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RESEARCH ARTICLE

Improving an integrative framework of health system resilience and climate change: Lessons from Bangladesh and Haiti

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Abstract

The analysis of health system resilience has advanced considerably, yet a wide range of conceptual frameworks continues to be employed. The ClimHB conceptual framework, developed in 2019, combines two influential models: the Levesque model of healthcare access and the DFID's resilience framework. It is designed to examine health system resilience in response to climate-induced events. What sets the ClimHB framework apart is its emphasis on the population as an active participant on the demand side, complementing the supply side represented by healthcare services and providers. The framework is defined by three key dimensions – exposure, sensitivity, adaptive capacity. Its dual focus on demand and supply highlights their dynamic interaction in shaping health system resilience. A workshop and the World Café method refined the ClimHB framework by incorporating empirical data from Haiti and Bangladesh with findings from a literature review. The updated framework offers a dynamic perspective on resilience, focusing on the interconnected nature of its elements to guide decision-making across all levels of health systems. Key enhancements include greater emphasis on contextual factors, highlighting the influence of socio-economic and ecological conditions. It also features strengthened connections between resilience outcomes and contextual variables, improving the understanding of how context affects results. Governance and professional awareness were highlighted as critical elements for improving health system responses, and feedback loops were integrated in the supply side to enhance adaptability and decision-making processes. Empirical studies have demonstrated the ClimHB framework's adaptability and capacity to create synergy between theoretical concepts and practical

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implementation. However, challenges remain in operationalising the framework for policymakers. These challenges highlight the need for further validation of the framework, the development of standardised measures, and a deeper understanding of resilience dynamics. Future research should prioritise the framework's implications for structural management, workforce training, and resource allocation, addressing critical gaps in resilience research.

Author summary

The connections between climate change and population health have been studied extensively. However, in the context of multiple crises such as epidemics and terrorism, researchers are increasingly focused on the capacity of health systems to cope, adapt, and respond effectively. Despite this growing interest, the two fields of climate change and health system resilience remain loosely connected. There is a notable lack of studies that examine how health systems can maintain access to care for populations during climate-related events. One of the main concerns related to climate events is their impact on population (im)mobility, whether sudden or long-term. While clear patterns of "climate migration" may not always be evident, understanding the challenges faced by health systems in the context of climate change requires integrating the (im)mobility of populations. Populations represent the potential users of these systems, and their movement- or lack thereof directly affects healthcare access and delivery. Over the past five years, our international research team has explored these issues using a conceptual framework specifically developed for this study in 2019. Drawing from fieldwork applications in Bangladesh and Haiti, an analysis of the latest scientific literature, and insights from team members, this article introduces an improved version of the analytical framework in 2024. The goal is to explain the rationale behind these enhancements and encourage the scientific community to continue research in this area through this conceptual lens. The next phase will involve applying the framework across diverse contexts and adapting it for use by the public and decision-makers.

Introduction

With the Ebola crisis in Africa and, above all, the global COVID-19 pandemic, analyses of the resilience of health systems have advanced considerably over the last few years [1–5]. These analyses have highlighted the characteristics and factors essential for health systems to cope with crises, adapt, and even transform to maintain access to healthcare for the population [6–8]. While studies have often focused on the tangible aspects of health systems, an increasing number of authors have suggested that power dynamics and stakeholder interactions should not be overlooked in these analyses [9,10]. A recent scoping review has again confirmed our analyses of

the lack of consensus on the definition of resilience [5,7]. Although the scientific community seems to have made progress on the empirical front, we are still far from reaching a consensus and the conceptual maturity essential to any scientific approach. The diversity of the conceptual frameworks used in these studies and the changing nature of the situation suggest that further progress is needed in clarifying our study objectives [1,5,11,12].

The aim of this article is to present the improvements made to our integrative conceptual framework for analysing the resilience of health systems and structures. The ClimHB framework has developed an integrative model of health system resilience, addressing the challenges posed by climate change-induced events and population mobility. This was achieved by combining the Levesque model of healthcare access [13] and the UK Department for International Development's (DFID) conceptualisation of resilience (DFID, 2011). Within this framework, healthcare access is viewed as a critical outcome of health system resilience and a key determinant of population health.

The rationale for an integrative analytical framework

The rationale for our article comes from the observation that in 2019, when we initiated our research, there was a scarcity of analytical frameworks offering a comprehensive and integrative approach to analyse health system resilience in the context of climate change [1,5,9]. Over the past fifteen years, significant advancements have been made in scientific literature concerning both the resilience of health systems and their relevant analytical frameworks [1,7,12], as well as the relationship between climate change and health [14–16]. However, at that time, very few studies had attempted to establish links between these two research areas [17]. Studies on health system resilience often considered climate change primarily in terms of infrastructure adaptation [18,19], with little focus on its impact on population's access to healthcare. Conversely, studies on climate change began to explore population health but often overlooked health systems as one of its determinants [16]. Furthermore, while climate migration receives substantial media attention, its heuristic scope and conceptual relevance are debated, and minimal attention has been given to it in the context of studying health system resilience [17,20]. Our conceptual framework, therefore, aims to consider population (im)mobility as a crucial dimension in healthcare utilisation. Although geographical accessibility has been a longstanding topic discussed in healthcare access literature [13], the issue of (im)mobility in the context of climate change has been largely overlooked. The rationale for our article is thus based on these various needs to enhance our understanding of health system resilience, particularly in the face of climate related challenges and population mobility dynamics.

Taking account of both sides of a health system

Initially conceptualised in 2019 for a grant proposal [17] and later published with the study protocol in 2022 [21], the ClimHB framework introduces a novel approach by incorporating the population as an active participant on the demand-side, alongside the supply-side comprising health services and providers. Within this construct, health systems' demand and supply sides are characterised through the dimensions of exposure and sensitivity, which shape the resilience process in combination with adaptive capacities. This process, in turn, directly influences healthcare access and the population's health status (S1 Fig).

Although the framework was originally designed to study events induced by climate change (such as floods, extreme temperatures, and population mobility, etc.), it also encountered an additional major challenge, the complexity of the COVID-19 pandemic [22].

The challenges of conceptualising the resilience of health systems

Conceptual frameworks serve as a bridge between empirical approaches and the theoretical foundations used to study health systems [23–25]. In health system research, conceptual frameworks can be employed in various ways: *a priori* to structure hypotheses and guide data collection, *a posteriori* to interpret empirical data collected inductively, or a "*bricolage*" approach combining both methods [26].

In this paper, resilience is not considered as a normative concept. Consequently, the ClimHB framework for health system resilience in the context of climate change and population (im)mobilities was designed to encapsulate these complexities, guide our data collection, and summarise our findings in Haiti and Bangladesh to ensure validity and facilitate its applicability. While the details of the original framework's construction and justification are available in the study protocol [21], this paper retains the following definition of health system and structure resilience: "the capacities of a health system and healthcare structure facing shocks, stress or chronic destabilising tensions (unexpected or anticipated, sudden or subtle, internal or external to the system), to absorb, adapt and/or transform to maintain and/or improve universal access to comprehensive, relevant and quality healthcare". The framework places healthcare access as a critical outcome of health system resilience and a key determinant of population health. This focus aligns with the urgent call from the seventy-seventh World Health Assembly "*to make health systems more climate resilient*" [14]. This objective has now become central to the draft of the 'Fourteenth General Programme of Work (GPW 14)' by the WHO for 2025–2028.

Adopting a reflective stance

As the ClimHB project concluded, we utilised a framework analysis approach during the final workshop to critically evaluate and enhance the conceptual model [27]. It is important to note that this analytical framework has been specifically used to study health system resilience, particularly in the context of climate change and population (im)mobilities in Haiti and Bangladesh. The project aimed to achieve two primary objectives: (i) to assess the relative resilience of local health service providers and (ii) to delineate the health status and healthcare access patterns among (im)mobile populations within these diverse environments.

This article does not present the empirical results from these studies, as they are still being analysed. Instead, it offers conceptual insights for refining the framework. Two empirical articles focusing on local contexts, seasonal rural-to-rural migration and mental health issues have already been published, providing a foundation for our analyses [28,29].

The article primarily describes the challenges encountered and perceived by the ClimHB research consortium team in implementing the ClimHB conceptual framework. It highlights the need for its adaptation to better suit practical applications. The revised framework is presented, incorporating emerging research findings from Bangladesh and Haiti and insights gained from interdisciplinary discussion. Finally, the article outlines potential avenues for applying the framework and identifies areas for future research.

Materials and methods

Ethics statement

Ethics approval and inclusivity in global research: Ethics approvals have been granted from the Institutional Review Board (IRB) of the BRAC James P Grant School of Public Health, BRAC University (ref: IRB-19 November'20–050) in Bangladesh and from the National Bioethics Committee in Haiti (ref: 2021–10/2425–3). Information about the study was provided before data collection, written consent was collected, respondents were informed of their right to withdraw at any moment, a debrief with respondents was conducted at the end, and written consent was collected before leaving. However, the data used in this article is not drawn from the field primary data collection authorised by the ethics committees but solely from the collective reflections of all the authors of this article.

A collective reflective approach

This article is one of the few reflective analyses of the use of conceptual frameworks to analyse health systems [5]. Following a preliminary analysis [30], this paper provides a collective reflective analysis [31] to present the outcomes of a group reflection aimed at revising the framework.

A world café workshop

We convened an on-site workshop in November 2023 to enhance the ClimHB project's integrative conceptual framework through collaborative engagement with stakeholders (senior and junior researchers) directly involved in the project's execution and oversight.

The workshop employed the World Café methodology, a participatory technique designed to facilitate open and creative conversations to shape a collective understanding of the subject matter [32]. The workshop was planned by CM, VR, and SM and facilitated by CM. We utilised a framework analysis approach to analyse its results [27]. Posters of the ClimHB framework were displayed on the walls, and participants were provided sticky notes and markers to offer their corrections directly on the printed version (S2 Fig).

Data collection and analysis

We first recorded verbal reactions to the initial framework by prompting participants to empathise with end-users. Participants then identified a component of the framework they considered critical and provided a rationale for their selection. Next, we displayed each framework element (i.e., demand, supply, outcomes) on separate tables, along with key results. We conducted 30-minute rounds of discussion to improve the framework, during which participants placed relevant empirical findings where they fit within the framework and provided suggestions for improvement using sticky notes. The workshop concluded with a plenary session where the modifications proposed by the various sub-groups were collectively reviewed. Consensus was reached on the amendments to be adopted, ensuring that all perspectives were integrated into the revised framework.

To accurately capture data, the workshop was recorded using manual devices and transcribed verbatim using the Otter.ai service. To ensure confidentiality, no personally identifiable information was recorded in the transcription process, resulting in fully anonymised transcripts. CM subsequently reviewed and corrected the transcripts for accuracy (S3 Data).

The conceptual framework underwent refinement through a thematic analysis of workshop transcripts and the visual outputs provided by the participants. Visual aids are often essential for understanding concepts. Dagognet's [33] work highlights the importance of visual representation in constructing knowledge. It's noteworthy that the initial version of the framework was developed through collaboration between researchers and specialised scientific graphic design firm (Agence IMPAKT Scientifik, https://www.impaktsci.co).

This analysis used a deductive approach to identify required changes in the existing dimensions and links or to pinpoint missing elements. This was supplemented by an inductive approach aimed at uncovering research gaps mentioned by the participants. Representative quotations from the transcripts are incorporated into the results section to substantiate the modifications made to the framework.

Once all the data had been analysed and a first draft of the article had been produced, YL and VR conducted a literature review focusing on the elements that would strengthen the argument and suggest further improvements. Finally, all the article's authors reviewed the paper and provided feedback on how to improve it.

Results

Participants

Twelve people participated in the workshop. Attendees included four members from the Paris-based coordination and research team, two representatives from the research team in Haiti, three from the research team in Bangladesh, and three external collaborators.

Box 1. Presents the challenges in understanding and applying the ClimHB conceptual framework.

- ClimHB framework's potential users:
  - Policymakers
  - Researchers
  - Educators
  - Healthcare providers
  - Study participants
- Challenges in application:
  - Overly complex for policymakers needing quick, actionable insights
  - Lack of clarity and explicit articulation of components
  - Failure to establish several connections necessary for a comprehensive understanding of health system resilience
  - Framework perceived differently depending on the user's perspective and needs
  - The concepts and complexity of the framework may require a level of literacy and scientific knowledge that is not readily accessible to the study participants

Potential users and refinements

Research teams in Haiti and Bangladesh were the primary users of the ClimHB conceptual framework. During our final workshop, we identified several stakeholders who could benefit from using the ClimHB conceptual framework. These included policymakers, researchers, educators, healthcare providers, and study participants. However, after considering the perspectives of its potential users and uses, it became evident that the ClimHB framework required refinement. Specifically, the conceptual framework appeared overly complex for policymakers who require a quick understanding of actionable areas and the identification of pertinent actors, facilitators, and barriers in decision-making processes.

Similarly, depending on its use, it appeared overly intricate or incomplete for students and researchers. While regarded as a "good summary", the conceptual framework failed to establish several connections between domains necessary for a comprehensive understanding of health systems resilience. The section related to the latter prompted confusion among participants due to a lack of clarity and insufficient articulation of its components.

The new framework

Below, we describe the revised ClimHB conceptual framework (Fig 1), its components, and the changes we made to them. It is aimed primarily at an academic audience that is relatively well-acquainted with the concepts addressed. Further efforts are ongoing to facilitate knowledge transfer so that the framework can be adapted and made accessible for a wider audience, particularly decision-makers and health professionals.

A key feature of the ClimHB framework is its visual representation of the population as an integral component of the health system - i.e., the demand side – positioned alongside and interacting/interdependencies with health services and providers - i.e., the supply side. Together, these two sides encompass all dimensions of the health system, shaping access to care. In this synergistic model, the demand and supply sides are conceptualised as reflective entities,

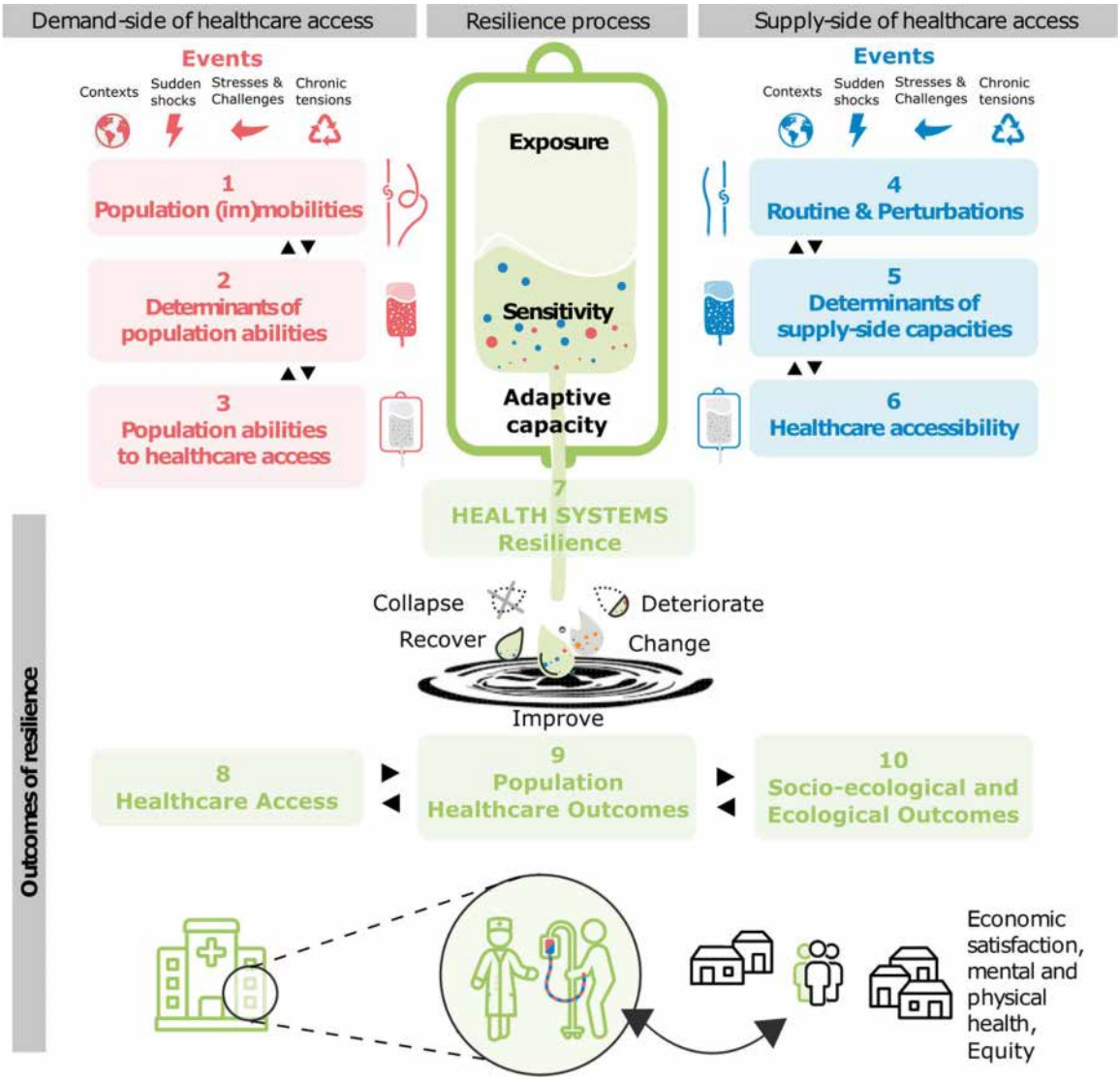

Fig 1. Revised ClimHB integrative conceptual framework. In our conceptual model, access to healthcare is achieved when the health services available (supply-side) meet the population's needs (demand-side). However, in a context where climate change may lead to disruptive events on both the demand and the supply sides, health systems will change (collapse, deteriorate, recover, improve) through a process of resilience influenced by their exposure, sensitivity, and capacity to adapt. It follows that health system resilience will impact access to care, population health, and socio-ecological outcomes. Finally, it is essential to note that population health is not solely linked to the health system; other factors outside it also shape population health.

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underscoring their equal contribution to the health system's resilience. The two sides mirror each other to highlight their similarity in their contribution to the resilience process. At the center of Fig 1, the process of resilience and its impacts on the health system or health facilities is represented using the image of a transfusion bag. This visual metaphor depicts a fluid – comprised of a mixture of exposure and sensitivity (containing elements of both demand and supply side access) - is flowing through the system. While acknowledging that other social determinants also affect these outcomes, these have not been visually represented in the figure. This decision was made to avoid overloading the visual and maintain clarity by focusing solely on outcomes directly associated with the health system.

Health system resilience

The resilience of the health system, depicted in green, is the combination of the demand side (red) and the supply side (blue) of healthcare access, spanning across exposure, sensitivity, and adaptive capacities (also represented in green). The interplay between these attributes—where adaptive capacities are influenced by the nature and magnitude of exposure and sensitivity—determines the health system's ability to respond to disruptions. Exposure refers to "the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected" [34]. It can be measured as an "assessment of the magnitude or/and frequency" of "disturbing" events [35]. Sensitivity is the degree to which a system will/might be affected by or respond to a disturbing event [35], such as climate change or variability [34]. Adaptive capacities and abilities are determined by the abilities of systems, institutions, humans and other organisms to adjust to potential damage, take advantage of opportunities, or respond to consequences [34]. This includes actors' abilities "to anticipate, plan, react to, and learn from events" [35]. The system's capacity to handle all types of disturbances depends on these three dimensions, exposure, sensitivity, and adaptive capacities, with adaptive capacities interacting with the nature and degree of exposure and sensitivity.

Figs 2 and 3 detail the components of the health system's demand and supply sides and illustrate how they affect and contribute to its resilience.

Framework's dimensions in detail

In the following, we present the framework's dimensions in more detail, as outlined in the previously published protocol [21].

(1) Population (im)mobilities refer to a) all mobilities, from daily movements to displacement or long-term migration, and b) all situations of immobility, whether involuntary or voluntary. Mobility is represented by the red tube/line, while

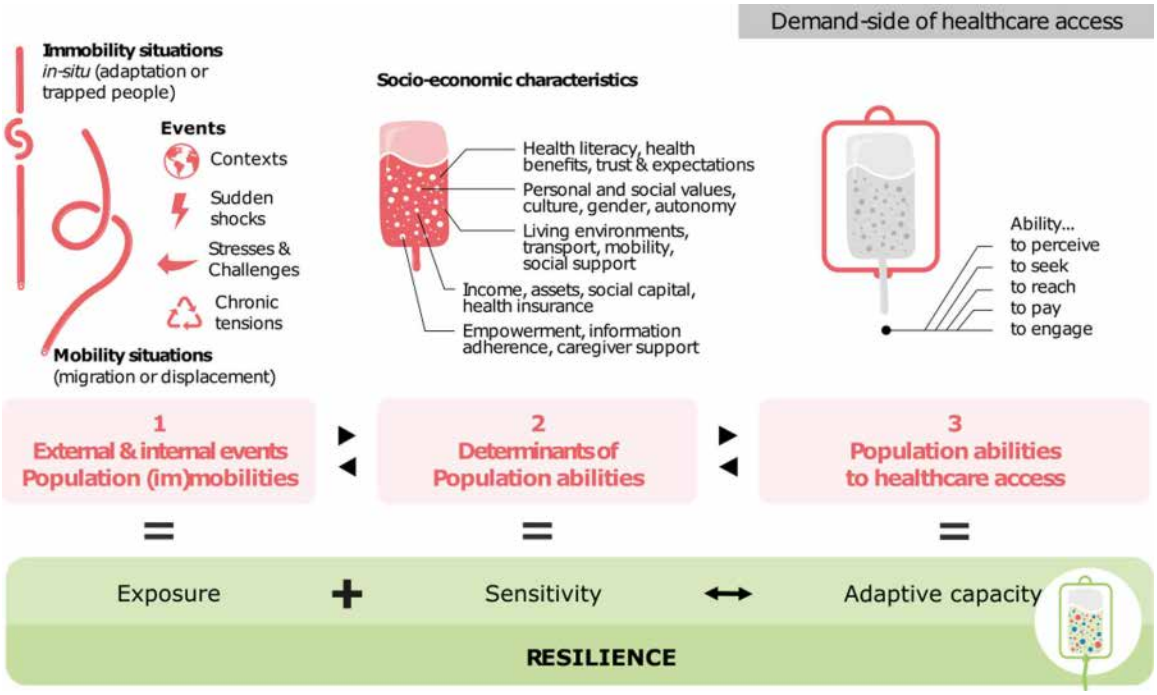

Fig 2. Demand-side of healthcare access and health system resilience in the context of climate change and population (im)mobilities.

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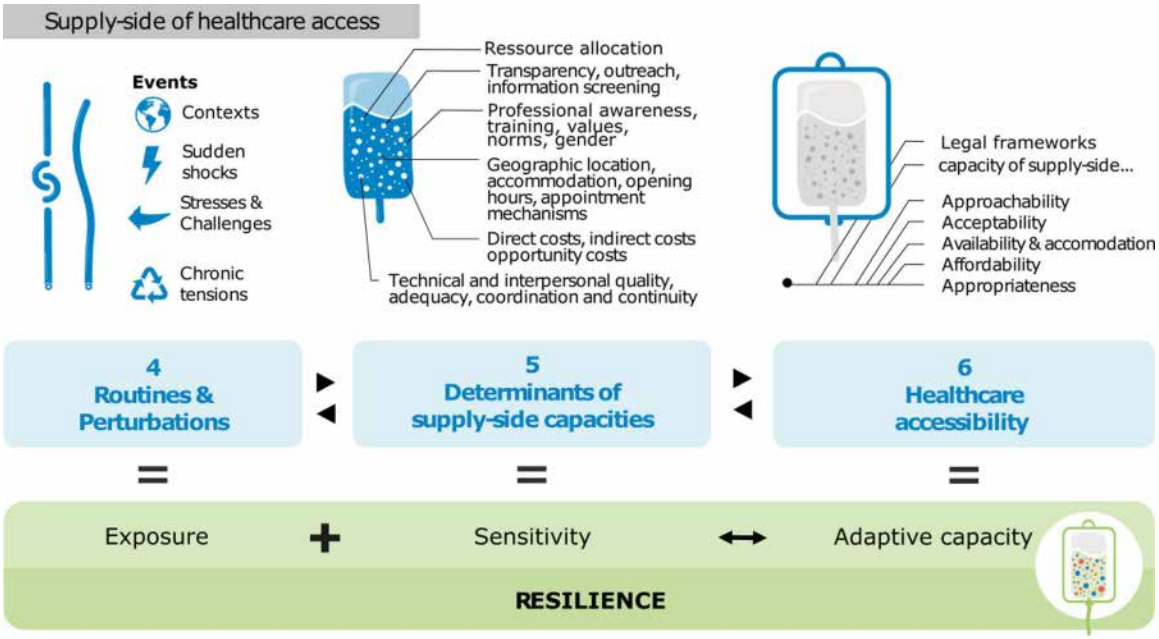

Fig 3. Supply-side of healthcare access and health system resilience in the context of climate change and (im)mobilities.

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immobility is depicted by the red tube with a knot. The four symbols above represent all events disrupting the determinants of population abilities and healthcare access abilities, such as contexts (political, e.g., elections, geographical, e.g., as distance or mountains, economic, e.g., as price fluctuations), sudden shocks (or sudden events), stresses (long-term trends), challenges, and chronic tensions (regular challenges: e.g., unplanned births or deaths, shortages of medicines, difficulty in retaining staff in rural areas) affecting both the supply and/or the demand sides. As the ClimHB project focuses on the context of climate change and population mobilities and (im)mobilities, which may influence other determinants, (im)mobility was selected from Levesque's list of determinants and included in (1.) with a focus on migratory status, in interaction with shocks and events. Due to the numerous categories of mobilities that might interact with each other, "(im)mobility" was also retained in the determinants (2.), with a focus on physical capacities (ability to move or stay).

(2) Determinants of population abilities include all socio-economic characteristics of individuals and their communities, ranging from empowerment to various forms of capital and health literacy, represented by the red fluid.

(3) Population abilities to access healthcare encompass the five dimensions of access, capturing the demand-side determinants (cited in 2.): the abilities to perceive, seek, reach, pay, and engage, represented by the red bag (tube and fluid).

Population (im)mobilities, population abilities, and population abilities to access healthcare (1., 2., and 3.) are presented linearly due to the 2D format but are interconnected in 3D space; i.e., population abilities to access healthcare might be influenced by, and might influence, both population abilities and population (im)mobilities. Events may (or may not) impact mobilities and population abilities.

(4) Routines and Perturbations: Routines are regularly organised activities that tend to continue over time [36]. Perturbations are events that disrupt or have the potential to disrupt the supply side's normal functioning, routines and habits

(healthcare services and providers), represented by the four symbols above. These include sudden shocks, stresses, challenges, and chronic tensions, which may stem from climate changes and population (im)mobilities, among other events. The straight blue tube represents the usual functioning (routine) of healthcare access from the supply side, whilst the second blue tube (with a knot) represents perturbations.

(5) Determinants of supply-side capacities: These include all characteristics impacted by or resulting (or not) from changes following the events, such as the building blocks, hardware, and software of a health system, or from information screening to transparency outreach as defined by Levesque [13,37]. The determinants are represented by the blue fluid.

(6) Healthcare accessibility: This encompasses the five dimensions of service accessibility, capturing the supply-side determinants (the health system dimensions in 5.): approachability, acceptability, availability and accommodation, affordability, and appropriateness.

Routines and perturbations, health system dimensions, and healthcare accessibility (4., 5., 6.) are also presented linearly here. However, they are interconnected and non-linear over time, i.e., routines and perturbations impact the determinants of supply-side capacities, which, in turn, interact with healthcare accessibility.

(7) Resilience: Health system resilience is characterised by assessing its outcomes, which depend on exposure, sensitivity, and adaptive capacities. Healthcare access (8.), which might collapse, recover, deteriorate, or improve compared to the usual trend (state and dynamic, without effects from disturbing events); Population health outcomes (9.), are considered the ultimate indicator of system and structural resilience and are a key result of healthcare access; and socio-ecological outcomes (10.). Other determinants of healthcare access are represented in grey (Fig 4).

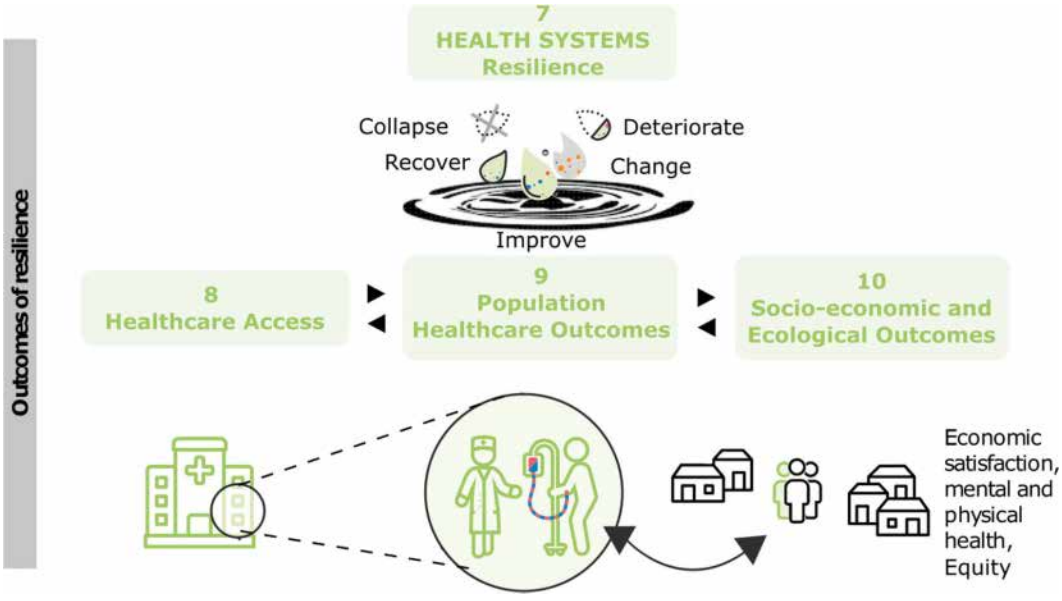

Fig 4. Resilience and outcome of resilience of healthcare access and health system resilience in the context of climate change and (im) mobilities.

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Box 2. Presents the summary of changes in the ClimHB conceptual framework.

- Incorporated contextual factors—political, social, economic and ecological
- Established a clear parallelism between the demand (population) and supply (provider) aspects
- Refined the conceptual model to better articulate the interplay between exposure and sensitivity
- Emphasised temporal and dynamic aspects using a water ripple metaphor
- Expanded the model to include 'Change'
- Integrated socio-economic and ecological outcomes
- Highlighted the symbiotic relationship between various outcomes
- Incorporated the principle of 'Equity'
- Integrated governance, resource allocation, and legal framework on the supply-side

Improved design clarity

To improve design clarity, we integrated resilience dimensions by establishing a clear parallel between the global framework's demand (populations) and supply (providers) aspects. This was achieved by horizontally aligning corresponding terms and centralising related icons to represent their interconnectivity visually. Exposure was defined as a function of events combined with dimension 1 or 4; sensitivity as influenced by dimensions 2 and 5; and adaptive capacity as determined by dimensions 3 and 6. The conceptual model was further refined to better articulate the interplay between exposure and sensitivity, which are now encapsulated within a 'bag' metaphor, to signifying their interaction. This combined entity subsequently interacts with adaptive capacity, strategically positioned to symbolise the system's threshold for resistance and elasticity. Improving the clarity of the design was essential, particularly in presenting a clear separation between each determinant to enhance understanding (S4 Data).

Contextual factors

We integrated contextual factors, including political, social, and economic dimensions, into the range of events that impact exposure on both the demand and supply sides. This integration was directly informed by findings from Haiti and Bangladesh and corroborated by verbatim statements during the workshop (S2 Data). For example, in Haiti, scarcity and inflation in gas prices created significant challenges for patients and healthcare providers in accessing healthcare facilities. Similarly, findings in Bangladesh highlighted that waterlogging had analogous effects.

Resilience dynamic and temporal aspect

The water ripple metaphor effectively illustrates health system resilience's temporal and dynamic dimensions. This metaphor demonstrates how effects propagate over time and how specific stressors cyclically impact (feedback loops) impacts the health system's condition, influencing its response to future challenges. Our findings demonstrate that the health system's condition at a given point directly impacts its ability to recover or adapt. The model was enhanced by incorporating "change" as a fundamental aspect of health system outcomes. This aligns with recent experiences during the COVID-19 pandemic, where some hospitals returned to pre-existing state of insufficient resources (S4 Data), and therefore abnormal [3,38]. Additionally, we underscored the value of case studies in elucidating the implications of recovery and transformation within local, regional, and national contexts. Despite being connected to the WHO Operational Framework for building

climate-resilient health systems [19], we emphasise that more work is needed to illustrate these temporal and dynamic dimensions for health systems resilience (S4 Data).

Reinforcing the link between outcomes

In the initial framework (S1 Fig), the connections between the various categories of health system resilience outcomes, namely healthcare access and population health, were unclear. After a collective reflection during our workshop, we clarified the hierarchy among health system resilience outcomes by positioning it above the others. We then realigned the other dimensions of outcomes and introduced bidirectional arrows to highlight their interrelatedness (S4 Data).

Feedback loop between determinants and supply-side routines

Our findings from Haiti and Bangladesh suggest that specific supply-side determinants, such as healthcare professionals' awareness of climate-induced events or (im)mobilities, can directly influence them (S4 Data). To reflect this, we incorporated a looping arrow to depict the feedback loop between the determinants of the supply side (5) and routines and perturbations (4).

Governance aspects on the supply-side

Upon reflecting on the conceptual framework's various applications and uses, workshop participants identified its potential applicability across different levels of the health system (S4 Data). Consequently, governance was emphasised as a critical determinant of the supply side. Climate change impacts on health system resilience will require health systems to mobilise all actors and enhance collaboration across all levels of governance [39]. Recent studies underscore the importance of good governance, strategic planning, and stakeholder collaboration in building climate-resilient health systems [40].

On the demand side, governance structures significantly influence population behaviours. Public trust in government is essential for adherence to health guidelines, legitimising decisions, and ensuring effective crisis management. Evidence from the Ebola outbreak and COVID-19 shows that higher public trust results in better compliance and health outcomes, while distrust hampers public health responses [41]. Distrusting attitudes often stem from a lack of trust in the government and its institutions and are often associated with refusing medical care [41]. Therefore, good supply-side governance directly shapes the demand-side response by influencing whether individuals seek healthcare services. Additionally, it is evident that the governance of sectors other than healthcare (e.g., water and land management) also impacts health system governance, including population and healthcare providers.

Awareness and training of healthcare professionals

Our findings from Haiti and Bangladesh reveal that the training and awareness of healthcare professionals regarding climate change and (im)mobilities significantly impact their sensitivity to events affecting their patients, communities, and the health facilities where they operate (S4 Data). These insights were deliberated during the workshop, prompting us to incorporate them as integral components of the sensitivity dimension within the conceptual framework.

Integration of socio-ecological outcomes

We acknowledge the intricate nature of complex adaptive systems such as climate change, health systems, and socio-ecological systems [5,42,43]. This is why the ClimHB framework allows the integration of other conceptual approaches, as we did with the socio-ecological approach [28] based on complex adaptive systems and the configuration approach [29,44]. However, fully capturing the interplay of these dynamics within a two-dimensional representation that fits into a A4 format is unrealistic due to the non-linear interactions involved [45]. Despite this limitation, there was

consensus during our discussions on incorporating these interactions as a critical health resilience outcome (S4 Data). For instance, zoonotic diseases are a fundamental example illustrating the interconnectedness between human population health and the health of ecological ecosystems.

Community engagement

Involving communities in active decision-making alongside decision-makers is integral to strengthening health systems [46], as it builds trust and ensures equity [47]. The ClimHB framework differs from other health system resilience frameworks as it is a synergistic model that mirrors the population (demand side) across the healthcare services/providers (supply side) and reflecting their active contribution to the resilience process of a health system. By engaging communities as active partners rather than mere recipients of health services, it can better address the tailored needs of communities, leading to improved health outcomes and overall health system strengthening [46]. Community engagement is a critical component of "adaptive capacity" within the ClimHB conceptual framework. "Adaptive capacities and abilities are defined as the abilities of systems, institutions, humans, communities, and other organisms to adjust to potential damage, take advantage of opportunities, or respond to consequences" [34], enabling actors to anticipate, plan, react to, and learn from events. This definition includes the capacity of communities to actively engage in planning, implementing, and monitoring context-specific adaptation measures. According to Schwedtle et al [48], community engagement is often underrepresented in existing climate-resilient health system frameworks. However, the literature highlights community engagement as a crucial element for building climate-resilient health system frameworks [49]: "Building the climate resilience of communities has the potential to reduce the demand on health systems." By participating in context-specific adaptation measures, communities contribute significantly by raising awareness, promoting education and developing community-based health programmes and services [48] as well as the resilience of health systems, as recently demonstrated in the Eastern Democratic Republic of the Congo [50].

Climate-specific health literacy

Despite scientific evidence linking climate change and human health, the concept of climate health literacy remains poorly understood by the general public and many health professionals [52]. Limited data and information have been collected regarding climate health literacy in less developed regions [53]. The literature reveals that while a blueprint for climate and health literacy exists, its applicability in low-to-middle-income countries remains uncertain [52], highlighting the need for much more targeted research and developing a standardised assessment tool to measure climate health literacy [51].

The ClimHB framework recognises climate-specific health literacy as a concept transcending the dichotomy between demand (population) and supply (healthcare sector). This perspective highlights the importance of climate health literacy in building a resilient and climate-adaptive global society. Although our initial assessment of the ClimHB framework did not deeply explore this element, its vital importance is acknowledged, and further research on this topic is strongly encouraged.

The ClimHB framework views climate-specific health literacy not merely as an aspect of either the population (demand) or healthcare sector (supply), but as a concept encompassing our entire global society and decision-makers. This comprehensive perspective ensures that the literacy of the general population and health professionals is integral to the framework's approach. This emphasis is reflected in the ClimHB framework's components (2) Population and (5) Healthcare sector.

Potential application of the framework

As mentioned, various stakeholders can benefit from using the ClimHB conceptual framework including policymakers, researchers, educators, healthcare providers, and study participants. However, this article is aimed primarily at an

academic audience, and we will continue our efforts to make it accessible to a wider public. Below, we outline two types of potential applications based on the evidence we collected in Haiti and Bangladesh. Therefore, this final section of the paper describes how we believe the framework could be applied and strengthened. We hope that this proposal can be taken up in future research on the resilience of health systems.

Facilitating decision-making

One significant finding from our discussions is that this framework can be interpreted across various levels of health systems. On one hand, employing this framework can unveil the roles of different actors at different levels in relation to resilience. On the other hand, customising it for these specific actors can streamline their decision-making processes or inform policy design. Below is an example of a framework adapted for the supply-side of healthcare (Fig 5).

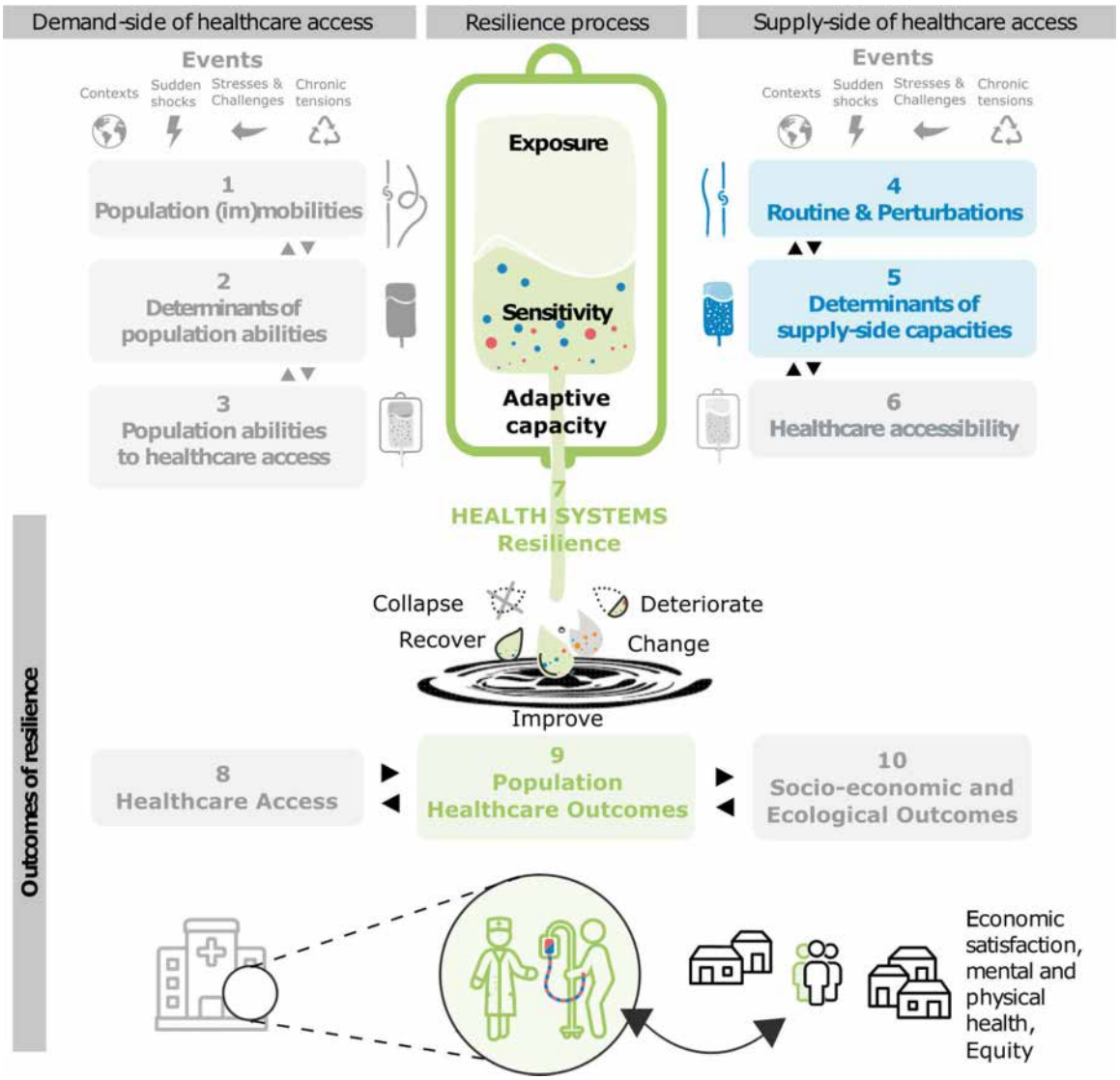

Fig 5. ClimHB conceptual framework adapted to healthcare providers. Coloured elements are areas they can act upon or are affected by.

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"And I was trying to focus on whether we understand what the people's determinants are. You know, their abilities to have access to health? It's not very clear. And I think this is one thing that might be missing. How to understand and make it clear to the policymakers that there is more to investigate about the people's capacities to access health. Do they understand they have to have access; do they understand they have the right to it, and all that? I think a few things are missing. It's not only about money, but also more than that—it's about the education aspect as well."

Country case study: Illustrating health system resilience

One advantage of the ClimHB conceptual framework is its ability to systematically explain resilience across different scales, including national, regional, and local health systems or structures. It helps identify what research or information systems capture regarding demand, supply, and health system resilience and highlights data gaps that need to be addressed. Below, we present the results from our qualitative study conducted in Bangladesh (Fig 6) and Haiti (Fig 7).

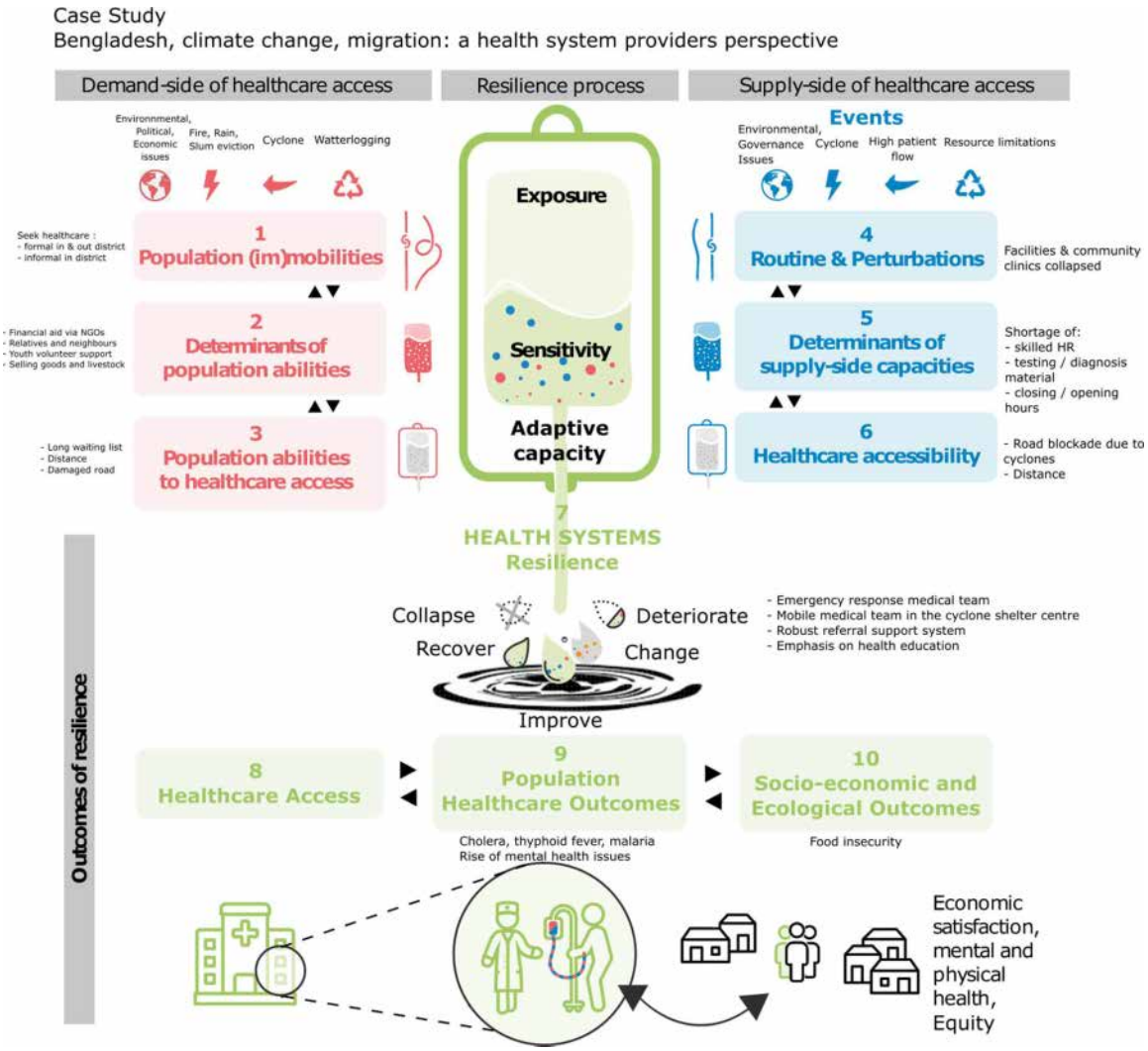

Fig 6. ClimHB conceptual framework adapted to the case study of Bangladesh.

https://doi.org/10.1371/journal.pclm.0000512.g006

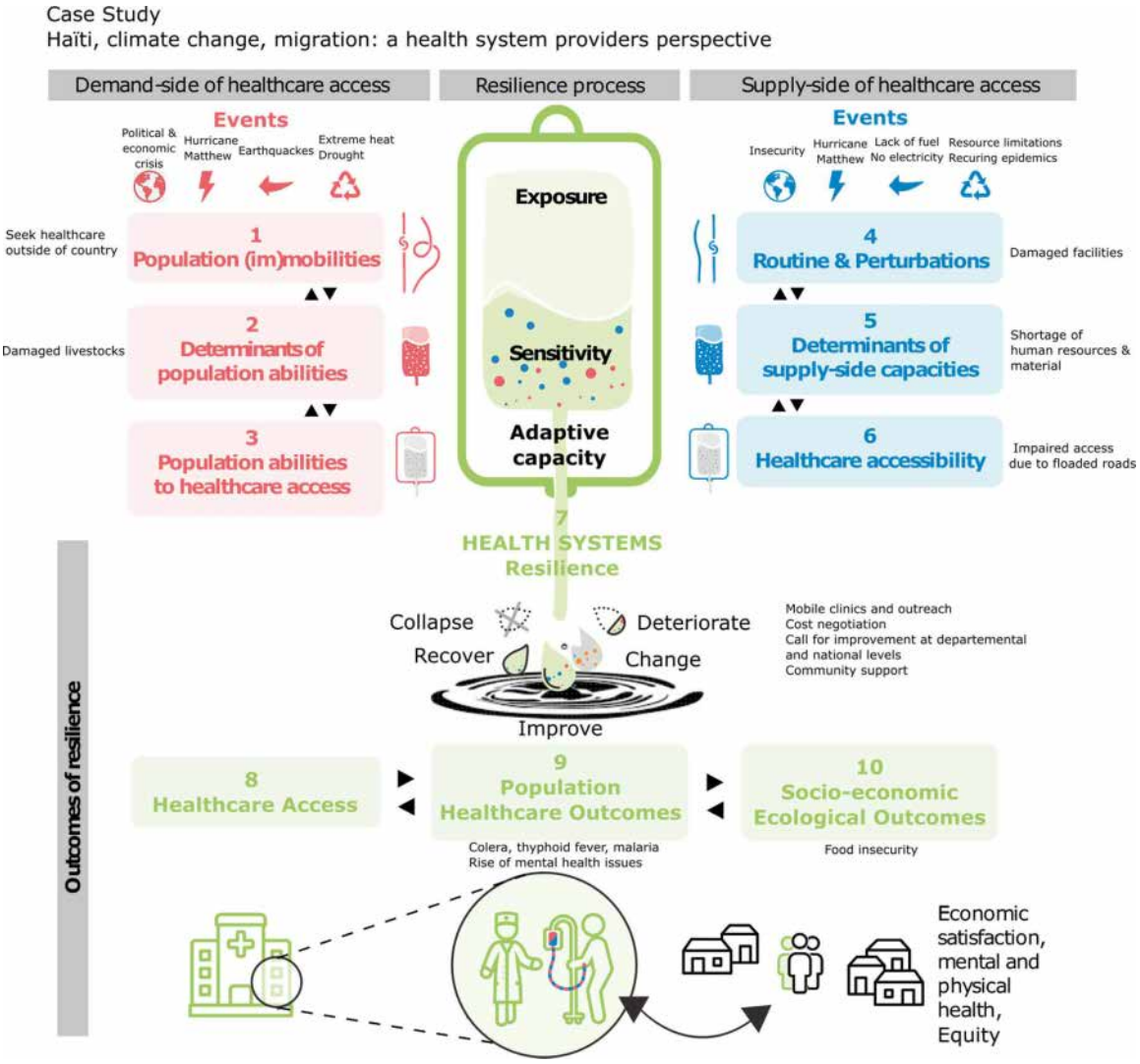

Fig 7. ClimHB conceptual framework adapted to the case study of Haiti.

https://doi.org/10.1371/journal.pclm.0000512.g007

Discussion

Using a framework approach, we enhanced the ClimHB conceptual model. The conceptual framework was refined to incorporate contextual factors, reinforce linkages between outcomes, and integrate socio-ecological outcomes. Governance aspects of the supply side, awareness and training of healthcare professionals, and feedback loops between determinants and routines on the supply side were also emphasised. The revised ClimHB framework now offers a more comprehensive and dynamic depiction of health system resilience, capable of informing decision-making processes and policy design across various health system levels.

Compared to other existing frameworks [2,5,8,19,54–57], the ClimHB framework was designed to enhance health system resilience by integrating climate change-induced events and population (im)mobility impacts. This makes it uniquely suited for regions like Haiti and Bangladesh. Building on the WHO operational framework, which addresses health system components [19] and more recently low-carbon considerations [58], ClimHB specifically incorporates socio-ecological

outcomes and emphasising adaptive capacities, exposure, and sensitivity. It balances both demand (population) and supply (health services) sides. Developed with input from a diverse team of researchers and their various disciplines, the framework is adaptable and context-specific, considering political, social, and economic factors. It also highlights resilience's temporal and dynamic aspects, an element often missing from similar health system analyses [5]. ClimHB's comprehensive framework approach makes it particularly valuable for regions heavily impacted by these factors, complementing existing frameworks. While we are not experts in the complex systems approach, we recognise its importance and have endeavoured to apply it within our conceptual model [9,28,45]. However, further work is required to develop this perspective fully.

The framework's adaptability to portray case studies in Haiti and Bangladesh demonstrates its robustness and highlights the need for further empirical application in other settings. In our research context, this framework proved beneficial in two key aspects. First, its conceptual elements guided the design of more comprehensive qualitative and quantitative data collection tools for assessing the relative resilience of local health service providers and delineating the health status and healthcare access patterns among (im)mobile populations within these diverse environments. Second, the results of our qualitative research revealed the adjustments needed for the framework to be applicable. This created a virtuous circle between theorising and implementing the concept of health system resilience. Furthermore, we demonstrated its potential for adaptation to accommodate the perspectives of key informants, such as healthcare providers. However, ambiguity remains regarding how this framework can be effectively operationalised, particularly among and for policymakers and decision-makers.

We have identified some gaps requiring further research and attention to reduce challenges in operationalising the conceptual framework.

Conceptual challenges

The resilience of health systems is increasingly recognised as a critical component in responding to various challenges, such as climate change, polycrises, and public health crises [8,59,60]. However, resilience has many definitions [1], lacks consensus [4,5,39,61,62], is multidimensional [7,12], and is interpreted differently among stakeholders and professions, depending on the context [63]. This variability complicates efforts to enhance health system resilience and has monitoring, evaluation [7,12,42] and learning [62] implications. Differing definitions can lead to miscommunication, incomplete understanding, and challenges in research mobilisation and policy developments [63]. To operationalise frameworks effectively, concepts must be clear and precise [5,7], ensuring consistent communication and ease of empirical application.

The ClimHB framework emphasises the interconnectedness of factors influencing climate health resilience. The term "polycrisis" has gained prominence in recent discussions, particularly since the global COVID-19 pandemic [42,60,64,65] and is increasingly recognised as a security threat to health systems [66]. Though not yet fully understood, this emerging concept is increasingly becoming recognised by researchers and policymakers. The term "polycrisis" describes the interconnectedness of multiple crises—political issues, climate change, and pandemics—that collectively push global systems out of equilibrium, leading to harmful states [67]. Despite its growing usage, the term remains inconsistently understood, particularly in providing clear guidance for policymakers and national and subnational-level crisis management. As global crises intensify, largely due to the impacts of climate change, it is urgent to place the concept of polycrisis at the forefront of research within the ClimHB framework and other systems-thinking approaches [60]. This will help better understand the causal interactions among different crises, essential for generating actionable insights to address these challenges. While globally articulated, debates continue how to operationalise the concept domestically. Existing crisis management research remains relevant, with polycrisis complementing rather than replacing established practices [60,64].

As this work predates the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) Propeller diagram, which conceptualises risk as a product of hazard + vulnerability + exposure, future research should consider integrating this conceptualisation of risk despite its criticisms [68].

Methodological challenges

The extensive nature of the conceptual framework, encompassing climate change, population dynamics, and health service providers, presented significant challenges in transitioning from conceptualisation to operationalisation for data collection and analysis. Primary data collection spanned from 2022 to 2024, with quantitative data collected once in the summer of 2022. The recall period for the quantitative data was 2017, while inductive qualitative data extended much further back. We also covered several decades of public health reform and climate analyses dating back to the 1980s [69]. Given that resilience is both a mechanism and a product of a mechanism [62], temporality and scale were essential considerations. Analyses are needed to account for varying recall periods, temporalities, and scales, with data collected at the individual, household, community, district, regional, and national levels.

To utilise the conceptual framework effectively, it was broken down into several coherent parts, following the development of sub-questions and hypotheses. Attempting to comprehensively address the entire conceptual framework within a single analytical framework in this exploratory project presented significant challenges. To do so, an analysis plan should be conceived at the outset with an hypothetico-deductive approach, which contrasts with our exploratory approach and sequential design, where each phase informs the next. The nature of the data, the novelty of the sub-studies and the team's skills determined the prioritisation in a very pragmatic manner [70]. We used quantitative and qualitative methods to collect data in the social and health sciences encountering all the typical challenges of mixed-method integration [71]. Climate and environmental data were secondary and were included at a later stage. We had to choose what was most relevant and feasible in line with our research questions, data, and established methodologies to articulate a set of mixed data across disciplines. While mixed methods are frequent in social and health sciences, it was more complex to integrate transdisciplinary data, such as quantitative climate data and qualitative social data.

Another challenge emerged from lacking a universally developed, standardised tool for measuring climate health system resilience [1,55,72]. There is no standardised tool for assessing resilience in health systems, and limited research has been conducted on indicators to measure resilient performance [8,19]. The stakes are high, but so is the complexity of developing such an instrument (if relevant), much like the challenge of creating an index to operationalise the access to care model [37]. Such a tool is crucial for operationalising resilience and presenting it to decision-makers, particularly in the context of climate health resilience. The aim is to develop standardised operational indicators for easy evaluation, moving from conceptual thinking to practical applications to address gaps [73].

Developing a standardised climate health literacy assessment tool is another important area for further refinement. Climate literacy among all health system actors is increasingly recognised as a crucial factor in combating the climate crisis [74], especially since there are currently "little to no assessments on climate change literacy for populations living in lower-to-middle income countries" [75]. Despite growing evidence, this knowledge remains limited among the public and many professionals [52]. Measuring climate health literacy is complex due to varied definitions and contextual factors [76]. Existing health literacy assessment tools, like the WHO's Health Literacy Questionnaire [77], have limitations in capturing the full scope of climate health literacy in this concept, particularly in low-resource settings. Understanding climate change and its health risks is further complicated by cultural background, sociodemographic factors, education level, and residential location. Because climate health literacy can be encompassed by experience, mobility, and community engagement and cannot be easily quantified, it presents challenges when developing an adequate tool to measure the multi-dimensional concept [76]. Climate-specific health literacy among health professionals is crucial for addressing the climate crisis and managing its related impacts [78].

Knowledge transfer

The current conceptual framework may appear overly complex for policymakers who require a quick understanding of actionable areas and the key actors, facilitators, and barriers in decision-making processes.

Fig 8 proposes a simplified framework version to ease use for decision-makers and implementors.

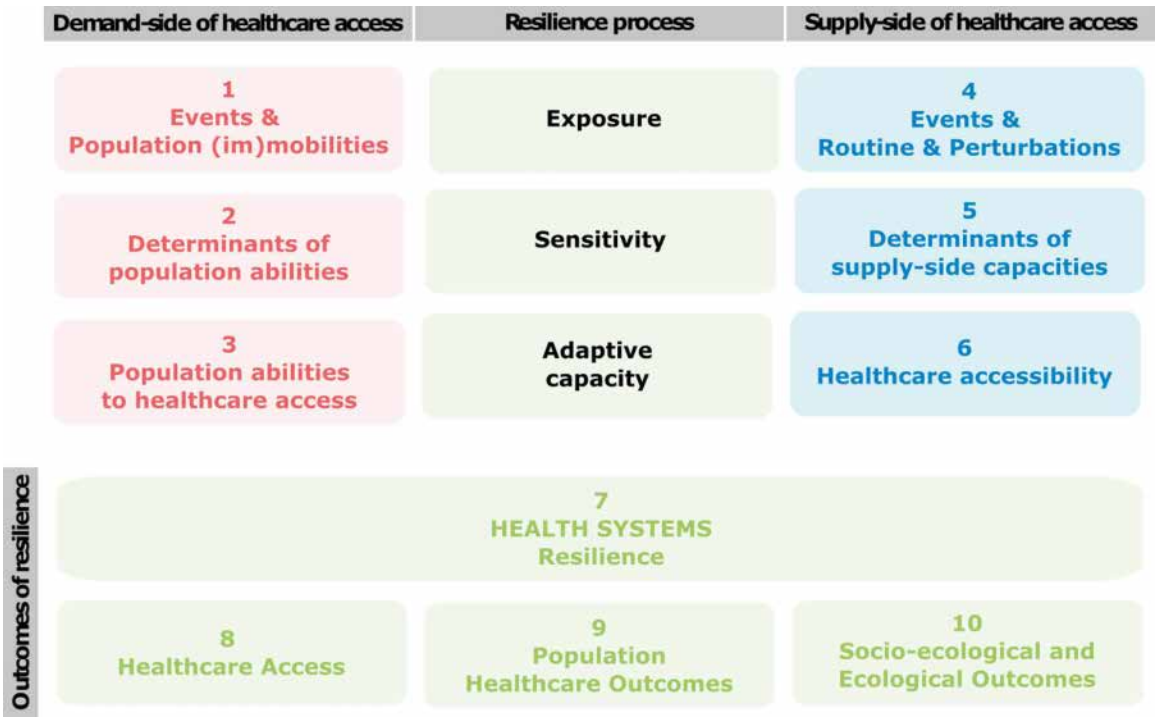

Fig 8. ClimHB simplified conceptual framework. This simplified figure shows, on the same plane, that although their relationships are complex (Fig 1), the 10 dimensions are to be considered to study and strengthen the resilience of a health system facing multiple shocks (1 and 4). It should be noted that resilience is not only a process (exposure, sensitivity, adaptation) but also an outcome (7) aimed at guaranteeing access to healthcare (8).

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As demonstrated in this article, presenting specific parts of the framework, depending on the decision-makers' interests might also be useful. However, simplifying complexity without distorting it is challenging, and constructing a system is already a form of reductionism to build knowledge on complex questions. Effective communication of evidence to policymakers and stakeholders should include concise measures and present evidence quality [79]. Developing a streamlined version of the framework, incorporating insights from researchers, can provide a clear, simplified conceptual framework tailored for decision-making processes [60]. Finally, the relevance of such a framework for future studies could be enhanced by involving decision-makers and study participants at key stages of the framework's development, particularly during post-empirical or restitution stages. This approach would help avoid introducing additional barriers to health literacy and enhance knowledge transfer. However, implementing this involvement is often easier said than done.

Conclusion

Events linked to climate change are indeed exacerbating existing crises, and daily challenges faced by health systems. This reflective article by an international, interdisciplinary team aims to present a framework that could enable us to better understand these complex interrelationships in the context of polycrisis. It is therefore becoming increasingly urgent to study resilience strategies in the face of this polycrisis to guarantee universal access to healthcare [39]. We anticipate this new conceptual framework will support international thinking and, above all, actions to achieve outcome 1.1 proposed by the WHO for its general work programme over the next four years: « *More climate-resilient health systems are addressing health risks and impacts* » [59].

Supporting information

S1 Fig. Initial conceptual framework.
(DOCX)

S2 Fig. Workshop pictures.
(DOCX)

S1 Data. Worldcafe transcript.
(DOCX)

S2 Data. Verbatim statements and thematic.
(DOCX)

S1 Checklist. Inclusivity in Global Research Questionnaire.
(DOCX)

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