PLOS CLIMATE

RESEARCH ARTICLE

# A demand-driven climate services for health implementation framework: A case study for climate-sensitive diseases in Caribbean Small Island Developing States

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**Citation:** Díaz AR, Rollock L, Boodram L-LG, Mahon R, Best S, Trotman A, et al. (2024) A demand-driven climate services for health implementation framework: A case study for climate-sensitive diseases in Caribbean Small Island Developing States. PLOS Clim 3(10): e0000282. https://doi.org/10.1371/journal.pclm.0000282

**Editor:** Kai Chen, Yale University School of Public Health, UNITED STATES OF AMERICA

**Received:** July 7, 2023

**Accepted:** July 7, 2024

**Published:** October 2, 2024



**Data Availability Statement:** Supplementary data has been made fully available and without restriction. It is attached as supporting information.

**Funding:** This work was supported by: European Development Fund CRIS: FED/2019/41949 Wellcome Trust grant number 226069/Z/22/Z. Royal Society Dorothy Hodgkin Fellowship: DH150120 European Union NextGenerationEU/ PRTR: RYC2021-034691-I and MCIN/AEI/

## Abstract

Here we introduce a demand-driven framework designed to implement climate services in the health sector, with a particular focus on the Caribbean region. Climate services are essential for supporting informed decision-making and response strategies in relation to climate-related health risks. Through collaborative efforts, we are co-producing a climate-driven dengue early warning system (EWS) to target vector-borne diseases effectively. While challenges exist in implementing such systems, EWSs provide valuable tools for managing epidemic risks by predicting potential disease outbreaks in advance. The scarcity of operational climate tools in the health sector underscores the need for increased investment and strategic implementation practices. To address these challenges, a demand-driven framework is proposed, emphasizing strategic planning focused on health intervention development, partnership building, data, communication, human resources, capacity building, and sustainable funding. This framework aims to integrate climate services seamlessly into health systems, thereby enhancing public health resilience and facilitating well-informed decision-making to effectively address climate-sensitive diseases.

10.13039/501100011033 Funders had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

**Competing interests:** The authors have declared that no competing interests exist.

## Introduction

According to the World Health Organization, "climate change is the single biggest health threat facing humanity" [1]. Changing temperature and precipitation patterns, and more frequent extreme weather events threaten human health worldwide [2,3]. These impacts are further compounded by the distribution of socioeconomic and demographic factors, placing vulnerable populations at greater risk, including low-income communities, children, the elderly, individuals with pre-existing health conditions, and those residing in low-lying coastal cities prone to flooding and sea level rise [4]. The Caribbean Small Island Developing States (SIDS) are uniquely vulnerable to climate-related health hazards due to their location within the North Atlantic hurricane belt, composition of small, low-lying islands, and dependence on natural resources and tourism. Critical climate and health concerns in the Caribbean include the increased frequency and intensity of tropical storms, heat waves, droughts, worsening air pollution, disruption of food production and supply, interruption of water supply and sanitation services, and increased transmission of infectious diseases [5]. Thus, it is critical that current and future climate-related human impacts are embedded into public health decision-making, primarily through the development of climate services for the health sector.

Climate services for health leverage climate information to support health sector decisions by improving the efficiency and effectiveness of long-term planning and short-term response. This in turn can improve the efficiency of resource mobilization in anticipation of climate-related health risks, enabling more effective prevention and response strategies. The Caribbean region is placing significant emphasis on developing climate services to improve preparedness and response to vector-borne diseases (VBDs), that is, dengue, Zika, and chikungunya [6]. To enhance regional integrated surveillance efforts for the prevention of VBD outbreaks, the Caribbean Public Health Agency (CARPHA), the Pan American Health Organization (PAHO) and the World Meteorological Organization (WMO)-designated Regional Climate Centre for the Caribbean (Caribbean RCC) hosted by the Caribbean Institute for Meteorology and Hydrology (CIMH) are focusing on the co-production of climate-driven impact based disease early warning systems (EWS) with member states in the region [Fig 1] [7–11]. At its operational core, an EWS can be defined as a system that collects, analyzes, and disseminates information about potential hazards or risks. We will hereinafter refer to this operational core as the EWS. However, it should be noted that an EWS further comprises (1) an information portal where the early warning information is stored and accessed and from where the information is disseminated; and (2) awareness, education and outreach to enhance capacity for both the providers and the users of the information."

Climate variability and change have both short- and long-term effects on VBDs, interacting with many biological, social and environmental factors [13]. For example, climate impacts human interactions with pathogens, vectors, and non-human hosts, affecting the transmission dynamics, geographic spread and re-emergence of VBDs. Vector abundance, survival, and feeding activity increase with rising temperatures (up to thermal optima) due to the dependence of arthropod body temperature on the external environment. Rising temperatures may also increase viral production in the host, thus making it more infectious [14]. The relationship between precipitation and VBD is complex and context specific. Increased precipitation can fill containers and provide more suitable breeding sites for disease vectors (it is important to note that too much precipitation can also flush oviposition sites). However, drought can also increase the number of breeding sites around households due to the increased need to store water-if improperly stored [9].

Together with the CARPHA, PAHO, CIMH and other regional partners, we are working to co-develop tailored statistical climate-and-health models and simultaneously co-design

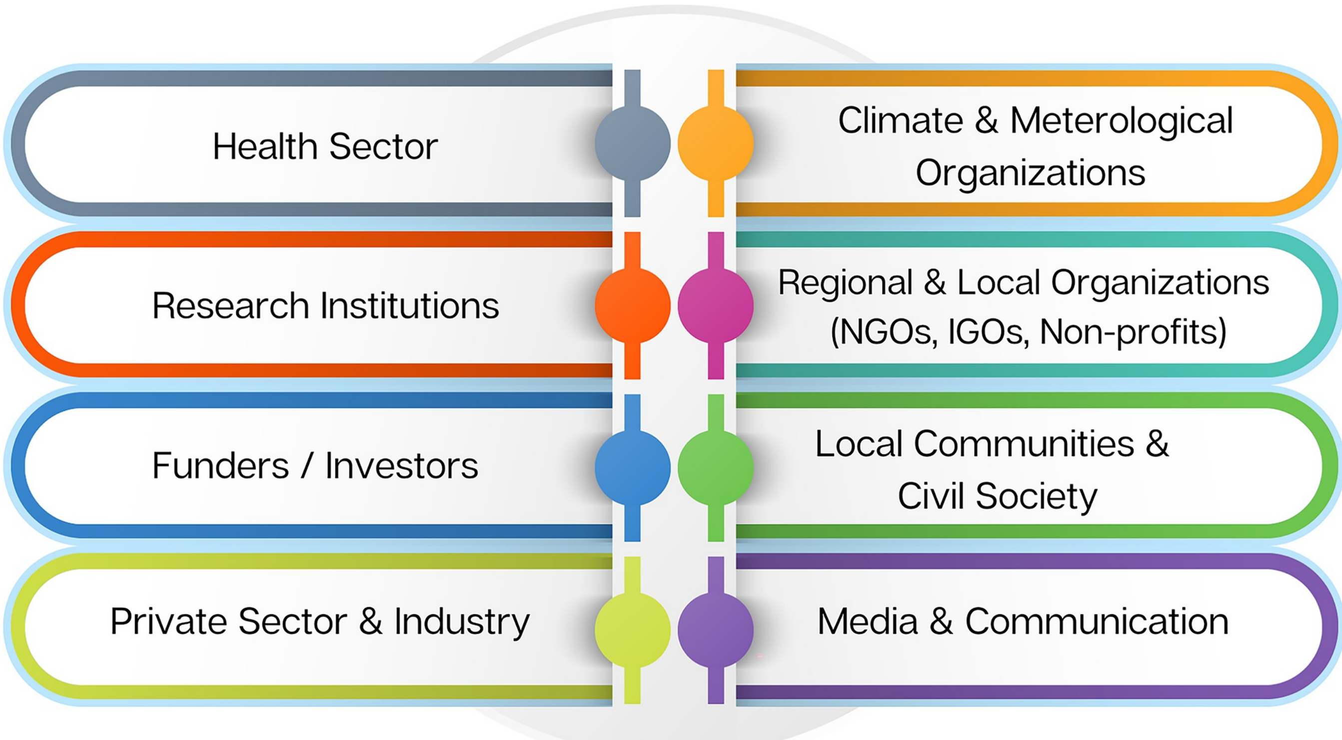


**Fig 1. When developing climate services for climate-sensitive infectious diseases (CSIDs), stakeholders across multiple sectors are involved.** Therefore, developing comprehensive public health action requires collaboration, cooperation, communication, and an understanding of common goals and outcomes, as well as recognition of the contributions from different parts of the stakeholder community to the decision-making and response processes [12].

https://doi.org/10.1371/journal.pclm.0000282.g001

sustainable tools that can be implemented and operationalized to support long-term decision-making and help build resilience to climate-sensitive infectious disease threats [Fig 2]. Here, 'operationalization' is defined as the act to turn disease surveillance, demographic data and climate indicators into valuable tools and information that health practitioners and disease control and prevention teams can use to protect the public from climate-related health risks. We define climate tools as a resource, application, or technology designed to help decision-makers; these tools can encompass a range of functionalities, such as climate data visualization, vulnerability mapping, and decision-support. Finally, we distinguish between partner and stakeholder as the following: a partner is actively involved in the co-creation and decision-making processes of a project, while a stakeholder is affected by or has an interest in the outcomes of the project but may not be directly involved in its execution.

Developing climate services for the health sector is a prominent subject in climate adaptation [15,16]. However, transitioning from theoretical models to practical implementation can be challenging [17]. Disease early warning systems provide tools for decision-makers in the health sector to proactively manage and mitigate epidemic risks, enabling more targeted and timely responses to protect public health. EWSs which employ seasonal climate forecasts can predict changes in impending disease risk up to 3–4 months in advance [18]. This is critical in resource-limited areas where sufficient lead time permits the timely optimization of resource allocation and preventive measures, reducing the overall burden on healthcare systems. The extended disease response time provided by early warnings can improve the likelihood that community members, hospitals and healthcare facilities are prepared and do not collapse [19], particularly in resource-constrained contexts such as Caribbean Small Island Developing


**Fig 2. Partners involved in the co-production of the Early Warning System (EWS).** Top left: National-level partners; top right: Regional partners; bottom right: Academic institutions and inter-governmental organizations; bottom left: Funders who have supported this process. All partners *excluding funders* were present at the 2022 regional meeting where we discussed early warning system opportunities and challenges for implementation. Partners present at the meeting are co-authors on the paper.

https://doi.org/10.1371/journal.pclm.0000282.g002

States (SIDS). Further, the health sector can develop tailored interventions to support communities in taking action to prevent an outbreak from occurring [Fig 3] [20].

Although EWSs are invaluable climate-and-health services, few of these systems have been implemented and operationalized. A 2021 landscaping analysis on available climate tools for


**Fig 3. The co-production of climate services, information, and resources for the *health sector* is an important step in addressing the health impacts of climate change and variability.** It is critical that the health sector is equipped with proper climate services that can help to reduce negative health outcomes and crises [21,22].

https://doi.org/10.1371/journal.pclm.0000282.g003

infectious diseases [23] showed that globally over the last ten years, of the 9,500 papers identified in the literature review, only 37 tools were available for use by decision-makers. One example is the AeDES interactive map room climate-and-health service which incorporates four different environmental suitability models, considering climate factors and mosquito life cycles, that allow decision-makers to monitor and forecast diseases in several parts of the Americas [24]. However, the low number of available tools suggests a lack of investment or incentives for researchers in academia or companies to develop operational climate tools for the health sector. Finally, most of the identified tools (81.1%) were focused on vector-borne diseases, demonstrating a shortage of tools for respiratory, foodborne, and waterborne diseases [23].

The 2021 landscaping study also featured interviews with worldwide experts to determine the top barriers that prevent decision-makers from using climate tools in the health sector [25]. Key barriers included a lack of funding to move from tool to service, lack of political mandate for the health sector to address climate issues, lack of communication between decision-makers and scientists, language barriers, lack of formal education (e.g., university curriculum or professional training), and lack of formal collaboration agreements between climate and health sectors to facilitate joint work plans [10]. A 2021 literature review of climate change and health in the Caribbean found very few examples of integrated early warning information systems to increase the availability and dissemination of climate information to inform health sector planning. The study recognised the need for more comprehensive and responsive national systems based on multi-sectoral design and implementation approaches [26].

Implementing climate services can be challenging. Here, a demand-driven implementation guideline is proposed. This guideline was developed through years of capacity building dialogues and stakeholder meetings across the Caribbean region and further refined during a 2022 multi-sectoral national workshop held in Barbados, which focused on implementing a climate-driven dengue early warning system with key stakeholders across the climate and health sectors. This study aims to create a general implementation framework for climate services for the health sector that is useful for scientists and decision-makers in the Latin America and Caribbean (LAC) region. Here, a case study from Barbados is being used to validate guidelines for the implementation process. Finally, the objective of this work is to provide a framework for the effective design, development, and integration of climate services into health systems, with the aim of enhancing public health resilience, reducing climate-related health risks, and promoting informed decision-making in response to and in anticipation of changing climate conditions.

# Methods

## General approach

Our approach to developing this implementation framework is rooted in dynamic collaboration rather than traditional methodologies (i.e., survey or interviews). This process was finely honed and brought to fruition during a key regional meeting held at the Caribbean Institute for Meteorology and Hydrology (CIMH) in Bridgetown, Barbados, in 2022 with core project partners who are all co-authors on this paper [Fig 2]. The meeting was scheduled as part of the CARPHA project to create, implement and operationalize a climate-driven dengue early warning system. The goal of the meeting was to discuss how we would use our tool and implement the EWS at both national and regional levels.

Since 2016, key participating experts and stakeholders have continuously and collaboratively contributed their knowledge and insights regarding early warning and climate-sensitive disease in the Caribbean. This ongoing engagement has ensured a rich base of expertise that underpins our entire framework. At the regional meeting (2022), which marked a pivotal moment in our process, we (the co-authors of the paper), who represent diverse partners involved in this work, engaged in in-depth discussions. This was not merely a meeting; it was a culmination of years of collaborative efforts, where every voice was not just heard but integrated into the planning process [Fig 4]. Through our discussions, we identified key themes and ideas as well as plans to move implementation of the EWS forward. These discussions

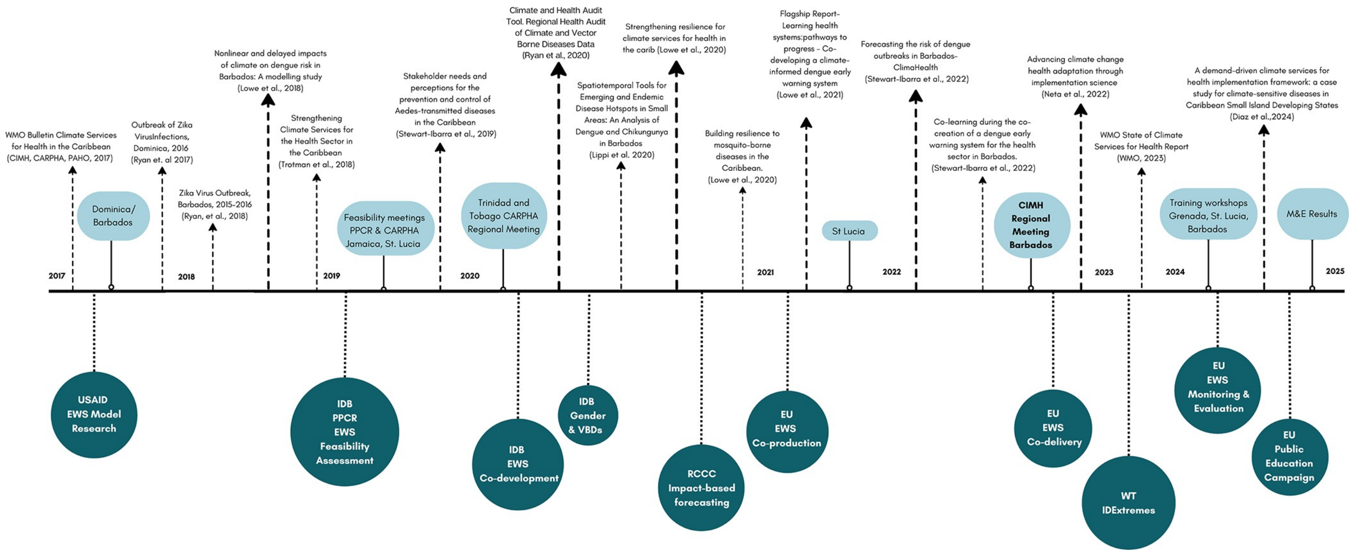


**Fig 4. Timeline of past co-authored work, in-person key meetings, and funding mechanisms.** **Top Row** lists co-authored papers resulting from years of dynamic collaboration ordered by the year published. **Middle row** in light blue are key in person meetings with partners and stakeholders to advance the co-production and implementation of the EWS. **Bottom row** in dark teal are funding mechanisms and associate project names. From left to right, funder followed by project name: **USAID**, Building Regional Climate Capacity in the Caribbean, Development of health-climate spatio-temporal modeling framework for the Caribbean, **Inter-American Development Bank (IDB)** via the Pilot Programme for Climate Resilience, Regional Health Audit of Climate and Vector Borne Diseases Data, **Inter-American Development Bank (IDB)** via the University of West Indies (UWI), Vector Borne Diseases and Gender Dynamics Study in the Caribbean. **Inter-American Development Bank (IDB)** via the University of West Indies (UWI), Integrating Climate Variability into Surveillance, Prevention and Control of Vector-Borne Diseases. Red Cross Climate Centre (RCCC), Impact-based forecasting for epidemics. **European Development Fund**, Developing, Designing, Piloting and Implementing an Early Warning System Integrating Climate Variability for Climate Sensitive Diseases in Order to Support Public Health Planning in the Caribbean. This project funding was extended twice, the first time to include new funding for implementation /co-delivery and then again to include funding for monitoring and evaluation. **Wellcome Trust**, IDExtremes: Co-production of a modelling tool to predict the probability of infectious disease outbreaks given compound extreme climatic events. **European Development Fund**, the Implementation of a vector borne disease focused public education campaign in one CARPHA member state.

https://doi.org/10.1371/journal.pclm.0000282.g004

were then organized into distinct themes and categories. To ensure these categories were actionable and relevant, we reverse-engineered the questions that we felt were essential for implementing a successful Early Warning System (EWS). The partners felt that this framework was applicable to many others in the field and decided to publish the framework to help guide new projects and teams in this type of transdisciplinary collaborative process.

The framework's guiding questions and models were inspired by both past published work and recent discussions. These include influential modeling and co-learning papers and the wealth of knowledge generated from years of meetings and workshops, which involved many of our partners [Fig 4]. This method emphasizes co-creation, recognizing all contributors as partners rather than mere participants. By engaging in a process that values each partner's input equally, we have built a foundation of trust that is crucial for the ongoing success and expansion of our initiative. This trust has also been instrumental in securing new funding to support continued collaboration and implementation. The regional meeting was the final step before formalizing our findings and recommendations in a comprehensive paper. This document not only reflects a consensus on how to move forward but also serves as a testament to the robust, cooperative approach we advocate for in environmental and climate-related projects.

Our approach demonstrates that effective implementation frameworks can emerge from processes that prioritize transdisciplinary partnership, dialogue, and mutual respect over hierarchical methodologies. By focusing on collaboration and co-creation, we ensure that our framework is not only inclusive but also equipped to address the complex challenges of environmental and climate justice.

## Details on the development of the framework

The development of the implementation framework was refined through a process of identifying recurring themes from the discussions and debates over strategies for pathways forward held at the 2022 regional meeting held at CIMH in Bridgetown, Barbados. We then reverse engineered these discussions to outline clear implementation questions and guidance. The framework consists of key components such as partnership building and stakeholder engagement, data collection, audit tool outputs, public communication, health interventions, server and storage management, human resources and technical capacity development, funding and resource mobilization, training, and monitoring and evaluation.

Throughout the collaborative meeting, partners shared insights, challenges and successes, and certain themes emerged. These recurring themes were grouped and analyzed to identify common patterns, areas needing improvement, and critical challenges across different aspects of the project. Questions addressed critical aspects of climate services implementation, such as data collection, analysis, communication, and decision-making. We then identified different strategies for addressing issues and opportunities highlighted by these themes. This aspect was critical for planning practical pathways and solutions that leverage the collective expertise and resources of the partners. Once we had concrete strategies in place to address all key themes we reverse engineered from theme to question. We looked at the proposed solution of a theme and asked, "What did we need to ask or know to arrive at these solutions?" This questioning helped to outline the specific steps and groups of questions per theme needed for implementing the EWS. It ensured that each step was directly linked to an element of the discussion and tied back to initial themes (themes are the headings in the framework i.e., funding, data, etc.). From the reverse engineered steps, we formulated specific implementation questions. These questions were designed to be general enough to guide any team in addressing climate service implementation challenges.

The questions and corresponding implementation guidance were then reviewed by all partners. The feedback phase was essential to ensure the questions were practical, relevant and could be adapted to various contexts. Based on partner feedback, questions were refined, and guidance (see results section) was updated. The final questions and implementation guidelines were compiled into the final framework [Fig 7]. We used the software *Canva* to create a visual representation of the framework for teams to view the whole picture in an easy to understand and visually appealing way. Guiding questions and themes can be found in S1 Annex. Finally, the entire framework and corresponding visuals were meticulously reviewed to ensure consensus among all partners, affirming the collaborative and participatory nature of the process.

This approach and output ensure that the resulting framework is actionable, directly tied to identified needs of various sectors, and equipped with practical steps for successful implementation. **This framework is meant to be flexible and guide transdisciplinary teams working across sectors to think about the big picture and major components of implementing a climate service in the health sector.** We encourage teams to build on these questions and adapt them to meet the needs of their specific endeavor.

## Approach to collaboration

The framework development process placed a strong emphasis on fostering collaboration among stakeholders and promoting effective communication and coordination throughout its creation. As a result, the framework is better equipped to address diverse needs and facilitate the successful integration of climate services into public health decision-making and resource allocation. Our approach to enhancing collaboration and communication is multi-faceted and tailored to the unique challenges of climate-sensitive health issues in the Caribbean. We have identified and engaged a diverse group of stakeholders, including health professionals, climate experts, and regional and local authorities. This engagement is facilitated through a variety of platforms, including both digital (Zoom and Microsoft Teams–for data sharing and regular updates, RShiny–for training, and Miro Boards–for collaborative mapping) and in-country visits (for feasibility assessments, knowledge exchange, and training). Additionally, we place significant emphasis on regular meetings (bi-weekly for project entirety) among the partners (the co-authors of this paper), which serve as platforms for brainstorming, problem-solving, and tracking project progress. These interactions are crucial for ensuring all voices are heard and integrated into the decision-making process. Furthermore, we actively solicit and incorporate feedback from stakeholders through online meetings and during the visits. This feedback is vital in refining our strategies and ensuring they remain aligned with stakeholder needs and expectations. We are also implementing training sessions aiming at enhancing stakeholders' understanding of the intersection between climate data and health outcomes. This is crucial for building a knowledgeable base of stakeholders. Lastly, we have designed our collaboration and communication strategies to be scalable and adaptable, for example hybrid participation i.e. in person or virtual, accommodating moving schedules, and meeting with different stakeholders at varying times, and using WhatsApp instead of email for best communication. This ensures that they can be effectively applied in different contexts or regions, particularly in the Caribbean Small Island Developing States.

This dynamic and collaborative approach has helped to shape a detailed and adaptable implementation framework for climate services in the health sector and serves as a guide for effectively implementing health interventions at regional and national levels, ensuring robust climate services meet the needs of diverse stakeholders. It has the potential to guide future efforts in climate and health adaptation, though it is still undergoing testing and validation in Barbados and soon in two other CARPHA member states (St. Lucia and Grenada).

### In set box: Case study Barbados

In 2017, a co-creation process to build a dengue EWS began in Barbados [8,9]. This was led by the national health sector, the Regional Climate Center (RCC), Caribbean Institute for Meteorology and Hydrology (CIMH), the Caribbean Public Health Agency (CARPHA), the national meteorological services (Barbados Meteorological Services), and other governmental, intergovernmental, and academic institutions [7]. Stakeholder engagement plans were used to conduct both formal and informal meetings to gain insights into the demand, which informed the co-design process of a set of climate-and-health services for the country, including a prediction model [11,27]. The concluding demands of the health sector were to create a system that uses a minimum three-month lead time to alert the healthcare system of increased disease risk in the country. This risk would trigger a health system intervention that includes, but is not limited to, community engagement campaigns, increased medical personnel training of disease symptomatology, more frequent vector control visits, and re-allocating funds to prevent outbreaks.

Throughout the COVID-19 pandemic, stakeholder engagement was maintained using virtual methods despite strict travel restrictions. New methods of bringing stakeholders together were used, including virtual breakout rooms, and other virtual interaction techniques. In 2022, strict travel restrictions were lifted and a one-week long set of meetings with key institutional partners was held in Barbados to continue discussing EWS construction along with implementation and operationalization plans for the climate-driven dengue EWS. Meetings were held with the health and climate sectors to revisit past goals and ensure that model outputs were still consistent with decision-makers' needs. It was also pertinent that model inputs be revisited to determine whether the model configuration needed to be updated. Key discussions regarding stakeholder involvement and roles, human resources and technical capacity, design and usability of user interfaces, return on investments, and monitoring and evaluation of the EWS took place [Figs 5 & 6].

### Ethics statement

IRB approval from the regional governing body and project implementation partner the Caribbean Public Health Agency was received (FWA #: FW A00023242 and HHS IRB Registration Number: IRB00010238). In addition, formal consent to publish meeting discoveries which led to the development of the framework was granted by the Barbados Ministry of Health and Wellness. A meeting was arranged to discuss the guidelines presented here, meeting invitations were sent to partners on October 11th and the meeting was held on November 3rd, 2022. Verbal informed consent was obtained to publish the implementation framework questions defined during the meeting. All partners present at the meeting contributed to this work and are co-authors of this paper. See S1 Checklist for all information regarding inclusivity protocols and S1 Data for summary of data.

## Results

### Partnership building and stakeholder engagement

The workshop in Barbados sought to understand partners' perspectives and responses to key implementation themes. The meeting also established clear roles and responsibilities for each of the sectors involved, for example, who will be accountable, consulted, and/or informed. The Barbados Ministry of Health and Wellness would be responsible and accountable for providing health data to formulate and inform early warning models, interpreting model outputs, enacting health interventions, and communicating model results to the public. The Barbados Meteorological Services would be responsible for generating seasonal forecasts and running health-impact models, which are informed by a combination of observed and forecast climate data. As the technical arm of the Caribbean Meteorological Organisation–of which Barbados is one of 16 member states–, the Caribbean Institute for Meteorology and Hydrology (CIMH), would be consulted when running the model and work to automate inputs of climate forecasts. As the regional lead health organization, CARPHA would monitor the outputs of the EWS, ensure communication between different member states and facilitate regional and local collaborations. Finally, academic institutions would be consulted for maintenance and hiccups that may evolve during the implementation and operation of the EWS.

The workshop held in Barbados allowed for discussion and negotiation of roles and responsibilities between stakeholders. For example, dialogue around location of host servers to run models and expansion and application to other Caribbean Small Island Developing States in the future. Opportunities for stakeholders to come together should be provided to discuss both

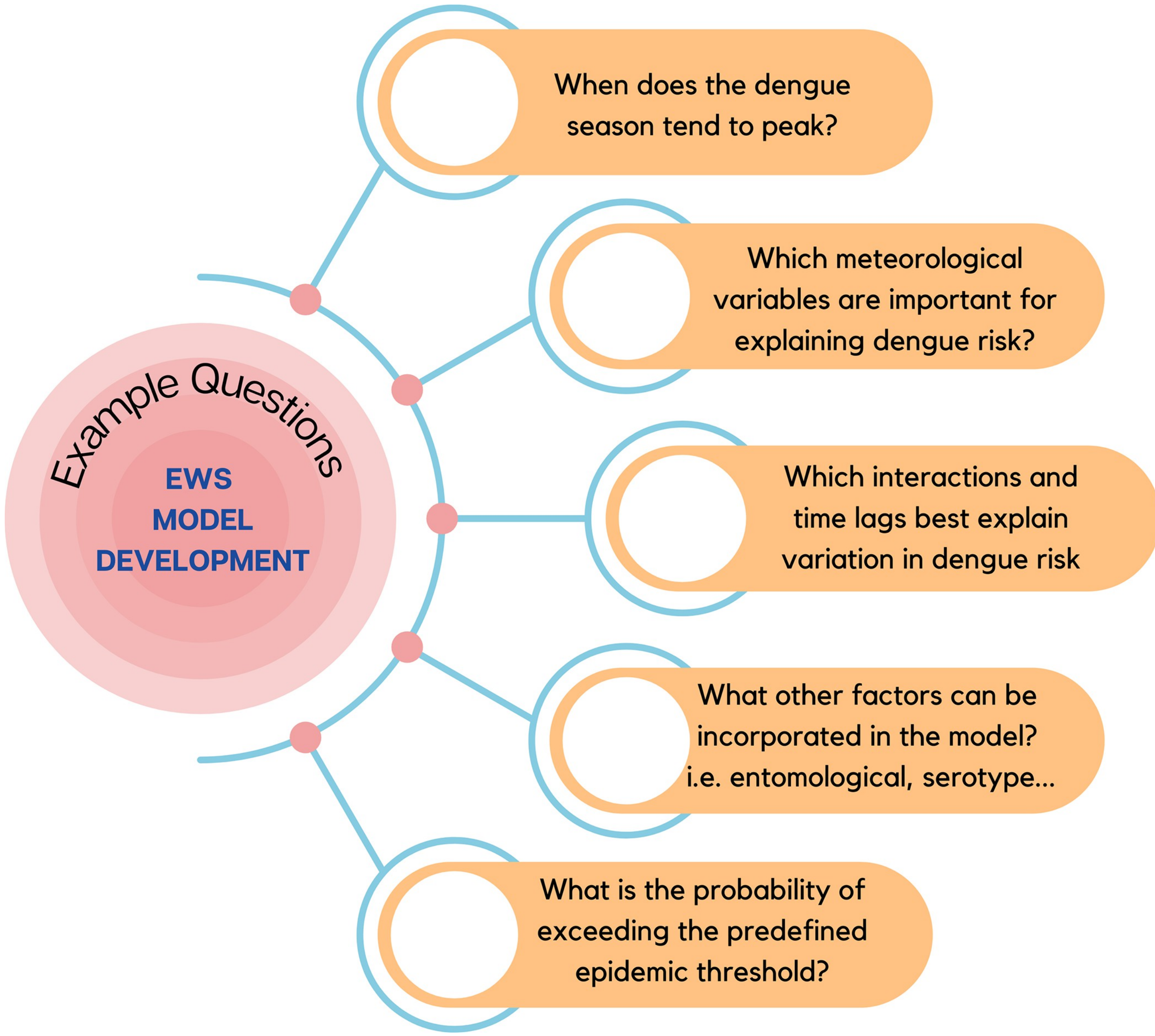


**Fig 5. Example of guiding questions used to create predictive models for the climate-driven Dengue EWS in Barbados by Lowe et al. 2018 [9].**

https://doi.org/10.1371/journal.pclm.0000282.g005

major and minor details of implementation, ensuring that all who should be involved are up to date and in agreement about pathways forward.

Building a strong partnership amongst stakeholders and partners is critical. It is important to outline the role and capacity of each stakeholder's involvement and make sure all are aware of each other's duties. A table can help break down roles and actions using the following categories: involved, oversight, managing, and/or operating. Continued engagement from the beginning to the end of the project will help maintain ownership, create confidence, and build trust which will support the move from model to EWS implementation more efficiently. Moreover, involving local community members in the climate and health adaptation plans is crucial for building resilient health systems. Their unique knowledge, experiences, and perspectives can enhance the effectiveness and relevance of adaptation measures, leading to more

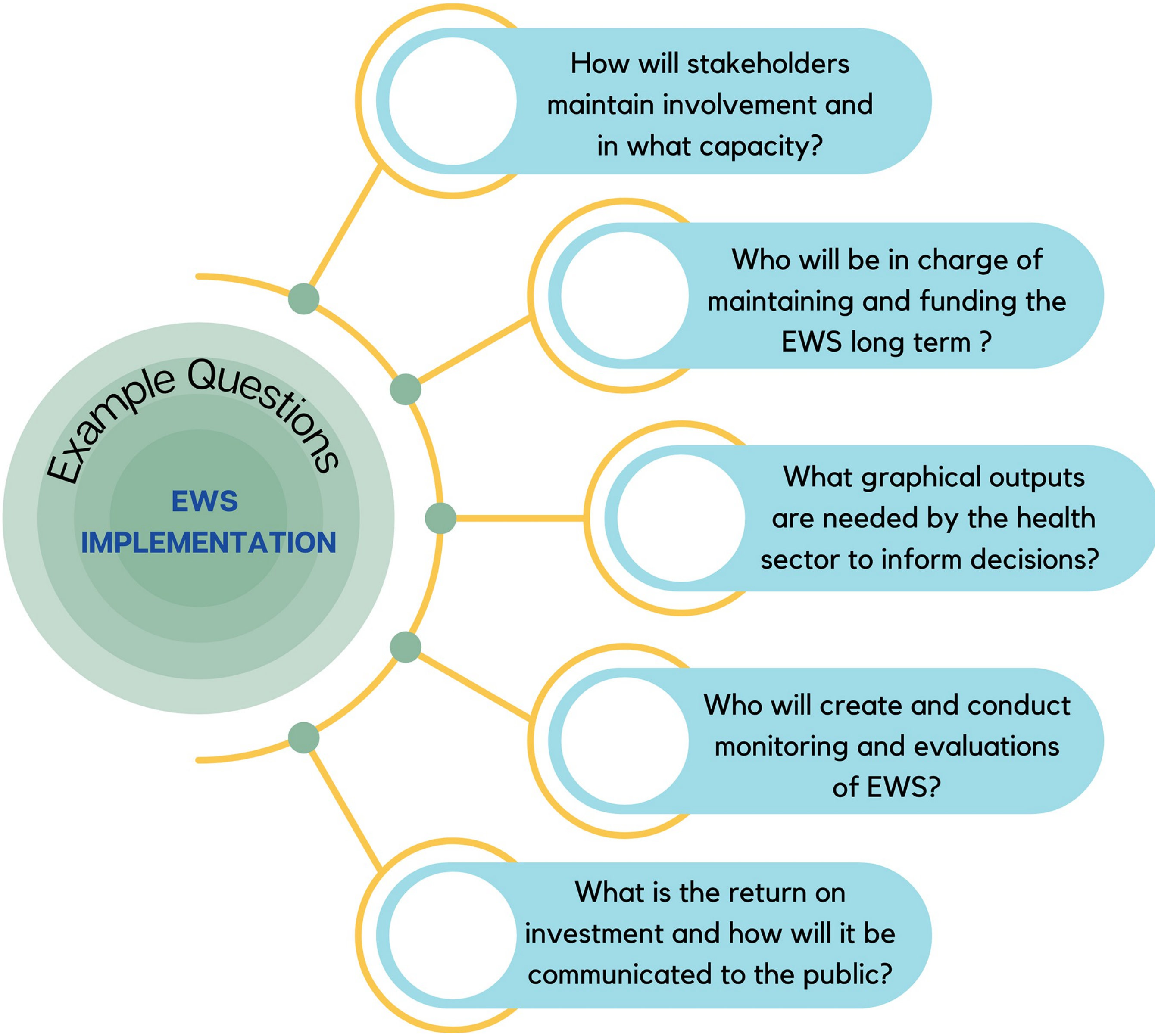


**Fig 6. Example of guiding questions used in the development of the implementation framework for climate-driven Dengue EWS.**

https://doi.org/10.1371/journal.pclm.0000282.g006

sustainable solutions. Targeted educational programs and campaigns can empower communities to understand the connections between climate change and variability, health impacts, and the importance of climate driven early warning systems. Equipped with this knowledge, community members can actively participate in and support the development of health-resilient strategies, fostering a collective effort to address climate-related health challenges [Fig 7, section 1].

## Data, permissions, and models

In many places, long-term weather and climate data is more consistent and accessible than health data. Climate data are often collected and analyzed over long periods of time and can be

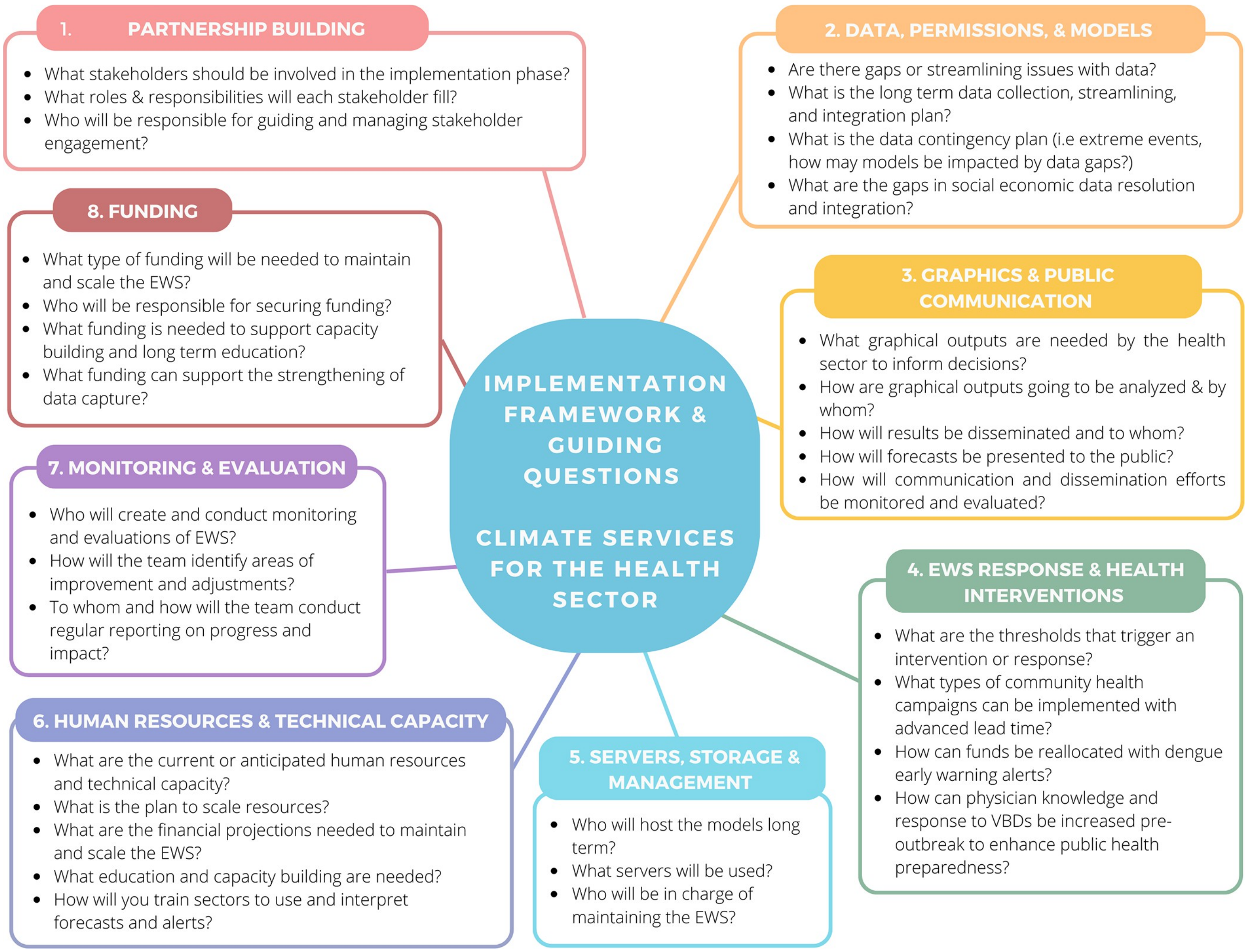


**Fig 7. Visual representation of implementation framework and guiding questions for climate services for the health sector.** See S1 Annex for extended list format.

https://doi.org/10.1371/journal.pclm.0000282.g007

used to identify patterns and trends in variables relevant to disease transmission, including temperature, precipitation and humidity. The Barbados Meteorological Services has long-term records (more than 5 decades) from weather stations on the island (one at the airport and the other at CIMH). Elements recorded through BMS include wind vectors, temperature, precipitation, humidity, pressure, cloud cover and type, visibility, and present weather. The historical datasets have been digitized and cleaned. On the other hand, health data refers to information related to an individual's or population's health. Health data can be more complex to obtain as it involves sensitive information and is subject to privacy laws that vary by country and state. Examples of health data include disease case data, mortality, hospitalization, and vaccination coverage. Health data collection can also be difficult to analyze due to unknown influences of socioeconomic status and environmental factors. Moreover, health data can be challenging to implement into models because of gaps in data reporting, lack of electronic health information systems, and differences in data collection formats. For these reasons, it is essential to account for contingency plans. In Barbados, the health sector noted that hurricanes and floods had impacted the continued collection of health data. The health sector also reported that COVID-

19 virtually stopped dengue testing for roughly two years exposing the greater need for data risk management.

Finally, using socio-economic data can help strengthen model predictions and public health outcomes [28]. The Barbados Ministry of Health reported that some social and economic data are collected for inpatient visits. Factors such as income, education level, occupation, and access to healthcare all have a significant impact on a person's health status and should not be overlooked. By collecting and analyzing these data, public health officials can better understand the needs of different populations and tailor interventions accordingly. Funding schemes must, therefore, prioritize socio-economic data collection and usage. Investing in new technologies or workflows to make it easier for providers to collect and enter socio-economic data, as well as offering training on data intake, will help providers address social determinants of health. Finally, it is important to note that there is a need for critical mass, and staff dedicated to these roles [Fig 5, section 2].

## Addressing data gaps

Barbados has standardized disease surveillance reporting forms and standard operating procedures (SOPs). However, gaps in data reporting could stem from different issues; sometimes lack of sufficient personnel at frontline/sentinel sites, competing public health priorities, need for more trained personnel at different levels etc. Recommendations to address data gaps include building more human resource capacity, from ground level upwards, and shift from more manual to electronic reporting. This would require more IT infrastructure and government investment, which is a common barrier. Thus, new SOPs should be drafted and coupled with (Monitoring and Evaluation) M&E to assess performance of any newly implemented systems.

## Tool outputs: Graphics and public communication

Creating an interface that is useful and manageable to help analyze model outputs is a crucial component of a decision-support tool. Understanding what graphical outputs are most useful and interpretable to decision-makers is essential and those with user-friendly interfaces that simplify model outputs will encourage use. Developers must work with decision-makers to understand the thought process behind a health intervention when building interfaces. Tools created with simple measures in which users can walk through basic steps before performing more complex analyses will ensure optimal utilization of the service [29].

Communication and dissemination of climate information and resources are critical for ensuring that decision-makers and practitioners have the information they need to respond to the impacts of climate change on health. It is essential to develop materials and strategies that are appropriate for the population to be reached, for example, climate bulletins, brochures, and fact sheets using a diverse set of imagery and text, social media, radio, or other materials [27]. Different strategies may be needed to communicate with decision-makers versus practitioners or to communicate with different sectors of the health system. Strategies may also need to consider cultural and linguistic differences [30]. Working with a design team to relay alerts is crucial to ensure the population is informed and understands what health intervention may take place or may be implemented. Working with communities to explain how the EWS works and gain their trust will ensure that communities can be a part of the intervention at hand, therefore, increasing intervention efficacy.

Using qualitative methods such as targeted surveys and feedback collection from the stakeholders; along with focus groups and interviews with representatives from each group would provide deeper insights into the effectiveness of communication strategies and help identify any areas needing improvement. Based on the evaluation findings, platforms could be adapted and refined for better communication strategies. This iterative process would ensure communication remains effective and responsive to the needs and preferences of decision makers [Fig 7, section 3].

## Health interventions

An EWS provides forecasts of disease risk to the health sector to prevent public health crises and limit overall health risks. A crucial step in developing forecasts is understanding what public health interventions will occur when an alert meets a specific threshold. It is also essential to understand how and why an intervention is suggested. This means examining the underlying rationale and evidence supporting the proposed intervention, as well as considering its potential impact and effectiveness in addressing the issue at hand. Additionally, it is important to evaluate the feasibility of implementing the intervention, considering the resources, time and support required for successful execution. An EWS can trigger several types of interventions, including, but not limited to, community health campaigns, increased medicine and supply chains to hospitals and clinics, increased capacity training for health professionals, increased vector control such as fogging and tracing the vector source and identifying other cases in the vicinity, as well as re-allocation of human resources funding to high-risk regions. When developing an EWS, it is also essential to know which agency is activated in the response plan, what defines the threshold, what committee is responsible for enacting an intervention, and the branching logic for emergency dissemination. Finally, it is key to establish a thorough monitoring and evaluation plan for each health intervention implemented [Fig 5, section 4].

## Servers, storage, and management

The maintenance and management of an EWS is a critical task that requires specialized knowledge and expertise. It is essential to identify who will oversee maintaining the EWS to ensure it functions properly. This includes managing the servers and storage systems that are needed to collect and store observed and modeled data (e.g., forecasts), as well as overseeing other technical aspects of the system to ensure smooth operation.

Regional partnerships can be instrumental in hosting servers and providing technical assistance to smaller countries. For example, small island states can benefit from a similar setup to that of a Regional Climate Centre, which can provide them with access to climate forecasts and other critical data. By partnering with larger, more established institutions, smaller countries can leverage their expertise and human resources. This can help to ensure that the EWS will be managed effectively and that it is providing accurate and valuable information to decision-makers in the health sector [Fig 7, section 5].

## Human resources and technical capacity

Technical capacity refers to the knowledge, skills, and infrastructure necessary to operate and maintain climate tools (i.e., EWS), such as computing systems, software, and data management. Many low-income countries lack the financial resources to hire or create new positions that are essential to running, maintaining, and operating an EWS. The more automated the processes, the better, as human resources do not have to add to an already extended workload. Automated processes can help alleviate the strain on human resources and improve the sustainability of the EWS. It can reduce the need for manual data entry and oversight, freeing up staff time for other tasks. However, it is important to note that even an automated system needs someone responsible for maintenance to perform updates as data systems change. The Barbados Meteorological Services advocated that one way to ensure a more sustainable implementation of the EWS was to ensure the automatic feeding of climate data into the models, with limited need for human oversight. Stakeholders emphasized that in countries with limited resources, automating, and streamlining inputs and outputs as much as possible will help ensure the usage of tools. Stakeholders further indicated that, due to the large volume of national projects, human resources are limited. To make the EWS tool viable and sustainable, maintenance of the system should be conducted by those who have the technical capacity, time, and funding to best support the project. Continued training is particularly vital for maintaining and enhancing technical capacity, as it ensures that employees stay up to date with rapidly evolving systems and can effectively adapt to emerging challenges in the field [Fig 5, section 6].

It is also essential that health sector professionals have the training and capacity to understand and respond to climate impacts. One way to address training and capacity building is through the development of tailored programs starting with a needs assessment to identify skill gaps and areas of improvement. Another aspect of capacity building is fostering a culture of continuous learning and professional development. Encouraging employees to participate in workshops, conferences and online courses can help staff to keep up with best practices [31–33]. One example of this is the Global Consortium for Climate and Health Education (GCCHE) open access course *Pan American Climate Resilience Health Systems*, with its goal to equip the health sector with the knowledge and tools needed to address climate change [34].

Moreover, developing formal high school and university curricula focused on climate change and variability and/or climate services would help to produce professionals in-country and eliminate or reduce the need to outsource professionals residing in the Global North. This could help ensure that experts on the ground could develop and manage early warning information system components such as research, monitoring and prediction tools, or awareness, education and outreach, reducing the economic burden on countries to outsource work and improving on sustainable climate services operations. Creating pipeline pathways for postgraduate students to enter the workforce would also increase the demand for creation of climate and health curriculum in universities. Ongoing training and capacity building can also help strengthen professional development on the job. An excellent example of this is the Pan American Health Organization (PAHO) Climate and Health Fellowship program, which first launched in 2021 and created a cohort of inter-sectorial, multidisciplinary leaders with the necessary skills to sustainably turn plans and policy into action [35] [Fig 7, section 6].

## Monitoring and evaluation

Effective monitoring and evaluation of the use of climate tools and resources is critical to ensure that decision-makers and practitioners in the health sector have the information they need to respond to the impacts of climate on health. Ongoing monitoring and evaluation, including the identification of areas for improvement and adjustments, and regular reporting on progress and impact, are key steps in this process. Reporting the evaluation updates helps to keep relevant stakeholders informed and engaged and promotes positive health outcomes [36].

Monitoring and evaluation of communication and dissemination efforts can help to ensure that resources are reaching the intended audiences and that they are being used successfully. There are a variety of methods that can be used including surveys, interviews, and focus groups to gather feedback from practitioners and decision-makers, as well as quantitative metrics such as website traffic, the number of downloads of specific resources, or social media engagement statistics [37] [Fig 5, section 7].

### Funding and resource mobilization

Funding and continuous resource mobilization is needed for implementation initiatives that are broad and far-reaching. One key area that requires funding is long-term data capture and storage. This includes developing the infrastructure needed to collect, store, and analyze data related to climate, climate(-related) hazards and their impact on public health. Without these data, it is difficult to identify patterns and trends, impossible to model them, and a missed opportunity to develop evidence-based interventions to protect public health. Another important area that requires funding is capacity building of the current workforce as well as the development of formal university curricula for climate and health specialties for future generations. This is critical to building a workforce that is capacitated to become competent in developing, coordinating and implementing appropriate mitigation and adaptation plans and strategies that are informed by the risk information. Additionally, funding is needed for the integration of electronic health information systems into climate-health informatics, to include hiring software developers for user interface creation, as well as social scientists and communication specialists to co-design and co-evaluate associated health intervention effectiveness. All of these are crucial professional roles in developing and implementing climate services for the health sector, thus, without adequate sustained funding, progress in this area may be limited. There are plans to join forces with DHIS2 to develop a CARPHA level platform that will integrate national level systems funded by 11th EDF EU/CARIFORUM Project, "Strengthening Climate Resilient Health Systems in the Caribbean". DHIS2 is an open source, web-based platform used as a health management information system (HMIS) used in more than 100 countries. DHIS2 software development is a global collaboration managed by the HISP Centre at the University of Oslo (UiO). HISP is a global network of 17 in-country and regional organizations, providing support to ministries and local implementers of DHIS2 [38].

The system is being designed in collaboration with Barbados Government and other national agencies. It is being built taking into account current national resources infrastructure and future expected input from these bodies to support long-term in-country sustainability [Fig 7, section 8].

## Discussion/Conclusion

The integration of climate information into health sector planning and decision-making is essential to ensure the continued health and well-being of populations [23,25]. Developing guidelines and protocols, as well as testing, monitoring, and evaluation, are critical steps in this process [6]. The implementation questions proposed here (S1 Annex) can guide readers on how to access, use, and interpret climate data and models in a way that supports real-time decision-making in the health sector.

Creating and implementing climate services for health is challenging [6], as for many sectors (i.e. Goddard et al 2020 and references therein). In the beginning stages of the EWS development, we faced the challenge of aligning the diverse interests and priorities of various stakeholders, including health and environment professionals. In these projects, stakeholders include a range of roles from implementing partners to recipient decision-makers, to scientific partners, to the funders and agency personnel directing projects. Traditionally, stakeholders tend to be the recipients of information (i.e. department of health, department of conservation, special interest groups, etc.), whereas true co-development and co-production methods think about equity, hierarchy and power dynamics. Input and decisions from various stakeholders on co-design or deliverable formats and co-development engagements are not static, and often rotate and remain dynamic. However, we facilitated open discussions and provided key information and technical expertise to all parties involved. One key strategy we employed, developed through prior projects, was using an interview guide for in-person inquiry and data auditing during the early stages of the work [39]. This established a relationship with key stakeholders in the data collection and recording realms, while allowing for investigation of the structure and distribution of those key data pipelines amongst the project partners and supporting ministries, sectors, and agencies. The development and implementation of the current framework was tailored for the Caribbean, and potential challenges of adapting this EWS framework more broadly span many of the limitations outlined in earlier sections, such as establishing partnerships, and discrepancies in minimum technical capacity and human resources requirements. Publishing this tool for users to adapt to future projects and discussions is crucial. It serves as a central part of the overall process, acting as a catalyst for interactions and discussions, rather than just being a technical tool in the larger toolkit'.

Keeping stakeholders continuously engaged and motivated throughout the project is also challenging. Therefore, we implement regular feedback mechanisms and progress updates and acknowledge the contributions of stakeholders to keep them actively involved and invested in the project's success. Progress readouts, online and in-person stakeholder engagement meetings on specific components (e.g. syntheses of interview themes, database development, discussions of alert system styles across sectors), provide ongoing, yet dynamic opportunities for co-development and co-design. Future efforts could also include periodic reviews of original goals, and collaborative mapping of shifts or redesign of pathways might provide a reflection tool, particularly in the inevitable scenario of protracted timelines due to externalities (e.g. global pandemics, bureaucratic changes, political unrest). While implementation of climate-health tools, by its very nature, does not have an endpoint, there will be endpoints in the process, and similarly, novel starting points may arise during the undertaking. Another future consideration is to celebrate and appreciate a rotating organogram of stakeholders and roles, e.g. when personnel from different sectors change their role in the implementation, in their organization, or encounter shifting responsibilities. For specific implementations of climate-health services, there may indeed be a fundamental minimum network of roles, or size of network of personnel, needed to promote success of the overall implementation. This remains to be seen, as we are still in nascent stages of full implementations, globally.

The Caribbean has set regional cooperation on health and climate change as a top priority [40,41]. Having the political will and mandate ensures this pressing issue remains at the top of the agenda for key government sectors. Within the larger Caribbean context, Barbados has taken on a leading role on climate and health initiatives, pioneering these approaches within the region. Barbados is providing a template and a roadmap for additional partners and some major takeaways from this work in Barbados includes the following: 1) equity must be at the heart of every climate adaptation strategy—academic institutions must support research and development in the region and encourage long term sustainability through education and funding opportunities; 2) partnerships need to be developed and built on trust—and this process cannot be rushed as it involves shifting mindsets away from historic colonial approaches; 3) in order to advance in climate tool development, it is critical to invest in basic infrastructure including new weather stations, servers, data capture, storage and electronic health information systems; 4) there is still a need to sensitize the general public to climate variability and change, as well as to empower communities to take action now; 5) decision-makers need simple user interfaces that can help them to understand the risks at hand and communicate them effectively to the general public; and 6) climate services need to be as automated as possible to reduce the workload in human resource limited areas.

Implementing climate services for the health sector is a critical step in protecting public health in the face of climate change [42–44]. Further research must be conducted on the return on investment of climate-driven disease early warning systems to showcase their impact.

Defining what the return on investment may look like is important and may differ between countries and projects, i.e. number of lives saved, illness prevented, or monetary cost saved. Moreover, future work for climate-and-health EWS development and research may include demand-driven forecasting to predict monetary resources needed in prevention, control, and outbreak scenarios which would help low- and middle-income countries (LMICs) to allocate public health funds accordingly. Moving forward, promoting funding initiatives and supporting the professional development of stakeholders in the Global South will bolster capacity building and address critical skill gaps that may limit EWS implementation in the Caribbean and beyond. Finally, the authors of this paper recommend that these guidelines could be used to implement the climate-driven dengue EWS sustainably into the Barbados health sector and guide future implementation work across the LAC region.

## Supporting information

**S1 Checklist. Inclusivity in global research.**
(PDF)

**S1 Annex. Implementation framework and guiding questions.**
(PDF)

**S1 Data. Strengthening climate resilient health systems in the Caribbean.**
(PDF)

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## References


1. WHO-Fast-facts-on-climate-and-health.pdf [Internet]. [cited 2023 Mar 6]. Available from: https://cdn.who.int/media/docs/default-source/climate-change/fast-facts-on-climate-and-health.pdf?sfvrsn=157ecd81_5.
2. Thomson MC, Muñoz ÁG, Cousin R, Shumake-Guillemot J. Climate drivers of vector-borne diseases in Africa and their relevance to control programmes. Infect Dis Poverty. 2018 Aug 10; 7(1):81. https://doi.org/10.1186/s40249-018-0460-1 PMID: 30092816
3. Patz JA, Thomson MC. Climate change and health: Moving from theory to practice. PLOS Medicine. 2018 Jul 31; 15(7):e1002628. https://doi.org/10.1371/journal.pmed.1002628 PMID: 30063707
4. Sorensen CJ, Borbor-Cordova MJ, Calvello-Hynes E, Diaz A, Lemery J, Stewart-Ibarra AM. Climate Variability, Vulnerability, and Natural Disasters: A Case Study of Zika Virus in Manabi, Ecuador Following the 2016 Earthquake. Geohealth. 2017 Oct; 1(8):298–304. https://doi.org/10.1002/2017GH000104 PMID: 32158994
5. Romanello M, McGushin A, Di Napoli C, Drummond P, Hughes N, Jamart L, et al. The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future. The Lancet. 2021 Oct; 398(10311):1619–62.
6. Neta G, Pan W, Ebi K, Buss DF, Castranio T, Lowe R, et al. Advancing climate change health adaptation through implementation science. The Lancet Planetary Health. 2022 Nov 1; 6(11):e909–18. https://doi.org/10.1016/S2542-5196(22)00199-1 PMID: 36370729
7. Stewart-Ibarra AM, Romero M, Hinds AQJ, Lowe R, Mahon R, Meerbeeck CJV, et al. Co-developing climate services for public health: Stakeholder needs and perceptions for the prevention and control of Aedes-transmitted diseases in the Caribbean. PLOS Neglected Tropical Diseases. 2019 Oct 28; 13(10):e0007772. https://doi.org/10.1371/journal.pntd.0007772 PMID: 31658267
8. Stewart-Ibarra AM, Rollock L, Best S, Brown T, Diaz AR, Dunbar W, et al. Co-learning during the co-creation of a dengue early warning system for the health sector in Barbados. BMJ Glob Health. 2022 Jan; 7(1):e007842. https://doi.org/10.1136/bmjgh-2021-007842 PMID: 34992079
9. Lowe R, Gasparrini A, Meerbeeck CJV, Lippi CA, Mahon R, Trotman AR, et al. Nonlinear and delayed impacts of climate on dengue risk in Barbados: A modelling study. PLOS Medicine. 2018 Jul 17; 15(7):e1002613. https://doi.org/10.1371/journal.pmed.1002613 PMID: 30016319
10. Lowe R, Ryan SJ, Mahon R, Meerbeeck CJV, Trotman AR, Boodram LLG, et al. Building resilience to mosquito-borne diseases in the Caribbean. PLOS Biology. 2020 Nov 24; 18(11):e3000791. https://doi.org/10.1371/journal.pbio.3000791 PMID: 33232312
11. Lippi CA, Stewart-Ibarra AM, Romero M, Lowe R, Mahon R, Van Meerbeeck CJ, et al. Spatiotemporal Tools for Emerging and Endemic Disease Hotspots in Small Areas: An Analysis of Dengue and Chikungunya in Barbados, 2013–2016. Am J Trop Med Hyg. 2020 Jul; 103(1):149–56. https://doi.org/10.4269/ajtmh.19-0919 PMID: 32342853
12. Covert HH, Soares LF, Wahid FA, Allen T, Guido Z, Johnson D, et al. Priorities for Bolstering Public Health Resilience in the Context of Climate Change in Dominica and Puerto Rico. Ann Glob Health. 88(1):63. https://doi.org/10.5334/aogh.3876 PMID: 35974983
13. Diaz A, Stewart-Ibarra AM. Zika virus infections and psychological distress following natural disasters. Future Virology. 2018 Jun; 13(6):379–83.
14. Reinhold JM, Lazzari CR, Lahondère C. Effects of the Environmental Temperature on Aedes aegypti and Aedes albopictus Mosquitoes: A Review. Insects. 2018 Nov 6; 9(4):158. https://doi.org/10.3390/insects9040158 PMID: 30404142
15. Romanello M, Napoli CD, Drummond P, Green C, Kennard H, Lampard P, et al. The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. The Lancet. 2022 Nov 5; 400(10363):1619–54. https://doi.org/10.1016/S0140-6736(22)01540-9 PMID: 36306815
16. Shaftel H. Climate Change: Vital Signs of the Planet. 2023 [cited 2023 Mar 6]. Overview: Weather, Global Warming and Climate Change. Available from: https://climate.nasa.gov/global-warming-vs-climate-change.
17. Hussain-Alkhateeb L, Ramírez TR, Kroeger A, Gozzer E, Runge-Ranzinger S. Early warning systems (EWSs) for chikungunya, dengue, malaria, yellow fever, and Zika outbreaks: What is the evidence? A scoping review. PLOS Neglected Tropical Diseases. 2021 Sep 16; 15(9):e0009686. https://doi.org/10.1371/journal.pntd.0009686 PMID: 34529649
18. Lowe R, Bailey TC, Stephenson DB, Jupp TE, Graham RJ, Barcellos C, et al. The development of an early warning system for climate-sensitive disease risk with a focus on dengue epidemics in Southeast Brazil. Statistics in Medicine. 2013; 32(5):864–83. https://doi.org/10.1002/sim.5549 PMID: 22927252
19. Lowe R, Stewart-Ibarra AM, Petrova D, García-Díez M, Borbor-Cordova MJ, Mejía R, et al. Climate services for health: predicting the evolution of the 2016 dengue season in Machala, Ecuador. The Lancet

Planetary Health. 2017 Jul 1; 1(4):e142–51. https://doi.org/10.1016/S2542-5196(17)30064-5 PMID: 29851600

20. Vásquez P, Loría A, Sánchez F, Barboza LA. Climate-driven statistical models as effective predictors of local dengue incidence in Costa Rica: a generalized additive model and random forest approach. RMTA. 2019 Dec 17; 27(1):1–21.
21. DiSera L, Sjödin H, Rocklöv J, Tozan Y, Súdre B, Zeller H, et al. The Mosquito, the Virus, the Climate: An Unforeseen Réunion in 2018. GeoHealth. 2020; 4(8):e2020GH000253.
22. Ibarra AMS, Ryan SJ, Beltrán E, Mejía R, Silva M, Muñoz Á. Dengue Vector Dynamics (Aedes aegypti) Influenced by Climate and Social Factors in Ecuador: Implications for Targeted Control. PLOS ONE. 2013 Nov 12; 8(11):e78263. https://doi.org/10.1371/journal.pone.0078263 PMID: 24324542
23. Ryan SJ, Lippi CA, Caplan T, Diaz A, Dunbar W, Grover S, et al. The current landscape of software tools for the climate-sensitive infectious disease modelling community. Lancet Planetary Health. 2023 Jun; 7(6):e527–36. https://doi.org/10.1016/S2542-5196(23)00056-6 PMID: 37286249
24. Muñoz ÁG, Chourio X, Rivière-Cinnamond A, Diuk-Wasser MA, Kache PA, Mordecai EA, et al. AeDES: a next-generation monitoring and forecasting system for environmental suitability of Aedes-borne disease transmission. Sci Rep. 2020 Jul 28; 10(1):12640. https://doi.org/10.1038/s41598-020-69625-4 PMID: 32724218
25. Ryan SJ, Lowe R, Lippi CA, Diaz A, Dunbar W, Johnson S, et al. Landscape mapping of software tools for climate- sensitive infectious disease modelling. Technical Report [Internet]. 2020; Available from: https://cms.wellcome.org/sites/default/files/2022-01/landscape-mapping-software-tools-CSID-modelling.pdf.
26. IRI–International Research Institute for Climate and Society | Climate Variability [Internet]. [cited 2023 Mar 5]. Available from: https://iri.columbia.edu/our-expertise/climate/climate-variability/.
27. Strengthening Climate Services for the Health Sector in the Caribbean [Internet]. 2018 [cited 2023 Feb 1]. Available from: https://public.wmo.int/en/resources/bulletin/strengthening-climate-services-health-sector-caribbean.
28. Hawkins RB, Charles EJ, Mehaffey JH. Socio-economic status and COVID-19–related cases and fatalities. Public Health. 2020 Dec 1; 189:129–34. https://doi.org/10.1016/j.puhe.2020.09.016 PMID: 33227595
29. Alonso WJ, McCormick BJ. EPIPOI: A user-friendly analytical tool for the extraction and visualization of temporal parameters from epidemiological time series. BMC Public Health. 2012 Nov 15; 12(1):982. https://doi.org/10.1186/1471-2458-12-982 PMID: 23153033
30. Marten R, Yangchen S, Campbell-Lendrum D, Prats EV, Neira MP, Ghaffar A. Climate change: an urgent priority for health policy and systems research. Health Policy and Planning. 2021 Mar 1; 36 (2):218–20. https://doi.org/10.1093/heapol/czaa165 PMID: 33347561
31. Partners | Columbia Public Health [Internet]. [cited 2023 Feb 5]. Available from: https://www.publichealth.columbia.edu/research/global-consortium-climate-and-health-education/partners.
32. IAI—Inter-American Institute for Global Change Research [Internet]. 2023 [cited 2023 Feb 5]. Available from: https://www.iai.int/en/post/detail/Webinar-on-Climate-and-Health.
33. IRI–International Research Institute for Climate and Society | Public Health [Internet]. [cited 2023 Feb 5]. Available from: https://iri.columbia.edu/our-expertise/public-health/.
34. Columbia University Mailman School of Public Health [Internet]. 2023 [cited 2023 May 18]. Pan American Climate Resilient Health Systems. Available from: https://www.publichealth.columbia.edu/research/centers/global-consortium-climate-health-education/courses/past-courses/pan-american-climate-resilient-health-systems.
35. Climate Change and Health Leaders Fellowship—PAHO/WHO | Pan American Health Organization [Internet]. [cited 2023 Feb 5]. Available from: https://www.paho.org/en/events/climate-change-and-health-leaders-fellowship.
36. Farid M, Keen M, Papaioannou MG, Parry IWH, Pattillo CA, Ter-Martirosyan A. After Paris: Fiscal, Macroeconomic and Financial Implications of Global Climate Change. Staff Discussion Notes [Internet]. 2016 Jan 11 [cited 2023 Feb 1];2016(001). Available from: https://www.elibrary.imf.org/view/journals/006/2016/001/article-A001-en.xml.
37. Roy J, Tschakert P, Waisman H, Halim S, Antwi-Agyei P, Dasgupta P, et al. Sustainable development, poverty eradication and reducing inequalities. In: Global warming of 1.5˚C. An IPCC Special Report. In 2018.
38. DHIS2 [Internet]. [cited 2023 Dec 20]. About DHIS2. Available from: https://dhis2.org/about/.
39. Ryan S.J., Stewart-Ibarra A., Dunbar W., Diaz A., Lowe R., Thomas S.J. Climate health audit tool: regional health audit of climate and vector borne diseases data, Haiti, St. Lucia, Jamaica. University of the West Indies, Mona.; 2020. (Pilot Programme for Climate Resilience (PPCR)).

**40.** Pan American Health Organization. Caribbean Action Plan on Health and Climate Change. 2019. Washington DC.

**41.** CARICOM. Caribbean Cooperation in Health Phase IV (CCH IV): Summary of the Regional Health Framework 2016–2025. [Internet]. 2018. Available from: Available from: https://caricom.org/documents/16429-cch-ivpublication_rev-7_health_sector_development.pdf.

**42.** Global Heat Health Information Network [Internet]. [cited 2023 Dec 20]. Final Report: From the G7 Health Communiqué to Action: Health and Climate—Heat Preparedness through Early Warning Systems. Available from: https://ghhin.org/resources/final-report-from-the-g7-health-communique-to-action-health-and-climate-heat-preparedness-through-early-warning-systems/.

**43.** Organization (WMO) WM. 2023 State of Climate Services: Health [Internet]. [cited 2023 Dec 20]. Available from: https://library.wmo.int/records/item/68500-2023-state-of-climate-services-health.

**44.** Organization WMOH. Climate Services for Health: Improving public health decision-making in a new climate [Internet]. [cited 2023 Dec 20]. Available from: https://library.wmo.int/records/item/41941-climate-services-for-health-improving-public-health-decision-making-in-a-new-climate#.Yr7iM-xBwvo.