Building health resilience through climate services: An analysis of the current state of implementation and future policy directions

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1. Background

Climate services for health (tools and platforms that translate climate and health data into actions and insights) have become essential for protecting public health amid escalating climate change and variability (World Meteorological Organization, 2023). Their potential to mitigate climate-related health risks such as heat-related mortality, vector-borne diseases and extreme weather events is widely recognized (Manyuchi *et al.,* 2021). However, proven pathways to the effective, timely and sustained implementation of these services have yet to be systematically defined in existing literature. Most studies focus on documenting the outputs, like early warning systems, risk maps, seasonal calendars and climate projections, rather than examining how these services are developed, integrated and operationalized within health systems (Climate Services for Supporting Climate Change Adaptation, 2016; Schmidt & Platzer, 2024). Critical questions, such as who drives implementation, how services are tailored to local contexts, and what governance structures enable success, are often overlooked, creating a gap in understanding how to bridge climate science and health-sector action effectively (Shumake-Guillemot *et al*., 2023).

This report assesses the implementation of climate services for health through a structured analysis of case studies identified in the literature. Using the 2023 World Meteorological Organization (WMO) framework, which conceptualizes implementation as a multi-phased process (pre-implementation, active implementation and evaluation), this report focuses on the analysis of two core phases: pre-implementation and active implementation operationalizing climate services for health, with attention to five key components: leadership, governance, stakeholder engagement, data integration and dissemination. The pre-implementation stage involves needs assessment, awareness raising, stakeholder mapping and resource planning, laying a foundation for effective service design for active implementation. These phases have been prioritized in this report, given the importance of generating more evidence and diagnostics on the implementation and execution of climate–health service functions.

Leadership involves active sponsorship and direction from high- and operational-level decision-makers to develop and implement climate services for health. It includes prioritizing resources, establishing mandates, removing barriers, raising awareness among ministers and other leaders during the pre-implementation phase, and empowering practitioners (e.g., environmental health officers) to integrate climate services into their routine work.

Governance encompasses the set of formal structures, coordination and financing mechanisms, policies, strategic plans and strong leadership needed to oversee climate–health initiatives, foster cross-sector collaboration and ensure accountability. It enables the sharing of data, best practices and resources across actors, with clear roles and effective oversight bodies (e.g., national climate–health task forces, regional platforms) to maintain momentum and align with health and climate objectives.

Stakeholder engagement ensures the assessment of aspects like a user-centred, demand-driven approach that meaningfully involves health professionals, policymakers, community leaders and at-risk populations to ensure climate–health services are relevant, accessible and decision-ready. It emphasizes understanding local contexts, co-designing and testing tools (e.g., risk maps, alerts), building trust and ensuring tools meet real needs for sustained use.

Data integration involves the process of converting raw climate data into practical, decision-relevant information tailored to local health needs. It requires reliable, context-appropriate data

presented in accessible formats (such as dashboards, early warning systems and risk maps), as well as close collaboration between climate scientists and health professionals, to ensure that outputs are meaningful and usable.

Dissemination involves the reliable and timely delivery of climate–health information through various channels, including dashboards, alerts (such as SMS and apps), community radio and reports, while accounting for barriers and facilitators to uptake. Effective dissemination enhances reach, comprehension and action by end-users in diverse contexts.

By systematically examining these components across diverse regional contexts, the report identifies common challenges, best practices and enabling factors influencing the successful implementation of climate services for health. The goal is to deepen understanding of implementation dynamics and offer actionable insights for policymakers, practitioners and researchers working to operationalize climate services within health systems.

Case studies from Africa, Asia and South America provide local insights into implementing climate services for health, uncovering challenges, stakeholder roles and adaptive strategies that are often overlooked in broader analyses. Qualitative analysis demonstrates how climate services inform priorities such as disease surveillance and resource allocation, thereby linking theory to practice. Rather than focusing on outcomes, the report highlights recurring patterns in inherently nonlinear processes, providing a foundation for best practices and local strategies that can be scaled across tools and contexts.

Although this report emphasizes the importance of the evaluation stage, it is not an evaluation report. Consequently, it does not focus on assessing the effectiveness, usability and impact of climate services through monitoring, feedback and iterative learning. Existing literature shows how continuous evaluation refines service delivery over time, influencing health outcomes and system performance. Instead, this study conducts a comparison between four countries across three regions (Africa, Asia and South America) to identify standard implementation processes. By analysing how stakeholders utilize climate data in health alongside the mandates and governance structures in place, as well as the prioritization and resource allocation given to climate–health services, recurring patterns and contextual challenges are highlighted here. The findings can inform other settings with similar characteristics and help address bottlenecks in implementing climate services for health.

2. Methods

This work synthesizes evidence on climate services for health through six integrated steps. First, we conducted a systematic literature review to identify sources linking climate data with health decision-making. This review included peer-reviewed articles, technical reports, case studies and grey literature from various sources such as academic databases, Google Scholar and reports from organizations like the United Nations (UN), World Health Organization (WHO), WMO and the Intergovernmental Panel on Climate Change (IPCC). Screening was facilitated by the Rayyan platform. Second, we used structured coding and data extraction to gather detailed information on title, URL, decision level and climate-related health risks, along with study methodologies, tool outcomes, impact evidence, product categories, data formats, customization options, delivery frequency, communication channels and intersectoral collaboration.

Third, a thematic analysis classified the literature by decision-making applications, types of climate services and data integration strategies. It also assessed temporal trends and regional variations to illuminate the evolving landscape of climate services for health. Fourth, we conducted a structured qualitative synthesis to map the translation of climate information into public health actions. This process outlined the phases of readiness, implementation and evaluation, while identifying key building blocks such as leadership, governance, engagement, usable data and dissemination. Fifth, we developed three typologies of implementation approaches – centralized/top-down, decentralized/bottom-up and hybrid/phased. These typologies were analysed in relation to governance building blocks to inform practical deployment strategies.

Finally, we examined four diverse case studies (Bangladesh, Colombia, Malawi and Senegal) through key informant interviews and literature analysis to identify barriers, facilitators and lessons for creating inclusive, scalable climate services for health. AI-assisted transcription supported the interviews, with human verification ensuring accuracy. Full methodology details are provided in Annex 1.

3. Results

3.1 Study classification

We identified 128 studies that reported the development of tools combining health and climate data/information. Of these, 45 proceeded to full-text screening. Based on the screening, we categorized the studies into four types of climate services for health: 1) early warning systems (EWSs); 2) seasonal calendars; 3) risk maps; and 4) climate projection studies.

Description of the four types of climate services for health

1. Early warning systems are proactive tools that use real-time data collection and predictive models to detect and communicate imminent health risks associated with climate-related events. This enables timely alerts that facilitate preventive measures.

2. Seasonal calendars offer a long-term perspective on seasonal climate patterns and related health risks, facilitating planning for issues such as malaria outbreaks.

3. Risk maps visually represent geographic areas that are vulnerable to climate-related health threats. They help in identifying high-risk zones and inform resource allocation and preparedness strategies.

4. Climate–health projection studies utilize climate models to estimate future climate scenarios and their potential health impacts.

These studies focus on long-term forecasts rather than immediate warnings, helping policymakers to anticipate changes in health patterns and resource requirements related to climate change. Projection studies utilize climate models to estimate future climate scenarios and their potential health impacts.

We studied spatial disparities and contextual differences by grouping studies by region or country to understand how climate services for health differ across various geographical and developmental settings. Our analysis reveals a general pattern: high income countries have a more developed data infrastructure, which facilitates better integration of climate and health data. Nevertheless, many services have also been established in lower- and middle-income countries, with notable activity in nations such as Bangladesh, Brazil, Ethiopia, India and Kenya. However, very few studies highlight the importance of adopting intersectional approaches that consider how factors like age, disability, socioeconomic status and others impact vulnerability and access to health services. To ensure equitable access to climate services for health worldwide, it is crucial to develop context-sensitive, scalable solutions and effective knowledge transfer mechanisms.

Figure 1 shows how most climate services for health in the literature are primarily developed as EWSs, followed by risk maps and climate change projection tools. Analysis shows that 53 per cent of these tools were created by academic institutions, 19 per cent by government agencies, 10 per cent by meteorological services and 4 per cent by private entities. These findings depict the diversity of sources and approaches employed in developing climate–health tools across various sectors. It is important to note that much of the academic work tends to

focus on developing individual tools rather than the integrated, service-oriented implementation needed for real-world impact (see Box 1). These findings also highlight the inherent bias in academia, as academic studies are often more likely to be published than the data or conclusions from meteorological services and agencies. This discrepancy can lead to an incomplete understanding of the broader context.

Box 1. Climate services versus climate tools

- Climate services for health are comprehensive decision-support systems that encompass governance, dissemination, capacity building and user-oriented actions. These systems translate data into actionable health decisions and interventions. In contrast, a tool may combine and analyse climate and health data and could be used to support decision-making. Climate services for health may employ a suite of different tools.

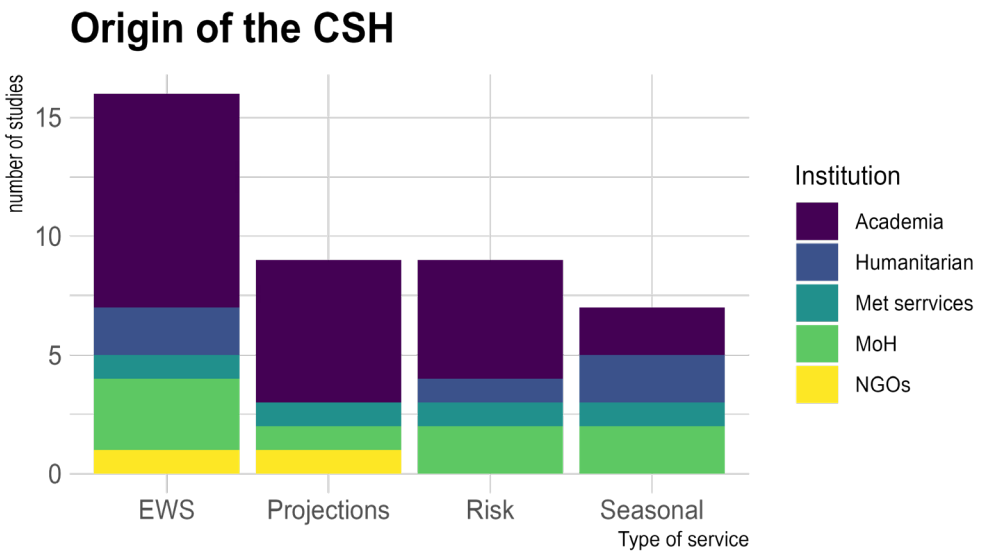

Figure 1. Distribution of the climate services and their source. Source: authors' own.

Based on the literature review, we identified key objectives guiding the implementation of climate services for health. Figure 2 shows that of the services analysed, most focused on strategic planning and preparedness as well as enabling rapid and timely interventions. Additionally, resource allocation and response actions were particularly important for EWS and risk maps. However, very few services aimed to increase public awareness through campaigns, strengthen capacity building or promote advocacy efforts. The analysis illustrates that strategic planning and preparedness are prioritized, particularly in EWS and projections. Response actions are the main focus of these products, with 30 per cent and 50 per cent respectively reporting that this is the key objective of the product. This indicates a strong focus on forward-looking coordination and readiness of resources. Public awareness campaigns are utilized most for projections at 30 per cent, while contributions to EWS and risk maps are more modest. This suggests that communication efforts described in the literature tend to target future scenarios rather than immediate alerts or risk mapping. Targeted interventions and resource allocation are mainly concentrated in risk maps and EWS, emphasizing geographic priorities and capacity-focused actions. Proof of concept as an objective demonstrates a balanced distribution across all categories; however, community engagement, capacity building and advocacy show minimal utilization. There are varying emphases on rapid and timely interventions as well as geographic prioritization across the categories. This underscores the necessity for an integrated approach that combines surveillance, risk assessment, communication and institutional capacity to enhance anticipatory action and crisis response.

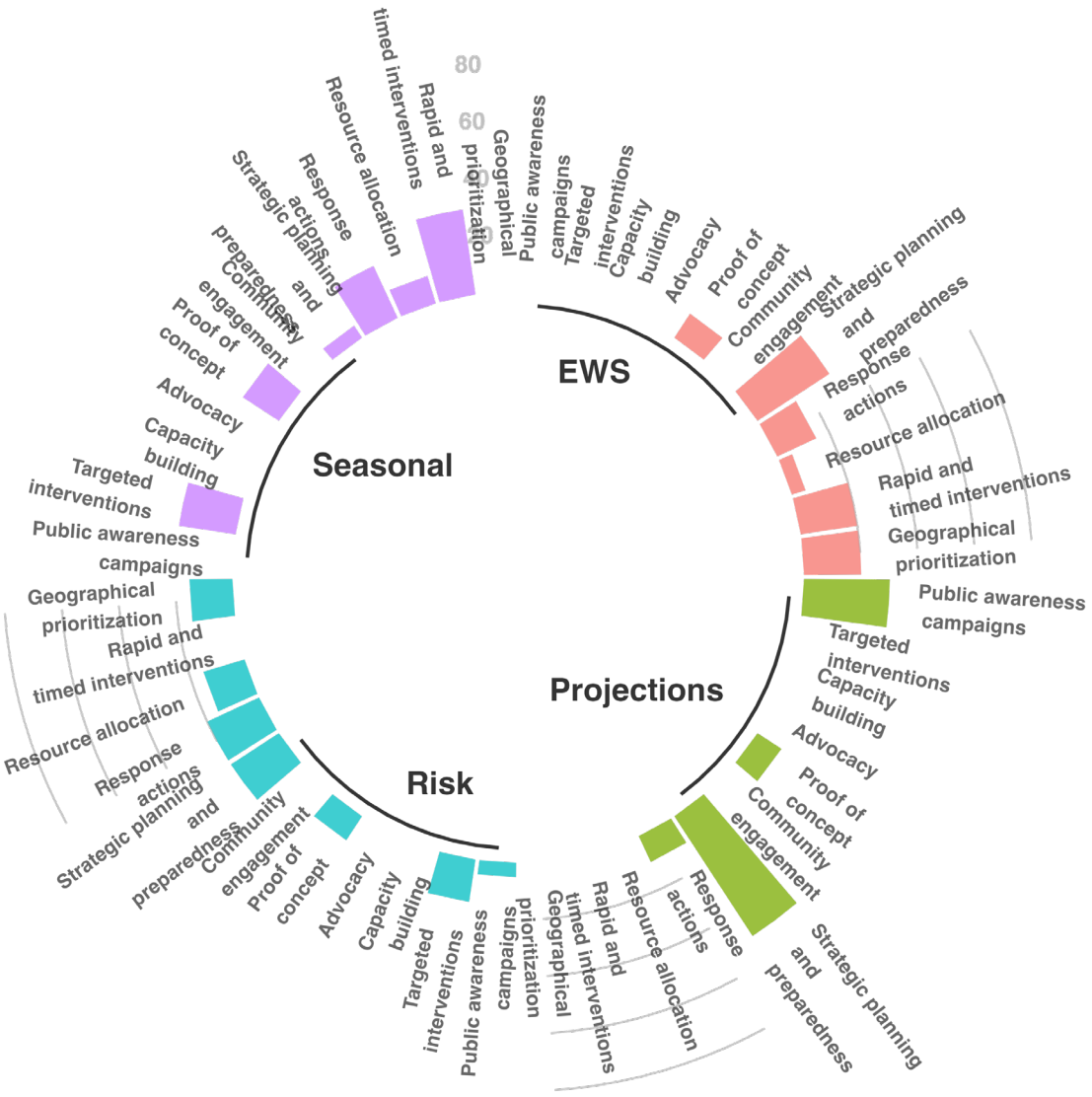

Figure 2. Key objectives guiding the implementation of climate services for health highlight a focus on strategic planning, preparedness and rapid interventions. The figure illustrates that most services prioritized response actions and resource allocation, particularly for early warning systems and risk maps, while fewer efforts targeted public awareness, capacity building or advocacy. Source: authors' own.

3.2 Literature review analysis

We also coded information from the 45 reports and papers focused on climate and health tools for decision-making, emphasizing five implementation building blocks: leadership, governance, engagement, data and dissemination. Our analysis aimed to answer critical questions, such as whether there is leadership – both within and outside the health sector – and to gain an understanding of the value added by climate services for health. We examined which institutions or agencies are responsible for implementing these services, whether roles and responsibilities are clearly defined among stakeholders, and if mechanisms or structures exist (or need strengthening) to facilitate coordination and collaboration across sectors and partners. Additionally, we assessed the level of transparent engagement and communication with different stakeholder groups, exploring how community involvement, strategic actions and communication influence the design and implementation of climate services for health.

Furthermore, we assessed the technical capacity and skills available for developing and executing climate and health services, examining how data is processed, analysed and communicated to support decision-making. We investigated whether systems are in place to ensure the adequate flow of climate–health data from providers to users and identified the range of products and tools used to communicate climate information to different audiences. This

comprehensive coding enables us to understand the current landscape, including its strengths, gaps and opportunities for enhancing climate services for health across diverse contexts.

Table 1 presents the contribution of each building block, characterized by several key features, for the tools identified across different types of climate services for health, namely EWS, risk maps, seasonal outlooks and climate projection tools. For each tool type, we calculated the percentage of studies evaluated that met specific sub-criteria. This analysis provides a diagnostic of the current state of climate services for health, highlighting the main gaps and areas for improvement within each component.

Table 1. Building block approach coding table

This table describes the criteria most frequently met by the studies examined, identifying key features that characterize effective climate services for health. It highlights which aspects of the implementation building blocks are widely represented across different tools and services evaluated, according to descriptions in the literature, and where gaps remain, providing an overview of the current landscape of climate services for health. Red indicates that less than 20 per cent of the studies report on that sub-criterion; orange signifies that more than 20 per cent but less than 40 per cent report it; yellow represents that more than 40 per cent of the studies report the sub-criterion; and green indicates that more than 60 per cent of the screened studies report the criterion. Sub-criteria percentages may not add up to 100 per cent due to overlaps, missing data or varying reporting granularity across studies.

Building block	Implementation guiding questions	Sub-criteria	EWS	Risk	Seasonal	Projec-tions
Leadership	Is there lead (within and outside the health sector) and understanding of the value-added of climate services for health?	N/A	29%	35%	28%	42%
	What are the institutions or agencies in charge of the implementation of the climate service?	Humanitarian organizations	16%	12%	30%	0%
		UN development partner agencies	12%	14%	0%	14%
		NGOs	4%	0%	0%	0%
		Ministry of health	22%	20%	18%	12%
		Disaster risk reduction or management	3%	5%	8%	5%
		Meteorological services	2%	8%	9%	29%
		Academia	32%	41%	35%	50%
		Regional health and climate organizations	12%	0%	0%	0%
Governance	Are there clear roles and responsibilities for stakeholders, including agency or individual in charge of implementation?	N/A	10%	0%	0%	28%
	What mechanisms / structures are in place (or need to be strengthened) to support coordination / collaboration across sectors / partners to guide implementation of climate services for health?	Institutional coordination mechanisms (MoU between relevant ministries / agencies)	41%	38%	12%	22%
		Active technical working group / steering committee focused on climate change and health	21%	32%	0%	37%
		Permissions and policies (e.g., data sharing or privacy regulations)	0%	0%	0%	0%
		Policy or plan in place to guide implementation of climate services for health	10%	14%	0%	18%
		Funding sources or budgetary allocations	35%	12%	5%	22%
		Mechansims to engage local populations and communities	37%	19%	10%	4%
		Established monitoring and evaluation system in place with metrics to track progress	11%	5%	0%	0%
Engagement	Is there clear and transparent engagement / communication with different stakeholder groups?	N/A	5%	10%	0%	0%
	How is climate services for health design and implementation influenced through community engagement, communication and strategic actions?	User-centred approaches	10%	30%	35%	0%
		Demand-driven approaches	20%	0%	0%	15%
		Co-design / co-creation methods	20%	14%	25%	0%
		Stakeholder mapping	25%	0%	0%	15%
Data	Are there adequate technical skills and capacity for designing and implementing climate services for health?	N/A	18%	24%	16%	26%
	How is data processed, analysed and communicated to support decision-making?	Data is locally available and accessible	48%	28%	45%	12%
		Data platforms and modelling tools	31%	24%	0%	21%
		Statistical and epidemiological analysis	46%	56%	21%	62%
		Machine learning and mathematical models	14%	8%	0%	11%
		Spatial analyses	49%	75%	4%	63%
Dissemination	Are there systems in place to support the flow of climate–health data / information from providers to users?	N/A	24%	19%	8%	11%
	What products / tools are available to communicate climate data / information to different audiences?	Contextualized risk communication tools	41%	32%	29%	11%
		Maps, seasonal outlooks, feedback mechanisms	36%	68%	46%	61%
		Scenario development	12%	0%	0%	100%

Leadership findings

Box 2. Leadership highlights

- Lack of consistent supportive leadership is a persistent barrier to implementing climate services for health, with only about 35 per cent of studies reporting both internal and external support and limited recognition of the added value of climate–health tools. Among the types of climate services for health, climate change projections receive the strongest support across settings.
- Academia currently drives most climate and health initiatives oriented to producing tools and methods that are often not fully translated into national-scale delivery, leading to gaps in scalability and integration despite locally relevant outputs.

The characterization of climate services for health highlights that the lack of supportive leadership remains a significant barrier for implementation in this field. On average, approximately 35 per cent of studies report both internal (e.g., relevant government agencies such as ministries of health and/or meteorological departments) and external (e.g., academic institutions and/or regional/international partners such as WHO) support, as well as acknowledgment of the added value of tools that connect climate and health information. In this context, climate change projections are recognized as the most relied-upon and valued components, consistently receiving the highest levels of support among the evaluated tools. Following projections, EWS also gains notable attention; however, the perceived usefulness of these tools varies by setting and sector. Most scenario projection studies evaluated a few climate and health variables to project future risks under various emissions and socioeconomic paths. Common health outcomes of interest include heat-related morbidity and mortality, including cardiovascular risk and heat stress, respiratory illness, vector-borne and diarrhoeal diseases, death and injuries from extreme weather events. Methodologies feature deterministic climate models paired with Representative Concentration Pathways and Shared Socioeconomic Pathways (RCPs/SSPs), end-to-end health models, statistical/epidemiological approaches and exposure–response functions, often incorporating downscaling, uncertainty analysis and, occasionally, agent-based or system dynamics models to capture adaptation. Outputs typically include projected case counts, risk maps/indexes and health burden estimates across scenarios.

Most initiatives are conceived, developed and often tested in academic settings, leveraging available methodological resources and analytical expertise. Government involvement often happens without established co-design or co-creation methods, or it occurs late in the development process. Typically, ministries of health, national emergency and disaster management agencies and humanitarian organizations are responsible for implementing this involvement. This arrangement can create a gap between cutting-edge research and operational delivery, with implications for scalability, sustainability and integration into routine health systems. The data and tools produced in these efforts are often tailored for local relevance; however, the pathways to national adoption and inter-institutional coordination remain uneven across different contexts. Academic initiatives developed by academia are also responsible for implementing the tools and, in some cases, transforming them into services.

Governance findings

Box 3. Governance highlights

- Fragmented and/or ineffective governance is a significant barrier to integrating climate services into health systems. Integration requires strong and lasting policy frameworks, formal agreements and well-defined roles that go beyond just data governance.
- Without consistent funding, evaluation frameworks and coordination among agencies, climate services tend to remain as pilot projects. To ensure successful and accountable implementation, it is essential to engage in co-design, foster inter-agency collaboration and create local adaptation plans.
- From the studies assessed, we found that the development of tools and services is supported by a diverse range of funding sources, including private foundations, philanthropic contributions, national research agencies and targeted initiatives from national governments.

Lack of governance stands out as the key obstacle to integrating climate services into health systems, even more critical than data availability and accessibility. Strong governance structures are necessary to turn data into actionable insights and foster meaningful integration. Reviews often display a bias towards academic tools rather than practical approaches to effective governance. Challenges encompass not just permissions and sustainable funding but also the absence of established, enduring frameworks for data sharing, inter-institutional collaboration and co-designing climate services health. For example, about half of the examined studies mention formal agreements, like memoranda of understanding (MoUs) between key agencies such as national meteorological services, health ministries and technical groups, demonstrating some coordination. Yet, explicit protocols for data sharing, privacy or regulation are usually absent. Most projects depend on short-term academic grants, with little documentation of long-term funding strategies. Moreover, without evaluation frameworks, it becomes challenging to measure impact, build on successes or justify continued investment. Ultimately, the lack of integrated adaptation plans and operational guidelines prevents climate services from evolving beyond the pilot stage within health systems.

Our review reveals that for climate services to effectively support public health, robust policies and strategic planning are required – extending beyond basic data governance. For example, Table 1 shows that most evidence indicates a lack of governance – such as working groups, coordination mechanisms, policies or plans to guide the implementation of climate services for health – which becomes a major bottleneck even when climate and health data are ready and harmonized. These frameworks are crucial for fostering stakeholder collaboration and accountability. Information from key informants has shown that where national guidelines are absent, local health departments often act independently, resulting in fragmented and inconsistent responses to climate-related health threats and, in some instances, increasing the vulnerability of health systems during events such as heatwaves and floods. Additionally, the review highlights significant gaps in operational frameworks, inter-agency partnerships and clarity regarding roles and responsibilities across stakeholder groups. These findings collectively stress the importance of establishing stronger governance, securing sustainable funding and promoting co-designed, collaborative strategies that embed climate services into health authority operations and routine care.

Engagement findings

Box 4. Engagement highlights

- A user-centred, demand-driven focus is common and beneficial for tailored forecasts and guidance, but co-design and iterative stakeholder engagement are often underutilized, limiting relevance and accountability.
- Although end-user needs are prioritized, most work is driven by academia rather than health agencies, with limited use of advanced data science techniques and insufficient regular stakeholder mapping and feedback for sustainable, scalable implementation.

The identified services often adopt a user-centred or demand-driven approach, prioritizing the needs and usability of end-users to enhance their implementation and effectiveness. Climate services for health particularly emphasize supporting vulnerable subpopulations by creating forecasts, risk maps and guidance tailored to high-risk groups and evaluating their impact. Effective strategies include targeting specific demographics with accessible, tailored messages, providing actionable information (e.g., evacuation routes, cooling centre locations) and fostering inclusive governance through community co-production and feedback (Díaz *et al*., 2024; Shumake-Guillemot *et al*., 2023). Improving coverage requires high-resolution data, diverse communication channels and consistent monitoring of equity metrics to measure reach and impact. However, co-design or co-creation methods are rarely employed, which may limit the relevance of services for diverse populations and sustained implementation beyond the pilot phase. Stakeholder mapping in many reports is shaped by academia's local data-building priorities and often highlights data availability and accessibility at the local level. While several reports demonstrate a user-centred, demand-driven and co-creative approach, few address regular stakeholder mapping or the collection of iterative feedback from users and/or implementers. Most processes and academic tool development lack clear, ongoing stakeholder engagement, which undermines accountability and programme continuity.

Although health ministries and government institutions have some statistical and analytical capabilities, academic institutions lead most climate–health research in peer-reviewed literature. The public sector rarely uses advanced data science techniques such as machine learning and AI, highlighting the need for ongoing, transparent stakeholder engagement and increased adoption of data-driven methods to improve decision-making and operations. However, many barriers still need to be overcome for implementing these approaches in several countries. Examples of these barriers include access to data and the development or improvement of methods to be transformed into white-box approaches, allowing practitioners to have a rational explanation of the results (Ethics and Governance of Artificial Intelligence for Health, 2021; Fiske *et al.,* 2025).

Data findings

Box 5. Data highlights

- Governance and engagement are the main bottlenecks for climate services in health. While data quantity is less critical, data quality remains an issue, with context-dependent challenges in health and climate data. There is a need for stronger stewardship and ongoing collaboration.
- The literature emphasizes technical data tools and methods but underrepresents long-term infrastructure – such as platform maintenance and capacity-building within health systems – crucial for sustaining data-driven climate services.

Data plays a vital role in climate services related to health, but the challenges vary based on the context. Findings from key informant interviews has shown that, in some countries, limited health data can impede the ability to convert climate information into actionable steps. In others, the main issues are related to the availability and accessibility of climate data, which impacts forecasts, risk assessments and timely communication. Additionally, many studies emphasize that accurate analysis of local health and climate data often relies on reanalysis products. Our findings show that while the data domain demonstrates many positive indicators, it is the governance and engagement domains that remain the primary barriers to fully realizing the potential of climate services for health. This challenges the common misconception that data itself is the main obstacle. It would be helpful to determine whether one type of data is consistently scarce while the other is plentiful and of high quality, or if gaps in both areas worsen each other. Shifting focus in this way is essential for advancing the implementation of climate services that can better support improved public health outcomes. Lastly, we observed that the literature frequently describes data platforms, modelling tools and various analytical methods, including statistical analyses, epidemiological assessments, machine learning, mathematical models and spatial analyses. While these details are useful for technical replication, there is less emphasis on the infrastructure needed to sustain these data services over time, such as data stewardship practices, platform maintenance and capacity building within health systems for ongoing use.

Dissemination findings

Box 6. Dissemination highlights

- Defining clear user profiles and tailoring communication strategies to a range of stakeholder groups (officials, public health staff, researchers, the public) enhances the reach, relevance and uptake of climate–health information, while academic tools often lack participatory, user-driven design.
- Government-produced climate–health tools tend to disseminate more effectively through dashboards and inter-agency channels, suggesting a need for academia to adopt similar user-focused dissemination and co-design with end users to build trust and drive action.

Defining user profiles is crucial for climate services related to health, as it enables more effective responses to climate-related health risks. These profiles may encompass healthcare administrators, public health emergency officials, environmental health officers, other health programme staff, policymakers, researchers and the public – each with distinct needs and varying familiarity with climate data. Adapting communication methods to these groups, such as providing detailed reports for officials and infographics for the broader public, can maximize the reach and impact of information.

Academic and research-driven climate–health tools often target ministries of health, local health units and researchers examining climate–health trends, but active user participation with these resources is limited. Few allow users to interact with or tailor the tools to their needs. In contrast, tools produced by government agencies are generally disseminated more successfully, with results often shared through dashboards and inter-agency communications, promoting quicker acceptance and collaboration. This contrast highlights the need for academic initiatives to prioritize participatory, user-focused designs and to disseminate their outputs through channels accessible to a broader range of users, not just institutions.

Bridging scientific outputs with public understanding is also key to building trust and involvement in health interventions. Clearly defined user profiles can inform policy decisions, enable better resource allocation and ensure interventions focus on those most at risk from climate change.


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3.3 Case studies

Bangladesh

3.3.1 Case study: Bangladesh – Climate services for health

Overview and context

Bangladesh is advancing the integration of climate and health data across national health, disaster management and urban planning. There is an increasing focus on inter-agency coordination and the development of early warning systems that incorporate health indicators. This shift aims to transition from reactive responses to anticipatory actions for climate-sensitive diseases, along with forecasts that are downscaled to the community level. Key operational focus areas include addressing the urban heat island effects in Dhaka, managing storm surge risks in Satkhira, and responding to flash flood risks in the northeastern Haor region. These context-specific forecasts help guide targeted interventions to protect vulnerable populations.

Two climate services for health have the potential to serve as examples of strong governance, clear data sharing, modelling and structured decision-making. First, the Heatwave Alert Portal – part of the El Niño Anticipatory Actions to Drought and Heatwave in Bangladesh Project, launched in May 2024 by the Bangladesh Meteorological Department (BMD) and Dhaka North City Corporation (DNCC) with technical support from the Regional Integrated Multi-Hazard Early Warning System (RIMES) in collaboration with Save the Children. The portal generates ward- and *upazila*-level maps of forecast heatwave conditions up to five days in advance, enabling the DNCC to activate anticipatory actions, such as setting up cooling shelters, distributing water and launching public awareness campaigns. This enhanced forecasting provides BMD with the critical information needed to issue timely alerts, enabling communities to take precautionary measures ahead of heatwave events. Although still in its pilot stage, discussions with BMD officials as part of this study highlighted their intention to host the official BMD website service, reinforcing institutional ownership and enabling public access.

Secondly, there is increasing use of climate-informed dengue early warning models, developed by technical partners such as RIMES, to support the Ministry of Health and Family Welfare (MoHFW) and the Directorate General of Health Services (DGHS). These models integrate routine dengue surveillance data with climate drivers, including temperature, rainfall and humidity, to forecast outbreaks several weeks in advance. Such forecasts have also played a significant role in guiding the timing of vector-control campaigns, hospital surge planning and community mobilization in advance of the peak in case numbers, thereby enhancing preparedness. While much of this work has been at the research or pilot stage, the record dengue epidemic in 2023 underscored the need to operationalize these forecasts as a regular decision-support tool within DGHS, as also emphasized by MoHFW officials.

Leadership, governance and capacity

The MoHFW has assumed a central coordinating role in integrating climate and health data, particularly for climate-sensitive diseases such as dengue, acute diarrhoea and malaria. Predictive models are usually developed by technical partners and projects under the MoHFW. Partnerships with meteorological agencies tend to be informal and project-based, often relying on donor support. It is worth noting that throughout discussions with MoHFW officials, it was highlighted that many climate services for health in Bangladesh have been largely donor-driven and project-based with very few concrete steps to move away from this model. This raises important questions about the long-term sustainability of such climate services in Bangladesh, with no evidence of a shift towards institutionalization and a dedicated MoHFW budget allocation. At present, priority climate–health threats are identified mainly through surveillance data, hazard

Bangladesh

risk-mapping and project-driven vulnerability assessments. However, much of this work remains donor-driven and project-based as MoHFW has yet to institutionalize a systematic priority-setting mechanism. While recent efforts in training, data integration and inter-ministerial coordination suggest a shift towards greater institutional ownership, it remains to be seen whether these services will move beyond short-term project cycles as was noted by officials.

EWS, risk mapping and predictive modelling are being utilized to inform health actions. Strong partnerships with meteorological and hydrometeorological agencies, such as BMD, regional centres, like RIMES, other government ministries and key stakeholders are crucial for accessing reliable forecasts of heatwaves, floods and cyclones, and for integrating these data with disease information to inform timely public health actions. While not all these partnerships have a formal mandate, they primarily collaborate through the sharing of data stemming from ad hoc requests. For example, the Institute of Epidemiology, Disease Control and Research (IEDCR) under the MoHFW frequently relies on climate-related data from the BMD and its management information systems to inform surveillance and response. However, officials have informed us that the process of data integration, aimed at consolidating all such datasets on a central server, is still ongoing.

These collaborations enable timely public health actions, although persistent coordination challenges exist at local levels. The MoHFW is prioritizing capacity-building and digital innovation by expanding training for health and climate professionals, enhancing educational curricula and scaling the use of mobile technology, AI and big data tools for delivering rapid climate–health alerts. Notably, RIMES has developed several impactful platforms in collaboration with the MoHFW and other government ministries, integrating weather forecasts and climate projections to support decision-making. For instance, under the World Bank-supported CARE for South Asia Project, the National Livestock Advisory System is a decision-support system – integrating weather forecasts, climate projections and livestock risk parameters, including health, growth, production, diseases, fodder and shelter – enabling government officials to generate semi-automated advisories, enhancing the resilience of Bangladesh's livestock sector. It also implemented the SHOUHARDO III project, focusing on improving community resilience to climate-induced hazards, targeting 15 unions across 13 *upazilas* in eight districts, selecting sites based on criteria such as flood risk, extreme weather conditions and vulnerability. They collaborated through agreements with national partners, including the BMD, Bangladesh Water Development Board (BWDB), Department of Disaster Management (DDM), Department of Agricultural Extension (DAE) and Department of Livestock Services (DLS), to develop systems for generating and disseminating forecasts and early warnings.

Engagement and data governance

The MoHFW's approach involves collaboration among health professionals, disaster management authorities, urban planners and local government bodies (city corporations) to translate climate forecasts into actionable health interventions. Special attention is given to vulnerable communities with efforts to tailor advisories to their specific contexts. Vulnerable populations are often identified using existing vulnerability and hazard databases maintained by BMD, DDM and the MoHFW. In some instances, local government information about community-level vulnerabilities, including socioeconomic factors, infrastructure and access to services, is also extracted for these purposes. The MoHFW coordinates such integration, the underlying data is often sourced from multiple agencies under the Ministry – like the IEDCR – as well as other departments like BMD and regional bodies such as RIMES for climate and hazard data. As highlighted by MoHFW officials, technical mapping and risk assessment, combining meteorological data with social and health indicators, are also sourced from nongovernmental organizations (NGOs) and other partner research institutions. Agencies, like the IEDCR, are

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developing advanced surveillance and predictive tools under the MoHFW by integrating health, meteorological and hydrological data with geographic information systems (GIS) and remote sensing. This integration enables the monitoring and prediction of vector-borne, water-borne and airborne diseases. However, improvements are needed in data quality, local visualization, automation and addressing data gaps. While the integration of climate projections and meteorological data with health information is advancing, concerns remain regarding data sharing and privacy. Sustainable funding for data infrastructure and ongoing quality assurance has yet to be fully established.

A compelling best practice example is the Bangladesh Red Crescent Society's (BDRCS) Heat Early Action Protocol, which was activated in April 2024 in Dhaka. The EAP established a robust framework for coordination, data integration, threshold setting and anticipatory action. This activation was triggered by forecasts from the BMD predicting sustained extreme heat above 38°C, supported by heat index projections. This data-driven action framework enabled timely interventions, including public awareness campaigns, water distribution, cash support for vulnerable groups, cooling stations and ambulance services in selected high-risk wards. The protocol was supported by pre-agreed financing through the Disaster Response Emergency Fund of the International Federation of Red Cross and Red Crescent Societies (IFRC), enabling resources to be deployed rapidly once the thresholds were met. Built on earlier feasibility studies and simulation exercises that mapped vulnerabilities and tested interventions, the EAP ensured readiness and effectiveness. Coordination across BMD, city authorities, IFRC, BDRCS and other actors further smoothened dissemination, offering a replicable model for integrating climate forecasts into health and social protection measures. While coordination is weak at local levels, particularly in data visualization, automation and the operationalization of insights, replicating such compelling best practices across ministries and departments can be beneficial in the long run.

Dissemination and implementation

Climate–health forecasts and guidelines are shared with city corporations, health workers at the community (ward), *upazila* and district levels as well as other frontline actors, through a combination of channels like official circulars and bulletins along with community announcements to guide targeted interventions, such as dengue vector surveys, cyclone evacuations and heatwave response plans. Some of the major pathways for dissemination include climate forecasts by the BMD, health surveillance data in conjunction with climate information by the IEDCR under MoHFW, and actionable advisories from such forecasts by other organizations and technical partners such as RIMES, CARE Bangladesh and Save the Children. Efforts are underway to scale automated dashboards, strengthen institutional coordination and embed climate–health training into medical curricula, along with ongoing professional development for health workers.

Current challenges and gaps

There is a need to enhance preventive measures in programming, ensuring that climate information translates into proactive health strategies rather than primarily reactive responses. Officials have highlighted an acute shortage of technically trained personnel across all levels of government to conduct research at the intersection of health and climate projections. They note that limited emphasis is placed on the prevention and control of climate-related diseases, with a predominantly reactive approach persisting throughout the health and climate ecosystem. Furthermore, most professionals in the healthcare sector are focused on treatment and service delivery, rather than climate-related health prevention. Officials highlighted that there are currently few dedicated professionals working on climate–health intersections, and a lack of willingness among some healthcare personnel to engage in this area is also evident. The absence of specialized training opportunities compounds this challenge, as do limited career pathways in

climate–health and weak institutional incentives, which collectively contribute to a reactive rather than preventive approach. A lack of effective collaboration among key stakeholders, including the BMD, DDM, MoHFW and the Department of Environment, is also a challenge. While significant gaps existed just a few years ago, progress is being made through the formation of several committees and joint initiatives, typically convened by the MoHFW with support from development partners. Agencies participate not only to fulfil national policy mandates but also to gain access to data, enhance networking possibilities and receive access to technical resources and sometimes training, which creates tangible incentives for attendance. Coordination remains an ongoing process, but these efforts are gradually narrowing the gap and laying the groundwork for more integrated action across departments. Additionally, the lack of sustained, long-term funding for climate–health initiatives hampers institutionalization and lasting impact. There is also no formal mechanism for ongoing evaluation and learning.

Colombia

3.3.2 Case study: Colombia – Climate services for health

Overview and context

Colombia serves as an essential case study for evaluating climate services for health due to its significant vulnerability to climate-sensitive diseases. The country has made strides in integrating climate information into health initiatives through a collaborative approach that involves the National Institute of Health (INS), the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) and the Ministry of Health and Social Protection (MinSalud). The Climate Variability and Change Board of the National Commission for Environmental Health (CONASA) has played a key role in fostering research and developing climate–health products, notably the Climate and Health Bulletin launched in 2017. This bulletin combines climate predictions with epidemiological data for climate-sensitive diseases, such as dengue, acute diarrhoeal diseases, leptospirosis, malaria and yellow fever, to provide a report on the potential onset of vector-borne diseases, acute diarrhoeal diseases and acute respiratory infections along with the main vulnerable geographic areas. Additionally, it offers recommendations for local health authorities on preventive and response actions for each disease as well as intervention areas and actions to facilitate inter-institutional collaboration, thereby supporting prevention and control efforts within communities.

Despite these advancements, significant gaps still exist in the practical use of climate information. Although Colombia has developed sophisticated models and early warning tools mainly as academic initiatives, much potentially valuable climate data remains underutilized by stakeholders. To effectively translate scientific findings into actionable decision-making and risk management, there is a need for improved provision, accessibility and adoption of climate services within health systems. Ongoing research focuses on understanding the relationships between climatic variables, such as rainfall, temperature and humidity, and disease transmission patterns. This research aims to create methodologies that link favourable climatic conditions to the behaviour of outbreaks. Colombia provides a good example of integrating climate expertise into health planning and public health practices, as demonstrated by the Climate and Health Bulletin, which informs decision-making and actions taken at both local and national levels. This bulletin is an example of inter-institutional collaboration, where MinSalud, INS and IDEAM work together to produce this product every month.

Leadership, governance and capacity

Colombia's climate and health governance operates within a multi-institutional framework that combines technical leadership, policy direction and operational delivery. The IDEAM provides essential meteorological data, forecasts and analyses that form the foundation of climate

Colombia

service products. MinSalud (specifically the Environmental Health division, Non-Communicable Diseases division, Communicable Diseases sub-division) serves as the decision-making authority for policy formulation and national budget resource allocation, setting priorities and ensuring alignment with national health objectives. The INS analyses and adapts meteorological information to create the Climate and Health Bulletin, which connects climate data with epidemiological insights to inform prevention and control measures at the national, regional and local levels, including recommendations for decision-makers and the general population. Academia, along with municipal and departmental health services, plays a crucial role as a knowledge producer and local decision-maker. However, there are academic spaces organized by the INS, usually to engage investigators – often researchers who work on climate and health – who do not attend those spaces.

Another space of engagement is the monthly reunion of the intersectoral table on climate change and climate variability. The Climate Variability and Health Technical Roundtable in Colombia coordinates health and environmental institutions to anticipate and manage climate-related health risks. Led by MinSalud with IDEAM and INS, it produces monthly Climate and Health Bulletins, integrates forecasts with epidemiological surveillance, issues early warnings and promotes adaptation strategies to reduce vulnerabilities and strengthen public health resilience nationwide. Here, academics are invited to present their work sometimes. The members of the table can use these results to translate climate insights into health interventions and policies that are appropriate for their local contexts.

Several coordination mechanisms guide cross-sector collaboration and implementation. CONASA, created by decree N°2972 of 2010, hosts thematic working groups, one of which is the climate-related working group that includes MinSalud, IDEAM and INS, which focuses on publishing the Climate and Health Bulletin and coordinating actions at the community level and within institutions. For example, actions aim to protect people from mosquito bites and arbovirus risk by reducing personal exposure, eliminating breeding sites for *Aedes aegypti* and prioritizing protection for vulnerable groups. They also focus on implementing practical, repeatable measures (such as screens, treated nets, repellents and proper storage and cleaning) during peak risk times to maximize effectiveness. A committee focusing on climate variability and change oversees annual action plans and reviews national decrees, laws and technical documents relevant to health and climate, ensuring coherent planning and implementation.

Another initiative developed under the INS's VIGIFRA system involves three integrated dashboards – SATAES, MASSAES and five climate-sensitive health dashboards – that collect and analyse environmental and health data. These dashboards produce daily alerts at the municipality level for key health risks such as dengue, acute diarrhoeal diseases, hepatitis A, acute respiratory infections and snakebites. The system combines weekly environmental monitoring, daily alerts from IDEAM and epidemiological expertise to generate predictive insights that inform resource allocation and targeted public health actions.

A key insight from leadership is that automation accelerates analysis and helps prioritize responses across different territories. However, model validation is still ongoing due to Colombia's diverse geographies. While dengue forecasts may not be perfect, VIGIFRA facilitates trend detection and the strategic deployment of limited resources. This underscores the importance of governance, stakeholder engagement and adaptive leadership in translating data into timely health interventions.

Engagement and data governance

Interviewees reported that resource constraints hinder implementation, but governance challenges also arise from differing views on environmental health among various entities. Key insights from the interviews reveal a persistent divide between health and environmental

administrations. There is no collaborative space between these sectors and health bulletins often fail to address air quality topics, largely due to the lack of participation from the Ministry of Environment. Practitioners suggest a way forward is to broaden the concept of health to include an environmental perspective, acknowledging the interdependence of humans, other species and ecosystems. A significant obstacle to this approach is the limited political will and prioritization of budgets for environmental health, which is influenced by how authorities define strategic importance.

Community engagement primarily occurs at the local level. At this level, the INS coordinates with the local health secretaries to collect local information and warnings, implement measures and disseminate analyses at local scales. However, Colombia's climate and health initiatives integrate top-down national design with targeted local input. At the national level, climate services for health are organized around governmental priorities and sectoral needs. In Bogotá, the District Health Secretariat actively engages residents through surveys to understand local dynamics regarding air quality and health actions. This bottom-up approach complements national planning by providing context-specific insights that help refine climate–health products and the actions they inform. Such community engagement is crucial for tailoring alerts, risk communications and interventions to the unique realities of urban areas and the behaviours of their populations.

Data processing, analysis and communication are centralized through a collaborative, inter-institutional approach. IDEAM provides core meteorological data from both automatic and conventional stations, encompassing variables such as maximum, average and minimum temperatures, relative humidity, wind speed and precipitation. In addition, IDEAM provides climate re-analyses, typically conducted monthly, with climate maps generated to indicate the suitability of rainfall, temperature and other climate covariates relevant to diseases such as dengue, chikungunya, malaria and zika. The INS uses this information as the climate inputs for epidemiological use, initially using map algebra and now transitioning to more flexible methodologies that integrate multiple variables and weigh them according to disease knowledge. The Climate and Health Bulletin results from this joint effort, synthesizing meteorological and health data to produce forecasts that MinSalud – specifically the deputy directorates responsible for coordinating policies and decision-making within the climate and health sector, namely the sub-directorate of Environmental Health and the sub-directorate of Non-Communicable Diseases – then reviews for decision-making and dissemination. While this process supports informed action, ongoing governance challenges remain regarding data standardization, access and translating these interventions into potential actions (for example, anticipatory actions for dengue or malaria).

Dissemination and implementation

In Colombia, the dissemination of climate services for health relies on integrated, multi-layer dashboards (SATAES, MASSAES and five climate-sensitive health dashboards) that generate municipal-level alerts to guide proactive public health actions. These alerts are complemented by ongoing media monitoring and interagency communication through the National Liaison Centre and the INS's Immediate Response Team, ensuring timely risk communication and coordinated responses across the national and local levels. In addition, the climate–health toolkit focuses on the Climate and Health Bulletin as the primary national product to prioritize municipalities at high risk of outbreaks in the coming month. IDEAM additionally produces maps with graphical information on the incidence and favourability for vector-borne diseases to raise awareness and trigger actions when needed. The Climate Variability and Health Technical Roundtable in Colombia is an intersectoral platform that connects MinSalud, INS, IDEAM and several specialized sub-directorates to address the intersection of climate and public health. Its central role is to anticipate the health impacts of climate variability – such as vector-borne diseases, diarrhoeal

Colombia

outbreaks, respiratory problems and heat-related illnesses – by integrating climate forecasts with epidemiological surveillance.

Current challenges and gaps

The most effective climate–health implementation emerges from strong, multi-directional engagement and formalized collaboration. Key facilitators include maintaining clear, ongoing communication among ministries, national leaders and local authorities to reinforce the value of the Climate and Health Bulletin; conducting phased, low-cost research with integrated delivery to align findings with decision-making needs; and ensuring the alignment of stakeholders and workflows so policymakers, end users, providers, finance staff and data managers share a common understanding of roles. Investing in capacity-building across institutions, enhancing analytics and promoting data literacy helps staff analyse, interpret and apply climate information effectively. Institutionalizing decision-making through formal structures and routines that persist beyond political changes and stabilizing the data-to-action loop with governance and data-sharing agreements are also critical to ensuring timely, locally actionable climate information.

Despite Colombia exhibiting governance structures that enable the potential implementation and scaling of tools and services, several obstacles hinder progress. A limited technical staff knowledgeable in data analysis, high turnover and insufficient training can slow momentum and increase workload; leadership changes and shifting political priorities can also stall essential actions. The transition from conventional to automated data collection requires substantial investment and alignment with maintenance practices, creating data and infrastructure gaps. Operationalization remains a challenge, as mechanisms to translate data into concrete decisions and community actions are still evolving. Funding sustainability is a significant constraint, with long-term, predictable financing often lacking. The primary source of funding for all climate services is the general budget that each governmental institution receives annually, rather than a specific project or funding institution. Funding limitations for climate services related to health in Colombia impact data collection, modelling and analysis, as well as governance. Data collection requires multi-year funding for surveillance, sensors, data standardization and sharing – such as fever and heat-stress monitoring – as well as real-time climate dashboards. Modelling requires ongoing resources for regional downscaling, updating exposure–response functions and maintaining infrastructure. Analysis depends on stable funding for trained analysts and quick risk advisories. Embedding climate–health financing in the general budget could boost sustainability through multi-year appropriations and improved cross-ministerial coordination. By 'funding institution' we mean the entity that allocates and manages money (ministry, fund or platform) and its mechanisms (grants, earmarks, public–private partnerships). At the local level, ensuring data standardization, timely dissemination and user-friendly communication remains challenging, limiting uptake and impact.

3.3.3 Case study: Senegal – Climate services for health

Senegal

Overview and context

The Sahelian zone of Senegal has experienced several heatwaves in recent decades, notably in 2013, 2016 and 2018, characterized by temperatures exceeding 45°C for up to three consecutive days. These extreme weather events have been linked to increased morbidity and mortality rates, leading to a growing burden of climate-sensitive diseases and posing significant public health concerns for the region.

In response to these challenges, Senegal piloted a Heat-Health Early Warning System (HHEWS) in 2022. This system was developed by the National Agency of Civil Aviation and Meteorology (ANACIM) in collaboration with the Directorate General of Public Health (DGSP) at the Ministry of Health and Social Action (MSAS) and various international partners. The Heatwave Early Warning Bulletins feature colour-coded maps of heatwave-prone areas, detailed information on health impacts and practical advice on potential mitigation measures. The system is designed to be user-friendly for individuals, public officials and local community groups.

To assess the HHEWS's impact, the ANACIM and DGSP surveyed Red Cross Red Crescent volunteers to understand how the forecast information influenced people's behaviour. The pilot programme also tested various communication channels, including community radio and targeted outreach to vulnerable groups, and evaluated the effectiveness of early warning systems at the community level. Additionally, workshops and training sessions were held to enhance the capability of health professionals to interpret and apply climate data, with an emphasis on the connections between climate variability and health outcomes.

Leadership, governance and capacity

Senegal's climate–health governance is primarily managed by the ANACIM, which oversees a multi-hazard EWS that addresses dust storms, heatwaves and floods. Collaborative efforts with the MSAS, Ecological Monitoring Centre (CSE) and the Senegalese Red Cross Society enhance technical expertise and field reach. For example, collaborative efforts between these three organizations strengthen technical knowledge and field reach by combining public health and environmental surveillance with local community networks. Health professionals contribute to epidemiology, disease surveillance and the integration of health systems. The CSE combines climate, ecological and biodiversity data, facilitating risk mapping and exposure assessments. The Senegalese Red Cross Society extends its reach on the ground through trained community volunteers, rapid response capabilities and trusted channels for risk communication. Together, these partners collaboratively support fieldwork, including vector and environmental sampling, community risk assessments and the co-design of early warning systems, dashboards and health advisories tailored to local needs. This multi-sectoral teamwork enhances data quality, enables cross-sector analysis and ensures climate-informed health actions are delivered across districts promptly, thus improving preparedness and resilience.

Established in 2025, the Health–Environment Division of the MSAS serves as the central authority for climate and health action, providing dedicated leadership to integrate environmental and climatic considerations into public health planning and operations. Its responsibilities include developing a national environmental health strategy and action plan, ensuring data integration and interoperability between climate, ecological and health systems, setting evidence-based EWS thresholds, co-designing health advisories and dashboards, improving surveillance and risk mapping, building workforce capacities and mobilizing support to scale effective interventions.

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By consolidating multiple roles previously performed by different organizations, the Division streamlines governance, clarifies responsibilities and standardizes protocols. Key partners – the ANACIM, CSE, Senegalese Red Cross Society, Civil Protection Directorate, relevant ministries (Environment, Agriculture, Energy), research and training institutes, health teams and technical / financial partners – are vital for implementing climate services. The ANACIM contributes meteorological and multi-hazard forecasting to the EWS; the CSE provides data for risk analyses; the Senegalese Red Cross Society facilitates community outreach via volunteers and translates government bulletins for local dissemination. Bulletins combine hazard and health impact maps for targeted responses. The National Oceanic and Atmospheric Administration (NOAA) and technical partners contribute expertise and funding, while the Civil Protection Directorate incorporates heatwaves into national contingency planning, promoting sectoral alignment. The Division also works to bridge previous governance and coordination gaps, ensuring district health responses are linked to risk information.

The Senegalese Red Cross Society is instrumental in translating health and climate bulletins produced by the MSAS and ANACIM into accessible formats, including local languages and voice messages. Each bulletin overlays climate risks with health impact areas, facilitating targeted interventions. Coordination between health, meteorological services, civil protection and sectoral ministries informs adaptation planning, with funding and technical support from NOAA and sectoral budgets. The recent integration of heatwaves into the national contingency plan elevates priority and cross-sector alignment. However, there is a continuing need to develop formal governance structures connecting risk data to health actions.

Engagement and data governance

Engagement occurs at both the national and community levels, with multiple stakeholders involved in risk communication and data collection. However, there is currently no unified system for capturing user feedback and using it for system improvements. Feedback from users and communities is gathered separately by the MSAS and the Senegalese Red Cross Society, resulting in gaps and a limited understanding of how climate–health risks are perceived and addressed at the community level. Data governance faces additional challenges due to the lack of standardized processes for tracking how information is utilized in decision-making and for monitoring the effectiveness of risk communications across diverse audiences, including marginalized groups and individuals with disabilities.

Dissemination and implementation

The dissemination framework relies on weekly early warning bulletins for heatwaves and flood risks, utilizing a broader multi-hazard approach. The ANACIM produces health-relevant risk maps with health impact layers, which are shared with partners like the MSAS, civil protection and the Senegalese Red Cross Society for operational planning. The Senegalese Red Cross Society plays a vital role in translating and disseminating information at the community level, including local-language bulletins and voice messages. However, these bulletins are not fully adapted for all audiences, especially those with limited literacy, disabilities or specific language needs (Wolof, Balanta-Ganja, Arabic, Jola-Fonyi, Mandinka). While coordination at the central level is strong and the volunteer network is extensive, there are few concrete health response plans beyond preventive awareness campaigns. The lack of unified mechanisms for translating climate information into tangible health actions, such as targeted vector control, hospital preparedness, or community-based adaptive measures, remains inconsistent.

Current challenges and gaps

Key challenges include the need for unified feedback and learning loops to understand how communities utilize climate–health information and to adjust messaging accordingly. Although

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the bulletins are comprehensive, they require better adaptation for diverse audiences to enhance comprehension and promote behaviour change. Additionally, there is a lack of concrete health response plans that translate early warnings into standardized actions, along with gaps in tracking the effectiveness of risk communications at the community level. Data interoperability and a formalized data governance framework are critical for aligning inputs from the ANACIM, MSAS, CSE, and the Senegalese Red Cross Society, ensuring timely, actionable outputs and accountability. Lastly, while international support from NOAA and sectoral budgets provides necessary resources, sustained, scalable financing and explicit risk-communication protocols are essential to transition from awareness to resilient health outcomes regarding dust, flood and heat hazards. The health sector budget enhances data management, response capacity and EWSs for vector-borne and waterborne diseases.

In contrast, the Environment and Climate Change budget funds climate risk assessments and projections to inform health planning and decision-making. Other sectors, including agriculture, water and sanitation, and disaster risk management, provide dedicated funds for vector control, water safety and emergency health interventions. Public–private partnerships and international donors supplement domestic funds to support pilots, capacity building and scaling successful climate–health services, boosting early warning, risk assessment and adaptive health planning amid climate variability.

3.3.4 Case study: Malawi – Climate services for health

Malawi

Overview and context

Malawi is among the most climate-vulnerable countries in the world, exposed to increasing temperatures, changing rainfall patterns and extreme weather events. These result in a range of health impacts, including malaria, diarrhoea, heat-related illnesses, food and nutrition insecurity, and mental health conditions. To help address these risks, Malawi has developed a range of climate services, including seasonal forecasts, daily weather updates, climate risk assessments, risk maps and EWSs for extreme events, which are a central feature at both the national and community levels. These services are developed using a combination of methods, including the analysis of historical station data, climate models with downscaling techniques and impact-based forecasting. At the national level, the country relies on continuous meteorological monitoring from the Department of Climate Change and Meteorological Services (DCCMS) to track the formation and movement of cyclones as well as patterns of rainfall.

Climate and health data are also integrated at the national level by the DCCMS, where climate trends are analysed alongside health records to identify risks such as heatwaves and cold waves, enabling the delivery of timely warnings and advisories that help the health sector prepare for and reduce the impact of weather-related health hazards. In many flood-prone areas, community-based EWSs have been developed to complement national efforts. These include the installation of manual river gauges, which community members use to observe upstream and downstream water levels. Seasonal outlooks are also downscaled from the national level to districts and even communities. This enables local authorities and community members to anticipate not only floods and cyclones but also dry spells and droughts, allowing for targeted preparedness actions such as crop selection or evacuation planning. The timely dissemination of forecasts enables communities to respond before a disaster strikes. Malawi is part of the CREWS (Climate Risk and Early Warning Systems) initiative, which aims to expand access to early warnings and risk information. In

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collaboration with national agencies – the DCCMS, Department of Disaster Management Affairs (DoDMA), Department of Water Resources (DWR), IFRC/Malawi Red Cross Society and the International Research Institute (IRI) – the ongoing 2022–2026 project aims to strengthen drought and flood EWSs, improve urban flood risk management and enhance the dissemination and use of early warnings and climate information across sectors.

Leadership, governance and capacity

Malawi's climate services for health, including EWSs, have been designed and implemented through a collaborative effort led by three key organizations: the Ministry of Health and Population, the Malawi Meteorological Service under the DCCMS, and the National Climate Change Secretariat. This initiative is supported by the DoDMA for emergency management. The governance structure ensures cross-ministerial coordination, aligns health information systems with climate data and formalizes joint planning through MoUs between the Malawi Meteorological Service and the DoDMA to inform cross-sector work plans. Various governance bodies, including inter-ministerial committees and district coordinators, have established clear data roles, privacy safeguards and interoperability standards. Regular technical groups review forecasts, risk maps and surveillance data to inform district actions and allocate resources effectively. Internal integration is improving with shared dashboards, joint incident command structures and training that incorporates climate risk indicators into clinical decision-making and public health workflows.

Ongoing governance development that addresses data quality, privacy, consent and ethical use will help maintain trust and effective data-sharing practices for climate–health decision-making. These government roles are complemented by international and local partners, including the WHO, UNICEF, Save the Children, Malawi Red Cross Society, academic institutions such as the University of Malawi and various NGOs, which provide technical expertise and operational support. Coordination is organized through a multi-sector cluster approach, with each cluster led by a government ministry and supported by partners. Within this framework, key departments – including Agriculture, DoDMA and DCCMS – work closely with health authorities and local communities to ensure climate information informs preparedness and response. Clusters meet every two weeks, regardless of whether there is an active emergency, to plan, share information and refine contingency measures. The Ministry of Health and Population hosts a dedicated Climate and Health Unit, which oversees all climate–health actions nationwide through a designated focal person.

Community engagement and data governance

Malawi's climate services for health are built on strong community engagement within the health cluster, where risk information and community participation are central to preparedness and response. This approach ensures that data-driven insights are interpreted and applied at the local level. Engagement activities include door-to-door risk communication by health surveillance workers, community-based EWSs and inclusive mass media campaigns supported by visual materials. Data governance relies on intersectoral coordination that enables the sharing of climate data across health, environment, agriculture, and disaster management, with clearly defined roles for data quality, privacy and access controls. Local messaging is adapted through collaboration with community leaders and translated into accessible formats. Meanwhile, channels like WhatsApp groups, managed by the DCCMS, enable the rapid dissemination of forecasts and the collection of feedback from local spotters.

Key institutions and examples include the Ministry of Health and Population, District Health Offices and public health facilities applying climate-informed alerts in clinical practice, complemented by Health Surveillance Officers conducting community risk communication. The Malawi Meteorological Service within the DCCMS issues forecasts and feeds climate data into

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health planning, with the National Climate Change Secretariat coordinating cross-cutting initiatives. The DoDMA and District Disaster Management Committees integrate climate information into contingency planning, while the Central Medical Stores, universities and training institutes collaborate on climate–health curricula and field training. Partnerships with the WHO, UNICEF and other donors support data platforms, dashboards and capacity-building initiatives, with the Malawi Red Cross Society acting as a broker for community engagement and cross-sector collaboration. Data governance mechanisms include cross-ministry data-sharing agreements, standardized data dictionaries, privacy and ethics guidelines as well as governance bodies that oversee data quality, interoperability and access to decision-making.

Dissemination and implementation

At the national level, the National Climate Outlook Forum brings together all sectors to participate in discussions and coordination. This serves as the first platform for engagement with key decision-makers, including government ministries (e.g., Agriculture, Disaster, Health, and Climate Services) as well as UN agencies (such as the WHO and UNICEF), to collaboratively interpret and apply the forecasts effectively. In addition, seasonal forecast dissemination forums are organized, particularly when downscaled forecasts are released. These forums are held both nationally and in every district, ensuring that information reaches local authorities and communities. These platforms offer structured channels for communication, coordination and decision-making related to climate and disaster preparedness. Seasonal forecasts are also disseminated directly to Parliament through dedicated committee sessions. These special meetings enable Members of Parliament to access information and help ensure that the nation is well-informed. Information from climate services is further communicated to the public through various channels, including television, radio, public announcements, posters, door-to-door communication and mobile apps like Zanyengo. To reach diverse audiences, information is also provided in multiple languages, including English, Tumbuka, Chichewa and Yao. EWSs use automated alarms and colour-coded river gauges, while health workers receive timely updates to trigger community action and preparedness. User feedback is collected through various channels, including social media platforms, which are actively monitored to improve and adapt climate services based on public needs. For instance, each district has created WhatsApp groups to share weather information, allowing community members to give real-time updates on local conditions. However, these groups are not connected to health-related information.

Current challenges and gaps

Despite this progress, gaps remain in internal integration and external collaboration. Improving coordination among disaster management, communications and policy teams across various ministries can help address challenges during rapid-onset events. Expanding partnerships with the private sector, academia and civil society would enhance data sources and dissemination channels, especially in hard-to-reach communities. Ensuring equitable access to data infrastructure and trained personnel in climate and health across all districts is crucial for closing rural gaps.

Encouraging communities to accept and act on scientific information can be difficult when it conflicts with existing beliefs or practices. This resistance reflects tensions between indigenous knowledge, based on generations of lived experience, and scientific knowledge, which underpins climate services. When the two conflict, communities are more likely to trust their traditional practices, even when these leave them vulnerable. Overcoming this barrier requires sustained community engagement, trust-building and communication strategies that respect local perspectives while encouraging evidence-based action. Ultimately, mindset change is an essential challenge in the effective use of climate services in Malawi. Financing is another major constraint.

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Budgets are often insufficient to support the expansion of services, and coordination challenges further limit progress. Data availability and quality also pose obstacles. While Malawi has a network of weather stations, accessing long-term historical data is difficult. Similarly, health data is often incomplete or only available for recent years, making it hard to conduct robust long-term analyses. These limitations, combined with a shortage of technical expertise – particularly at the district level – restrict the ability of surveillance officers to analyse data, generate reports and produce forecasts that could inform local decision-making. Finally, the country tends to operate in a reactive mode. Resources are usually released only once emergencies occur, rather than being allocated proactively for preparedness and planning. As a result, instruments, guidelines and systems that would strengthen resilience remain underdeveloped. Moving towards a proactive approach, with sustained investment in preparedness, community engagement and data capacity, will be essential to enhancing climate and health services.

3.4 Climate services typologies

We used a matrix to analyse and detail the aspects of implementation as well as the building blocks of various climate services for health across different case study contexts. This matrix served as the foundation for developing a decision tree that classified the prioritized types of climate services for health (EWS, risk maps, projection / scenario modelling, seasonal outlooks) based on their implementation approaches. The classification included categories such as top-down, bottom-up and hybrid or phased approaches. Additionally, the services were categorized by funding source, public, private or mixed (public–private partnerships) as well as by data strategy, distinguishing between data-driven (which relies on climate and health data analysis) and demand-driven (which responds to specific user needs) approaches. In addition, the study further considered levels of stakeholder engagement, which we classified as limited or inclusive and described the delivery methods, including the types of products and tools (such as dashboards, alerts and reports) as well as communication channels (digital platforms, workshops and community outreach). Where case studies demonstrated a mix or combination of sub-criteria or if a determination was not precise, this was indicated. This comprehensive framework enabled us to systematically categorize and compare climate services for health, providing insights into how implementation varied across case studies and identifying opportunities for optimization.

Table 2 shows a range of implementation typologies and maturity across countries, with Colombia and Senegal leaning towards hybrid models that blend national-level design with local inputs. At the same time, Malawi and Bangladesh show stronger top-down or hybrid patterns. All countries emphasize some form of climate services for health, including EWSs and seasonal outlooks; projects are mostly data-driven although, in some cases, it was difficult to determine the extent to which services were demand-driven and by whom. Leadership is uniformly supportive and governance is generally well-established at the national level; however, local effectiveness varies. Bangladesh and Senegal both demonstrate strong national coordination across sectors and with international collaboration, while Malawi places an emphasis on community inputs and has established two-way communication channels. All identified cases struggle with local operations and require strengthened mechanisms to support implementation at the sub-national level. Funding sources vary from public-led to mixed or ongoing external support, and stakeholder engagement ranges from limited to inclusive, with some countries prioritizing district or community-level involvement to translate forecasts into action. Delivery methods commonly combine dashboards, alerts, reports and outreach, supported by multiple communication channels (digital platforms, radio, TV, mobile apps) to disseminate information to decision-makers, health workers and communities.

Table 2: Climate services for health typology classification

		Case studies			
Criteria	Sub-criteria	Bangladesh	Colombia	Malawi	Senegal
Implementation typology	Top-down OR Bottom-up OR Hybrid	Top-down (Coordination is strong at national level between key ministries and drives implementation down to sub-national levels)	Hybrid (Climate services for health designed and implemented at the national level to include priorities established by government authorities, institutions and community / district level inputs)	Hybrid (Community engagement prioritized, national level coordination mechanisms exist, and established communication channels for two-way information sharing)	Top-down (Strong central organization with limited mechanisms to operationalize responses at local levels)
Type of climate services	EWSs OR Risk maps OR Projections / Scenario modelling OR Seasonal outlooks	All	EWSs; Seasonal outlooks	EWSs; Seasonal outlooks	EWSs; Seasonal outlooks; Risk maps
Leadership	Supportive OR Non-supportive	Supportive	Supportive	Supportive	Supportive
Governance	Well-established (e.g., TWG, steering committee, national coordination) OR Undefined / ad hoc	Mixed (National level is well-established, but challenges at local level)	Well-established (Collaborative, inter-institutional approach)	Well-established (National level coordination via MoU between MoH and met service and collaboration with international / local partners)	Well-established (Guided by a multi-actor framework, including MoU with key agencies)
Funding source	Public OR Private	Not clear	Public	Mixed (Active CREWS project underway)	Mixed (Mostly led by government with some outside funding / technical support)
Data strategy	Data-driven OR Demand-driven	Data-driven	Data-driven	Not clear	Data-driven
Stakeholder engagement	Limited OR Inclusive	Inclusive (Efforts exist to support local government to translate climate forecasts into actions)	Inclusive (Community engagement conducted through district health officials via surveys)	Inclusive (Community engagement prioritized for EWS)	Limited (Community-level data collection and validation conducted, but limited systematic feedback mechanisms to integrate local information formally)
Delivery method	Focus on products / tools (dashboards, alerts, reports) OR Communication channels (digital platforms, workshops, community outreach)	Both (Forecasts, dashboards, and outreach to communities / health workers)	Both (National and district climate outlook forums; automated alarms to health workers; dissemination via radio, TV, mobile apps; user feedback mechanisms)	Both (National and district climate outlook forums; automated alarms to health workers; dissemination via radio, TV, mobile apps; user feedback mechanisms)	Both (Formal approach to develop forecasts, bulletins for climate hazards and community-level workshops / meetings)

4. Recommendations

Leadership

- Government: Prioritize stronger government leadership, especially from meteorological, health, and disaster departments. This leadership should align priorities, mobilize resources, streamline governance and foster cross-sector collaboration to implement, fund and scale climate–health services nationwide. This involves establishing accountability, incentivizing interagency coordination and integrating climate–health into national health and emergency plans.
- Donors: Create innovation and exchange platforms (e.g., workshops, conferences) with ministries of health (MoH), national meteorological and hydrological services (NMHS), disaster risk management agencies, finance ministries, academia, nongovernmental organizations (NGOs) and the private sector to showcase the added value of climate services for health and stimulate demand for the development of climate services for health.
- Academia / private developers: Ensure all new climate–health tools include a national steering group (with implementation agencies) to guide co-development into operational climate services.

Governance

- MoH and NMHS: Develop MoUs and establish multi-stakeholder leadership models to clarify roles, secure co-development partnerships and advocate for both project-based and sustained funding.
- MoH and NHMS coalitions: Create structured mechanisms for regular community engagement and feedback on the design and effectiveness of climate services.
- MoH and NMHS: Institutionalize monitoring and evaluation (M&E) frameworks with clear metrics to track impact, capture lessons learned and align services with national priorities.

Stakeholder engagement

- Donors and MoH: Allocate funding for sustained capacity building at multiple levels (data managers, analysts, policymakers, health workers) to enable effective use of climate information within the health sector.
- MoH and NMHS: Establish staff exchange programmes (e.g., MoH secondments to NMHS and vice versa) to strengthen cross-sector collaboration and mutual understanding.

Data

- MoH and NMHS: Jointly advocate for and invest in local data infrastructure for collection and processing, ensuring harmonized formats, standards and sub-national integration.
- Donors: Support long-term investment in interoperable data systems to minimize data gaps as a barrier.

Dissemination

- All actors (MoH, NMHS, developers, donors): Ensure climate–health information is presented in formats accessible to decision-makers and communities.
- MoH and NMHS: Establish clear responsibilities for monitoring, timely information flow and action based on early warnings.

Annex 1.

1.1 Literature review

A systematic literature review was conducted to identify relevant sources related to climate services that explicitly or implicitly incorporate climate–health tools, climate and health services, and the development of tools linking climate data with health data to guide decision-making for public health. The review aimed to encompass peer-reviewed articles, technical reports, case studies and other relevant sources, including grey literature.

The search process involved multiple data sources:

- Academic databases, including PubMed, Scopus and Web of Science, were searched to identify peer-reviewed scientific articles and research studies.
- Search engines: Google Scholar was used to locate technical reports, policy documents and grey literature not indexed in academic databases.
- Organizational reports: Reports from major organizations, including the United Nations (UN), World Health Organization (WHO), World Meteorological Organization (WMO), and Intergovernmental Panel on Climate Change (IPCC), as well as regional health and climate agencies, were reviewed for relevant policy and technical documents.
- Additional sources, including conference proceedings, policy briefs and repositories of grey literature, were also examined to ensure comprehensiveness.

The search strategy involved using relevant keywords and combinations related to climate services, climate–health tools, climate and health data integration, and outcomes from such integrations. Inclusion criteria focused on sources that explicitly described tools, models or services utilizing climate data to inform health interventions or outcomes, with particular attention to those that demonstrated links between climate and health data to produce actionable results. The authors did not use any AI to collate datasets or for writing. The Rayyan platform was used to assist and expedite the process of conducting a systematic literature review.

1.2 Coding and extraction

In our review, we systematically coded the information extracted from the literature using a methodology that encompasses multiple dimensions relevant to climate services and health interventions. For each reference, we documented details such as the title and URL, decision level (local, regional, national, international) and the specific climate change-related health risk addressed. We also recorded the methodological approach, the tool's outcome and the evidence of impact demonstrating the outcomes. Additional attributes included product categories, data formats, customization options, delivery frequency, communication channels and intersectoral collaboration mechanisms.

1.3 Climate services for health classification

Using coding and extraction methods, we conducted a thematic analysis to classify the studies into key themes such as decision-making applications, types of climate services and data integration strategies. This process helped us to identify common patterns and a variety of approaches within the literature. We also examined the tools and services over time to detect trends and changes in climate services for health methodologies and their implementation. To understand spatial disparities and differences in context, we categorized the studies by region or country, which enabled us to analyse how climate–health services differ across various geographic and socioeconomic settings. This detailed classification provided valuable insights into the evolving field of climate services for health, highlighting areas for future development and research.

1.4 Literature review analyses

To analyse the data from the literature review and characterize implementation models of climate services for health, we undertook a structured qualitative synthesis of included studies and reports, combining thematic analysis with framework-informed coding to map how climate information was translated into public health actions. Specifically, we examined decision-making processes by coding the roles and responsibilities of the various stakeholders involved in public health decisions and by mapping how decisions were initiated, reviewed and acted upon in different settings; identified incentives for stakeholders by extracting and categorizing motivations, including financial, political, organizational and normative drivers that influenced engagement with climate-informed health strategies; analysed communication strategies and information flows by identifying how climate data and health information were produced, packaged, disseminated, interpreted and used across stakeholder networks; and assessed mechanisms that facilitated or hindered data sharing and translation into action.

In Supplementary Figure 1, we present a generalized framework based on the literature, which characterizes the implementation of climate services for health through a series of interconnected phases. The framework also identifies building blocks that encompass critical components for effective implementation. These phases include: 1) a pre-implementation or readiness phase, where needs assessment, stakeholder engagement and resource planning occur; and 2) an implementation phase, during which the developed climate services are actively deployed and integrated into health systems. This could involve the development of early warning systems, capacity-building workshops or integrating climate data into existing health decision-making processes, as seen in case studies from various regions. Finally, 3) an evaluation phase assessed the climate services' effectiveness, usability and impact, often through monitoring and feedback mechanisms, with the view to feedback learning. This stage may include evaluating health outcomes (e.g., impact of the intervention), user satisfaction and system performance, with literature examples illustrating how feedback has led to iterative improvements in service delivery. While the framework outlines phases of implementation, it is worth noting that, in practice, implementation is not a linear process.

Figure S1: Overview of a simplified implementation framework for climate services for health identified from the literature, illustrating the three phases: pre-implementation, active implementation and evaluation as well as highlighting building blocks for effective implementation, namely governance, leadership, engagement, data and dissemination. Source: authors' own.

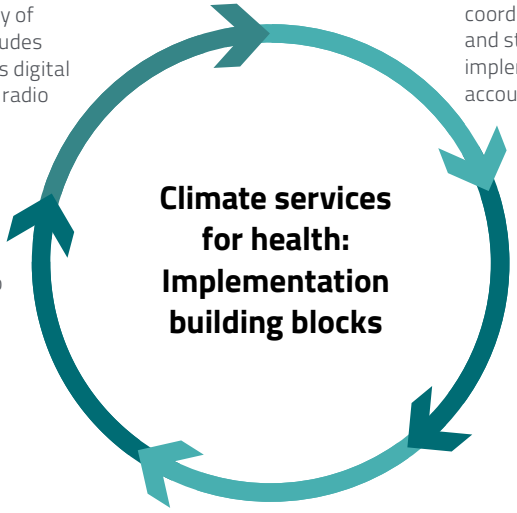
We utilized the information gathered from the literature review (reports and papers) to extract, classify and analyse data. This process enabled us to categorize implementation model types, identify key drivers and barriers, and develop practical, adaptable strategies for translating climate data into public health actions. The exercise yielded essential insights into implementing various initiatives, including stakeholder mapping, incentive structures, communication channels and funding strategies to facilitate the promotion and expansion of climate-aware health interventions (Annex 2).

Based on an initial review of the literature and the extension of sound practice principles for integrated climate and health science and services (World Meteorological Organization, 2023), we identified key components crucial for effective implementation. Building on the implementation framework shown in Figure S1, we present a new framework centred on building blocks, which are parts of the implementation cycle. An ideal service can combine these blocks in various configurations. The Figure S2 summarizes each component. This building block approach helps in identifying and comparing the different elements involved in deploying climate services for health.

Key building blocks for implementing climate services for health include, *leadership* from well-informed, high-level decision-makers who recognize the value of these services and act as champions by prioritizing resources and establishing mandates; *governance* structures (including financing) with precise coordination mechanisms, strategic plans and collaborative processes to ensure accountability and smooth implementation; *engagement* through user-centred, demand-driven approaches that foster collaboration with end users, practitioners, policymakers and community leaders to keep services relevant and decision-aligned; *data* that are usable, transformable into practical decisions, harmonizable and openly accessible in formats understandable to non-experts; and *dissemination* mechanisms, such as dashboards, platforms, SMS alerts and bulletins, that enable the efficient, timely delivery of climate and health information.

Dissemination mechanisms are essential for the efficient and effective delivery of climate-health information. This includes establishing reliable channels such as digital dashboards, SMS alerts, community radio or printed reports to ensure timely communication of warnings and recommended actions

Governance structures – including established coordination mechanisms, policies, strategic plans and strong leadership – are necessary to oversee implementation, collaboration and ensure accountability.



Data that is usable can be transformed into practical, decision-relevant information, integrate specific insights for health decision-makers, and must be relevant to local contexts, reliable and presented in formats accessible to non-experts.

Leadership made up of well-informed, high-level decision-makers who understand the value-added of climate services for health can serve as champions for implementation, including prioritizing resource allocation, establishing mandates and overcoming legislative barriers.

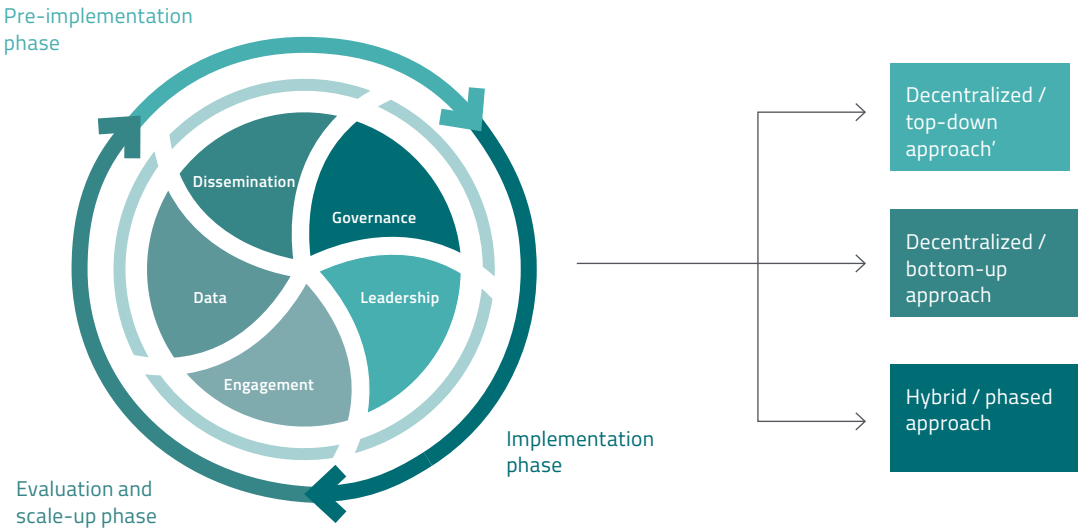
Figure S2: Summary of climate services for the health implementation of building blocks. These can be considered core elements that are interconnected and essential for effective implementation. Source: authors' own.

Engagement that is user-centred and demand-driven emphasizes meaningful collaboration with end-users – health professionals, policymakers, community leaders and at-risk populations – to ensure that climate health services are relevant, accessible and aligned with their decision-making processes.

1.5 Typology

We classified the literature on climate services for health based on their implementation approach. Implementation needs vary depending on the type of service, the scale (community, national, regional), the complexity of the intervention, and the local context. We organized the literature into three typologies: 1) centralized or top-down, where national-level agencies lead the interpretation and dissemination of climate–health information; 2) decentralized or bottom-up, where local authorities adapt climate information to meet community needs; and 3) hybrid or phased, which combines mechanisms to promote interactions between national actors and sub-national or community inputs, along with a systematic rollout of new climate services. These typologies are analysed alongside the project's building blocks (such as governance structures) to better understand practical implementation.

Figure S3: Linkages between the implementation cycle and building blocks with specific implementation typologies, including 1) centralized / top-down approaches; 2) de-centralized / bottom-up approaches; and 3) hybrid or phased approaches. Source: authors' own.



1.6 Interviews and case studies

We selected four case studies in Bangladesh, Colombia, Malawi and Senegal to understand how climate services for health are applied across regions. While existing literature outlined parts of the implementation cycle, it offered limited insight into how climate data results in health actions. Our goal was to examine the entire process – from data collection and dissemination to decision-making and health interventions – by studying actions and differences in various contexts. We conducted key informant interviews in all four countries with experts from meteorological agencies, health ministries and research institutions, and reviewed literature to identify barriers, facilitators and contextual factors affecting implementation.

Four diverse case studies from different regions and with varying service needs were chosen to examine these implementation models. This method enabled us to define the essential components, highlight best practices and examine how local infrastructure, governance and stakeholder involvement function in real-world settings. The insights gained aim to guide strategies for better translating climate data into health actions, potentially increasing the effectiveness and scalability of climate services globally. The selection of Colombia, Senegal, Bangladesh and Malawi as case study sites was driven by their distinct vulnerabilities to climate-related health risks and their notable efforts to integrate climate services within health systems. Colombia was chosen for its pronounced exposure to climate-sensitive diseases such as vector-borne, respiratory and diarrhoeal illnesses, alongside its advanced multi-sectoral initiatives – including the Climate and Health Bulletin – that exemplify progress and ongoing challenges in operationalizing climate information for health decision-making. Senegal's Sahelian context, marked by recurrent extreme heat events, has prompted the development of a Heat-Health Early Warning System, offering insights into cross-sector collaboration, community engagement and the practicalities of implementing early warning tools at the local level. Bangladesh, facing intensifying heatwaves and record-breaking temperatures, provides a compelling case of leveraging technology through its Heatwave Alert Portal and community-based responses, highlighting both successes and barriers in scaling climate services for health. Lastly, Malawi's high vulnerability to climate impacts, coupled with its participation in the Climate Risk and Early Warning Systems (CREWS) initiative, offers valuable lessons on community engagement, risk communication and the operationalization of early warning systems in resource-constrained settings. Together, these cases represent a diverse spectrum of climatic, infrastructural and governance contexts, enabling a comprehensive examination of how climate services are developed, implemented and used to improve health outcomes worldwide.

The case studies illustrate how climate services for health are perceived and tailored to local contexts, with a focus on effectively reaching the most vulnerable communities. We examined the roles of leadership, governance, stakeholder engagement, data utilization and dissemination strategies at the local level. Additionally, the study identified existing gaps and challenges in delivering these services to groups most at risk – particularly women, children, older adults and people with disabilities – who often face limited access to information, technology and financial resources.

Based on insights from the literature and key informant interviews, we examined the pros and cons of different implementation methods. The study emphasized governance frameworks, investigated emerging strategies and showcased examples of best practice. We used AI-assisted transcription to facilitate interview workflows in Teams, supplemented by human review to maintain accuracy and thoroughness.

Annex 2.

Title	URL	Year	Full review	Decision level: Local, sub-national, national, regional or global
Climate information for public health action	https://www.taylorfrancis.com/books/oa-edit/10.4324/9781315115603/climate-information-public-health-action-simon-mason-madeleine-thomson	2018		Regional, national
Do climate services make a difference? A review of evaluation methodologies and practices to assess the value of climate information services for farmers: Implications for Africa	https://www.sciencedirect.com/science/article/pii/S2405880717300882?via%3Dihub	2018		Local
Data and tools to integrate climate and environmental information into public health	https://idpjournal.biomedcentral.com/articles/10.1186/s40249-018-0501-9	2018		National, local
Health and climate – Needs	https://www.sciencedirect.com/science/article/pii/S1878029610000058?via%3Dihub	2010		Local, sub-national, national, regional, global (this paper is a synthesis/review intended to inform policymakers, health practitioners)
Delivering climate services: Organizational strategies and approaches for producing useful climate-science information	https://journals.ametsoc.org/view/journals/wcas/5/1/wcas-d-11-00034_1.xml	2013		National, regional
Strengthening health systems for climate adaptation and health security: Key considerations for policy and programming	https://www.liebertpub.com/doi/10.1089/hs.2022.0050	2022		National, sub-national
Scoping review on assessing climate sensitive health risks	https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-025-22148-x	2025		Global
Co-learning during the co-creation of a dengue early warning system for the health sector in Barbados	https://gh.bmj.com/content/7/Suppl_7/e007842	2022		National
Climate services for health: Cooperation for climate-informed dengue surveillance	https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(17)30065-7/fulltext	2017		Commentary on climate services for dengue
Climate services for health: From global observations to local interventions	https://www.sciencedirect.com/science/article/pii/S2666634021001124?via%3Dihub	2021		Global (using global climate products to supplement lack of local observations)
Harmonizing multisource data to inform vector-borne disease risk management strategies	https://www.annualreviews.org/content/journals/10.1146/annurev-ento-040124-015101	2025		Global (review)

Title	URL	Year	Full review	Decision level: Local, sub-national, national, regional or global
The role of global reanalyses in climate services for health: Insights from the Lancet Countdown	https://rmets.onlinelibrary.wiley.com/doi/10.1002/met.2122	2023		Global
Early warning systems for vector-borne diseases: Engagement, methods and implementation	https://brill.com/edcollchap-oa/book/9789004688650/BP000023.xml	2023		Global
Climate-informed EWS require collaborative data generation between global and local stakeholders	https://linkinghub.elsevier.com/retrieve/pii/S2405880720300510	2020		Global (comprehensive review of climate services)
Leveraging implementation science to solve the big problems: A scoping review of health system preparations for the effects of pandemics and climate change	https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(25)00056-7/fulltext	2025		Global scoping review on the use of implementation science within health systems
Improving the cost-effectiveness of IRS with climate informed health surveillance systems	https://malariajournal.biomedcentral.com/articles/10.1186/1475-2875-7-263	2008		Should be excluded due to date of publication
Adaptation to health outcomes of climate change and variability at the city level: An empirical decision support tool	https://www.sciencedirect.com/science/article/abs/pii/S2210670718321280?via%3Dihub	2019		The article is not direcly based on climate services for health, but proposes a framework for evaluating health adaptation and coping strategies at the city level, using a household health production function (HPF) approach
El Niño Southern Oscillation as an early warning tool for dengue outbreak in India	https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-020-09609-1	2020		National, sub-national
Predictive factors and risk mapping for Rift Valley Fever epidemics in Kenya	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0144570	2016		National, sub-national
Decision tool for climate disasters and infectious disease at sub-national level in India: Ensuring a paradigm shift in health planning from prevalence to vulnerability	https://www.sciencedirect.com/science/article/abs/pii/S0001706X17314912?via%3Dihub	2019		This article is not fully available publicly; only parts of the article are shown
Advancing climate change health adaptation through implementation science	https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(22)00199-1/fulltext	2022		Article based on the role of implementation science in guiding climate-related health adaptation. It provides examples from case studies, decision-level being regional, national
Climate drivers of vector-borne diseases in Africa and their relevance to control programmes	https://idpjournal.biomedcentral.com/articles/10.1186/s40249-018-0460-1	2018		Regional (AFR), national

Title	URL	Year	Full review	Decision level: Local, sub-national, national, regional or global
Association between environmental factors and dengue incidence in Lao People's Democratic Republic: A nationwide time-series study	https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-023-17277-0	2023		National
A reproducible ensemble machine learning approach to forecast dengue outbreaks	https://www.nature.com/articles/s41598-024-52796-9	2024		National, sub-national
Climate change and infectious disease in Europe: Impact, projection and adaptation	https://linkinghub.elsevier.com/retrieve/pii/S2666776221002167	2021		Regional (EUR)
Development of a probabilistic early health warning system based on meteorological parameters	https://www.nature.com/articles/s41598-020-71668-6	2020		National
Unexplored opportunities: Use of climate- and weather-driven early warning systems to reduce the burden of infectious diseases	https://link.springer.com/10.1007/s40572-018-0221-0	2018		Global, regional (EUR)
Towards development of functional climate-driven early warning systems for climate-sensitive infectious diseases: Statistical models and recommendations	https://linkinghub.elsevier.com/retrieve/pii/S0013935124004729	2024		Global (non-specific)
The development of an early warning system for climate-sensitive disease risk with a focus on dengue epidemics in south-east Brazil	https://onlinelibrary.wiley.com/doi/10.1002/sim.5549	2013		Sub-national
Spatio-temporal modelling of climate-sensitive disease risk: Towards an early warning system for dengue in Brazil	https://linkinghub.elsevier.com/retrieve/pii/S0098300410001445	2011		National
A new integrative perspective on early warning systems for health in the context of climate change	https://linkinghub.elsevier.com/retrieve/pii/S0013935120305168	2020		Global (non-specific)
Dengue outlook for the World Cup in Brazil: An early warning model framework driven by real-time seasonal climate forecasts	https://linkinghub.elsevier.com/retrieve/pii/S1473309914707819	2014		National, sub-national
Early warning climate indices for malaria and meningitis in tropical ecological zones	https://www.nature.com/articles/s41598-020-71094-8	2020		National
Models of spatial analysis for vector-borne diseases studies: A systematic review	https://pubmed.ncbi.nlm.nih.gov/36313837/	2022		Global (systematic review)

Title	URL	Year	Full review	Decision level: Local, sub-national, national, regional or global
Using Earth observation images to inform risk assessment and mapping of climate change-related infectious diseases	https://www.canada.ca/content/dam/phac-aspc/documents/services/reports-publications/canada-communicable-disease-report-ccdr/monthly-issue/2019-45/issue-5-may-2-2019/ccdrv45i05a04-eng.pdf	2019		National
Modelling tools for dengue risk mapping: A systematic review	http://ij-healthgeographics.biomedcentral.com/articles/10.1186/1476-072X-13-50	2014		Global
Making society climate resilient: International progress under the Global Framework for Climate Services	https://journals.ametsoc.org/view/journals/bams/101/2/bams-d-18-0211.1.xml	2020		Global, regional, national
Climate information for public health: The role of the IRI climate data library in an integrated knowledge system	http://geospatialhealth.net/index.php/gh/article/view/118	2012		Global, regional (AFR)
Climate, environmental and socioeconomic change: Weighing up the balance in vector-borne disease transmission	https://royalsocietypublishing.org/doi/10.1098/rstb.2013.0551	2015		Global
Mapping the global potential distributions of two arboviral vectors *Aedes aegypti* and *Ae. albopictus* under changing climate	https://dx.plos.org/10.1371/journal.pone.0210122	2018		Global
Identifying research priorities to advance climate services	https://linkinghub.elsevier.com/retrieve/pii/S2405880716300358	2016		Global
The use of climate information to estimate future mortality from high ambient temperature: A systematic literature review	https://dx.plos.org/10.1371/journal.pone.0180369	2017		Global
Impact of climate change in health in Colombia and recommendations for mitigation and adaptation	http://hdl.handle.net/10986/40494	2023		National, sub-national
Climate-sensitive infectious diseases, economic costs and health information systems in Latin America and the Caribbean	https://hdl.handle.net/10625/64525	2025		Regional, national, sub-national
Health and climate change: How do we protect people's health in the climate crisis?	http://dx.doi.org/10.18235/0004845	2023		Regional (LAC)
Anticipatory action for climate-sensitive infectious diseases: Latin America regional assessment	https://www.climatecentre.org/publications/13989/anticipatory-action-for-climate-sensitive-infectious-diseases-latin-america-regional-assessment	2024		Regional (LAC)
Design of a surveillance system for public health events of interest due to environmental risk factors in Colombia	https://doi.org/10.33610/28059611.154	2024		National, sub-national
The 2023 Latin America report of the Lancet Countdown on health and climate change: The imperative for health-centred climate-resilient development	https://doi.org/10.1016/j.lana.2024.100746	2024		Regional (LAC)

Title	URL	Year	Full review	Decision level: Local, sub-national, national, regional or global
The essential environmental public health functions. A framework to implement the agenda for the Americas on health, environment, and climate change 2021–2030	https://iris.paho.org/handle/10665.2/55673	2022		Regional (LAC)
2024 state of climate services: Five-year progress report (2019–2024)	https://climahealth.info/wp-content/uploads/2024/11/20241106_WMO_2024-State-of-the-climate-services_en.pdf	2024		Global
Resumen ejecutivo sobre la inclusión de servicios climáticos para la formulación de políticas públicas para el sector salud / Executive summary on the inclusion of climate services in public policymaking for the health sector	https://hdl.handle.net/20.500.12542/1352	2021		National, sub-national
Co-developing climate services for public health: Stakeholder needs and perceptions for the prevention and control of Aedes-transmitted diseases in the Caribbean.	https://doi.org/10.1371/journal.pntd.0007772	2019		Regional (LAC), national
Climate services for health: Predicting the evolution of the 2016 dengue season in Machala, Ecuador	https://doi.org/10.1016/S2542-5196(17)30064-5	2017		National, sub-national
Plan integral de gestión del cambio climático sector salud – componente de adaptación / Comprehensive climate change management plan for the health sector – adaptation component	https://www.atachcommunity.com/fileadmin/uploads/atach/Documents/Country_documents/Colombia_HNAP_2021_PIGCCS.pdf	2021		National, sub-national
Etapa 1. Sistema de alerta temprana: identificación del riesgo en salud pública / Stage 1. Early warning system: Identification of public health risks	https://www.ins.gov.co/Noticias/ImagenesBanner/ABECE-GESTION-DEL-RIESGO-COLECTIVO/Etapa-1-Sistema-de-Alerta-Temprana_Identificacion-del-riesgo-en-salud-publica.pdf	2022		National, sub-national
Estrategia climática de largo plazo de Colombia E2050 para cumplir con el Acuerdo de París / Colombia's long-term climate strategy E2050 to comply with the Paris Agreement	https://www.minambiente.gov.co/wp-content/uploads/2024/12/2.-Estrategia-Climatica-de-Largo-Plazo-de-Colombia-E2050.pdf	2021		National, sub-national
Salud y cambio climático: Metodologías y políticas públicas / Health and climate change: Methodologies and public policies	https://repositorio.cepal.org/server/api/core/bitstreams/78113b74-754c-4163-8c4f-e61f7c34e192/content	2021		Regional (LAC)
SaluData, el observatorio de salud en Bogotá: Conoce qué es / SaluData, the health observatory in Bogotá: Learn what it is	https://bogota.gov.co/mi-ciudad/salud/saludata-el-observatorio-de-salud-en-bogota-conoce-que-es	2024		Sub-national (Bogotá - Colombia)
Developing climate and health systems: Maps for building shared understanding and identifying priority action	https://resourcecentre.savethechildren.net/document/developing-climate-and-health-systems-maps-for-building-shared-understanding-and-identifying-priority-action	2024		National (Colombia / Somalia / Vietnam)

Title	URL	Year	Full review	Decision level: Local, sub-national, national, regional or global
Navigating the climate–health nexus: Linking health data with climate data to advance public health interventions	https://doi.org/10.1186/s44263-024-00109-7	2024		Global
Climate services for inclusive decision-making on resilience in the Sahel	https://careclimatechange.org/wp-content/uploads/2021/01/ALFA-Sahel-webinar-3-summary-FINAL.pdf	2020		Regional (Africa / Sahel)
Applying climate information for adaptation decision-making	https://www.undp.org/publications/applying-climate-information-adaptation-decision-making	2015		Global
Co-production of climate services: Challenges and enablers	https://www.researchgate.net/publication/390180967_Co-production_of_climate_services_challenges_and_enablers	2025		Global
Climate information services for health systems strengthening	https://www.preventionweb.net/publication/climate-information-services-health-systems-strengthening	2024		Global
Quality criteria for the evaluation of climate-informed early warning systems for infectious diseases	https://www.who.int/publications/i/item/9789240036147	2021		Global
Innovation and collaboration: The EWARS Framework for infectious diseases	https://www.gu.se/sites/default/files/2022-03/GHHG_PolicyBrief_EWARS-2022.pdf	2022		Global
Global framework for climate services: Health exemplar	https://www.researchgate.net/publication/321807174_Global_Framework_for_Climate_Services_Health_Exemplar	2014		
Implementation plan for advancing climate, environment and health science and services 2023–2033	https://climahealth.info/resource-library/who-wmo-implementation-plan-2023-2033/	2023		
Use of climate information for decision-making and impact research: State of our understanding	https://na-cordex.org/files/Use-of-Climate-Information-for-Decision-Making.pdf	2016		
2021 WHO health and climate change survey report	https://www.who.int/publications/i/item/9789240038509	2021		
Climate services for supporting climate change adaptation	https://unfccc.int/sites/default/files/resource/WMO_Climate_Services_for_Supporting_CCA.pdf	2016		
+Clima transpartencia para la acción climática / +Climate transparency for climate action	https://colaboracion.dnp.gov.co/CDT/Sinergia/Documentos/Brochure_MasClima_final_2024_12_03.pdf	2024		National (Colombia)

Annex 3.

Country	Stakeholder name	Stakeholder type (Government, NGO, research institution)
Bangladesh	ENDA Santé	Government
	ExtramSen	Government
	Ministry of Health and Family Welfare	Government
	Health Services Division (under MoHFW)	Government
	Medical Education and Family Welfare Division (under MoHFW)	Government
	Directorate General of Health Services (DGHS)	Government
	Directorate General of Family Planning (DGFP)	Government
	Directorate General of Drug Administration (DGDA)	Government
	Institute of Epidemiology, Disease Control and Research (IEDCR)	Government
	National Institute of Preventive and Social Medicine (NIPSOM)	Government
	Bangladesh Medical and Dental Council (BMDC)	Government
	Bangladesh Nursing and Midwifery Council (BNMC)	Government
	Essential Drugs Company Limited (EDCL)	NGO
	Climate Change and Health Promotion Unit (CCHPU)	NGO
	Bangladesh Rural Advancement Committee (BRAC)	NGO
	International Centre for Diarrhoeal Disease Research, Bangladesh	NGO
	CARE Bangladesh	NGO
	Save the Children, Bangladesh	NGO
	Friendship	NGO
	RTM International	NGO
	Dhaka Ahsania Mission	Government
	Gonoshasthaya Kendra (People's Health Centre)	Government
	Sajida Foundation	Government
	WHO Bangladesh	NGO
	Ministry of Environment, Forest and Climate Change (MoEFCC)	Research institution
	Department of Environment	Government
	Bangladesh Forest Department	Government
	Bangladesh Forest Research Institute	Government
	Bangladesh Meteorological Department	Government
	Bangladesh Climate Change Trust (BCCT)	Government
	Ministry of Disaster Management and Relief	Government
	Ministry of Agriculture	Government
	Ministry of Water Resources	Government

Country	Stakeholder name	Stakeholder type (Government, NGO, research institution)
Colombia	Ministry of Health and Social Protection (MinSalud)	Government
	Ministerio de Ambiente y Desarrollo Sostenible	Government
	IDEAM (Instituto de Hidrología, Meteorología y Estudios Ambientales)	Government
	Instituto Nacional de Salud	Government
	Observatorio de Salud de Bogotá	Government
	Universidad de los Andes	Research institution
	Universidad de Antioquia	Research institution
	Universidad Nacional	Research institution
	Universidad Javeriana	Research institution
	Universidad del Valle	Research institution
	UNGRD (National Unit for Disaster Risk Management)	Government
	WHO, PAHO, UNICEF	NGOs
	IDB, World Bank	Development agencies
Malawi	Department of Climate Change and Meteorological Services	Government
	Department of Disaster Management Affairs	Government
	Save the Children	NGO
	Public Health Institute of Malawi	Research institution
	Ministry of Health	Government
	Amref Health Africa	NGO
	World Vision International	NGO
	Project Innovation Center	Research institution
	Malawi Red Cross Society	NGO
	Malawi Liverpool Wellcome Research Programme	Research institution
Senegal	Agence Nationale de l'Aviation Civile et de la Météorologie (ANACIM)	Government
	African Population and Health Reserch Centre	Research institution
	Ministère de la Santé et de l'Action Sociale	Government
	Centre de Suivi Écologique (CSE)	Research institution
	African Centre of Meteorological Applications for Development	Research institution
	Climate and Environmental Health, University Cheikh Anta Diop	Reserach institution
	Faculté de Médecin et de Pharmacie de l'Université Cheikh Anta Diop	Reserach institution
	Centre de Gestion de la Qualité de l'Air	Reserach institution
	PATH-MACEPA (Malaria Control and Elimination Partnership in Africa)	NGO

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