Climate-related health impact indicators for public health surveillance in a changing climate: a systematic review and local suitability analysis

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Summary

Climate change challenges public health. Effective management of climate-related health risks relies on robust public health surveillance (PHS) and population health indicators. Despite existing global and country-specific indicators, their integration into local PHS systems is limited, impacting decision-making. We conducted a systematic review examining population health indicators relevant to climate change impacts and their suitability for national PHS systems. Guided by a registered protocol, we searched multiple databases and included 41 articles. Of these, 35 reported morbidity indicators, and 39 reported mortality indicators. Using Chile as a case study, we identified three sets of indicators for the Chilean PHS. The high-priority set included vector-, food-, and water-borne diseases, as well as temperature-related health outcomes indicators due to their easy integration into existing PHS systems. This review highlights the importance of population health indicators in monitoring climate-related health impacts, emphasising the need for local contextual factors to guide indicator selection.

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Introduction

Although climate-related health outcomes have always occurred throughout the history of humanity, current anthropogenic climate change (hereafter climate change) is changing the pattern and exerting significant pressure on public health and health systems.[1,2] With global warming currently at 1.2 °C above pre-industrial levels, the world is witnessing record-breaking climate hazards[3] that are severely impacting people's health and wellbeing.[4] Under current climate change policies, global surface temperatures are likely to continue rising and even exceed 2 °C above pre-industrial levels by 2100, intensifying climate hazards and weather events, hence further affecting people's health, wellbeing, and livelihoods.[5,6] In this evolving scenario, a comprehensive understanding of population exposure to these hazards, vulnerability factors, and potential climate-related health outcomes is vital for effective and proactive health adaptation, hence mitigating associated health risks. Recently, this issue has been captured by the UEA Framework for Global Climate Resilience agreed at COP28, which established health as a key sector for climate change adaptation.[7]

Public health surveillance (PHS), is an essential function of public health,[8] and refers to the ongoing systematic collection, analysis, and interpretation of data that can be used for planning and implementation of health interventions, programmes, and policies according to social contexts.[9–11] Nonetheless, several challenges exist for PHS to effectively serve its purpose, such as integrating diverse data sources, ensuring complete high-quality data, and employing comprehensive and policy-relevant indicators.[11–13]

Historically, PHS systems have been primarily focused on infectious diseases,[13,14] but have expanded their scope given demographic and epidemiological population changes and the emergence of different hazards and technologies. Some PHS systems now include information on injuries, noncommunicable

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diseases, lifestyle factors, and environmental hazards.[12] From an environmental perspective, the most common hazards and exposures under surveillance have included chemicals, pesticides, radiation, and metalloids, as well as air, water, and soil pollution.[15–19] However, the inclusion of climatic and meteorological factors (e.g., heatwaves) is still in its infancy, and few public health agencies, mostly from High-Income countries, have considered them as part of PHS.[20]

Global[21] and country-specific[22–25] indicators at the intersection of climate and health have been developed, such as those from The *Lancet* Countdown, providing valuable information to other countries or locations. However, some challenges impede their seamless integration into national or sub-national PHS systems, including local relevance, context-specific factors that partly determine public health responses (e.g., sociopolitical context and health inequities), and PHS systems characteristics (e.g., local resources and capacities). In consequence, it is not quite straightforward to determine which indicators can be used as part of PHS at national and sub-national levels to track the impacts of climate-related hazards on population health under a changing climate.

From a practical perspective and before proposing new and potentially reiterative climate-related health impact indicators for PHS, it seems sensible to explore the evidence already published as well as its potential use in a local context. Therefore, we systematically reviewed the evidence on population health indicators related to the impacts of climate hazards under a changing climate. We then created and applied a guide that assesses the suitability of the indicators for their potential integration into a national PHS system. As an example, we present the case of Chile; however, this guide can be applied in other national or sub-national settings, especially in Latin America.

Methods

Study design, research question, and protocol

We conducted a systematic review following our previous published protocol (PROSPERO CRD42021253704),[26] and adhered to PRISMA guidelines for reporting.[27] The research question was *"What are the population indicators that monitor the health effects/impacts of climate change?"*, which was broad and open in order to comprehensively search the evidence on the topic.

Information sources

To cover most of the scientific evidence, we searched seven multidisciplinary and specialised databases: OVID/MEDLINE, Scopus, Web of Science Core Collection, PubMed, Cochrane Library, SciELO, and BIREME/LILACS. Complementary, we included grey literature from the World Health Organisation (WHO), the United Nations (UN), the European Centre for Disease Prevention and Control (ECDC), and Centre for Disease Prevention and Control (CDC) of the United States of America (USA). These sources were chosen for their role in informing public policy and their focus on climate change and population health.

Eligibility criteria

Studies were included if they i) were available in English, Spanish, or Portuguese; ii) focused on human populations; and iii) presented, summarised, discussed, or analysed population health indicators related to the impacts of climate change on population health. We imposed no restrictions on publication date, study type, or geographical scope. Unpublished work, news, or opinion articles were excluded due to the potential for redundant information and high risk of bias.

Search strategies

A generic search strategy consisted of: *(indicator* OR measure* OR metric* OR index OR indices) AND (health OR well?being) AND (monitor OR surveillance) AND ("climate* change*" OR "global warming" OR "climate crisis" OR "climate* varia*")*. The words "*effects*" or "*impacts*" were not included to make the search as broad as possible; however, any article unrelated to effects/impacts of climate change was excluded based on the eligibility criteria described above. Depending on the number and relevance of articles retrieved, the filter "humans" or keyword "human" was considered. The searches were conducted from the 15th to 24th of October 2021. Supplementary Tables S1 and S2 in the Supplementary Material present related terms and detailed search strategies for each database.

Two search updates were done: one in August 2022, which was conducted via Google Scholar using the syntax ("climate change" AND indicators AND impacts AND "human health"). The second update took place on the 12th of June 2024 and considered a revision of all seven multidisciplinary databases mentioned above and followed the same search strategies as in Supplementary Tables S1 and S2, plus a Google Scholar search. We also screened the reference lists of selected studies to identify any additional relevant articles not captured in the previous searches.

Study selection process

The retrieved articles were imported into Covidence.[28] After deduplication, two researchers (YPS and RAC or JIG) independently screened titles and abstracts, achieving an agreement rate of 90%. Full texts were also independently screened by two researchers, resulting in a 74% agreement rate. Titles, abstracts, and articles in disagreement were discussed with a third reviewer (RGT). Screening of the reference lists and grey literature was performed by one reviewer (YPS) in August 2022 and June 2024.

Data extraction process

Information on the title; year of publication; authors; type of publication; region or country; brief context; aim; overview of the methods; population considered; eligibility criteria; funding; conflict of interest; and main findings was extracted using a form designed in Covidence. The data extraction process was piloted using one article and necessary adjustments were made thereafter. Two reviewers independently extracted the data from each study (YPS and RAC or JIG), resolving any discrepancies through thorough re-analysis and discussion of the article in reference until complete agreement was reached.

Quality assessment

Given the broad scope of the research question, a diverse range of study designs was anticipated. Consequently, two complementary critical appraisal tools were employed: the Quality Assessment for Diverse Studies (QuADS), which facilitates the evaluation of various study designs in systematic reviews,[29] and the Joanna Briggs Institute (JBI) critical appraisal tools.[30] Each article, excluding grey literature, underwent appraisal by two researchers (YPS and RAC or JIG), with any discrepancies resolved through joint re-analysis and discussion. The critical appraisal was not used as a basis for inclusion/exclusion of articles, but rather to assess the overall quality of evidence and inform the suitability analysis. However, a qualitative sensitivity analysis was conducted in order to evaluate the potential influence of low quality/high risk of bias articles in the results, and thus, ensuring rigour and transparency of this review.

Data synthesis

We synthesised the evidence using a thematic approach with no pre-imposed themes.[31,32] Although we anticipated groups of all-cause and cause-specific morbidity and mortality indicators, we remained open to other categories emerging from the data. The indicators are presented as they were published to accurately reflect the breadth of evidence and mitigate potential interpretation biases.

Methods for the suitability analysis

A suitability analysis is essential for identifying scientifically sound and policy-relevant indicators that can be integrated into PHS systems. However, there is no standard process for this purpose; therefore, we developed a guide that comprises four dimensions and 13 sub-dimensions (Table 1; Spanish and Portuguese versions in Supplementary Tables S3 and S4). The development of this guide was performed in parallel to the current systematic review and consisted in a systematic approach of the following steps:

1) A literature review of the principles of PHS systems was conducted and included information from scientific literature, international frameworks (e.g., CDC and NHS England), and measurement theory.[33–44]
2) Information from step 1 was synthesised and analysed by one researcher (YPS) with feedback from a second senior researcher (IK). Several indicators' attributes or sub-dimensions were identified, which were grouped into four broad dimensions: scientific foundations that represent epidemiological attributes of the indicators; measurability, which refers to the capacity of the indicators of being measured; relevance to public health, which is one of the main purposes of the indicators in public health surveillance; and contextual to climate change, which refers to the indicators' attributes related to inherent climate change characteristics (e.g., long-term changes) rather than to any indicator for public health surveillance.
3) The first draft of the guide was then analysed with two policymakers in Chile and two external researchers to ascertain its precision and usefulness in guiding the suitability analysis of indicators. Experts looked at: definitions, words, assigned scores, and overall completeness of the guide. Feedback was integrated into the final guide.

By employing a simple 3-level scoring system for each sub-dimension, the guide facilitates indicator analysis and provides users with insights into the overall suitability of indicators for addressing population health and climate change concerns within a local context. Scores are not numerically combinable as they only represent categories.

Results

Findings from the systematic review

Searches in 2021 yielded 1587 references in scientific databases, of which 1068 remained after de-duplication, and 68 after screening titles and abstracts. After full-text review, 16 articles met eligibility criteria, while 52 were excluded: 30 did not include impact indicators[45–74]; seven were unrelated to human health[75–81]; eleven did not include indicators related to climate change[82–92]; three were inaccessible[93–95]; and one did not meet language criteria.[96] Three additional articles were included from reference lists,[19,97,98] and six from grey literature.[99–104] From the search update in August 2022, 80 references were identified, with four meeting eligibility criteria.[105–108]

The search update on the 12th of June 2024 yielded 963 references, of which 750 remained after de-duplication, and 11 after screening titles and abstracts. After full-text review, only five met eligibility criteria and six were excluded because did not explicitly include

Dimension I: Scientific foundations	
Sub-dimension	Definition and scores
Ia) Validity	*Degree to which a measurement measures what it purports to measure.*[33] • Score 0: Indicator does not measure what it intends to measure • Score 1: Indicator unclearly measure what intents to measure • Score 2: Indicator clearly measures what intents to measure
Ib) Reliability	*Degree of stability when a measurement is repeated under identical or similar conditions, either over time, different populations, or different datasets.*[34] • Score 0: Indicator is not stable under identical or similar conditions • Score 1: Indicator is to some extent stable under identical or similar conditions • Score 2: Indicator is stable under identical or similar conditions
Ic) Scientific rationale	*Degree to which an indicator is well-defined and supported by scientific evidence. Overall, scientific evidence is consistent and coherent regarding the indicator.* • Score 0: Indicator is not well-defined nor supported by scientific evidence • Score 1: Indicator is confusingly defined, or scientific evidence is not clear respect to the scientific rationale of the indicator • Score 2: Indicator is well-defined and scientific evidence is consistent and coherent regarding the indicator
Dimension II: Measurability (capacity of being measured)	
Sub-dimension	Definition and scores
IIa) Data availability	*Degree of availability of complete, valid, and reliable data.* • Score 0: Data are not available, and it is difficult to collect data within a short period of time (e.g., 1–2 years) • Score 1: Data are available, but national and local authorities have restricted access. Data are available, but data collection is not frequently available (e.g., surveys every 2–3 years) • Score 2: Data are frequently collected (every week, month, and/or year) and are already available to national and local authorities
IIb) Data analysis	*Process of cleaning, calculating, and modelling data to obtain useful information.* • Score 0: Data analysis is not easy to perform and needs specialised training • Score 1: Data analysis is easily performed because calculation methods are already standardised and widely available • Score 2: Data analysis is not needed because indicators are already calculated, analysed, and available, including modelled indicators
Dimension III: Relevance to public health	
Sub-dimension	Definition and scores
IIIa) Policy-relevance	*Degree to which an indicator is relevant to policy and informs public health policies or key policy issues according to local context.* • Score 0: Indicator is not relevant to population health and does not inform public health policies or key policy issues • Score 1: Indicator is relevant to a limited proportion of a target population and may partially inform public health policies or key policy issues • Score 2: Indicator is relevant to population health, covers the whole target population, and inform public health policies or key policy issues
IIIb) Cost-effectiveness	*Degree to which an indicator achieves desired aims at reasonable investments, including time and other resources.* • Score 0: Investments of producing and analysing the indicator exceed the value of using the indicator • Score 1: Investments of producing and analysing the indicator are similar in comparison to the value of using the indicator • Score 2: Investments of producing and analysing the indicator are well-below the value of using the indicator
IIIc) Simplicity	*Degree to which an indicator is easy to interpret and understand by users (i.e., decision- or policymakers and the general public).* • Score 0: The indicator is not easy to interpret and understand by users and requires specialised training to do it • Score 1: The indicator has standardised guidelines to be interpreted and understood by users • Score 2: The indicator is easy to interpret and understand by a wide range of users
IIId) Actionability	*Degree to which an indicator allows the planning and implementation of public health policies* • Score 0: The indicator does not allow action • Score 1: The indicator allows action, but more information or other indicators are needed • Score 2: The indicator allows action by itself
IIIe) Timeliness	*Degree to which an indicator can be measured and used in an appropriate period of time to inform public health policies.* • Score 0: The indicator needs a long period of time to be measured and is not ready when it is needed • Score 1: The indicator can be measured and used within the required period of time, but requires specialised skills to achieve it • Score 2: The indicator is measured and ready to be used within a short period of time (e.g., real-time, hours, or days)
Dimension IV: Contextual to climate change	
Sub-dimension	Definition and scores
IVa) Specificity	*Degree to which an indicator represents health impacts associated with changes in the climate or climate-related hazards.*[38] • Score 0: The indicator does not represent health impacts associated with climate-related hazards under climate change. There are important influences of other non-climatic factors • Score 1: The indicator represents the association with climate-related hazards under climate change, but further analyses are required in order to clarify influences of other non-climatic factors • Score 2: The indicator represents the association with climate-related hazards under climate change, and non-climatic factors are under control to some extent
IVb) Sensitivity	*Degree to which an indicator captures changes in health outcomes associated with changes in the climate or climate-related hazards.* • Score 0: The indicator does not capture changes in health outcomes associated with climate-related hazards under climate change • Score 1: The indicator partially captures changes in health outcomes associated with climate-related hazards under climate change, but further analyses are required in order to clarify potential aberrations • Score 2: The indicator captures changes in health outcomes associated with climate-related hazards under climate change
IVc) Comparability	*Degree to which an indicator can be comparable over time and across different populations, including different regions and countries.* • Score 0: The indicator is not comparable over time or across population groups due to different methods • Score 1: The indicator is comparable over time and some other populations • Score 2: The indicator is fully comparable over time and across populations at regional or international levels

Table 1: **Definitions and scores of dimensions for analysing indicators on climate change and population health.**

impact indicators.[109–114] Seven references were found through a Google Scholar search.[1,2,4,115–118]

A total of 41 references were included in this systematic review. Fig. 1 shows the PRISMA flow diagram.[27]

Overall study characteristics

Articles were published between 1993 and 2024. Geographically, 13 articles had a worldwide scope[1,4,19,97,100,102,104,107,108,119–122]; six were focused on the USA[99,101,116,123–125]; five on Australia[22,98,105,117,126]; three on Europe[103,127,128]; two on Canada[38,129]; two on China[106,130]; and one article on: Asia,[131] Korea,[132] Ireland,[36] Ghana,[133] Latin America,[118] South America,[2] Spain,[134] the UK[135]; and Vietnam.[136] Regarding the grey literature, three had a worldwide scope,[100,102,104] two were focused on the USA,[99,101] one on Europe,[103] and one on the UK.[115] A total of 13 articles were a literature review, either systematic or non-systematic[36,38,115,116,119,121–123,125,127,129,131,135]; 16 were ecological studies[1,2,4,19,22,97,98,105–108,117,118,120,128,130]; five were case-studies[126,132–134,136]; and one was a cross-sectional study.[124] Tables 2 and 3 summarise the articles included in this review.

The critical appraisal based on QuADS and JBI tools showed consistent results. A total of 23 articles were considered of acceptable quality ("include"),[1,2,4,19,22,38,97,98,105–108,117,118,120,123,127–132,135] while 11 articles were flagged as "further information is needed".[36,116,119,121,122,124–126,133,134,136] Overall, the weakest aspects of the articles were related to methods description, and strengths and limitations (Supplementary Table S5). These results underscore the need for caution when utilising the articles' findings in the review and suitability analysis.

Types of indicators

A total of 35 studies reported indicators for morbidity,[1,4,19,22,36,38,97,99–105,107,115–121,123–131,133–136] including cases of, incidence of, or prevalence of certain diseases, hospitalisations, and medical visits. A total of 39 studies reported indicators for mortality.[1,2,4,19,22,36,38,97–108,115,116,118–135] These indicators may also be classified according to specific exposures or causes (Table 4).

Some articles also highlighted analyses of indicators by subgroups, including different age categories,[104,126,131] sex,[126] aboriginal groups,[126] and seasons.[36]

Findings from the suitability analysis

The suitability analysis of indicators was performed based on the dimensions in Table 1 and the Chilean context, which is extensively described in Supplementary Box S1 in the Appendix. Briefly, there are different official PHS systems implemented in Chile, which mainly cover communicable and non-communicable diseases. Regarding communicable diseases, specific ones are subject to mandatory notification, including immediate and daily notification, as well as sentinel notification. Additionally, there are laboratory-based surveillance of specific and pre-defined microbiology agents, as well as surveillance for antimicrobial resistance.[137] A few non-communicable chronic and acute health conditions are under surveillance, including cancers,[138] pesticide poisoning,[139] and risk factors (e.g., physical inactivity, tobacco use).[140] There are other specific surveillance programmes focused on occupational health.[141] All these data are collected by the Ministry of Health and analysed considering different variables. The information that emerges is then used to inform national or local health programmes. Based on this background information, Supplementary Tables S6–S8 show the collective scores for each sub-dimension and provide insights into the suitability of each indicator for the Chilean PHS system. A brief example on how the scoring process was performed is provided.

Overall, general indicators with broad disease description received lower scores in scientific foundations and contextuality to climate change, while specific indicators scored higher in these areas. Most temperature-related indicators scored high in terms of scientific foundations; however, indicators requiring advanced statistical modelling may be relevant for climate change but have limited measurability. As a result, three primary prioritised sets of climate-related health impact indicators are proposed for PHS in Chile. Table 5 presents high-priority indicators, many of which are already under surveillance and/or data are already available for analysis, but they are not currently and explicitly considered for climate change and public health surveillance. Medium- and low-priority indicators may be relevant for PHS, but their measurability and contextuality to climate change are important challenges that might limit their use in the short-term (Supplementary Tables S9 and S10).

The sensitivity analysis showed that the results were robust and low quality/high risk of bias articles did not influence the primary prioritised indicators. Supplementary Table S11 shows all indicators that were identified from low quality/high risk of bias articles only if the indicators were not identified by high quality-low risk of bias articles. Some indicators, such as cases of leishmaniasis, chikungunya, zika fever, and shellfish poisoning are in Supplementary Table S11 and in Table 5 because these indicators are already part of the PHS system in Chile and were considered as primary prioritised indicators. In the case of number of cases and deaths due to heatstroke, these indicators are covered by temperature-related diseases indicators in Table 5, which were also primarily prioritised.

Discussion

This systematic review identified population health indicators that help monitor the health impacts of climate-

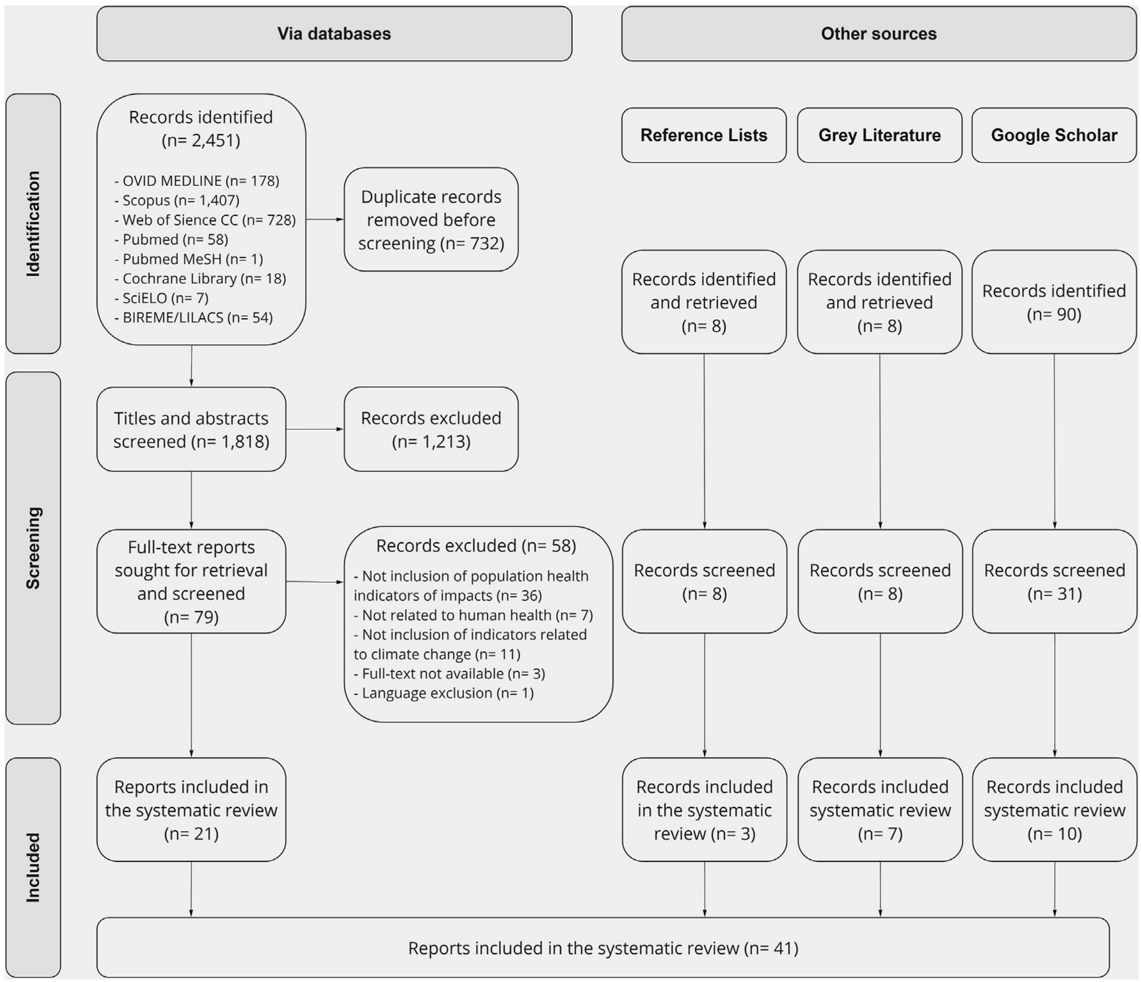

Fig. 1: PRISMA flow diagram of the systematic review.

related hazards in the context of climate change. Based on the revised literature, it is possible that current PHS systems already include several of the identified indicators; however, two main challenges remain. First, to better understand these indicators in a context of climate change, it is necessary to analyse whether the PHS systems and these indicators are compatible and adaptable. Second, although there are relevant indicators that can be integrated into PHS systems, the moderate quality of the literature may limit their use; therefore, specific analyses are needed.

In terms of geographical distribution, most of the evidence comes from High-Income countries, such as Canada, the USA, and the UK. Therefore, the use and adaptation of indicators from these countries to other countries may have some limitations since, for example, data collection methods, indicators definition, and spatial and temporal coverage are not quite compatible. This issue is relevant for PHS systems because one of the main characteristics of indicators for PHS is that they should represent and be aligned with characteristics of the local context, resulting in better use and acceptability by users.[12,142]

Regarding critical appraisal, several articles combined literature review processes and expert consultations; however, it was not always possible to analyse the associated methods due to limited description. Although literature reviews do not follow the same systematicity as systematic reviews, unclear methodology and methods undermine their reproducibility, replicability, and overall quality.[143] It is arguable whether true reproducibility and replicability can be achieved[144] and sometimes these qualities are not the main goal of literature reviews; however, clear methods would facilitate their critical assessment by providing a rationale for their structure and line of argument; and therefore, increasing their use in other contexts. Complementary, expert and stakeholder engagement is an important step when translating scientific evidence into public policies[145,146]; however, the methodology of expert

Reference	Setting & population	Brief methods	Main findings
Akearok et al. (2019)[129]	Canada, Nunavut territory	Scoping review and consultation to identify human health indicators of climate change relevant to the Canadian Arctic	i) number of injuries or mortality from extreme weather events or sea ice instability; ii) human cases of environmental infectious diseases/positive tests results in reservoirs/sentinels/vectors; iii) respiratory/allergic disease and mortality related to increased air pollution and pollens; iv) reports of depression, anxiety related to climate change.
Beggs et al. (2019)[98,a]	Australia	Review of scientific evidence and analysis of indicators in Australia	i) suicide rate associated with ambient temperature
Beggs et al. (2021)[105,a]	Australia	Review of scientific evidence and analysis of indicators in Australia	i) rates of cardiovascular and respiratory disease associated with heat stress; ii) heat stress risk of people participating in physical and sporting activities; iii) cold- and heat-related mortality; iv) dengue incidence; v) Ross River virus cases
Beggs et al. (2024)[117,b]	Australia	Review of scientific evidence and analysis of indicators in Australia	i) heat stress risk of people participating in physical and sporting activities
Benson et al. (2022)[122,b]	Worldwide	Literature review	i) Suicide mortality rate
Brown (1993)[126]	Australia	Analysis of evidence on social and environmental indicators to monitor health effects of climate change and application to Australia	i) rates of hospitalisation for circulatory diseases, respiratory diseases, and accidents, poisoning and violence; ii) infants death rates among aboriginal groups; iii) number of deaths of young men from accidents, poisoning, violence; iv) deaths before 65 years old.
Cai et al. (2021)[106,a]	China	Review of scientific evidence, expert consensus, and analysis of indicators in China	i) heatwaves-related mortality
Cheng et al. (2013)[38]	Canada	Literature review and analysis of key indicators to quantify health impacts of climate change on Canadians	Selected modelled indicators: i) excess daily all-cause mortality due to heat; ii) premature deaths due to air pollution (ozone and particulate matter 2.5); iii) preventable deaths from climate change; iv) disability-adjusted life years (DALYs) lost from climate change. Selected non-modelled indicators: i) daily all-cause mortality; ii) daily non-accidental mortality; iii) West Nile disease incidence (in humans); iv) Lyme borreliosis incidence (in humans).
Donnelly et al. (2004)[36]	Ireland	Review of evidence on indicators of the impact of climate change suitable for Ireland.	i) skin cancers; ii) seasonal pattern of mortality
Doubleday et al. (2020)[125]	United States of America, Pacific Northwest	Narrative review of literature and consultation with experts to develop indicators	Examples of indicators related to impacts are i) weather-related morbidity and mortality, including cold- and heat-related illness and mortality; ii) asthma exacerbations, and other respiratory hospitalisations related to wildfire events; iii) shellfish poisoning outbreaks, and iv) utilisation of mental health services.
Dovie et al. (2017)[133]	Ghana	Review of evidence, focus groups, and analysis as a case report.	i) mortality; ii) morbidity; iii) history of occurrence; iv) reported/confirmed cases
Driscoll et al. (2013)[124]	United States of America, Alaska	Participatory process to identify health risks related to climate change.	i) food security; ii) food security; iii) cold-related injuries and fatalities; iv) cases of allergic asthma; and v) paralytic shellfish poisoning cases.
Ebi et al. (2018)[121]	Worldwide	Review of evidence and expert consultation. Case report taking Cambodia as an example.	i) excess mortality associated with exposure to high ambient temperatures; ii) all-cause and cause-specific morbidity and mortality associated with other extreme weather events; iii) respiratory disease mortality from exposure to air pollutants such as ozone and particulate matter; iv) changes in the incidence and geographic range of climate-sensitive infectious diseases; v) undernutrition. Aggregated indicators: i) disability adjusted life years or years of life lost from climate variability and climate change. Other indicators: i) injuries, illnesses, and deaths attributed to wildfires; ii) the number of asthmatic episodes associated with high pollen events.
English et al. (2009)[123]	United States of America	Review of scientific evidence and expert consultation.	i) excess mortality due to extreme heat; ii) excess morbidity due to extreme heat; iii) number of injuries/mortality from extreme weather events; v) human cases of environmental infectious disease/positive tests results in reservoirs/sentinels/vectors; vi) respiratory/allergic disease and mortality related to increased air pollution and pollens.
Hartinger et al. (2022)[2,b]	South America	Review of scientific evidence and analysis of indicators in South America	i) heat-related mortality
Hartinger et al. (2023)[118,b]	Latin America	Review of scientific evidence and analysis of indicators in Latin America	i) heat-related mortality; ii) heat stress risk related to physical activity
Heo et al. (2019)[132]	South Korea (Seoul and Busan)	Analysis of heatwaves using different thermal indices from 2011 to 2015	i) daily all-cause mortality and excess mortality associated with heat index, humidex, apparent temperature, effective temperature, WetBulb Globe Temperature (WBGT).

(Table 2 continues on next page)

Reference	Setting & population	Brief methods	Main findings
(Continued from previous page)			
Jung et al. (2017)[131]	Asia, Low-and Middle-Income Countries	Systematic review and analysis of indicators that can be applied in Low- and Middle-Income countries	Indicators associated with respiratory diseases: i) incidence of morbidity due to respiratory diseases in children aged under 5 years; ii) annual mortality rate due to respiratory diseases in children aged under 5 years; iii) prevalence of chronic respiratory illnesses in children aged 0–14 years. Indicators associated with diarrhoeal diseases: i) incidence of outbreaks of water-borne diseases; ii) diarrhoea morbidity rate in children aged under 5 years; iii) diarrhoea mortality rate in children aged under 5 years; iv) recurrence rate of outbreaks of diarrhoeal disease among children aged under 5 years. Indicators associated with insect-borne diseases: i) prevalence of insect-borne diseases in children aged 0–14 years; ii) mortality rate of children aged under 5 years due to insect-borne diseases.
Liu et al. (2021)[116,b]	USA	Literature review	Allergies and other respiratory conditions: i) asthma mortality; ii) asthma and allergic disease–related hospitalisations; iii) asthma and allergic disease–related emergency room visits Vector-borne diseases: i) West Nile Virus neuroinvasive disease cases Vibriosis: i) Vibrio illnesses
Lowe et al. (2011)[127]	Europe	Scoping review of heatwave early warning system in Europe	i) real time mortality; ii) daily mortality; iii) number of calls to emergency services; iii) number of visits to general practitioner (GP); iv) heatwave-related morbidity and mortality
Mercuriali et al. (2022)[134,b]	Spain	Case study (presented as a field note) that included a literature review and expert consultations	Morbimortality related to heat: i) cases and deaths due to heatstroke; ii) daily deaths during heatwaves (extracted from funeral and mortality registries); iii) births, premature births, and low-weight births during heatwaves; iv) mortality attributable to heatwaves (all-cause and cause specific, hospital discharges, emergency visits, and primary healthcare services); v) deaths and mortality rate due to suicide and homicide. Vector related diseases: i) cases of dengue, Chikungunya, Zika, West Nile, malaria, leishmaniasis among residents; ii) viremic cases of dengue, Chikungunya, and Zika in periods of vector activity; iii) viremic cases of dengue, Chikungunya, and Zika with *Aedes albopictus activity* detected in the area (and proportion of the total viremic cases). Air quality: i) mortality and morbidity attributable to air pollution; ii) mortality due to asthma Water quality and water related diseases: i) Number of outbreaks related to drinkable water, leisure water, and food; ii) Notified cases of *Salmonella, Campylobacter,* and *Escherichia coli.*
Murage et al. (2024)[135,b]	United Kingdom	Three stage study that included: 1) consultation with key stakeholders, 2) literature review, and 3) expert consultations	i) annual heat-related attributable deaths; ii) heat illness indicator from syndromic surveillance data
National Research Council (2010)[119]	Worldwide	Workshop and technical review based on scientific evidence.	Epidemics/Pandemics: i) morbidity and mortality data; ii) disability-adjusted life years; iii) human cases of environmental infectious disease/positive tests results in reservoirs/sentinels/vectors Incidence of respiratory disease: i) respiratory/allergic disease and mortality related to increased air pollution and pollens; ii) general morbidity and mortality data; iii) disability-adjusted life years; iv) cancer rates Harmful Algal Blooms (HAB): human shellfish poisonings
Nguyen et al. (2018)[136]	Vietnam	Applications of remote sensing on health and vector-borne diseases using Vietnam as a case report.	i) number of human cases of malaria
Romanello et al. (2021)[107,a]	Worldwide	Review of scientific evidence and analysis of indicators worldwide	i) number of hours available for safe physical activity per day; ii) general sentiment of expressions (from Twitter) associated with heatwaves; iii) heat-related excess mortality; iv) number of deaths and affected people associated with weather-related disasters
Romanello et al. (2022)[1,b]	Worldwide	Review of scientific evidence and analysis of indicators worldwide	i) heat stress risk related to physical activity; ii) heat-related mortality; iii) sentiment of expressions (from Twitter) associated with heatwaves
Romanello et al. (2023)[4,b]	Worldwide	Review of scientific evidence and analysis of indicators worldwide	i) heat stress risk related to physical activity; ii) heat-related mortality; iii) sentiment of expressions (from Twitter) associated with heatwaves
Van Daalen et al. (2022)[128,b]	Europe	Review of scientific evidence and analysis of indicators in Europe	i) heat stress risk related to physical activity; ii) heat-related mortality
Watts et al. (2017)[120]	Worldwide	Review of scientific evidence and analysis of indicators worldwide	i) incidence of climate-sensitive infectious diseases; ii) incidence of food-borne diseases, vector-borne diseases, parasitic diseases or zoonotic diseases; iii) mortality attributed to heat.
Watts et al. (2018)[19,a]	Worldwide	Review of scientific evidence and analysis of indicators worldwide	i) number of deaths associated with weather-related disasters; ii) number of deaths due to: all causes, dengue, diarrhoeal disease, heat and cold exposure, malaria, malignant melanoma, and protein-energy malnutrition; iii) number of undernourished people

(Table 2 continues on next page)

Reference	Setting & population	Brief methods	Main findings
(Continued from previous page)			
Watts et al. (2019)[97,a]	Worldwide	Review of scientific evidence and analysis of indicators worldwide	i) number of deaths associated with weather-related disasters; ii) number of deaths due to: all causes, dengue, diarrhoeal disease, forces of nature, heat and cold exposure, malaria, malignant melanoma, and protein-energy malnutrition; iii) number of undernourished people
Watts et al. (2020)[108,a]	Worldwide	Review of scientific evidence and analysis of indicators worldwide	i) heat-related excess mortality; ii) number of deaths associated with weather-related disasters
Zhang et al. (2018)[22]	Australia	Review of scientific evidence and analysis of indicators in Australia	i) daily non-accidental deaths associated with temperature; ii) daily non-accidental deaths associated with heatwaves; iii) trends in overall burden of climate-sensitive diseases (Ross River, Barmah Forest virus, dengue incidence, and salmonella cases); iv) prevalence of malnutrition; v) suicide rates associated with mean annual maximum temperatures
Zhang et al. (2023)[130,b]	China	Review of scientific evidence and analysis of indicators in China	i) number of hours available for safe physical activity per day; ii) heatwave-related mortality

[a]From reference lists and updated searches in 2022. [b]From updated searches in 2024.

Table 2: **Summary of study characteristics and main findings related to indicators from literature.**

Reference	Setting & population	Main findings
CDC (2021)[101]	United States, general population	i) heat-related emergency department visits for heat stress; ii) heat-related hospitalisations for heat stress; iii) heat-related mortality
Climate-ADAPT (2021)[103]	Europe, general population	i) deaths related to flooding; ii) cases of vibriosis infections, salmonellosis, campylobacteriosis, cryptosporidiosis; iii) number of heat-related deaths.
UKHSA (2023)[115,a]	United Kingdom, general population	Heatwaves and heat risk to health: annual heat-related mortality; annual heat illness; health impacts of wildfires Cold and cold risks to health: i) annual cold-related mortality and morbidity Flooding and flood risks to health: i) death or injury from flood events; ii) estimated number of people suffering flood-related adverse mental health impacts Vector-borne disease: i) number (rate) of Lyme disease cases; ii) autochthonous cases of vector-borne disease Food systems and health impacts: i) incidence of foodborne diseases
United Nations (2017)[100]	Worldwide, general population	Indicator related to Sustainable Development Goal 13 (Take urgent action to combat climate change and its impacts): Number of deaths, missing persons, and directly affected persons attributed to disasters per 100,000 populations.
United Nations Statistics Division (2022)[102]	Worldwide, general population	i) incidence of cases of climate-related disease: airborne diseases and water-related diseases; ii) incidence of climate-related vector-borne diseases: Lyme disease, malaria, West Nile virus, yellow fever, and dengue; iii) incidence of heat- and cold-related illnesses or excess mortality: excess mortality related to heat, excess mortality related to cold
US EPA (2016)[99]	United States, general population	i) heat-related deaths; ii) heat-related illnesses; iii) cold-related deaths; iv) cases of Lyme disease; iv) cases of West Nile virus
World Health Organization (2022)[104]	Worldwide, general population	i) climate change attributable deaths; ii) climate change attributable DALYs; iii) climate change attributable deaths in children under 5 years; iv) climate change attributable DALYs in children under 5 years

[a]From updated searches in 2024.

Table 3: **Summary of reports characteristics and main findings related to indicators from grey literature.**

consultations was vaguely explained in some articles, limiting their quality and guiding role for other studies.

Despite of these challenges, several indicators related to morbidity and mortality outcomes were identified. Some articles clearly identified and defined indicators associated with specific climate-related hazards and exposures; however, the level of complexity in the exposure-response analysis and risk attribution varied. Based on the historical development of PHS systems, it is expected that the most common indicators are related to infectious and communicable diseases, which have been well-defined, and international and national supporting structures are relatively well-established.[10,14,147,148] The next group of relatively well-developed indicators – although not exempt from challenges– covers chronic non-communicable diseases and those related with occupational health.[149,150] However, the use of indicators related to mental health is less straightforward[151] mainly due to the challenges associated with population measurement and data collection,[152,153] and potential underdiagnosis of mental health issues in some populations (e.g., anxiety, depression, and post-traumatic stress disorder),[154] which affects non-modelled and modelled indicators. For example, suicide rates associated with ambient temperature,[98] although possible of modelling, are sometimes less reliable due to underreporting and misclassification of the cause of death.[155–158] Therefore, analysing the relationship with climate change can be complex, particularly when estimating the fraction of these outcomes attributable to climate change.[159]

Exposure[a]	Morbidity, mortality, wellbeing, other	Specific diseases or causes	Indicator
No specific exposure	Morbidity	No specific disease or cause	Morbidity rate[119,133]
		Accidents	Rates of hospitalisations[126]
		Cancer	Skin cancers[36]
			Cancer rates[119]
		Circulatory	Rates of hospitalisations[126]
		Nutrition	Number of undernourished people[19,97]
			Prevalence of malnutrition[22]
		Poisoning	Rates of hospitalisations[126]
		Respiratory	Rates of hospitalisations[126]
			Asthma hospitalisations[116]
			Allergic disease–related hospitalisations[116]
			Asthma emergency room visits[116]
			Allergic disease–related emergency room visits[116]
		Violence	Rates of hospitalisations[126]
	Mortality	No specific disease or cause	Number of deaths[36,38,97,119,126,127,133]
			Premature deaths[126]
		Accidents	Number of deaths[126]
		Cancer	Number of deaths due to malignant melanoma[19,97]
		Non-accidental	Number of deaths[38]
		Nutrition	Undernutrition mortality rates[121]
			Malnutrition mortality rates[19,97]
		Poisoning	Number of deaths[126]
		Respiratory	Asthma[116]
		Violence	Number of deaths[126]
	Other	No specific disease or cause	Number of calls to emergency services[127]
			Number of visits to general practitioner (GP)[127]
			Number of hours available for safe physical activity per day[107]
			Disability-adjusted life years[119]
		Mental health	Utilisation of mental health services[125]
Air pollution (i.e., ozone, particulate matter) and pollens	Morbidity	No specific disease or cause	Morbidity rate[134]
		Respiratory/allergic	Cases of respiratory diseases[119,123,129,131]
			Cases of allergic diseases[124,129]
			Number of asthmatic episodes[121]
			Cases of chronic respiratory diseases[131]
	Mortality	No specific disease or cause	Premature deaths[38]
			Mortality rate[134]
		Respiratory	Respiratory mortality[119,121,123,129,131,134]
Climate change	Morbidity	Mental health	Reports of depression, anxiety related to climate change[129]
	Mortality	No specific disease or cause	Attributable deaths[104]
			Preventable deaths[38]
	Other	No specific disease or cause	Attributable disability-adjusted life years (DALYs)[38,104,121]
Climate sensitive pathogens	Morbidity	Air-borne diseases	Airborne diseases[102]
		Food-borne and water-borne diseases	Incidence of food-borne diseases[115,120]
			Incidence of water-borne diseases[102]
			Incidence of outbreaks of water-borne diseases[131,134]
			Shellfish poisoning outbreaks[125]
			Shellfish poisoning cases[119,124]
			Cases of vibriosis infections[103,116]
			Cases of salmonellosis[103,134]

(Table 4 continues on next page)

Exposure[a]	Morbidity, mortality, wellbeing, other	Specific diseases or causes	Indicator
(Continued from previous page)			
			Cases of campylobacteriosis[103,134]
			Cases of cryptosporidiosis[103]
		Gastrointestinal: diarrhoeal diseases	Number of diarrhoeal cases[131]
			Recurrence rate of outbreaks of diarrhoeal disease[131]
		Infectious diseases	Incidence of climate-sensitive infectious diseases[119–121,123,129]
		Insect-borne diseases	Prevalence of insect-borne diseases[131]
			Leishmaniasis cases[134]
		Mosquito-borne diseases	Dengue incidence[102,105,134]
			Chikungunya cases[134]
			Zika cases[134]
			Ross River virus cases[105]
			West Nile disease incidence[38,99,102,116]
			Malaria cases[102,134,136]
			Yellow fever cases[102]
		Parasitic diseases	Parasitic diseases[120]
		Tick-borne diseases	Lyme disease cases[38,99,102,115]
		Vector-borne diseases	Vector-borne diseases[115,120]
		Zoonotic diseases	Zoonotic diseases[120]
	Mortality	Gastrointestinal: diarrhoeal diseases	Mortality rate diarrhoeal[19,131]
		Insect-borne diseases	Mortality rate of children[131]
		Mosquito-borne diseases	Mortality due to dengue[19,97]
			Mortality due to malaria[19,97]
Climatic variables	Morbidity	No specific disease or cause	Incidence of climate-related disease[102]
Extreme ambient temperatures (i.e., heat stress, heatwaves, cold waves)	Morbidity	No specific disease or cause	Rates of diseases[99,115,125,127,135]
			Excess morbidity[123]
			Hospitalisations[101,134]
		Cardiovascular	Rates of diseases[105]
		Heatstroke	Number of deaths[134]
		Injuries	Number of injuries[124]
		Pregnancy	Births[134]
			Premature births[134]
			Low-weight births[134]
		Respiratory	Rates of diseases[105]
	Mortality	No specific disease or cause	Mortality rate[1,2,4,19,97,99,101,103,105,106,115,118,120,124,125,127,128,130,132,134,135]
			Excess mortality[38,102,107,108,121,123,132]
		Heatstroke	Number of cases[134]
		Mental health	Suicide rate[22,98,122,134]
			Homicide rate[134]
		Non-accidental	Mortality rate[22]
	Wellbeing	No specific disease or cause	General sentiment of expressions[1,4,107]
			Heat stress risk of people participating in physical and sporting activities[1,4,105,117,118,128,130]
	Other	No specific disease or cause	Emergency department visits[101]
Extreme weather events	Morbidity	No specific disease or cause	Morbidity[121,125]
		Injuries	Number of injuries[123,129]
	Mortality	No specific disease or cause	Mortality[19,97,107,108,121,123,125]

(Table 4 continues on next page)

Exposure[a]	Morbidity, mortality, wellbeing, other	Specific diseases or causes	Indicator
(Continued from previous page)			
	Other	No specific disease or cause	Number of people affected[107]
Flooding	Morbidity	Injuries	Number of injuries[115]
		Mental health	Illnesses[115]
	Mortality	No specific disease or cause	Number of deaths[103,115]
Sea ice instability	Morbidity	Injuries	Number of injuries[129]
	Mortality	No specific disease or cause	Mortality[129]
Wildfires	Morbidity	No specific disease or cause	Illnesses[115,121]
		Respiratory	Asthma exacerbations[125]
			Hospitalisations[125]
			Injuries[121]
	Mortality	No specific disease or cause	Number of deaths[121]
Other	Mortality	No specific disease or cause	Number of deaths attributed to disasters per 100,000 population[100]
	Other	No specific disease or cause	Food security[124]
			Number missing persons and directly affected persons attributed to disasters per 100,000 population[100]
			Water security[124]

[a]"No specific exposure" category included indicators that were identified as being associated with climate change; however, no specific climate-related exposure category was implicitly established.

Table 4: **Indicators of morbidity, mortality, wellbeing, or other by exposure and causes.**

Additionally, the potential use of indicators by national and sub-national agencies varies depending on the technical capacities at these levels. Most of the articles proposed general and non-modelled population health indicators, such as all-cause mortality or incidence of respiratory diseases.[36,125,129,131,133] Although these indicators are relatively simple to measure and are already part of PHS systems, they need more advanced analyses in order to establish an association with climate and climate change. The reasons lie in that they are highly influenced by other social factors; for example, malaria is a parasitic disease transmitted by mosquitoes of the genus *Anopheles*, which are affected by climatic conditions and conditions in the built environment that are modified by human actions.[160] Similarly, food-borne diseases, such as salmonellosis, depend on multiple factors, including ambient temperature and human manipulation, such as the food chain quality.[161] Overall, these simple indicators may alert about population health issues; however, the link with climate-related hazards and climate change is less straightforward. To provide more targeted information on climate-sensitive health outcomes, it is usually necessary to consider multiple climatic and non-climatic factors to isolate the associations of primary interest. This is often done using statistical models leading to model-based indicators, where the quality of the modelling depends on the quality and management of the data, as well as the modelling assumptions. Additionally, model-based indicators might be more complex to analyse depending on the technical capacities at local levels.

One of the last areas to note is that all indicators in this review correspond to health outcomes related to the exposure to climate-related hazards, not directly to climate change. Although climate change affects climate-related hazards, it is important to differentiate their temporal scope. The assessment of health outcomes and climate change generally needs long-term analyses to capture long-term changes in the climate (i.e., climate signal)[162] and thus capture the effect of that climate signal on health outcomes. Complementary, it is important to consider the different drivers of climate-related hazards, including natural or anthropogenic drivers, as well as other non-climatic hazards. For example, there are several articles that included health outcomes associated with air pollution.[121,129] Although changes in the climate closely affect air quality and *vice versa*, most of the pollution (e.g., $PM_{2.5}$) comes from anthropogenic sources, such as wood burning, transport, and industry production.[163] It is important to identify where the health hazard comes in order to inform cost-effective interventions that act on the primary driver. Another example includes the analysis of population health outcomes associated with El Niño-Southern Oscillation (ENSO).[92] Although this natural phenomenon affect ecosystems (e.g., making them

Broad health outcome	Incidence and Mortality of (unless otherwise stated)	Observations
Vector-borne diseases and health outcomes	Malaria Zika virus disease West Nile virus disease Yellow fever Dengue fever Chikungunya fever	• These indicators are part of the PHS systems in Chile • Historically, mosquitoes that transmit these diseases have not been present in (mainland) Chile. However, given their presence in the region and potential changes in ecological niches due to climate change, it is relevant to include them into PHS.
	Leishmaniasis Schistosomiasis Onchocerciasis Lyme disease Chagas disease Hantavirus pulmonary syndrome	• Although some of these indicators did not explicitly appear in the systematic review, they are part of the PHS systems in Chile. • *Triatoma infestans*, the vector of *Trypanosoma cruzi* that causes chagas disease, is climate-sensitive; therefore, it is relevant to be integrated into PHS. • *Oligoryzomys longicaudatus* (i.e., long-tailed rat "colilargo"), the vector of Hantavirus that causes hantavirus pulmonary syndrome, may be climate-sensitive; therefore, it is relevant to be integrated into PHS.
Food- and water-borne diseases and health outcomes	Diarrhoea	• These indicators are part of the PHS systems in Chile. • The indicators on specific pathogens include all cases independently of the causing microorganisms (e.g., *Vibrio* spp, *Salmonella* spp.).
	Vibriosis	
	Salmonellosis	
	Campylobacteriosis	
	Cryptosporidiosis	
	Shellfish poisoning	
	Harmful algal blooms	
	Acute gastrointestinal illnesses	• Although these indicators did not explicitly appear in the systematic review, they are part of the PHS systems in Chile. • Diseases in these indicators are climate-sensitive; therefore, they are relevant for PHS
	Cholera	
	Hepatitis A and C	
	Brucellosis	
	Leptospirosis	
	Typhoid fever	
	Escherichia coli infections	
Temperature-related health outcomes (including heat and cold)	Temperature-related diseases	• Health data for these indicators can be obtained from databases that are compiled and published by the Department of Statistics and Health Information (DEIS). • Environmental data for these indicators can be obtained from reanalysis datasets. • These indicators are based on the International Classification of Disease (ICD); therefore, they should be used with caution due to potential underdiagnosis.
	Number (or incidence) of emergency department visits due to temperature-related diseases	
	Number (or incidence) of hospitalisations due to temperature-related diseases	
	Number (or incidence) of emergency department visits associated with extreme temperatures	• Health data for these indicators can be obtained from databases that are compiled and published by the Department of Statistics and Health Information (DEIS). • Environmental data for these indicators can be obtained from reanalysis datasets. • Extreme temperatures may be defined locally based on percentiles or another climate index, such as warm days, heatwaves, or cold spell. • These indicators need further analyses based on statistical models; however, data are already available.
	Number (or incidence) of hospitalisations associated with extreme temperatures	
	Mortality associated with extreme temperatures	
	Excess of emergency department visits due to temperature-related causes	
	Excess of hospitalisations due to temperature-related causes	
	Excess mortality due to temperature-related causes	
	Cardiovascular diseases associated with temperature-related causes	
	Respiratory diseases associated with temperature-related causes	

***Table 5:* Suggested high-priority indicators for PHS in Chile.**

prone to mosquitoes), the evidence still shows uncertainty between ENSO and climate change[164,165]; therefore, indicators analysed in the context of ENSO should be carefully analysed.

The selection and analysis of indicators that can be integrated into PHS systems involve several steps and requirements that need complementary scientific and policy perspectives. As it was shown in this review, it was not necessary to create new indicators as many are already proposed; however, their direct application to local contexts is complex and should be discussed with decision-makers at the corresponding levels. In this sense, the guide presented in this study informed the identification of indicators relevant for the Chilean context, resulting in three sets of prioritised indicators that can be considered for PHS under a climate change and health framework. Nonetheless, all indicators are related to the most severe impacts of climate-related hazards, leaving aside potential less severe outcomes but that affect a higher proportion of the population. Fig. 2 shows the outcome/data iceberg for indicators on climate change and population health in Chile. All elements that are above the horizontal line represent measurable outcomes/data; however, currently only some of them are reliably and systematically collected and available for analysis (i.e., those marked with **) while others need careful analysis if used (i.e., those marked with *). Up to date, elements below the horizontal line (i.e., unknown and unmeasured) may encompass a high proportion of the impacts of climate change and climate-related hazards on population health, but it is not yet possible to understand their actual magnitude due to limitations related to measurement, data collection, and reporting/diagnosis.

In this regard, it would be desirable to integrate other indicators that track upstream climate-related exposures and outcomes, which would allow anticipated and preventive public health measures. The DPSEEA (Driving, Pressure, State, Exposure, Effect, and Action) or the MEME (Multiple Exposures-Multiple Effects) frameworks may help identify and organise indicators that inform public health decision-making according to different stages of exposures and outcomes in the population, including intermediate indicators (i.e., indicators on changes in the environment) and indicators of health impacts.[43,166] These frameworks may be complemented by others, such as the social determinants of health framework,[167] which can expand the perspective of social vulnerabilities to climate change and climate-related hazards, including indicators from other health-determining sectors (e.g., urban planning, energy, transport, and housing) and different levels of disaggregation. The rationale behind the use of complementary frameworks relies on the issue that several public agencies, not only public health agencies, are already collecting data and evaluating indicators that can be integrated into PHS systems. All these indicators may be evaluated with the suitability guide presented in this study to facilitate the selection for local PHS systems, which may maximise resources and strengthen climate adaptation and population health policies.

This study has several strengths. First, it is one of the first that systematically searched and assessed scientific and grey literature in relation to population health indicators related to the impacts of climate change and climate-related hazards for PHS. As it was shown, several literature reviews proposed indicators based on expert opinion rather than a more comprehensive

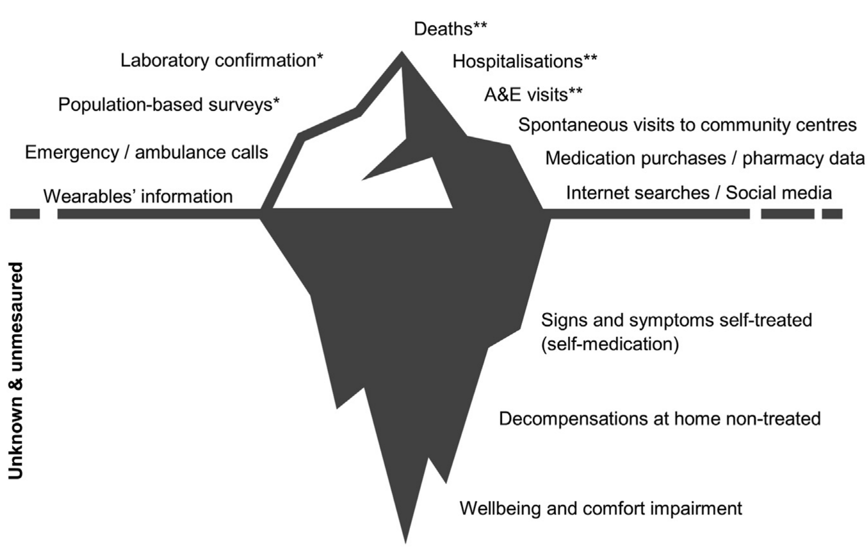

Fig. 2: Data iceberg for indicators of impacts of climate change on population health in Chile. NB: ** valid and reliable sources of data; * sources with limited use. Source: Own elaboration.

analysis. Second, the systematic use of two critical appraisal tools (i.e., QuADS and JBI) allowed a thorough evaluation of the evidence with different designs of studies. Third, the suitability analysis provided a comprehensive and systematic evaluation of indicators according to a national scenario, in this case Chile. This approach, in contrast to several indicators developed with limited application to PHS systems, maximises the probability of evidence translation into public policy.

This work supports public health surveillance systems in Chile, and potentially other Latin American countries, helping decision- and policymaking processes monitor the impacts of climate-related hazards on population health in a changing climate by analysing the proposed high-priority indicators, and adapt a set of indicators that can be used at local levels by implementing the suitability analysis guide. Additionally, the findings of this study also contribute to the two-year UAE–Belém work programme, which was established at COP28 and aims at developing indicators for measuring progress of targets outlined in the UEA Framework for Global Climate Resilience, including health and climate change-related impacts.[7]

Nonetheless, this study has also several limitations. First, the systematic review only included three languages relevant to the Chilean context (and other Spanish and Portuguese speaking contexts) and it is possible that a proportion of the literature was not included. Additionally, the quality of the articles varied and showed that current evidence lacks methodological systematicity when analysing and proposing indicators. This, together with the overrepresentation of evidence coming from High-Income settings, may introduce some biases in the conclusions, affecting the uptake of this evidence by end-users at different levels. Second, the tool for the suitability analysis needs further developments, including a validation of it and the results obtained by its application. The dimensions, subdimensions, and criteria are potentially subjective; therefore, it would be desirable to perform a co-construction process (e.g., analyses based on Delphi method) with other interested parties (e.g., experts, decision- and policymakers, researchers, public health practitioners) to determine their robustness, acceptability, and feasibility. Nonetheless, the two interviews with officials at the Ministry of Health and Ministry of the Environment in Chile revealed that the tool captures most of the relevant criteria and is useful for public health decision-making. Finally, the criteria for validity, reliability, sensitivity, specificity, and comparability from the suitability analysis need to be further evaluated using actual data. In this case, these criteria were only evaluated based on theoretical assumptions, which may be different when applying different datasets.

Finally, this study is not intended to be definitive and invites all public health experts to continue developing and discussing the evidence presented here. It is imperative that PHS systems are adaptative and dynamic because changes in the climate will continue as the 2023 and 2024 have already demonstrated.

Conclusion

There are several population health indicators that help monitor the health impacts of climate-related hazards in the context of climate change; however, local analyses are needed based on scientific foundations, measurability, relevance to public health, and contextual appropriateness. The guide for suitability analysis in this article seems useful for determining which indicator can be used in a local context for tracking the impacts of climate change and climate change-related hazards on population health. The process and information presented here may contribute to local public health surveillance systems and the two-year UAE–Belém work programme.

Contributors

YPS conceptualised the idea, wrote the protocol, planned and carried out the review, led the project, interpreted and prepared the results for publication, trained researchers, wrote the draft of the manuscript, and wrote the final manuscript. RAC, JIG, and RGT contributed to the screening and appraisal of references and reviewed the final manuscript. IK gave feedback during the review, writing process, and final manuscript. All authors agreed on the final manuscript and the decision to submit the study for publication. YPS was responsible for submitting it to the journal.

Declaration of interests

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lana.2024.100854.

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