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"SCALE-up" – a new framework to assess the effectiveness of climate change adaptation interventions for human health and health systems

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Abstract

Climate change is a grave threat to human health and wellbeing. Adaptation is one mechanism (the other is mitigation) by which we can intervene to increase adaptive capacity and preparedness to protect people. Adaptation interventions (evidence-based adjustment of programs/practices that lead to improved response and resilience to climate change) are being conducted around the world. However, existing conceptual frameworks to assess the effectiveness of these interventions, especially with respect to improving health outcomes and systems are not readily applied in areas where these are needed. This is applicable to both interventions intended to improve health as well as those without a health-focus but which may have health co-benefits. To address this gap, we conducted a multi-vocal review comprised of a scoping review and key informant interviews, which informed the development of an initial assessment framework. We included 21 academic articles and 12 reports (from the grey literature) for data collation and synthesis. Of the 21 articles analyzed, only seven presented primary evidence of health improvement outcomes, such as reduction in neo-natal care unit admissions was partially attributed to moving the maternity ward to the cooler, lower floor of the hospital. From the 10 interviewees, we learnt that most existing tools to assess the effectiveness of adaptation are for country or regional (several countries sharing borders within a large section of a continent) scales (e.g., Notre Dame Global Adaptation Initiative Index) and none focused specifically on health / health co-benefits. From these learnings together with a guiding concept, we crafted the first iteration of an assessment framework, SCALE-up, comprising six steps that prompt a researcher to consider the effectiveness of their adaptation intervention at a project-scale, including from a health benefit perspective. We apply the framework in four scenarios: hot days-heat; floods; droughts; and vector-borne diseases, to illustrate how the framework may help guide the researcher to think about effectiveness from project proposal stage. The next steps are to implement and pilot the framework in the four proposed scenarios and refine the framework.

Keywords Climate change, Environmental health, Impacts, Implementation science, Indicators, Methods, Monitoring and evaluation, Standardized measures

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Introduction

Climate change is recognized as a major contributor to increasing human health risks, with far-reaching impacts on both individuals and health systems globally [1]. The 2023 *Global Report of the Lancet Countdown* emphasizes the importance of a health-centered response to climate change [2]. The burden of health inequities resulting from climate change disproportionately affects the world's poorest nations [3]. This is particularly concerning given that the highest greenhouse gas emissions originate from more high-income countries that have the infrastructure for production of global supplies [4]. However, the high-income countries are not experiencing the negative impacts from greenhouse gases as much as lower-income countries, where resources are not available to adapt to climate change [5]. Although relatively old work, a study evaluating mortality from five climate-sensitive health outcomes—i.e., cardiovascular disease, malaria, flooding, and malnutrition—found that African countries had an estimated death rate of between 80 and 120 per million people, while death rates in other parts of the world were less than 80 per million people [6]. Consequently, while it is crucial for low- and middle-income countries to implement mitigation strategies, prioritizing adaptation measures is even more imperative. These countries urgently need adaptive interventions that are effective to address the severe impacts of climate change as they are home to vulnerable populations.

Mitigation aims to curb (or reduce) greenhouse gas emissions in the atmosphere, while adaptation is a 'process of adjustment to actual or expected climate and its effects including on health and wellbeing' [7]. 'An activity should be classified as adaptation-related if it intends to reduce the vulnerability of human or natural systems to the impacts of climate change and climate-related risks by maintaining or increasing adaptive capacity and resilience' [8]. Climate change effects vary widely, impacting different populations in diverse ways. For instance, in Kenya, adaptation to drought involves the introduction of drought-resistant crop varieties, which positively affects nutrition and overall health [9]. A robust health adaptation measure for this intervention would involve assessing malnutrition levels following the implementation of these crop varieties [10]. Similarly, in Uganda, adaptation to malaria outbreaks entails the deployment of malaria early warning systems [11]. The efficacy of this adaptation strategy can be evaluated by monitoring malaria prevalence before and after public health control measures are initiated in response to the early warnings.

Adaptation strategies aim to reduce risk and vulnerability to climate change, bolster resilience, enhance well-being, and build capacity to anticipate, prepare for, and effectively respond to climate change impacts [12]. Adaptation to climate change can be categorized into distinct types [13]. Anticipatory adaptation, also known as proactive adaptation, occurs before the impacts of climate change are observed, aiming to mitigate potential future risks. In contrast, autonomous adaptation or spontaneous adaptation, happens without a conscious response to climatic stimuli, being driven by ecological changes in natural systems or market and welfare changes in human systems. Planned adaptation arises from deliberate policy decisions, recognizing that conditions have or will change and requiring action to maintain or achieve a desired state. This can be further divided into private adaptation, which is initiated by individuals, households, or private companies usually for their self-interest, and public adaptation, which is undertaken by governments at various levels to address collective needs. Lastly, reactive adaptation takes place after the impacts of climate change have been observed, responding to immediate and evident challenges [13]. Understanding these adaptation types is crucial for developing and implementing effective strategies to enhance resilience and reduce vulnerability to climate change [14].

The diverse and context-specific nature of climate change adaptation necessitates an appropriate approach to measure its effectiveness. Adaptation efforts are inherently varied, tailored to the unique socio-cultural, socio-political, and local or regional settings of each country [15]. This variability means that countries have different objectives for adaptation, defined through national planning processes or prioritization exercises [16]. Consequently, adaptation measures can range widely from building water reservoirs [17] and planting mangroves [18] to improving building standards [19]. The heterogeneity of vulnerabilities and their causes further complicates the comparison of adaptation results and the identification of transferable recommendations [20].

Many adaptation projects and activities are being conducted in the climate change and health space [21, 22]. However, little has been done to guide these activities using pre- and post-measures or indicators that would help determine the success (both short-term and long-term) of the implemented activities, specifically in relation to human health outcomes. These interventions might purposefully include a health outcome (e.g., heat-stroke or respiratory disease pre- and post-intervention prevalence), access to healthcare services, or healthcare infrastructure demise or strengthening. In addition, some adaptation interventions may lead to unexpected health co-benefits. The use of measures or indicators to assess effectiveness should be integrated across all stages of the adaptation process, i.e., the application of formative evaluation measures pre-implementation, process evaluation

measures during implementation and outcome evaluation measures post-implementation [23, 24].

To evaluate the success of adaptation interventions in achieving their goals, it is crucial to develop and employ specific measures or indicators that can assess the positive, negative, or neutral impacts of adaptation actions on health and well-being [25]. These indicators are essential for understanding the extent to which adaptation efforts protect public health and enhance resilience in the face of climate change. Yet there are very few studies [26–28] that focus on adaptation measures or indicators, and especially with respect to health outcomes/systems. A recent search for indicators for monitoring and evaluation of climate change adaptation actions in South Africa found 37 indicators related to various aspects of climate change adaptation [27]. Among these, 12 were classified as output indicators, nine as input indicators, eight as process indicators, and eight as markers of results [27]. After engaging with stakeholders, eight indicators were deemed suitable for monitoring South Africa's progress in adapting to climate change [27]. However, these indicators were meant for application at a country scale, not at local or community level, or for a specific climate change and health adaptation project.

The long-term nature of climate change makes the success of adaptation efforts only measurable in retrospect, hampering the effectiveness of current and near-term assessments [29]. Adaptation and resilience interventions should be incorporated into national development assessments, including progress on the SDG's as well as in research intervention projects. The challenge in identifying appropriate adaptation assessment indicators lies in going beyond direct activities/outputs of a project and essentially capturing the derived impacts of the activity/project. Additionally, it is difficult to attribute conditions to the success of the adaptation intervention (providing due or undue praise) [30]. To assess the effectiveness of interventions, it is crucial to identify or develop appropriate measures or indicators that accurately reflect changes in health outcomes and health system performance. This process involves understanding the various tools and methodologies currently in use and determining the best practices for adaptation strategies.

To date, no published framework for evaluation of the success or effectiveness of adaptation activities/actions with consideration for health outcomes and health systems has been proposed. A recent review called for such a framework saying "We identify eight priorities for global adaptation research [including to] assess the effectiveness of adaptation responses" [22]. To fill this gap, we did three things: we conducted a 1) multi-vocal review comprising a scoping review of the white and grey literature together with 2) expert interviews, and we used the data collected from both activities to 3) develop a possible framework for assessing the effectiveness of adaptation interventions to improve health outcomes and health systems. Such a framework will assist researchers, funders and others in planning, monitoring and evaluating climate change-related health adaptation interventions.

Methods

Given the broad nature of the topic of adaptation to climate change, this multi-vocal review [31] encompassed a scoping review of the white and grey literature and key informant interviews, that were framed by climate change impacts on human health (Fig. 1) (adapted from [32]). The overarching methodological framework is outlined in Fig. 2 [33, 34]. The reporting guidelines are set out in the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation [35].

Identifying the research question

We identified the research question by defining key terms. Adaptation, as per the IPCC, is the process of adjustment to current or expected climate impacts, aiming to reduce harm or seize beneficial opportunities [36]. Human health, according to the CDC, involves protecting and improving health through promoting healthy lifestyles, disease prevention, and responding to infections [37].

Searching for relevant studies

We limited our search to quantified health outcomes/impacts on health systems since they provide a specific metric for monitoring and evaluation, as well as decision-making in adaptation activities. The search terms were prepared by reading reports by funders of adaptation research (e.g. Adaptation Fund, Clean Air Fund, Wellcome Trust etc.); other relevant reports (for example, UNFCCC, 2016; [16]),and research articles (e.g., [28, 38]) on topics related to adaptation interventions/activities for human health and health systems, and/or measuring the success of effectiveness of adaptation intervention success.

The search strategy was defined jointly by the author team and comprises three thematic blocks related to: 1) climate change; 2) adaptation; and 3) human health outcomes and health systems as well as the method, i.e., framework/metric (Table 1).

Four electronic literature databases namely, PubMed, Scopus, Web of Science, Embase, were searched for relevant articles without applying spatial restrictions, for the past 12 years (2013–2024) and only English articles were included. We adapted the search strategies for different databases because truncations and wildcards,

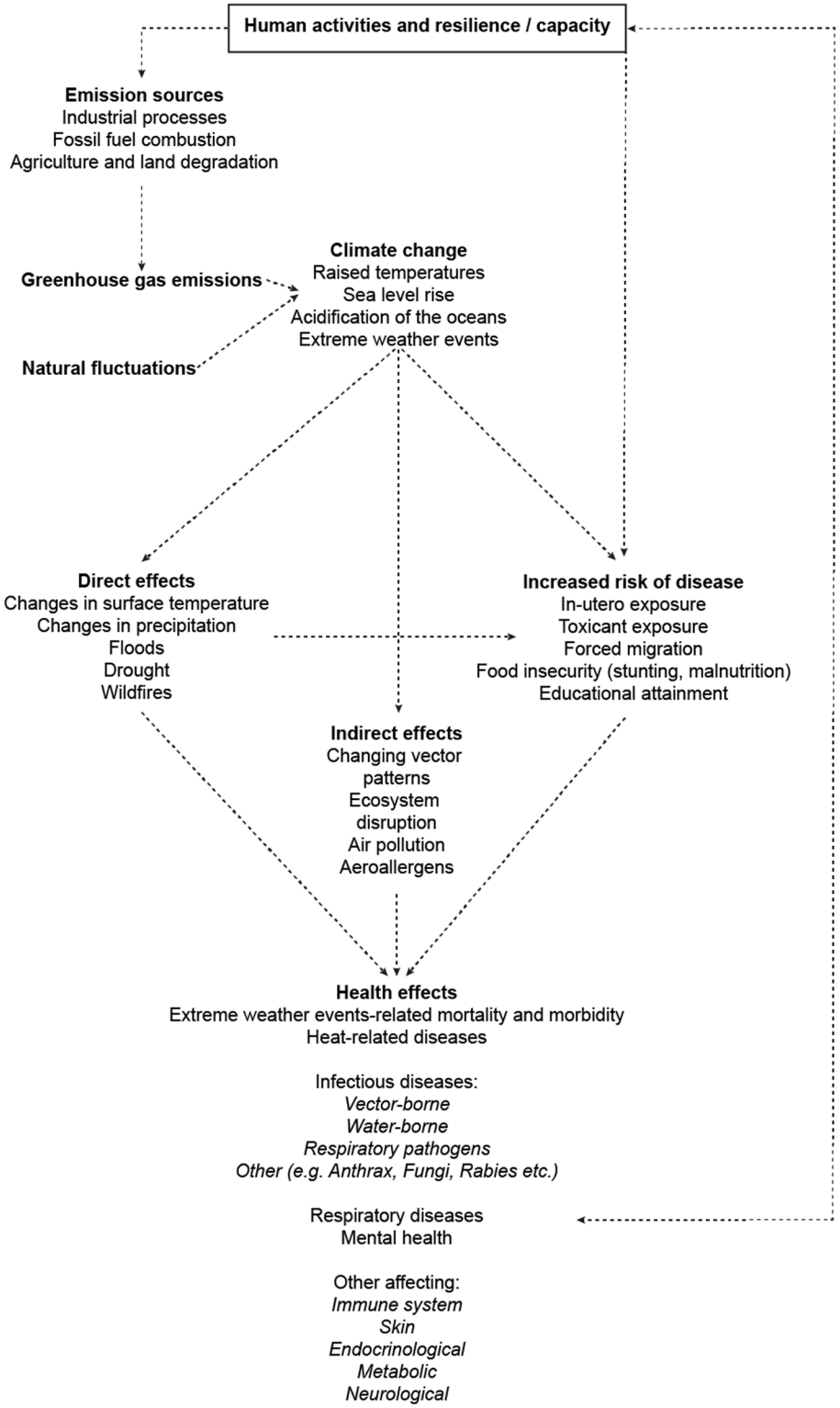

Fig. 1 Outline of climate change impacts on human health

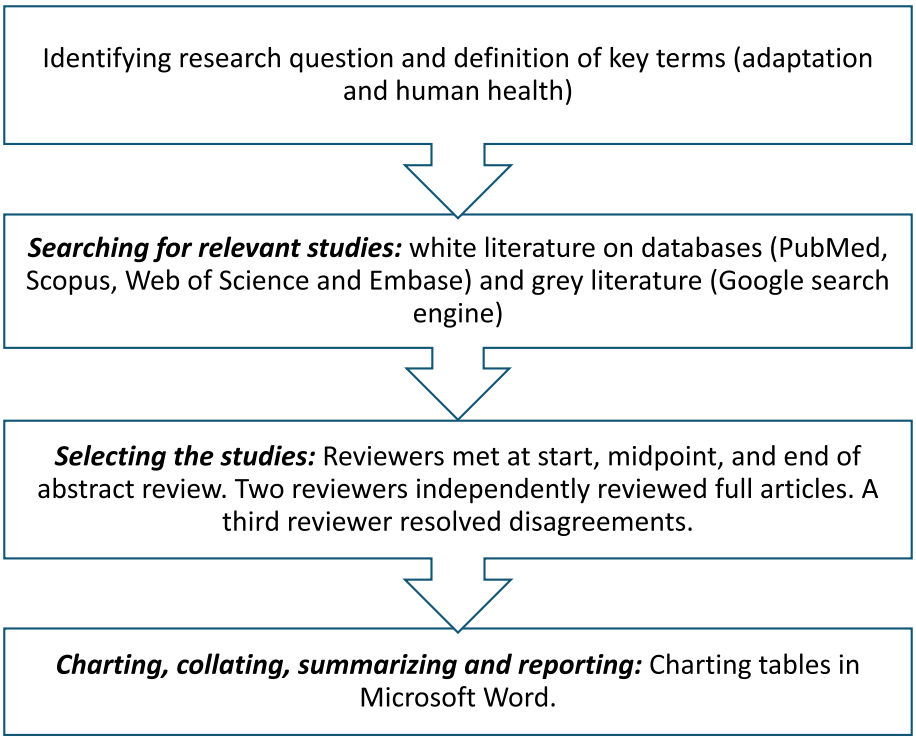

Fig. 2 Overarching methodological framework

Table 1 The search terms used in the identified search categories for the database literature search

Climate change	Adaptation	Human health and health systems impacts	Frameworks, metrics
Climate variability	Adaptation AND	Positive, negative, no impact	Indicators
Climatic changes	• coping	Mortality, morbidity	Measures
Climate sensitivity	• incremental	Nature of health and health systems impacts	Metrics
Environmental change	• transformative	Health outcomes reported: infectious disease,	Monitoring and evaluation
Climatology	• activities	non-communicable disease, trauma…	Outcome
Weather	• actions	Health systems impacts, healthcare, water,	Capacity
Extreme weather events	• implementation	sanitation, waste, food, infrastructure, capacity	Impact
Heat exposure	• intervention	of the healthcare / health system	Effectiveness
Cold exposure	• project		Success
Floods	Adaptation benefits: exposure, sensitivity,		Methods
Wildfires	adaptive capacity		Approach
Droughts	Climate resilience		Instrument
Rising temperatures			Strategy
Global warming			Quantifiable measure
			Practice
			Framework
			Adaptation Indicators

and even Boolean operators can vary between databases. The search strings were adapted to the specific technical requirements of each electronic literature database, and we filtered for research articles published between 2013 (inclusive) and 2024 (to date).

We also searched the grey literature using the Google search engine to include reports and documents outside of academic publishing matching our search criteria. The search terms for the grey literature search are included in Table 2.

Selecting the studies

All article citations were imported into Endnote. Duplicates were removed using the reference manager Endnote version 20. All documents were then transferred into Rayyan [39] which is a web application used to screen

Table 2 Search terms for the grey literature search

Climate Change	Adaptation strategies	Frameworks, metrics	Human Health and Health Systems Impacts
Climate	Adaptation	Methods	Health
Climate Change	Adaptation projects	Approach	Health systems
Extreme weather	Adaptation activities	Instrument	Disease
Global warming	Adaptation case studies	Strategy	Nutrition/food insecurity
Climate variability	Adaptation effects	Metric	Infectious diseases
Greenhouse effect	Climate resilience	Quantifiable measure	Non-communicable diseases
Rising temperature	Climate adaptation	Framework	Vector-borne disease
Extreme events	Adaptive capacity	Adaptation Indicators	Mental health
Flooding		Program evaluation	Physical trauma
Wildfires			Heatstroke
Drought			Climate sensitive diseases
			Weather-related morbidity
			Kidney disease
			Maternal and child health

documents for scoping reviews. The titles and abstracts of the obtained documents were screened independently by CYW, NN and TK by applying the inclusion criteria (Table 3). In the instance that a report did not have an abstract, the executive summary was screened. Conflicts regarding inclusion/exclusion of documents were discussed between CYW, TK and NN until consensus was reached. During the full text screening, CYW applied the same inclusion criteria (Table 3) and TK and NN assisted in the case of uncertainties. Consensus regarding inclusion and exclusion was reached for all documents.

Charting the data, collating, summarizing and reporting results

Document information on the following variables was extracted and charted:

1. Document characteristics (e.g., study location, first author country, year of publication, countries included in the study etc.). Countries were categorized according to the World Bank's income level classifications [40].
2. Proposed objectives and outcomes of the adaptation project to consider whether there were any common sectors or goals that saw health as an important potential side effect or secondary outcome (classifying by primary sector, outcome type etc.) and to see whether it was more commonly done in a certain sector, e.g., urban planning or farming or flood management etc.
3. Investigated/applied climate change adaptation/intervention/project or similar.
4. Measure/indicator/metric of effectiveness or success (examples include reduction in incidence/prevalence rates of a health outcome, health system capacity to prepare and manage risks, organizational diversity, internal monitoring, vertical/horizontal integration across sectors and health system levels, and number of GPs trained on climate change).
5. Investigated human health outcomes and health systems impacts (including spatial and temporal factors, such as how long after the adaptation intervention was an assessment made).

Table 3 Inclusion criteria and exclusion criteria applied during the title and abstract screening and the full-text screening of the articles identified through the literature search

Inclusion criteria	Exclusion criteria
• Publications and studies on climate change adaptation assessments	• Publications that do not have adaptation assessments
• Studies/publications that are focused on assessing an adaptation intervention/activity in relation of human health outcomes and health systems associated with climate change/climate/meteorology (with possible benefit of understanding in a climate change concept, given the difficulty of 'measuring' climate change)	• Publications not related to climate change and health
• Methods used for adaptation assessments for climate change	• No explicit mention of methods used for the study
• Original research articles, governmental reports, NGO reports, technical documents	• Commentaries, press releases, speeches, letters to the editor and conference
• English language	• Abstracts
• Publications during the last ten years – 2013 to 2024	• Non-English language publications
• All geographic locations permitted	• Publications older than ten years

Interviews

We conducted key informant interviews in step 2 of this study with ten interviewees (held virtually using Microsoft Teams) between 3 and 15 July 2024. Interviewees were purposefully selected from around the world to be representative of geographical region, gender, academic/non-academic, funder/donor etc. to try and hear as many voices as possible speak about ways to measure the effectiveness of climate change adaptation interventions for human health. A snowballing approach was used after the initial interviewees were selected to identify additional interviewees. A structured interview process (the interview guide is available in supplementary material Table S1– the guide was developed specifically for this project) was employed to identify indicators and measures for a framework to assess the effectiveness of adaptation activities in relation to public health and health systems strengthening. The interview methodology was designed to build on the findings of the preliminary scoping review. The primary goal of the interviews was to gather expert input on potential indicators and measures that could be integrated into a framework for evaluating the effectiveness of adaptation interventions on health outcomes and health systems. The first author conducted all of the interviews virtually on Microsoft Teams and transcriptions were kept, with permission, for each interview (of approximately 45 min).

The interviews commenced with a presentation of the scoping review's findings on the current evidence. Participants were then prompted to provide their insights and suggest potential indicators or measures for inclusion in the conceptual framework. Additionally, requests were made for relevant examples and case studies to illustrate these measures. Following the interviews, the feedback from informants was synthesized with the scoping review findings. This consolidation process aims to develop a comprehensive framework for assessing the effectiveness of adaptation activities in public health and health systems.

The interviewees were asked a range of questions (please see the questionnaire in the supplementary material) designed to gather insights on knowledge and practice related to climate change and health adaptation. They were asked about their specific areas of expertise related to climate change and health adaptation, including which indicators and frameworks they consider essential for evaluating the impact of adaptation interventions. The goal was to understand what parameters are crucial for assessing health outcomes and to identify any existing frameworks or indicators they might use or be familiar with. They were also asked to discuss the perceived strengths and weaknesses of these indicators and how well they measure relevant health outcomes. Additionally, the interviewees provided insights into successful climate change adaptation initiatives they have encountered, including those that positively impacted public health systems and how community engagement contributed to the sustainability of these strategies. Finally, they were asked for their perspectives on integrating community engagement and local knowledge into the development of an adaptation assessment framework. These discussions aimed to capture a comprehensive view of current practices, identify gaps, and gather recommendations for improving the evaluation and implementation of health adaptation strategies in the context of climate change. All interviews were captured in Microsoft Teams using transcription software and the interviewer took down notes of key points. Data were saved in password-protected Microsoft Word files and stored on a hard drive in a locked cupboard.

Research ethics clearance for conducting the interviews was obtained from the University of Pretoria Research Ethics Committee (NAS130/2024). All participants signed an informed consent form. No personal details were captured with their responses to the questions.

Collating, summarizing and reporting the findings

We divided this stage into three steps: 1) Analysis including descriptive numerical summary analysis and qualitative thematic analysis; 2) Reporting the results and presenting the outcomes in relation to our overarching goal of developing effective solutions for intervention studies; and 3) Translation of reported results into purposeful and practical solutions for measuring the effectiveness of adaptations/interventions during research studies and discuss implications for the future. For the interviewee data, these were checked for mention of specific tools, frameworks, indicators or projects that interviewees spoke about during the interview and all of these are included in this manuscript. We used deductive coding to extract details on specific tools, frameworks, indicators, or projects mentioned by interviewees during the interview. This was a top-down approach that we applied using our set of guiding questions and the conceptual framework. For each question asked of the interviewee, a response was given a thematic name and responses that were similar were grouped with the same thematic name. We went through both interviewer notes and the interviewee transcripts to deduce these thematic areas and they are all presented as descriptive text in the results. Additional points that interviewees explained were important for successful interventions are also captured in the results section.

Results

Overview of scoping review findings

In total, 6 787 articles and 501 reports were identified through the academic and grey literature search (Fig. 3, the PRISMA checklist is provided in Supplementary Table S2). Ultimately, 21 articles and 12 reports were included for data collation and synthesis. All included articles are listed in Table 4 and the grey literature search results are included in Table S3.

Summary of findings from the scoping review

Few studies assessed health outcomes

Of the 21 articles analyzed, only two studies presented primary evidence of health improvement outcomes. First, a reduction in neo-natal care unit (NICU) admissions was partially attributed to moving the maternity ward to the cooler lower floor of the hospital in Ahmedabad, India [51]. Second, a Western Ugandan chemoprevention intervention investigated spatial risk of malaria infection at multiple timepoints after severe flooding [59]. Children aged 12 years and under were given three rounds of fixed-dose combination anti-malarial treatments 30 days after the flood. They did evaluations at one-, two- and three-months post-flooding using a malaria rapid diagnostic test (RDT) and found a statistically significant reduction in RDTs in each consecutive month post-flooding thereby reducing malaria incidence. Longer-term interventions were planned, consisting of floodwater control mechanisms and policy solutions, incentivizing residents to relocate away from flood-prone areas permanently.

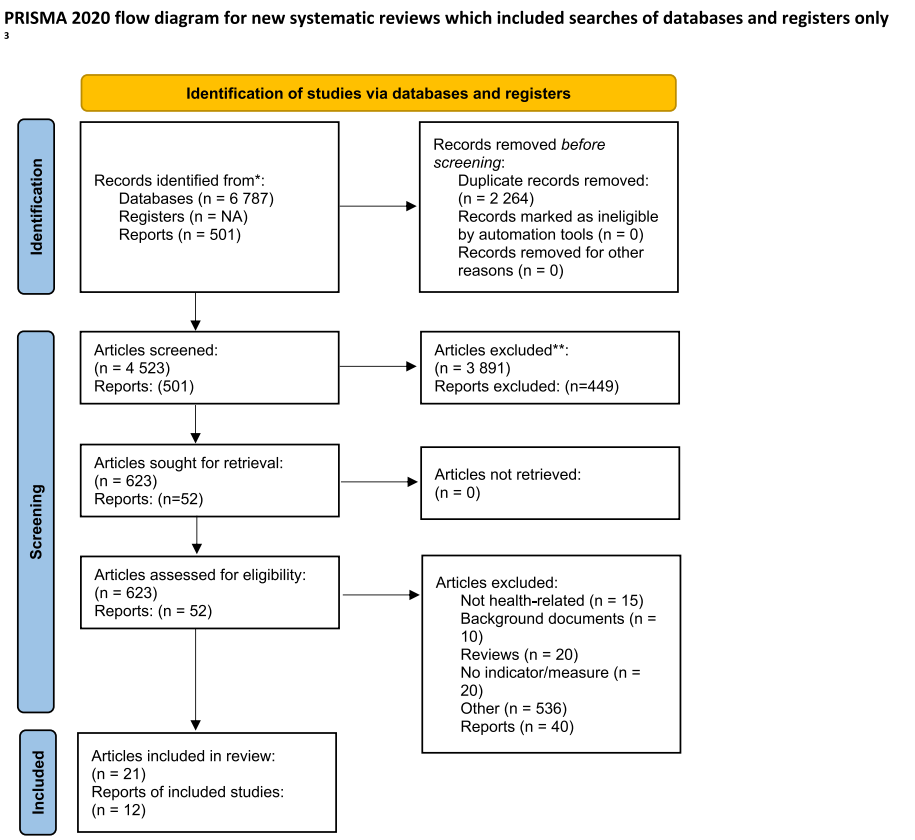

Fig. 3 Flow chart showing the number and reasons for including and excluding articles in the scoping review

Table 4 Characteristics of included articles in the scoping review

	First author, date	Study country/ countries/region	Adaptation activity/ intervention	Assessment of success/ effectiveness measures/ indicators	Climate variables	Health variables	Health/health systems impacts	Sector – if not health sector, e.g., flood management, and was health considered	Key Findings
1	Amaechina, 2022 [41]	Nigeria	The market cost approach was used to value the losses and damages due to climate change In response to increased climatic threats, farmers adopted various adaptation measures such as altering inputs such as varieties/ species, income diversification and chemical fertilizer and pesticide use	Success indicators were uptake of adjustments (%), range in measures applied (no health outcomes)	Flooding, rainfall	None	Poor health, sustained physical injuries, contaminated water	Flood management, no mention of health	Familiarization visit, local leader permission/entry/participant selection Wide range of partners (fishermen, youth opinion leaders etc.) Barriers were lack of resources and knowledge of adaptation options No further follow-up of uptake of adaptation activities post-study completion
2	Basel, 2020 [42]	Rendova Island in Western Province, Solomon Islands	Participatory community-based climate change adaptation planning process was used to engage with communities	Identifying community priorities and documenting them in adaptation plans for local implementation and evaluating whether these priorities addressed key vulnerabilities independently identified using a semi-quantitative vulnerability assessment	Climate change hazards and projections	Impacts of water quality, sanitation and food security on health	Community adaptation priority included improved health and sanitation	Vulnerability assessment community-wide, health mentioned	The communities identified adaptation priorities that encompassed governance, leadership, and planning; farming and livestock; sustainable livelihoods; natural resource management; and youth capacity building. These community adaptation priorities addressed the key climate change vulnerabilities identified in the semi-quantitative assessment and tackled additional drivers of social vulnerability and adaptive capacity

Table 4 (continued)

	First author, date	Study country/ countries/region	Adaptation activity/ intervention	Assessment of success/ effectiveness measures/ indicators	Climate variables	Health variables	Health/health systems impacts	Sector – if not health sector, e.g., flood management, and was health considered	Key Findings
3	Birkmann 2022, [43]	Global	Validation of two global vulnerability indicator systems, World Risk Index and INFORM Index	Indicators included physician density, health expenditure per capita, measles immunisation coverage, public/ private health expenditure, life expectancy at birth	-Climate change related disasters such as storms, floods and drought	Physician density, health expenditure per capita, measles immunisation coverage, public/ private health expenditure, life expectancy at birth	None	Vulnerability assessment, health mentioned	Two indicator systems (World Risk Index and INFORM index) helped identify countries with high vulnerability to inform climate resilience development
4	Boeckmann and Zeeb, 2014 [44]	18 European countries	Social justice and health framework	Document analysis using social justice and health framework	- Heat warning systems And extreme weather events	Mental health, vector borne diseases and infections, among other health outcomes	This study focused on adaptation strategies specifically in the health sector. General impacts of climate change on health	Policy, health mentioned	Four main adaptation types were discovered in the literature: data and surveillance, technological adaptation (including emergency plans and warning systems), behavioural adaptation and infrastructural adaptation. A social justice framework can serve as an evaluation guideline for adaptation policy documents
5	Bowen, 2014 [45]	Cambodia	Health-related and addressing climate change adaptation decision-making	Social network analysis of health-related adaptation decision-making	Climate change priorities for adaptation in ministries in government including disaster management and water	Several health outcomes, in particular mental health	Health-related decision-making	Broad policy framework, health mentioned	Interconnections between key agent organisations in climate change and health were identified
6	Chen, 2023 [46]	Jinan City, China	Heat health early warning model	Number of deaths averted	Daily 24-h average temperatures, relative humidity, ozone	Mortality: non-accidental, circulatory and respiratory diseases	Mortality	Health, health mentioned	Found a positive correlation between increasing mortality risks and heat warning levels for both sexes and individuals older than 75 years

Table 4 (continued)

	First author, date	Study country/ countries/region	Adaptation activity/ intervention	Assessment of success/ effectiveness measures/ indicators	Climate variables	Health variables	Health/health systems impacts	Sector – if not health sector, e.g., flood management, and was health considered	Key Findings
7	Deegan, 2022 [47]	British Columbia, Canada	Heat alert and response systems	Real-time health surveillance End of season evaluation Reduction of heat illness or death	Heat and heat-waves	Heat illness that ranges from heat rash to heat stroke, a medical emergency, excess mortality, etc	Heat-related health outcomes	Heat-related health, health mentioned	The development of a heat alert and response system can be done using a community-driven approach
8	Dovie, 2017 [48]	Ghana	Indicator development by assessing the scope of existing health indicators	New potential indicators in addition to health outcome indicators Adaptation indicators were well trained workforce, health facility accessibility and linked health surveillance and climate data Once-off assessment	Rainfall, atmospheric temperature, humidity, sunshine/heat, extreme weather	Morbidity: cerebrospinal meningitis, malaria, diarrhoea	Mortality, morbidity, history of occurrence, reported/confirmed cases	Health, health mentioned	Integrating traditional health indicators with social and ecological indicators is important for building climate resilience
9	Ebi, 2018 [24]	Global	Improved indicators for monitoring and evaluation in the health sector	Indicators of vulnerability and exposure to climate change Indicators of health impacts of climate change Indicators of adaptation and health system resilience	Weather, seasonality, climate variability, and long-term climate change	Several health outcomes were mentioned from many different studies	Climate change-related health impacts	Health system resilience, health mentioned	Indicators must be sensitive, valid and useful. They must account for uncertainties about the magnitude and pattern of climate change, upstream drivers of climate change and adaptation complexities, e.g., institutional learning

Table 4 (continued)

	First author, date	Study country/ countries/region	Adaptation activity/ intervention	Assessment of success/ effectiveness measures/ indicators	Climate variables	Health variables	Health/health systems impacts	Sector – if not health sector, e.g., flood management, and was health considered	Key Findings
10	Goonesekera, 2022 [26]	Global Athens, Aukland, Barcelona, Glasgow, Lima, Montrael, Nagoya, New York City, Portland, Tokyo, and Vancouver	Metric development guiding framework for city-level adaptation plans	Sourced 1841 adaptation-specific indicators: - Outcome indicators - Impact indicators	Climate specific adaptation plans of each city	None specifically mentioned	The majority of impact indicators were related to health and well-being,for example hospitalisations	Policy, health mentioned	This study focused on policy adaptation plans specific to climate change. It found many gaps in the planning process. Climate change adaptation planning is in its infancy. Thus, a guiding framework was established. It is important to have impact, outcome and output indicators and include the social and economic dimensions of these indicators
11	Houghton, 2017 [49]	Western Kentucky, USA	Populating baseline environmental public health indicators at the local level: environmental exposure, human health outcome, population and environmental vulnerability	Heat-related mortality during summer months Heat-related morbidity and mortality during extreme heat events Unintentional flooding-related mortality during flooding events Unintentional flooding-related morbidity during flooding events	Heat, drought, flooding	Mortality, morbidity	Number of heat-related deaths (ICD-10: X30) Number of heat stress hospitalisations and emergency department visits (ICD-9: 992, E900.0, E900.9) from May to September Number of unintentional drowning-related mortalities (ICD-10:W69,W70, and X38) and flooding-related hospitalizations and emergency department visits (ICD-9: E908.2, E908.9, E910.8, and E910.9)	Health, health mentioned	Consideration of rural – urban differences for indicator implementation is important

Table 4 (continued)

	First author, date	Study country/ countries/region	Adaptation activity/ intervention	Assessment of success/ effectiveness measures/ indicators	Climate variables	Health variables	Health/health systems impacts	Sector – if not health sector, e.g., flood management, and was health considered	Key Findings
12	Hunt, 2017 [50]	Europe London, Madrid and Prague	Heatwave warning system (economic analysis of costs and benefits)	Effectiveness of heatwave early warning systems Valuation of health improvements Number of health professionals employed	Heat	Mortality, morbidity	Savings to the health system	Health, health mentioned	Heatwave early warning systems are justified from an economic perspective as a no/low regret option and their benefits outweigh their costs
13	Kakkad, 2014 [51]	Ahmedabad, India	Moving the maternity ward to a lower floor in a non-airconditioned hospital	Reduction in NICU admissions pre- and post-moving the maternity ware from a higher to a lower floor in the hospital Once-off assessment	Temperature	Heat NICU admissions	Reduced NICU admissions	Health, policy, health mentioned	Moving the maternity ward led to fewer NICU admissions during hot weather
14	Macintyre, 2021 [52]	Europe	Cool roofs and its benefits for reducing mortality impacts	Modelled temperature in an urbanised region both outdoors and indoors in dwellings with cool roof paint on their roofs Once off assessment	Temperature	Temperature-related mortality	Cold and hot temperature-related mortality	Built environment/ housing, health mentioned	Cool roofs do not impact cold-mortality during winter
15	Martinez, 2017 [53]	Spain	Health promotion innovation called "Prescribe Healthy Life'	Level of collaboration	None	Healthy life principles	Healthy life principles	Health promotion, health mentioned	Identifying barriers and enablers for designing implementing strategies for health promotion in primary healthcare centres is essential for innovation success
16	Marvuglia, 2020 [54]	Europe	Simulations of temperature and mortality likelihood with and without green roofs on houses	Modelling of temperature scenarios based on an accurate study of the available data from literature	Heatwaves	Mortality	Mortality likelihood from heatwaves	Health, health mentioned	Green roofs can help lower mortality likelihood by reducing indoor temperatures during heatwaves but this is city-specific

Table 4 (continued)

	First author, date	Study country/ countries/region	Adaptation activity/ intervention	Assessment of success/ effectiveness measures/ indicators	Climate variables	Health variables	Health/health systems impacts	Sector – if not health sector, e.g., flood management, and was health considered	Key Findings
17	Mehiriz, 2018 [55]	Montreal, Canada	Automated phone warning and health advisory system for high heat episodes	Uptake of the automated phone warning and health advisory system The percentage of people who had heat-related symptoms The percentage of people who used the health care system	Temperature/heat episodes	Headaches, muscle cramps, chest pain, breathlessness, unusual fatigue or any other symptoms that are potentially related to excessive heat	Data on outcome variables show no statistically significant differences at the 5% risk of error level between the two groups (treatment and control) except in the case of the frequency of using air conditioner (4.28 versus 4.10, $p = 0.03$) Using a 10% risk of error, we also observe differences between the two groups concerning heat-related illness (56% versus 48%, $p = 0.08$) and frequency of using fans (4.31 versus 4.13, $p = 0.08$)	Health, health mentioned	The exposure to an automated phone warning seems to improve the adaptation to heat and reduce the use of health services by some important at-risk groups
18	Nzegbule, 2021 [56]	Aba City, Nigeria	Demonstrated increased resilience of rural and urban systems	Qualitative assessment of adaptation activities Once-off assessment	Flooding, erosion	Frequent sickness	Sickness	Climate hazards	Used a participatory action research approach to find out what communities felt were appropriate adaptation activities for climate hazards. Provided health centres, agriculture inputs, and improved sanitation

Table 4 (continued)

	First author, date	Study country/ countries/region	Adaptation activity/ intervention	Assessment of success/ effectiveness measures/ indicators	Climate variables	Health variables	Health/health systems impacts	Sector – if not health sector, e.g., flood management, and was health considered	Key Findings
19	Paterson, 2014 [57]	Canada	Toolkit/checklist for healthcare facility resilience to climate change	None	Several including extreme weather and its association with air pollution and water and sanitation challenges	Several health outcomes including heat illness, infectious diseases, waterborne diseases, malnutrition and foodborne diseases	Health facility resilience to climate change	Health, health mentioned	Development of the checklist that comprised more than 50 indicators and staff who were interviewed to review the checklist asked for it to be shorter, without repetition, more concise, among others. Addresses climate change risks to build community resilience
20	Westoby, 2019 [58]	Vanuatu in the Pacific Islands	A variety of community-based adaptation projects, e.g., disease proofing existing rainwater harvesting	Project's appropriateness, effectiveness, equity, impact and sustainability	Climate change hazards including cyclones, earthquakes, droughts, floods, volcanic eruptions and tsunamis	None	Improved health and well-being in the face of climate change	Adaptation, health mentioned	Locally-led adaptation initiatives are key for successful implementation
21	Xu, 2024 [59]	Western Uganda	Investigated spatial risk of malaria infection at multiple timepoints after severe flooding in rural western Uganda Children 12 years and younger were given 3 rounds of fixed-dose combination anti-malarial 30 days after the flood (chemoprevention intervention)	Proof of concept for programs aiming to prevent malaria outbreaks after flooding. Evaluations at one-, two- and three-months post-flooding using a malaria rapid diagnostic test (RDT)	Flooding	Statistically significant reduction in positive RDTs at each consecutive month post-flooding	Reduction in malaria incidence/prevalence	Health, health mentioned	Success could be enhanced with longer-term interventions such as floodwater control and policy solutions incentivizing residents to relocate permanently away from flood-prone areas

Learnings from other studies

None of the other included studies reached the point of assessing the effectiveness of their intervention (when they had one that was implemented). Hunt et al. [50], Chen et al. [46] and Deegan et al. [47] aimed to reduce heat-related mortality by using heat warning systems. One study explained how green roofs can lower mortality likelihood by reducing indoor temperatures during heatwaves [54]. These examples speak to adaptive capacity that can help improve resilience in terms of health but does still need to be measured with respect to a health indicator. An important study [52] showed how cool roof interventions do not impact cold-mortality during the cold winter season, demonstrating the importance of implementing adaptation strategies that account for region specific weather patterns.

Enhanced adaptive capacity

A further four articles [28, 38, 48, 54, 58] provided evidence of enhanced adaptive capacity (for example, better indicators for improved resilience in the health sector) [38] but did not show direct health outcome improvements of their interventions. For example, at the time of this review while yet to show health outcome reductions, exposure to an automated phone warning system alerting people about high heat episodes in Montreal Canada, did show initial signs of improving adaptation to heat and reducing the need for health service usage by at-risk groups during high heat events [55]. A study in Canada, evaluated climate change resilience in the health service using a checklist, comprising more than 50 indicators [57]. Stakeholders helped refine and shorten the checklist by removing redundancies, ensuring a user friendly format that would help guide officials to build resilience for climate threats and multiple health impacts [57].

Outcome-focused studies

Outcome-focused studies applied various methods, for example, [42] used quantitative methods to assess health impacts associated with water quality, sanitation and food security in the Solomon Islands. In Aba City, Nigeria, Nzegbule et al. [56] conducted a once-off, qualitative assessment of adaptation activities to demonstrate increased resilience of rural and urban systems to flooding and erosion. Using a participatory action research approach, communities suggested adaptation activities for climate hazards including health centres and improved sanitation services. Houghton et al. [49] also focused on heat as well as flooding and drought and considered rural–urban differences to help refine indicator implementation.

Another flood management-focused study aimed to reduce physical injuries and illness from consumption of contaminated water [41]. They co-created their project with their local leader and a range of partners including fishermen and youth leaders. While update of adaptation options did not occur, barriers were identified to the process, including lack of resources for implementation and limited knowledge on adaptation options.

A global assessment [43] used two indicator systems, the World Risk Index and INFORM index, to identify countries with high vulnerability to climate resilience development and did include indicators such as health expenditure per capita and measles immunization coverage, but no interventions [43]. A regional assessment of 18 European countries applied a social justice and health framework and used a document analysis to identify adaptation types for possible future implementation [44].

Other lessons about key elements that may help enhance the effectiveness of adaptation interventions

There were other lessons to learn from the studies. Interconnections between key agent organizations in climate change and health, such as ministries, public health agencies, non-governmental organizations (NGOs), academic institutions, international organizations like the World Health Organization (WHO) and United Nations Environment Programme (UNEP) and civil society groups geared towards climate action are critical for informed health-related adaptation decision-making [45]. Climate change and health adaptations also require sustained commitment to health promotion activities that support the interventions, as described in the 'Prescribe Healthy Live' health promotion innovation in Spain [53].

Summary of findings from the key informant interviews

The interviewees came from a variety of institutions and had different roles, including researchers ($n = 7$), funders ($n = 1$), policymakers ($n = 1$), and academic management ($n = 1$). The informants' expertise was related to adaptation to climate change and health as well as broader areas such as nutrition and sustainable development. Based on the questions asked of the interviewees, we grouped their responses into three sets of learnings to help inform the development of our assessment framework.

Familiarity with indicators/frameworks

The interviewees were familiar with indicators or frameworks being applied in climate change adaptation, for example, the Notre Dame Global Adaptation Initiative Index [60]. This Index is used to assess country-level vulnerability and readiness to implement adaptation; not the effectiveness of interventions related to adaptation

in climate change and health. The Tracking Adaptation and Measuring Development (TAMD) framework was developed to monitor and evaluate climate change adaptation [61]. It has six steps (namely, 1. Scope,2. Theory of change; 3. Defining and constructing indicators; 4. Measuring indicators; 5. Analyzing and interpreting results; and 6. Learning) and is intended for use of any level (country to project) by assessing institutional climate risk management and adaptation and development outcomes [62]. Its design encourages longer-term thinking about adaptation to climate change, which is important in intervention studies, however, the framework does not readily lend itself to application in research projects nor does it focus on health outcomes and health systems.

RE-AIM (Reach, Effectiveness, Adoption, Implementation, and Maintenance), a framework mentioned in the interviews, is not climate change and health specific, and is used for planning and evaluation and assessing interventions [63, 64]. The RE-AIM framework has been widely used in clinical, community, and corporate settings beyond its original focus on public health and health behaviour change research. It has been used to evaluate interventions such as chronic disease treatments, community health programs, and workplace wellness initiatives [65]. This leading implementation science framework [65] has multiple indicators for a broad assessment of key components that assist in a deciding if an intervention is effective,this goes beyond costs to consider a priori dimensions on which to focus evaluation pre-, during, and post-intervention. This framework may be useful in climate change and health-related adaptation interventions; however, it has not been applied in public health – to the best of our knowledge – as yet. In all of the above-mentioned frameworks, community engagement is noted as being key from conception of the project.

Use of indicators in research

Indicators were mentioned, such as in the Lancet Countdown [66], the Global Environment Facility (GEF) [67] and the Sendai Framework [68]. In addition, interviewees mentioned typical health variables that function as indicators for climate change and health surveillance, for example, premature mortality rates, number of hospital admissions and productivity losses.

Strengths and weaknesses of indicators/frameworks according to the interviewees

While indicators do exist to measure outcomes or impacts in the health system (e.g., number of people trained) these do not necessarily translate into understanding the effectiveness of adaptation efforts in the long-term, which is a critical aspect of sustainable adaptation to prevent against adverse climate change threats not only now but in the future. A major challenge is the lack of funding to support the use of indicators in effectiveness assessments during and after the intervention project so people tend to use typical indicators, like mortality in children under 5 years of age which may be influenced by many factors other than the adaptation intervention and are not tailored to the intervention.

For some indicators, such as those that are part of early warning systems, they need to be well integrated into broader health system policies and practices for them to function properly and have a tangible impact on public health. For example, a malaria early warning system in Limpopo province, South Africa helped public health officials to implement timely interventions to prevent an outbreak in 2022 by bringing the start of the spraying earlier than usual (anecdotal evidence, Neville Sweijd).

Frameworks, such as the World Health Organization's Operational Framework [69] and the World Bank's Health Adaptive Capacity Framework [70] are helpful, however, are too broad for precise application in specific local projects or in the climate change-related health adaptation space. For example, annual tracking is likely not sufficient for small-scale community-based climate-health interventions where quarterly tracking might be more helpful (however, this should be decided together with the community and key stakeholders to ensure uptake and acceptance of the intervention).

Guiding concept for an assessment framework

Applying our learnings from the scoping review and key informant interviewees' feedback, we prepared a guiding concept to inform the development of our climate change-health-adaptation assessment framework. The informed concept (Fig. 4) comprises six steps: 1. Assess climate change-related health risks and vulnerabilities; 2. Consider, evaluate and select health adaptation interventions; 3. Implement the selected interventions; 4. Engagement with community and partners to solicit feedback; 5. Assess outcomes and impacts, revise interventions and share lessons learned; and 6. Scale up and monitor impact. The first two steps require formative evaluation measures, steps 2 to 4 require process evaluation measures, and steps 5 and 6 require outcome evaluation measures. It is important to note that community and stakeholder engagement begins in step 1 as well as has a dedicated step (step 4) later on in the process.

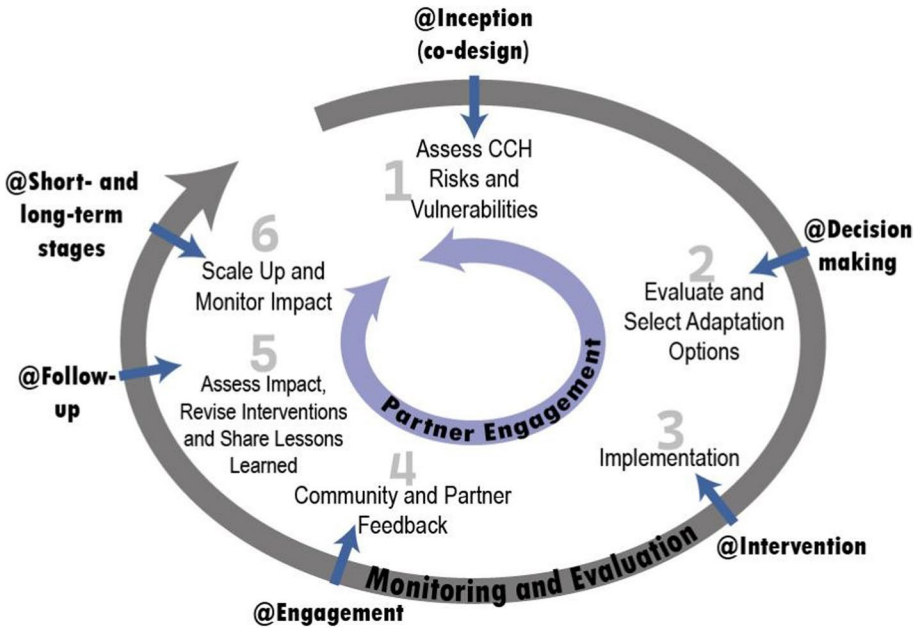

Fig. 4 Guiding concept to inform the development of a climate change-health-adaptation assessment framework to evaluate effectiveness

Proposed framework for assessing the effectiveness of climate change-related health adaptation interventions

The proposed framework for assessing the effectiveness of climate change-related health adaptation interventions is provided in the supplementary material. Called "SCALE-up" (for **S**uccessful **C**limate change and health **A**daptation **L**earning and **E**valuation) the assessment framework is underpinned by the guiding concept in Fig. 3. We developed four iterations of SCALE-up for use in climate change-related health adaptation interventions, namely for 1) heat exposure, 2) floods, 3) drought and 4) malaria adaptations. However, SCALE-up can be adapted to any climate change or extreme weather threat.

The dropdown menus to answer the indicator questions include simple yes/no responses together with a suite of other options (see supplementary Table S5). In this way, one can use the most appropriate option as a prompt for what to consider and include as steps at the earliest stage, i.e., conceptualization and proposal writing. This also provides one with the opportunity to reflect on the indicators on the framework, and note any learnings or difficulties found during the initial application of the framework as well as during the project itself.

During the development of SCALE-up, we made certain that our choice of measures/indicators measured adaptation as an outcome (e.g., adapted to a risk, with reduced rates of the outcome as a result) and/or as a process (e.g., political and institutional commitment to adaptation engagement and/or the presence of systems and processes for facilitating institutional learning). This was in line with an implementation science approach and process model thinking [71].

It is necessary to validate the theory of change by directly measuring resilience levels before and after an intervention. One approach is to conduct a perception resilience survey (that asks participants about their perception of climate risks and their adaptive capacity) combined with direct impact surveys (enquiring about their experiences following the intervention e.g., 'were your crops impacted by drought or storm?'). This combination creates a more elaborate composite resilience index. Given the multi-scale and multi-sector nature of climate adaptation interventions, some practitioners assess the contribution of specific adaptation interventions to a common objective, instead of attempting to attribute changes to specific projects, programmes or policies [30].

Discussion

Review

We searched the academic and grey literature for tools or frameworks that have been used to assess the effectiveness of climate change adaptation interventions especially to evaluate health outcomes and health systems. Key learnings from the review which we drew into the development of SCALE-up included the eleven principles for effective adaptation [72], especially 'be co-produced with communities to ensure inclusive and sustainable adaptation' and 'take into account unintended negative consequences and explicitly look at the cross-scale, long-term impacts of adaptation actions.' Other key elements

we considered were equity, specifically health equity (Collective Minds Climate Council) [73] and ensuring a logical theory of change was in place early in the project (funded by the Adaptation Fund) [74].

We developed a new framework, SCALE-up, that is similar to the Global Environment Facility (GEF) 'Tracking Tool for Climate Change Adaptation Projects (available here: https://www.thegef.org/sites/default/files/documents/Adaptation-tracking-tool-2014.xlsx#:~:text=The%20tracking%20tool%20for%20climate,SCCF) [75]. This tracking tool is intended to facilitate the monitoring of a project's contribution towards the goal, objective and outcomes of the GEF Adaptation Program. It is designed to enable the collection, aggregation and communication of progress and results across several projects simultaneously. In a Microsoft Excel file, with 14 indicators and a focus on quantitative data and consistent formatting, it provides output that enhances comprehensive monitoring and evaluation. Another tool, called the CAMELS (climate adaptation monitoring, evaluation and learning systems) (Brooks) model [76] aims to support countries in designing and implementing appropriate adaptation responses, tracking their effectiveness and delivering valuable learning and report on adaptation activities through global mechanisms such as the Paris Agreement's Enhanced Transparency Framework [77]. The seven key functions were considered implicitly in the six steps in SCALE-up.

In relation to how we conceived our indicators, we considered the Lancet Countdown, which is detailed and pragmatic, with systematic evidence synthesis methods that minimize bias. It uses specific health indicators, making it easier for policymakers to understand health impacts and progress toward the SDGs. On the other hand, the Sendai Framework is less specific in its outcomes and measurements but does well at contextualizing climate change impacts. It highlights the importance of considering cascading risks and how the same climate event can have varying impacts based on a country's resilience. This broader perspective is crucial for understanding and modeling health impacts, though it can be complex to implement in health models. The Sendai Framework does not focus specifically on health outcomes, instead it is more concerned with food systems and food availability, which indirectly affects health. The National Adaptation Plan (NAP) process or the Health NAP process is similar to SCALE-up comprising planning, implementation and monitoring and evaluation but its focus is on national level, although sub-national actors have an important role to play in the process.

Strengths, weaknesses and limitations

The limitations of the scoping review include potential publication and selection biases. The review may have missed some small grey literature pieces such as blogs which may have included important evolving information in the area of study. New articles and reports may have considered this topic since we concluded our search in mid-2024 while different or more refined search terms may have uncovered different articles that we missed. We used the IPCC and CDC definitions of climate change adaptation and health, respectively, since these are generally universally acceptable definitions. We may also have missed climate change interventions that were assessed for health co-benefits but did not have a framework or set of indicators to do so. Our search was limited to the English language and articles from other languages, such as from authors in Francophone countries, were not included.

Some limitations of conducting the key informant interviews were that we conducted ten in total, however, we believe that we reached saturation after the ten interviews were completed. We also made sure to select our key informants carefully to ensure correct representation of all fields of expertise as well as roles (e.g., academic, non-government organization, government and others) to reduce bias. Two limitations exist for all key information interviews, namely interviewer influence where the interviewer may have unintentionally influenced the responses of the informants; and proving the validity of the data. For the former, the interviewer used a question guide (Table S1) to ensure consistency in all interviews, and for data validity, the risks were deemed low.

SCALE-up is newly developed and grounded on the findings of the scoping review and the key informant interviews. It has been 'pilot-tested' in theory (the authors worked through the heat-focused framework using one of the existing heat-health studies) but still needs to be evaluated in the field. We also only prepared SCALE-up for four climate change-related health interventions. In the future, we plan to create additional iterations of the SCALE-up for other health interventions, such as dust storms, tropical cyclones, wildfires, snowstorms and others. SCALE-up will also be made available online for download and adjustment by users to meet their specific needs.

SCALE-up is relatively complex despite our aim to create a simple tool. It is not intended that a researcher or funder 'answer' every question and even when answering a question, we have provided multiple answers. We recommend that users of SCALE-up read the six steps and associated indicators and then identify the most appropriate aspects for their project or intervention. Our goal is to trigger thinking about all the critical elements of an adaptation intervention through a health lens. We also recommend that when researchers or funders do apply the framework, the primary

investigator is not the person implementing the framework to ensure non-biased results. The person who will be responsible for or working closely with the implementation person should monitor the integration of the framework's indicators into the proposal/project. We also need to bolster our research efforts more broadly in the climate change and health adaptation monitoring and evaluation field since SCALE-up is considered, to the best of our knowledge, the first of its kind.

Conclusions

By examining the literature and conducting expert perspectives, we provided a comprehensive overview of how to effectively measure and enhance the impact of climate adaptation strategies for human health and wellbeing. These findings will inform gaps and opportunities for future studies for researchers, inform policymakers and practitioners, and guide efforts to strengthen health resilience in the face of a changing climate.

Abbreviations

CDC	Centers for Disease Control
GEF	Global Environment Facility
GP	General practitioner
NAP	National Adaptation Plan
NGO	Non-governmental organization
NICU	Neonatal care unit;
PRISMA-ScR	Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews
OECD	Organization for Economic Co-operation and Development
RDT	Rapid diagnostic test
SDG	Sustainable Development Goal
TAMD	Tracking Adaptation and Measurement Development
UNEP	United Nations Environment Programme
WHO	World Health Organization

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-23358-z.

Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

Supplementary Material 4.

Supplementary Material 5.

Supplementary Material 6.

Supplementary Material 7.

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Authors' contributions

CYW conducted literature search. CYW, TK, CW and NN evaluated the study articles and made decisions on inclusion and exclusion of the articles. CYW wrote the manuscript and all authors participated in its revision. All authors read and approved the final manuscript.

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Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files.

Declarations

Ethics approval and consent to participate

Research ethics clearance for conducting the interviews was obtained from the University of Pretoria Research Ethics Committee (NAS130/2024). All participants signed an informed consent form. No personal details were captured with their responses to the questions. The researchers abided by the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Wyman O. Quantifying the Impact of Climate Change on Human Health. 2024.
2. Romanello M, Di Napoli C, Green C, et al. The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms. The Lancet. 2023;402:2346–94.
3. Chaudhry D. Climate change and health of the urban poor: The role of environmental justice. J Climate Change Health. 2024;15:100277. https://doi.org/10.1016/j.joclim.2023.100277.
4. Guizzardi D, Pagani F, Banja M, Muntean M, Schaaf E, Becker W, Monforti-Ferrario F, Quadrelli R, Risquez Martin A, Taghavi-Moharamli P, Köykkä J, Grassi G, Rossi S, Brandao De Melo J, Oom D, Branco A, San-Miguel J, Vignati E. GHG emissions of all world countries. Publications Office of the European Union. 2023. https://doi.org/10.2760/953322.
5. Fankhauser S, McDermott TKJ. Understanding the adaptation deficit: Why are poor countries more vulnerable to climate events than rich countries? Glob Environ Chang. 2014;27:9–18. https://doi.org/10.1016/j.gloenvcha.2014.04.014.
6. Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. Impact of regional climate change on human health. Nature. 2005;438(7066):310–7. https://doi.org/10.1038/nature04188.
7. IPCC. Global Warming of 1.5°C. Cambridge University Press. 2022. https://doi.org/10.1017/9781009157940.

8. OECD. DAC Quality Standards for Development Evaluation. DAC Guidelines and Reference Series: OECD Publishing; 2010. https://doi.org/10.1787/9789264083905-en.
9. Hawkins P, Geza W, Mabhaudhi T, Sutherland C, Queenan K, Dangour A, Scheelbeek P. Dietary and agricultural adaptations to drought among smallholder farmers in South Africa: A qualitative study. Weather and Climate Extremes. 2022;35: 100413. https://doi.org/10.1016/j.wace.2022.100413.
10. Bird FA, Pradhan A, Bhavani RV, Dangour AD. Interventions in agriculture for nutrition outcomes: A systematic review focused on South Asia. Food Policy. 2019;82:39–49. https://doi.org/10.1016/j.foodpol.2018.10.015.
11. Ssempiira J, Kissa J, Nambuusi B, Mukooyo E, Opigo J, Makumbi F, Kasasa S, Vounatsou P. Interactions between climatic changes and intervention effects on malaria spatio-temporal dynamics in Uganda. Parasite Epidemiology Control. 2018;3(3): e00070. https://doi.org/10.1016/j.parepi.2018.e00070.
12. FAU. *What are* the goals of climate change adaptation? IPCC Report Info Bite. 2022. https://www.fau.eu/2022/03/15/news/research/what-are-the-goals-of-climate-change-adaptation/.
13. Calvin K, Dasgupta D, Krinner G, Mukherji A, Thorne PW, Trisos C, Romero J, Aldunce P, Barrett K, Blanco G, Cheung WWL, Connors S, Denton F, Diongue-Niang A, Dodman D, Garschagen M, Geden O, Hayward B, Jones C, Ha M. IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. Geneva: IPCC; 2023. https://doi.org/10.59327/IPCC/AR6-9789291691647.
14. Lawler JJ, Spencer B, Olden JD, Kim S-H, Lowe C, Bolton S, Beamon BM, Thompson L, Voss JG. Mitigation and Adaptation Strategies to Reduce Climate Vulnerabilities and Maintain Ecosystem Services. In Climate Vulnerability. Elsevier; 2013. p. 315–335. https://doi.org/10.1016/B978-0-12-384703-4.00436-6.
15. Fuldauer LI, Thacker S, Haggis RA, Fuso-Nerini F, Nicholls RJ, Hall JW. Targeting climate adaptation to safeguard and advance the Sustainable Development Goals. Nat Commun. 2022;13(1):3579. https://doi.org/10.1038/s41467-022-31202-w.
16. Craft B, Fisher S. Measuring effective and adequate adaptation. 2016.
17. USEPA. (2023). Adaptation Actions for Water Utilities. https://www.epa.gov/arc-x/adaptation-actions-water-utilities.
18. Zimmer M, Helfer V. Mangrove forest - a nature -based solution for climate change mitigation and adaptation. Rural21. 2022. https://www.rural21.com/english/archive/2022/01/detail/article/mangrove-forests-a-nature-based-solution-for-climate-change-mitigation-and-adaptation.html.
19. Liyanage DR, Hewage K, Hussain SA, Razi F, Sadiq R. Climate adaptation of existing buildings: A critical review on planning energy retrofit strategies for future climate. Renew Sustain Energy Rev. 2024;199:114476. https://doi.org/10.1016/j.rser.2024.114476.
20. Olivier J, Leiter T, Linke J. Adaptation made to measure: A guidebook to the design and results-based monitoring of climate change adaptation projects (2nd ed.). GIZ. 2013.
21. Scheelbeek PFD, Dangour AD, Jarmul S, Turner G, Sietsma AJ, Minx JC, Callaghan M, Ajibade I, Austin SE, Biesbroek R, Bowen KJ, Chen T, Davis K, Ensor T, Ford JD, Galappaththi EK, Joe ET, Musah-Surugu IJ, Alverio GN, Berrang-Ford L. The effects on public health of climate change adaptation responses: a systematic review of evidence from low- and middle-income countries. Environ Res Lett. 2021;16(7):073001. https://doi.org/10.1088/1748-9326/ac092c.
22. Berrang-Ford L, Siders AR, Lesnikowski A, Fischer AP, Callaghan MW, Haddaway NR, Mach KJ, Araos M, Shah MAR, Wannewitz M, Doshi D, Leiter T, Matavel C, Musah-Surugu JI, Wong-Parodi G, Antwi-Agyei P, Ajibade I, Chauhan N, Kakenmaster W, Abu TZ. A systematic global stocktake of evidence on human adaptation to climate change. Nat Clim Chang. 2021;11(11):989–1000. https://doi.org/10.1038/s41558-021-01170-y.
23. UNEP. (2023). Underfinanced. Underprepared. Inadequate investment and planning on climate adaptation leaves world exposed. https://doi.org/10.59117/20.500.11822/43796.
24. Ebi KL, Hasegawa T, Hayes K, Monaghan A, Paz S, Berry P. Health risks of warming of 1.5 °C, 2 °C, and higher, above pre-industrial temperatures. Environ Res Lett. 2018;13(6):063007. https://doi.org/10.1088/1748-9326/aac4bd.
25. Christiansen L, Martinez G, Naswa P. Adaptation metrics: perspectives on measuring, aggregating and comparing adaptation results. 2018.
26. Donatti CI, Harvey CA, Hole D, Panfil SN, Schurman H. Indicators to measure the climate change adaptation outcomes of ecosystem-based adaptation. Clim Change. 2020;158(3–4):413–33. https://doi.org/10.1007/s10584-019-02565-9.
27. Seyisi E, Mantlana B, Ndhleve S. Indicators for monitoring and evaluating climate change adaptation efforts in South Africa. Jàmbá J Disaster Risk Stud. 2023;15(1). https://doi.org/10.4102/jamba.v15i1.1426.
28. Goonesekera SM, Olazabal M. Climate adaptation indicators and metrics: State of local policy practice. Ecol Ind. 2022;145: 109657. https://doi.org/10.1016/j.ecolind.2022.109657.
29. STAP. (2017). Strengthening Monitoring and Evaluation of Climate Change Adaptation: A STAP Advisory Document.
30. Christiansen L, Schaer C, Larsen C, Naswa P. Monitoring & Evaluation for climate change adaptation: A summary of key challenges and emerging practice. Understanding, discussing and exemplifying the key challenges of M&E for adaptation. 2016.
31. Garousi V, Felderer M, Mäntylä MV. Guidelines for including grey literature and conducting multivocal literature reviews in software engineering. Inf Softw Technol. 2019;106:101–21. https://doi.org/10.1016/j.infsof.2018.09.006.
32. Munn Z, Peters MDJ, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMC Med Res Methodol. 2018;18(1):143. https://doi.org/10.1186/s12874-018-0611-x.
33. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol. 2005;8(1):19–32. https://doi.org/10.1080/1364557032000119616.
34. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. Implement Sci. 2010;5(1):69. https://doi.org/10.1186/1748-5908-5-69.
35. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, Moher D, Peters MDJ, Horsley T, Weeks L, Hempel S, Akl EA, Chang C, McGowan J, Stewart L, Hartling L, Aldcroft A, Wilson MG, Garritty C, Straus SE. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann Intern Med. 2018;169(7):467–73. https://doi.org/10.7326/M18-0850.
36. IPCC. (2013). Annex 2: Glossary. In T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
37. CDC Foundation. (2024). What is public health? https://www.cdcfoundation.org/what-public-health.
38. Ebi KL, Boyer C, Bowen KJ, Frumkin H, Hess J (2018) Monitoring and Evaluation Indicators for Climate Change-Related Health Impacts, Risks, Adaptation, and Resilience. Int J Environ Res Public Health 15:1943.
39. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. Syst Rev. 2016;5(1):210. https://doi.org/10.1186/s13643-016-0384-4.
40. World Bank (2025) World Bank country classifications by income level for 2024-2025. In: World Bank Blog. https://blogs.worldbank.org/en/opendata/world-bank-country-classifications-by-income-level-for-2024-2025. Accessed 31 May 2025.
41. Amaechina EC, Anugwa IQ, Agwu AE, Ifelunini AI, Umeonuora TG, Okwor CA. Assessing climate change-related losses and damages and adaptation constraints to address them: Evidence from flood-prone riverine communities in Southern Nigeria. Environmental Development. 2022;44:100780. https://doi.org/10.1016/j.envdev.2022.100780.
42. Basel B, Goby G, Johnson J (2020) Community-based adaptation to climate change in villages of Western Province, Solomon Islands. Mar Pollut Bull 156:111266.
43. Birkmann J, Jamshed A, McMillan JM, Feldmeyer D, Totin E, Solecki W, Ibrahim ZZ, Roberts D, Kerr RB, Poertner H-O, Pelling M, Djalante R, Garschagen M, Leal Filho W, Guha-Sapir D, Alegría A. Understanding human vulnerability to climate change: A global perspective on index validation for adaptation planning. Sci Total Environ. 2022;803:150065. https://doi.org/10.1016/j.scitotenv.2021.150065.
44. Boeckmann M, Zeeb H. Using a Social Justice and Health Framework to Assess European Climate Change Adaptation Strategies. Int J Environ Res

Public Health. 2014;11(12):12389–411. https://doi.org/10.3390/ijerph111212389.
45. Bowen K, Alexander D, Miller F, Dany V (2014) Using Social Network Analysis to Evaluate Health-Related Adaptation Decision-Making in Cambodia. Int J Environ Res Public Health 11:1605–1625.
46. Chen C, Liu J, Wang M, Cui L, Li T. Evaluating the Applicability and Health Benefits of the Graded Heat Health Risk Early Warning Model — Jinan City, Shandong Province, China, 2022. China CDC Wkly. 2023;5(29):642–6. https://doi.org/10.46234/ccdcw2023.123.
47. Deegan HE, Green J, El Kurdi S, Allen M, Pollock SL. Development and implementation of a Heat Alert and Response System in rural British Columbia. Can J Public Health. 2022;113(3):446–54. https://doi.org/10.17269/s41997-022-00611-1.
48. Dovie DBK, Dzodzomenyo M, Ogunseitan OA. Sensitivity of health sector indicators' response to climate change in Ghana. Science of The Total Environment. 2017;574:837–46.
49. Houghton A, Austin J, Beerman A, Horton C. An Approach to Developing Local Climate Change Environmental Public Health Indicators in a Rural District. J Environ Public Health. 2017;2017:1–16. https://doi.org/10.1155/2017/3407325.
50. Hunt A, Ferguson J, Baccini M, Watkiss P, Kendrovski V. Climate and weather service provision: Economic appraisal of adaptation to health impacts. Clim Serv. 2017;7:78–86. https://doi.org/10.1016/j.cliser.2016.10.004.
51. Kakkad K, Barzaga ML, Wallenstein S, Azhar GS, Sheffield PE. Neonates in Ahmedabad, India, during the 2010 Heat Wave: A Climate Change Adaptation Study. J Environ Public Health. 2014;2014:1–8. https://doi.org/10.1155/2014/946875.
52. Macintyre HL, Heaviside C, Cai X, Phalkey R. Comparing temperature-related mortality impacts of cool roofs in winter and summer in a highly urbanized European region for present and future climate. Environ Int. 2021;154:106606.
53. Martinez C, Bacigalupe G, Cortada JM, Grandes G, Sanchez A, Pombo H, Bully P. The implementation of health promotion in primary and community care: a qualitative analysis of the 'Prescribe Vida Saludable' strategy. BMC Fam Pract. 2017;18:23.
54. Marvuglia A, Koppelaar R, Rugani B. The effect of green roofs on the reduction of mortality due to heatwaves: Results from the application of a spatial microsimulation model to four European cities. Ecol Modell. 2020;438:109351.
55. Mehiriz K, Gosselin P, Tardif I, Lemieux M-A. The Effect of an Automated Phone Warning and Health Advisory System on Adaptation to High Heat Episodes and Health Services Use in Vulnerable Groups—Evidence from a Randomized Controlled Study. Int J Environ Res Public Health. 2018;15:1581.
56. Nzegbule EC, Okpara E, Okali D. Climate Change Impact on Rural-Urban Inter-Dependence and Community Adaptation Response: Case Study with Aba City and its Environs. In Handbook of Climate Change Management. Springer International Publishing; 2021. p. 1–24 https://doi.org/10.1007/978-3-030-22759-3_100-1.
57. Paterson J, Berry P, Ebi K, Varangu L. Health Care Facilities Resilient to Climate Change Impacts. Int J Environ Res Public Health. 2014;11:13097–116.
58. Westoby R, McNamara KE, Kumar R, Nunn PD. From community-based to locally led adaptation: Evidence from Vanuatu. Ambio. 2020;49:1466–73.
59. Xu E, Goel V, Baguma E, Ayebare E, Hollingsworth BD, Brown-Marusiak A, Giandomenico D, Reyes R, Ntaro M, Mulogo EM, Boyce RM. Evolution of Spatial Risk of Malaria Infection After a Pragmatic Chemoprevention Program in Response to Severe Flooding in Rural Western Uganda. J Infect Dis. 2024;229(1):173–82. https://doi.org/10.1093/infdis/jiad348.
60. Notre Dame Global Adaptation Initiative. Helping countries and cities counter the risks of a changing climate. Helping countries and cities counter the risks of a changing climate. 2024.
61. IIED. (2024). Tracking adaptation and measuring development (TAMD). https://www.iied.org/tracking-adaptation-measuring-development-tamd.
62. Brooks N, Fisher S. Tracking Adaptation and Measuring Development: a step-by-step guide. 2014. https://www.iied.org/10100iied.
63. Glasgow RE, Trinkley KE, Ford B, Rabin BA. The Application and Evolution of the Practical, Robust Implementation and Sustainability Model (PRISM): History and Innovations. Global Implementation Res Appl. 2024;4(4):404–20. https://doi.org/10.1007/s43477-024-00134-6.
64. Hodgson W, Kirk A, Lennon M, Janssen X, Russell E, Wani C, Eskandarani D. RE-AIM (Reach, Effectiveness, Adoption, Implementation, and Maintenance) Evaluation of the Use of Activity Trackers in the Clinical Care of Adults Diagnosed With a Chronic Disease: Integrative Systematic Review. J Med Internet Res. 2023;25: e44919. https://doi.org/10.2196/44919.
65. Glasgow RE, Harden SM, Gaglio B, Rabin B, Smith ML, Porter GC, Ory MG, Estabrooks PA. RE-AIM Planning and Evaluation Framework: Adapting to New Science and Practice With a 20-Year Review. Front Public Health. 2019;7. https://doi.org/10.3389/fpubh.2019.00064.
66. Romanello M, McGushin A, Di Napoli C, Drummond P, Hughes N, Jamart L, Kennard H, Lampard P, Solano Rodriguez B, Arnell N, Ayeb-Karlsson S, Belesova K, Cai W, Campbell-Lendrum D, Capstick S, Chambers J, Chu L, Ciampi L, Dalin C, Hamilton I. The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future. The Lancet. 2021;398(10311):1619–62. https://doi.org/10.1016/S0140-6736(21)01787-6.
67. Temnenko K. Monitoring and Evaluation in the GEF. 2019. https://www.thegef.org/sites/default/files/events/1_IEO_0.pdf.
68. UNISDR. (2015). Sendai Framework for Disaster Risk Reduction 2015 - 2030.
69. Shamim T. The World Health Organization (WHO) operational frame work implemented in a Family Health Center (FHC) in Kerala. J Fam Med Primary Care. 2022;11(12):7517–8. https://doi.org/10.4103/jfmpc.jfmpc_1398_22.
70. World Bank Group (2024) Climate and Health Vulnerability Assessment (CHVA). https://openknowledge.worldbank.org/collections/57c53958-606c-462d-8c40-5f63f3f71140. Accessed 26 Nov 2024.
71. Nilsen P. Making sense of implementation theories, models and frameworks. Implement Sci. 2015;10(1):53. https://doi.org/10.1186/s13012-015-0242-0.
72. Singh C, Iyer S, New MG, Few R, Kuchimanchi B, Segnon AC, Morchain D. Interrogating 'effectiveness' in climate change adaptation: 11 guiding principles for adaptation research and practice. Climate Dev. 2022;14(7):650–64. https://doi.org/10.1080/17565529.2021.1964937.
73. MSH. (2024). Time to Adapt: Accelerating Climate Adaptation for Health Equity—Catalyzing Solutions for Community Action. https://msh.org/events/time-to-adapt-accelerating-climate-adaptation-for-health-equity/.
74. Meliane, I. (2023). Developing the theory of change and elaborating a logical framework. https://www.adaptation-fund.org/wp-content/uploads/2023/05/Theory-of-Change_Logframe_EDA-Example.pdf.
75. GEF. (2014). GEF Climate Change Adaptation Tracking Tool. https://www.thegef.org/documents/gef-climate-change-adaptation-tracking-tool.
76. Brooks N, Anderson S, Aragon I, Smith B, Kajumba T, Beauchamp E, d'Errico S, Rai N. Framing and tracking 21st century climateadaptation: monitoring, evaluation and learning for Paris, the SDGs and beyond. 2019.
77. United Nations. (2022). Preparing for the Enhanced Transparency Framework. https://unfccc.int/process-and-meetings/transparency-and-reporting/preparing-for-the-ETF.

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