent in the area; and new to the neighbourhood (moved within the previous year)
Trust	1	Reporting that most people can be trusted (index of 0–100)
Social cohesion	2	Provides help to others and neighbourhood cohesion scale
Civic participation	3	Percentage of households that participated as volunteers during disasters
Social exclusion	1	Social prejudice and discrimination (inability to fully engage in local society)

(Table 2 continues on next page)

	Frequency (n; N=230)	Selected indicators
(Continued from previous page)		
Housing and housing practices		
Housing tenure	16	Percentage of homeownership and percentage of people living in rental housing or social housing
Air-conditioning, fans, or cooling practice	15	Ownership of air-conditioning; no access to central air-conditioning; and use and count of cooling practices
Building age	15	Year of construction and dwellings built before 1980, 1960, 1970, 1975, 1940, and 1990–2009
Overcrowding	10	Living in crowded households and the average area of living accommodation (m^2/person)
Dwelling type	15	Multi-unit structures and the number of households living in multistorey apartment buildings or mobile homes
Building material	7	Construction materials; transportable homes (prefabricated); and thermally efficient homes
Housing security	7	Permanent housing structures; informal settlements; insecure shelter; unstable housing; and the number of informal settlements
Housing quality	5	Percentage of people living in precarious housing and percentage of households whose houses do not have a solid structure
Housing affordability	3	Percentage of people with low incomes who are severely burdened by housing costs and percentage of household income spent on housing costs
Housing location	3	Number of households not built above the ground; housing pattern (scattered or grouped); and the elevation at the residence
Dwelling size	2	Households with only one room and living spaces 8 m^2 or smaller
Floors	2	Number of floors in the building and the floor of residence
Solar orientation	1	Alignment of the building in relation to the sun
Energy efficiency	2	Residential energy efficiency score
Homelessness	2	People who are homeless or severely deprived of housing
Ventilation	2	Opening windows (cross ventilation *vs* single-sided) and cross ventilation (yes or no)
Envelope properties (windows, walls, and roof)	4	Reflective or cool roofs; mass (eg, brick or concrete) versus frame walls; and insulation of the envelope
Livelihood and occupation		
Agriculture	15	Percentage of workers engaged in agriculture and families primarily dependent on agriculture
Landownership	4	Land ownership and land tenure security
Livelihood diversity	5	Diversification of average agriculture industry livelihoods; crop diversity index; and livestock diversity index
Occupation, livelihood, or industry	25	Outdoor workers; council workers; farmers; percentage of people employed in low-skilled service sectors
Household and household composition		
Living alone	37	Living alone; older people living alone; and density of people living alone
Marital status	8	Married or unmarried; widower; separated or divorced; and mother is married
Household type	24	Single-parent households; lone-person households; and young breadwinners (aged 10–29 years)
Household size	9	Family size; number of children; average household size; and percentage of households with more than 7 members
Female head	5	Percentage of female-headed households and female heads of household with less than 4 years of education
Conflict	2	Family conflict and proximity to conflict
Homes with orphans	1	Percentage of homes with orphan members
Urbaneness and remoteness		
Urban or rural	32	Accessibility remoteness index; percentage of the population living in rural areas; and proportion of the population residing in urban, rural, or remote communities and areas
Urbanisation	11	Degree of urbanisation; sprawl index; and urban expansion
Population density	41	Population density (people/km^2); older population density; and child density
Population size or growth	10	Size of the community; high population growth; and total population count in each census tract
Governance and policy		
Political participation	4	Voter turn-out; poor political representation; and percentage of the electorate voting in municipal elections
Mitigation or adaptation policy	4	Greenhouse gas mitigation policies and the existence of municipal councils or consortia related to climate adaptation
Regulatory quality	4	Worldwide governance indicators and institutional quality index
Emergency coordination	5	Whether the jurisdiction has an independent emergency coordination body and the existence of risk management instruments
Surveillance infrastructure	5	Air pollution information systems and early warning systems for health risks from natural disasters

(Table 2 continues on next page)

	Frequency (n; N=230)	Selected indicators
(Continued from previous page)		
Social development		
Income inequality	5	Gini index
Human development	3	Human development index (also known as HDI)
Gender inequality	2	Gender gap (the difference between total literacy and female literacy)
Social norms	1	Stigma surrounding vulnerability and accessing support; and social norms acting as barriers to seeking support
Knowledge and experience		
Knowledge, skills, and awareness	6	Emergency knowledge; disaster rescue skills; and percentage of households that adopted risk management tools
Information seeking and access	5	Number of search engine inquiries; percentage of people unaware of evaluation centres or information about disasters; and poor access to daily information

COPD=chronic obstructive pulmonary disease. GDP=gross domestic product. GNI=gross national income. NGO=non-governmental organisation.

Table 2: **Social vulnerability measures in the reviewed studies**

the number of building units per land area, the normalised difference built-up index, etc), built conditions (measured with the number of slums, the obstructed sky factor, etc), distance from pollutants, and the social distribution of access to public cooling facilities or urban heat refuges, as social vulnerability factors.[16,37,51,52] The heat effects of climate change are modified or moderated by access to green and blue spaces and air-conditioning,[53,54] although evidence for increased heat-related health effects in areas with poor access to green space is not consistently reported across studies.[16] The distribution of green and blue spaces and access to public cooling centers is socioeconomically and racially stratified.[37,55,56]

Urbanness and remoteness

The spatial distribution of human populations in urban, suburban, and rural areas increases their vulnerability to the health impacts of climate change. Heterogeneity in the health effects of extreme temperatures in urban and rural areas varies across countries. Urban areas are associated with increased exposure to extreme heat due to their higher population densities and the processes associated with the urban heat island effect that put urban populations at increased risk of adverse health impacts,[37,54,55,57] with inequality within urban settings further decreasing people's adaptive capacity.[58] On the other hand, rural populations are more vulnerable at equivalent temperatures than urban populations, which is attributable to demographic and socioeconomic factors such as the older age of rural populations, their lower levels of education, lower use of air-conditioning, agricultural occupations, and poorer access to health-care services.[59]

Households and household composition

Living alone was the most common feature of household composition identified as a source of vulnerability to the risk of heat-related conditions, cardiovascular diseases, and mortality due to people having fewer social connections or less of the support that residing with others provides, especially during extreme heat and flooding events.[33,39,60] Other household composition factors indicative of vulnerability include the household type (eg, single-parent households, lone-person households, and young breadwinners), members' marital status,[45,48] household size,[41,51] female-headed households,[49] family conflict,[48] and homes with orphan members.[27]

Housing and housing practices

Multiple dimensions of housing and housing affordances that are inequitably distributed in society were used as indicators of social vulnerability to climate change impacts on both physical and mental health. Institutional arrangements (ie, tenure type, homeownership, and rental housing),[34,40,41,54] housing affordances (ie, air-conditioning),[38,54,61] building age,[16,39,60] and dwelling type[60] are more covered in the literature, followed by overcrowding,[55] building materials,[39,44] and housing security (eg, living in informal settlements).[42] Although residential air-conditioning enables adaptations that mitigate the impact of heatwaves and extreme temperatures in the home,[62] access is unevenly distributed across populations,[56] and private renting and overcrowding increase people's susceptibility to the detrimental health effects of climate change.[18] Housing adequacy in terms of housing affordability,[56] energy efficiency,[63] envelope properties (windows, walls, and roof),[64] and homelessness[19] are less studied.

Access to health services and infrastructure

Access to health-care services and facilities was measured through people's proximity to health services (eg, the absence of a health centre, distance from health services, and time taken to reach a nearby health-care facility), the density of health facilities (eg, number of hospitals per capita, proportion of the population covered by primary health care, and number of

emergency medical centres), the density of health professionals (eg, number of medical professionals per capita and ratio of health workers to the population), and health expenditure (eg, mean clinical expense and total health expenditure per capita).[51,61,65] Most measures are recorded at the area level and function as substantial modifiers of the risk of cardio-respiratory, heat-related, and psychological illness and mortality from extreme heat, dust, wildfire, and flooding events. Studies consistently found that access to health services and medical infrastructure are among the most influential indicators for sensitivity and adaptive capacity, especially in low-income countries.[51] Poor access to or a lower quality of health services is associated with higher vulnerability to climate-related health risks.[61,66] People with pre-existing illnesses are particularly vulnerable due to their additional medical needs and poor physical resistance to climate impacts.[37,67]

Access to community services and infrastructure

There were multiple approaches in the literature to measuring infrastructure access, which can affect people's ability to prepare for and respond to climate-related events, including access to clean water or irrigation (eg, distance to water resources and groundwater availability);[66] transportation (eg, density of roads and railways and distance to the nearest major roadway);[34,37,41,54] sanitation facilities (eg, dwellings without bathing facilities and access to improved toilet infrastructure);[40,65] electricity or utilities (eg, access to power and power outages during the summer);[52,66] communication (eg, access to television, radio, mobile phones, computers, or the internet);[66,68] sewage facilities (eg, drainage connection and age of sewer pipes);[65,68] waste disposal (eg, solid waste collection);[65,68] and other community and social services, such as education, banking, and government assistance.[69]

Health and health behaviour

People's pre-existing physical health[27,34,38,70] was more widely considered than people's pre-existing mental or cognitive health.[34] Some studies adopted ecological study designs with community-level health measures, such as area morbidity, area mortality, and life expectancy.[38,70] Others used individual-level measures, such as the presence of pre-existing medical conditions (eg, cardiovascular, respiratory, endocrine, neurological, diarrhoeal, and infectious diseases) or medication use.[67] Living with a disability considerably reduces adaptive capacity.[31,34] As health risk factors, health-related lifestyles and behaviours, such as smoking, drug use, and disaster preparedness (eg, food storage), were also included in a few studies.[71] People with pre-existing health conditions are disproportionately represented in low socioeconomic groups with poor access to infrastructure, contributing to (and compounding) their increased vulnerability to health impacts from climate change.[72]

Social connection and isolation

Strong social connection has been identified as being protective of people's health and wellbeing in the context of climate change, and social isolation as a source of vulnerability. Measures for social connection included social support, local connection, civic participation, social cohesion, and volunteering.[27,71] Inversely, social isolation, social exclusion, and living alone are measures of poor social connection.[33,34,54,73] Consistently throughout the literature, social connection is found to be a source of resilience as higher levels of social connection facilitate the protection of vulnerable individuals, whereas poor social connection leaves individuals and communities at risk of the health impacts of climate change without support or access to resources.[19]

Social development

Few studies included indicators of general human development. Human development indices cover many dimensions of the social vulnerability and adaptive capacity identified in this Review, including education, health, and income. Low human development index scores are associated with high health risks from extreme weather events.[70] Gender[28] and income inequality[65] (as measures of socioeconomic differences) are other indicators of social vulnerability that have been identified in both high-income and low-income settings.

Knowledge and experience

Limited information seeking, access to information, or awareness of information were identified as sources of vulnerability to climate change impacts as inadequate information limits adaptive capacity and climate resilience. High awareness of climatic threats (assessed by volume of Google searches) was correlated with high adaptive capacities to climate change impacts and low socioeconomic disadvantage, suggesting that the people most in need of increased information and awareness are not engaging in information-seeking behaviour in proportion to their exposure and risk.[55] Preparedness and emergency knowledge increase people's capacity to anticipate, cope with, and recover from climate-related events.[19]

Governance and policy

Issues around governance as social indicators of vulnerability or adaptive capacity were less referenced in the literature.[54] Research included the existence of emergency communication plans, early warning infrastructure, and greenhouse gas emissions mitigation policies as important coping and preventive mechanisms.[54,55] In one more direct test of the role of governance and regulatory quality, the worldwide governance indicators and institutional quality indicators were used to operationalise the measure of government effectiveness, which was found to be positively associated with lower mortality from climate-related disasters.[74]

Discussion

Research on social vulnerability to the health effects of climate change is a growing field, which has expanded since the early 2000s. Indicators of social vulnerability to climate change have been described by researchers, policy makers, and the IPCC as crucial to addressing the challenge of the climate crisis and helping the enactment of climate adaptation plans.[1] Therefore, research into social vulnerability is needed to increase the resilience of communities and prevent the further exacerbation of climate-related adverse health effects and health inequality.

Synthesising a body of 230 studies, our review assesses the current state of research on social vulnerability to the health impacts of climate change and analyses a broad range of social constructs that have been adopted in defining this vulnerability. Along with the 113 social vulnerability factors identified, a large array of climate-related health harms and losses that are aggravated by social vulnerabilities are outlined, ranging from cardiovascular, respiratory, genitourinary, endocrine, and infectious diseases to hospital admissions, emergency department presentations, mortality, and years of life lost. The studies reviewed provide strong evidence for the role of social vulnerability and capacity in exacerbating or mitigating the negative impacts of climate change on a range of health outcomes—rendering some groups more susceptible to health harms than others.

Overall, the results in this Review show that inequality in social vulnerability, both within and between countries, makes a substantial contribution to the health impacts of climate change. Health impacts are unevenly distributed across populations with children; older people; linguistically and socially isolated people; people with disabilities and pre-existing health conditions; people with poor access to or familiarity with services and infrastructure; people working in resource-based industries and outdoors; people living in poor housing and built environment conditions; socioeconomically disadvantaged groups; and communities with low social development or who are not supported by quality institutions, climate policies, or robust governance structures experiencing disproportionate health burdens from climate change.

Trends within the studies highlight areas that have been well researched or remain under-researched. Several gaps were identified within the literature. First, except for China, a disproportionate amount of the global literature is focused on high-income countries, which have more resources to respond to climate change hazards. Climate justice and resilience requires that existing global health inequality is not intensified, and thus more research is needed into social vulnerability in low-income countries.

Second, the most widely employed social vulnerability indicators are measures of demographic and socioeconomic status, including age, sex, ethnicity, income, poverty, unemployment, and education. A large proportion of studies employed secondary data that might not include data to operationalise other indicators. Other dimensions of social determinants of health, such as the role of housing, access to community facilities beyond health services, and governance in supporting and sustaining health, are under-researched. Housing indicators are needed to capture the translation between outdoor and indoor climates, to predict more accurately the impact of weather extremes on health, and to assess the social distribution of housing adequacy. Indicators on access to community facilities allow the identification of protective and preventive resources needed at the local area level. Governance and policy are vulnerability factors that moderate other social risks factors and require more attention. Broadening the range of social indicators of vulnerability included in research will enable studies to capture a more holistic picture of capacities and resources for reducing vulnerability and facilitating adaptation in response to climate-related risks to health.

Third, more research is needed that incorporates the structural and institutional dimensions of social vulnerability. Operationalisations of social vulnerability in this area could draw on the related concepts of structural vulnerability and structural violence[75,76] that seek to explain how social positionality can influence the outcomes of underprivileged or marginalised groups, and how social and political systems cause harm by failing to provide health protection and redress the compounding effects of climate change and inequalities. Indicators that encompass dimensions of governance, policy, discrimination, power, and structural disparities could be incorporated to broaden the operationalisation of vulnerability that is employed in adaptation planning and health impact assessments. This expansion will also enable researchers to explain the sociological context under which group membership translates into group susceptibility and avoid the pitfalls of a deficit discourse. Inclusion of capacity variables beyond sociodemographic factors also allows for an identification of leverage points for resilience building.

Fourth, the literature is largely descriptive rather than explanatory, and more engagement is needed with numerous social science frameworks on social vulnerability and the inequitable impacts of climate change. These perspectives seek to understand the link between environmental conditions and uneven health outcomes, including Planetary Health, One Health, Ecohealth, and Political Ecology, which take a systems approach to the dependence of human and non-human wellbeing on social–environmental interactions and could enrich the explanatory power of the empirical literature.[77] Sociological concepts ranging from structural violence to intersectionality could be employed to further explain the interaction of climate change and unequitable social systems and the effect of these social interactions and stratifications on dimensions of social positionality.

Despite this space for the re-theorisation of social vulnerability to incorporate relational or structural determinations of vulnerabilities more comprehensively, data availability and existing data infrastructures might hinder these efforts. Although most of the reviewed articles used secondary data, the lacuna in existing data infrastructures is an impediment to the development of indicators to measure and capture structural and institutional contexts that increase susceptibility in various populations. On a positive methodological note, a growing number of studies have employed longitudinal approaches to vulnerability. Improvement of data infrastructure and operationalisation of social vulnerability could help further the development of health impact assessment frameworks that have increasingly been employed to assess the impacts of climate change and ensure health protection for vulnerable populations.[78]

There are a few limitations to this scoping review. First, with the aim of mapping the scope, the review is broad in scale, providing an overview of a large body of literature, which comes at the expense of depth. Second, this Review does not include an assessment of quality or risk bias; nor was statistical information collected to estimate effect sizes across the literature. Third, this Review provides an evaluation of areas that require more research without bridging these gaps with novel empirical results. Fourth, the scoping review was limited to publications written in English and therefore omits studies published in other languages.

This scoping review provides a broad overview of the state of research into social vulnerability to the health impacts of climate change. Although measures of susceptibility to the health impacts of climate change are contextual, the use of limited sets of social vulnerability indicators that are restricted to sociodemographic variables will hamper the quality and ability of vulnerability and capacity assessments to capture the breadth of risk factors and leverage points needed for climate adaptation planning. Social structures and practices exacerbate or mitigate the effects of shifting climates on health, and understanding these social factors at multiple scales and in different contexts is necessary for developing adaptation strategies to mitigate climate-related health harms. Common factors (eg, age, sex, ethnicity, income, education, poverty, unemployment, social isolation, and access to health services and infrastructure) have been consistently investigated as sources of social vulnerability across climate events. This Review identified domains of social vulnerability research that are more established and areas that remain under-researched. It also identified the need for more research on social vulnerability beyond individual characteristics to capture more capacity-building factors. Less is known about social vulnerability in low-income countries and the role of structural and institutional determinants of vulnerability in preventing and reducing the health risks of climate change.

Search strategy and selection criteria

We conducted a literature search of four databases on May 7, 2022: Web of Science, Scopus, CAB Direct, and PubMed. These databases were selected for their comprehensive archives of literature across the social sciences, humanities, environmental sciences, and medical and health sciences. We used the same search terms for each database. These consisted of four blocks of search terms: vulnerability ("vulnerability" or "sensitivity" or "susceptibility"); climate change ("climate change" or "global warming" or "natural disaster" or "extreme weather" or "weather extreme" or "climate extreme" or "extreme temperature" or "extreme heat" or "flooding" or "wildfires"); health ("health" or "mortality" or "morbidity"); and indicators ("index" or "indices" or "indicator" or "factor" or "component" or "measurement").

The studies included in the review were peer-reviewed articles published in English between 2012 and 2022 that studied factors (quantitative) or themes (qualitative) of social vulnerability to the impact of climate change on human health. Studies were excluded if they did not include one of these three components (ie, climate change exposures, health outcomes, or social risk factors). Reviews, commentaries, and other documents without an empirical component were excluded. AL and MT independently examined the titles and abstracts of the articles that resulted from the four searches and conducted the full-text review; any disagreements were discussed and resolved with RB.

Contributors
All authors contributed to the study conceptualisation, study design, data analyses, and interpretation and presentation of results. AL and MT independently examined the titles and abstracts of articles and conducted the full literature review and charting, with any disagreements resolved by RB. AL and MT wrote the manuscript draft. All authors revised the manuscript.

Declaration of interests
We declare no competing interests.

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