PLOS CLIMATE

RESEARCH ARTICLE

Informing adaptation strategy through mapping the dynamics linking climate change, health, and other human systems: Case studies from Georgia, Lebanon, Mozambique and Costa Rica

Giulia Loffreda[1], Ivdity Chikovani[2], Ana O. Mocumbi[3,4], Michele Kosremelli Asmar[5], Laura C. Blanco[6], Liz Grant[7], Alastair Ager[1,8]*

1 Research Unit on Health in Situations of Fragility, Institute for Global Health and Development, Queen Margaret University, Edinburgh, United Kingdom, **2** Curatio International Foundation, Tbilisi, Georgia, **3** Instituto Nacional de Saúde, Marracuene, Mozambique, **4** Universidade Eduardo Mondlane, Maputo, Mozambique, **5** Institut Supérieur de Santé Publique, Saint Joseph University of Beirut, Beirut, Lebanon, **6** School of Economics, Universidad de Costa Rica, San José, Costa Rica, **7** Global Health Academy, University of Edinburgh, Edinburgh, United Kingdom, **8** Department of Population and Family Health, Columbia Mailman School of Public Health, New York, NY, United States of America

* alastair.ager@gmail.com

Citation: Loffreda G, Chikovani I, Mocumbi AO, Asmar MK, Blanco LC, Grant L, et al. (2023) Informing adaptation strategy through mapping the dynamics linking climate change, health, and other human systems: Case studies from Georgia, Lebanon, Mozambique and Costa Rica. PLOS Clim 2(4): e0000184. https://doi.org/10.1371/journal.pclm.0000184

Editor: Shouro Dasgupta, Centro Euro-Mediterraneo sui Cambiamenti Climatici, ITALY

Received: November 12, 2022

Accepted: March 20, 2023

Published: April 19, 2023

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: https://doi.org/10.1371/journal.pclm.0000184

Data Availability Statement: Causal loop diagrams refined during workshop discussion comprise the

Abstract

While scientific research supporting mitigation of further global temperature rise remains a major priority, CoP26 and CoP27 saw increased recognition of the importance of research that informs adaptation to irreversible changes in climate and the increasing threats of extreme weather events. Such work is inevitably and appropriately contextual, but efforts to generalise principles that inform local strategies for adaptation and resilience are likely crucial. Systems approaches are particularly promising in this regard. This study adopted a system dynamics framing to consider linkages between climate change and population health across four low- and middle-income country settings with a view to identifying priority intersectoral adaptation measures in each. On the basis of a focused literature review in each setting, we developed preliminary causal loop diagrams (CLD) addressing dynamics operating in Mozambique, Lebanon, Costa Rica, and Georgia. Participatory workshops in each setting convened technical experts from different disciplines to review and refine this causal loop analysis, and identify key drivers and leverage points for adaptation strategy. While analyses reflected the unique dynamics of each setting, common leverage points were identified across sites. These comprised: i) early warning/preparedness regarding extreme events (thus mitigating risk exposure); ii) adapted agricultural practices (to sustain food security and community livelihoods in changing environmental conditions); iii) urban planning (to strengthen the quality of housing and infrastructure and thus reduce population exposure to risks); iv) health systems resilience (to maintain access to quality healthcare for treatment of disease associated with increased risk exposure and other conditions for which access may be disrupted by extreme events); and v) social security (supporting the livelihoods of vulnerable communities and enabling their access to public services, including

major data source of the study and are included in the submitted manuscript. Search terms and the extraction matrix used for the literature search to develop preliminary causal loop models are included as Supplementary material. Listing of the literature accessed and data extracted are lodged on the QMU eData repository: https://eresearch.qmu.ac.uk/handle/20.500.12289/12889.

Funding: This work was supported by an NIHR grant (16/136/100) to AA (PI) and through a CoP26 International Climate Change Network award by the Royal Society of Edinburgh (RSE) to AA and LG for the work of the Research Unit on Heath in Fragility at Queen Margaret University, Edinburgh. This grant funded GL's role as research coordinator of the project. The funders had no role in 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.

healthcare). System dynamics modelling methods can provide a valuable mechanism for convening actors across multiple sectors to consider the development of adaptation strategies.

Introduction

Of all nations, low- and middle-income countries (LMIC) face the severest consequences of the climate crisis, despite having contributed the least to its occurrence [1, 2]. Climate change significantly threatens the major health gains witnessed across these settings over recent decades. Established direct and indirect pathways of influence [3] include: floods, increasing risk of water-borne disease; diminishing freshwater availability, eroding food security and sanitation; changes in temperature and rainfall impacting habitats and thus the spread of zoonotic and vector-borne disease; air pollution impacting pulmonary health and lung functions; land degradation and deforestation driving food insecurity and undernutrition; and environmental change compromising mental health [4]. Critically, highly inequitable, inefficient, and unsustainable patterns of resource consumption and technological development, together with population growth, exacerbate these risks [5].

Addressing these pathways therefore requires an understanding of their interaction and linkage. Adaptation and resilience measures are actions to accommodate environmental changes anticipated as a result of projected increases in global temperature, complementing mitigation actions seeking to reduce drivers of further temperature increase (centrally through reduction of carbon emissions). Resilience, a crucial theme within environmental research, has also emerged as a central concept in the health systems literature [6]. Reflecting a broader engagement in systems thinking [4, 7], research in this field has come to increasingly focus on identifying system capacities for absorption, adaptation, and transformation developed from system dynamic analyses [8, 9]. In a similar fashion, the planetary health education framework highlights the importance of using system dynamics to understand how different factors interact as part of a complex system [10].

Adaptation and resilience became focal points for CoP26: the Glasgow Climate Pact agreed by 197 countries at its conclusion set out a way forward from the 2015 Paris Agreement, emphasising the urgency of scaling up action and support to enhance adaptive capacity, strengthen resilience and reduce vulnerability [11]. The launch of the Sharm-El-Sheikh Adaptation Agenda at CoP27 then outlined thirty adaptation outcomes which can enhance resilience for up to 4 billion people living in the most climate vulnerable communities by 2030 [12]. Steps were taken to initiate a Loss and Damage Fund to pay for climate related damage for vulnerable nations made increasingly vulnerable because of the rapidity of climate related adverse events, with a Transitional Committee set up to provide recommendations on types of financing, levels of vulnerability and what the fund should cover. Understanding the interconnected nature of loss (and the amplification of different losses, such as economic impacts on the loss of cultural heritage, or habitable land) will require new data and new tools to interpret this. Systems science has strong potential in this regard [5, 7, 10, 13].

This study addressed the linkages between climate change and health, by adopting a case study approach drawing on system science. The aim was to map the complex dynamics between climate change and population health across four settings linked to the Research Unit on Health in Situations of Fragility (RUHF) network [14]. By making more explicit the interrelationships between the factors shaping climate and health in each context the aim was to

identify key entry-points and pathways for targeted adaptation and resilience measures. While other studies have used system dynamics to explore the dynamics of climate change and health, they have used it for specific settings or diseases [13]. To our knowledge, this is the first study to use a comparative case study design across different settings and consider the role of broader socio-political systems in connecting climate events and human health.

Methods

Theoretical framework

The study adopted a socio-ecological and political ecology approach. The emerging field of planetary health reinforces the importance of the interconnections between environmental and human health and the relevance of considering these to formulate feasible solutions to the complex challenges of climate change [10]. We also drew on system thinking to better understand the non-linear relationships that exist among the complex systems under study and to address key adaptation and resilience measures.

Research design

We conducted case studies with partners in four low- and middle-income countries (LMICs): Mozambique, Lebanon, Georgia, and Costa Rica. These four settings each reflect some form of fragility as reflected in current OECD definitions [15], but exhibit diverse geographical, social, and political characteristics and forms of climate vulnerability. We adopted a mixed method approach incorporating a preliminary scoping literature review followed by group-based system dynamic modelling (Fig 1).

Literature review. The search strategy for the preliminary scoping literature review included key terms such as climate change, country name, and adaptation or resilience. We intentionally kept our search approach wide to ensure retrieval of a sample of papers from

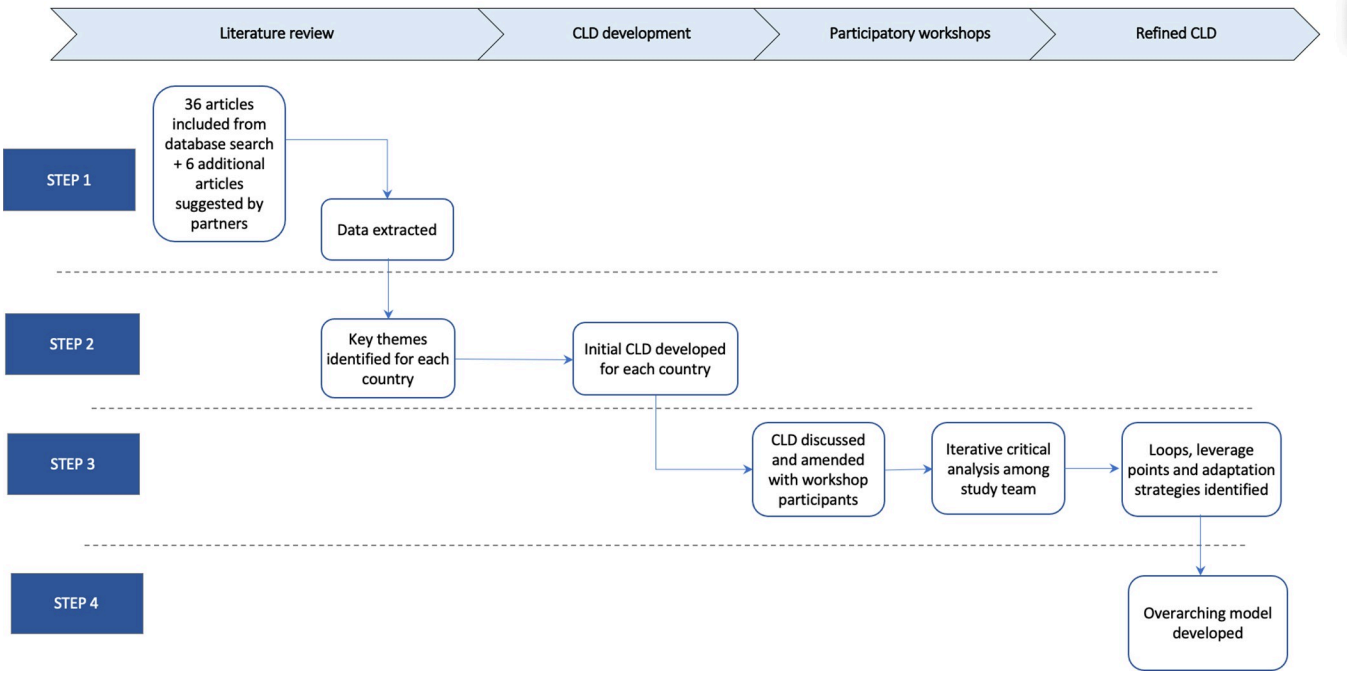

Fig 1. Flow diagram of research process used to develop case studies.

https://doi.org/10.1371/journal.pclm.0000184.g001

different disciplines. No timeframe restrictions were applied. We searched peer-reviewed articles and grey literature both in English and Spanish (for Costa Rica) in the following databases: PubMed/Medline, Google Scholar, WHO IRIS, World Bank. Based on our pre-defined inclusion criteria, we identified 36 papers. An additional six papers were shared by country partners and included for data extraction.

The country specific literature was complemented and triangulated with key references from the global literature to assess accuracy of information on the more general issues. We piloted, revised, and finalised an extraction matrix covering the following information: bibliographic information; socio-ecological factors (such as climate, political, social stressors, human health, animal health) [16]; adaptation and resilience measures proposed; political ecology factors [17]; and other themes such as gender [18].

Participatory workshops and system dynamic modelling. We collated information from this preliminary scoping literature review–separately for each country—using a causal loop seed model (see Fig 2) suggested by the work of Proust and colleagues [13]. This spatially located variables identified in the reviewed literature with respect to three core domains: the state of the earth system; human made influence/activities, and human health/wellbeing. An initial causal loop diagram (CLD) was then elaborated for each country linking geographical, socio-political, health system, disease, and extreme weather event variables on the basis of the evidence presented by the reviewed literature and the research team consultations. CLDs were developed using the software package Vensim MLE.

These CLDs were then refined during online consultations with collaborators in each setting. The consultations involved participatory workshops with health, climate and environment specialists. Each workshop lasted approximately 2.5 hours and was conducted online between July and August 2021. A total of 18 participants took part across the four workshops. Participants, selected using a snowballing approach, were predominantly academics in different fields (climate science, health, forestry, economics etc.) and all based in the countries under study.

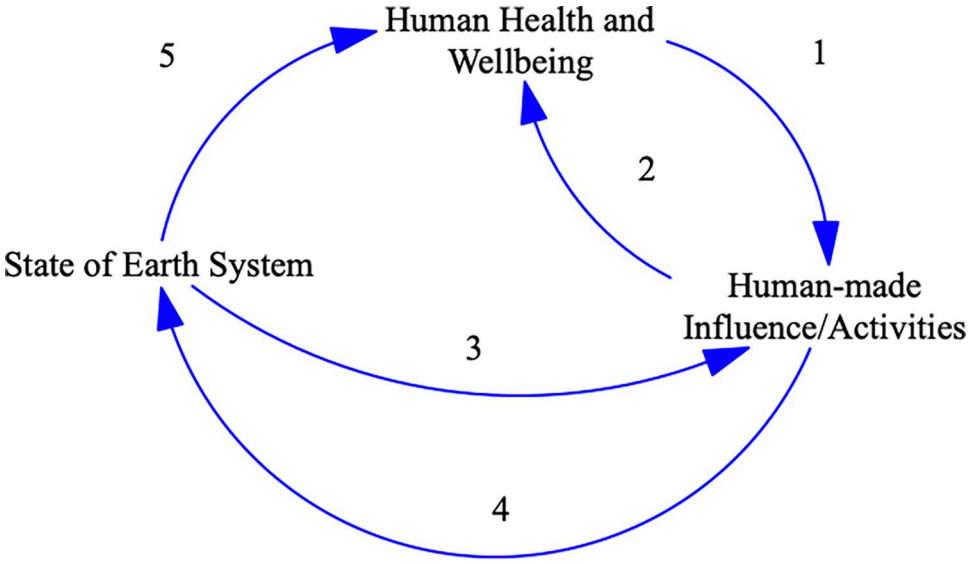

Fig 2. Seed model adopted for the development of causal loop diagrams. Adapted from Proust et al. (2012) showing five key causal linkages between the state of the earth system, human influence and activities and human health and well-being.

https://doi.org/10.1371/journal.pclm.0000184.g002

Workshops involved confirmation of the key variables of relevance and negotiation–on the basis of the local multidisciplinary expertise and evidence available–of the core dynamics linking them. Participants were asked to confirm the relevance of each variable in turn, confirm or revise its pathway of connections and suggest additional variables linked to that pathway [7]. Feedback from participants was integrated into the CLDs in an iterative manner, editing the diagram on screen. While discussions and model development followed the lead of participants (that is, the sequence of addressing variables and the pathways connecting them followed the flow of discussion of system dynamics by the group), it was ensured that all pathways were scrutinised at some stage of the workshop.

Once the CLD reflected the inputs of all participants, the group was invited to indicate potential leverage points for instituting adaptation measures that would impact the dynamics mapped for their setting [13]. The implications for national and local adaptation strategies were then discussed.

On the completion of each workshop the CLD was finalised by the research team, utilising a recording of the session to ensure that it reliably reflected the analysis of the group in terms of the directionality of connections and their polarity (i.e. whether they acted to increase or decrease the value of a connected variable) [7, 13].

Finally, after all four workshops were completed, researchers present at each conducted an integrative analysis, comparing the four models to identify common features and potential synergies regarding adaptation strategy. This analysis was shared and revised with input from the full research team.

Ethics. Ethical approval for the research was granted through the Research Ethics Panel at Queen Margaret University (QMU).

Results

We discuss each country case study in turn by providing a brief introduction to the setting and then presenting the emerging themes from the analysis, including adaptation strategies prioritized. We then present an integrative analysis noting commonalities in the dynamics observed across the four settings.

Georgia case study

Country profile. Georgia is a post-Soviet upper-middle-income country located in the South Caucasus, a region characterised by instability and economic challenges [19, 20]. It is rated as moderately fragile on the Fragile State Index (FSI) [21], with progressive erosion of state legitimacy and aspects of community cohesion. The country borders Armenia and Azerbaijan (now in conflict over the disputed region of Nagorno-Karabakh), Turkey and Russia. Armed conflict in 1990 in Tskhinvali region and Abkhazia, a history of civil war, rapid marketization and hyperinflation following independence from the Soviet Union in 1991, have left Georgia in a state of economic collapse [22]. Since 1994, policy reforms and economic growth have improved the economic situation in the country [23]; however, signs of economic stress were again observed in 2008 due to the conflict between Georgia and Russia over Tskhinvali region. While recent decades have witnessed rapid economic development, socio-economic inequalities continue to pose a challenge, with one-fifth of the population living in relative poverty.

The country's disease profile is dominated by non-communicable diseases (NCD) which account for over 97% of all deaths and comprise 9 out of 10 conditions presenting for care, with significant prevalence of circulatory diseases, cancer, diabetes and respiratory diseases [22]. While Georgia has made progress on a number of indicators, such as maternal and infant

mortality, others remain above the regional average, with multi-drug resistant tuberculous (TB) a continuing threat and an increasing incidence of HIV.

Since 2013 the government increased public spending on health to reduce financial barriers to access and use of services. As a result, the share of out-of-pocket payment in current spending on health reduced to 48% in 2018. However public spending on health remains low (2.8% of GDP) and degree of financial hardship (impoverishing and catastrophic health spending) is among the highest in the European region [24].

Topographically, Georgia is characterized by the Great Caucasus Mountains in the north and the Lesser Caucasus in the south. Georgia has many natural resources and is highly dependent upon tourism, both of which are highly vulnerable to climate variability and change [25]. Almost half of the population lives in rural areas. In 2015, Georgia submitted its Nationally Determined Contribution (NDC) and has pledged to reduce its Green House Gas (GHG) emissions by 15% by 2030. Georgia's National Adaptation Plan [26] includes the healthcare sector, although a lack of data is viewed as constraining progress in implementation. Georgia's 2030 Climate Change Strategy and Action Plan [27] explicitly seeks to integrate healthcare needs into climate change adaptation and mitigation strategy. It highlights a number of respiratory conditions (e.g. chronic obstructive pulmonary disease and asthma) clearly associated with climate change and high greenhouse gas emissions. Cases of infectious and parasitic diseases also doubled between 2008 and 2017, with the influence of changing climate again implicated.

Emerging themes and strategies. Workshop participants highlighted several dynamics characterising climate impact in the country (see Fig 3). One related to air pollution and climate change and how they influence each other through complex interactions in the atmosphere and their consequences on health. Air pollution has been directly associated with cardiovascular and pulmonary related health issues. This has received political attention and is being recognised as a research priority with health impact assessments now underway.

Heatwaves are becoming more common in the country and are associated with increased mortality due to cerebrovascular events, dehydration, and other health problems. Heatwaves additionally burden health services through increased strain on water, energy, and transportation resources. High temperatures also raise the levels of ozone and other pollutants in the air that exacerbate cardiovascular and respiratory disease. Food and livelihood security is also be impacted when people lose their crops or livestock due to extreme heat.

Extreme weather events (such as floods) are causing coastal erosion, which impacts the livelihoods and mental health of people living in coastal areas; coastal erosion has also led to the displacement of communities. Despite most of the Georgian population having access to improved water supplies, participants added an additional pathway in relation to the availability of water resources and sanitation, potentially at risk with projected increases in extreme weather events. For many of these pathways of impact it was observed that risks fell disproportionally on lower-income households, and act to increase socio-economic and health inequalities in the country.

In terms of adaptation, capacity building was considered to be a key requirement. In the health sector, one participant highlighted the importance of planetary health advocacy targeted to medical students and health professionals. Setting up multi-sectoral collaborations and a 'whole-of-society-approach' was viewed as essential for political progress on, and effective implementation of, adaptation strategies. To achieve this necessary coordination across actors and stakeholders in tackling climate change networks or institutions needed to be established connecting civil society, non-governmental organisations and academics. In terms of practical measures to strengthen resilience, discussion focused on the establishment of alerts and early warning systems to protect populations from the risks of floods and poor air quality.

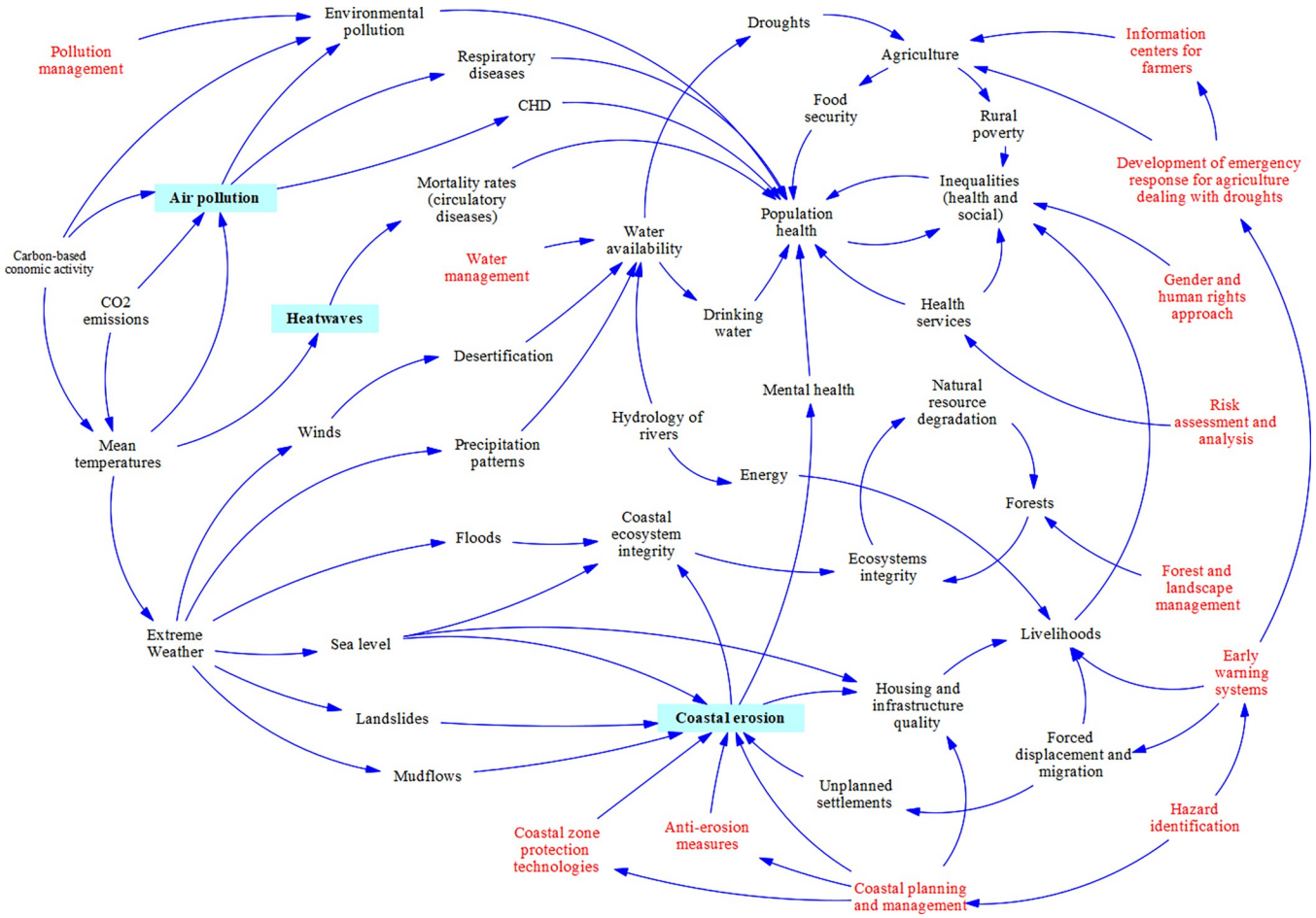

Fig 3. Georgia causal loop analysis. Key pathways exacerbating threat considered in the workshop flagged in light blue; potential foci of adaptation and resilience shown in red.

https://doi.org/10.1371/journal.pclm.0000184.g003

Mozambique case study

Country profile. Mozambique is located in sub-Saharan Africa, a region exposed to generally high levels of economic and environmental risk. The OECD formally classifies Mozambique as fragile, with several dimensions of fragility flagging concern, including environmental risk [15]. Following independence from Portugal in 1975, Mozambique experienced a long-lasting civil war which damaged the country's infrastructure and institutions, severely limiting the state's capacity to provide essential services [28]. The country faces many development challenges, including widespread poverty, low life expectancy, and wide gaps in educational achievement. Provision of social sector services is heavily dependent upon donor contributions, which have prevented greater deterioration of wellbeing of vulnerable groups [29].

Despite sustained economic growth and improvements in socio-economic indicators in recent years, Mozambique is still one of the poorest countries in the world [30]. Tropical cyclones Idai and Kenneth, which hit the country in 2019, massively damaged infrastructure and left 2.2 million people in need urgent assistance. Environmental, security and economic risks shape both resource availability for the health system and the burden of NCD in the country [31].

While communicable diseases (including HIV/AIDS) and maternal and neonatal conditions remain the greatest contributors to disease burden, 15 of the top 22 causes of loss of

disability-adjusted life-years (DALYs) relate to NCD, notably cardiovascular disease, neoplasms, unintentional injuries and mental health disorders [32].

Over two–thirds of the population live and work in rural areas. The country is endowed with ample arable land, water, energy, as well as newly discovered natural gas and mineral resources offshore; three, deep seaports; and a relatively large potential pool of labour. Agriculture remains the pillar of Mozambique's economy, contributing 28% of GDP and employing over 81% of the workforce. The majority of the country's agricultural production is through small-scale subsistence farming, with 95% of food production is rain-fed.

Through the Ministry for Coordination of Environmental Affairs (MICOA), the Government of Mozambique developed a national climate change strategy in 2011. This targeted increased resilience in communities and the national economy and the promotion of low-carbon development and the green economy through integrating adaptation and mitigation strategies across multiple sectors. The Government of Mozambique subsequently defined its climate mitigation and adaptation commitments through Mozambique's First Nationally Determined Contribution (NDC 1) 2020–30, which came into force in 2018 when the country formally became a party to the Paris Agreement [33]. WHO and the Ministry of Health developed the 2022–2025 National Health Adaption Plan for Climate Change, which reflects an integrated and multisectoral approach. This was informed by a district-by-district health vulnerability and adaptation to climate change assessment [34], utilising the WHO-recommended Health Vulnerability Index. This featured projections of the impact of climate change on the incidence of malaria and diarrhoea calculated considering the scenarios of low, medium and high emissions.

Emerging themes and strategies. Workshop participants addressed several dynamics linking climate change and health (see Fig 4). Key threats were identified in relation to the increased intensity and frequency of extreme weather events. Participants highlighted that water resources were a particular focus of concern with regard to both floods (influenced by La Niña, in the north) and droughts (by El Niño, in the south). During floods, large amounts of water (including from neighbour countries) strained the ability of the country to effectively manage water resources, impacting water quality and sanitation and thus population health risk from water-borne disease. This pathway had not been identified from the literature review. Population health was acknowledged to also be impacted by the influence of restricted access to health services due to flooding.

Due to its low-lying topography, rising sea level is a cause of coastal erosion, impacting both biodiversity and the livelihoods of the poor populations living in coastal zones depending on fishing and agriculture. With respect to such populations, the quality of housing was considered an important factor in mediating the impacts of climate change. Poor housing exposed households to much greater risks regarding health and livelihoods, and was linked to a range of factors including migration, unplanned urbanisation and dependence on biomass fuels.

Current governance of the health system, constraints on the health workforce due to migration and damage to infrastructure due to extreme events were all contributing to greater fragility of the health system, with implications for addressing the increasing burden of both non-communicable (including mental health) and communicable disease (including emerging infections and chronic infectious disease such as HIV and TB).

Discussion on adaptation strategies focused particularly on issues of water management. Monitoring and surveillance systems needed to be strengthened, particularly in the coastal areas and to anticipate flooding. Given hydrological linkages with neighbouring countries, the political security of water needed be addressed when designing water management strategies. In this regard, stronger data collection and information systems would enable and support political decision-making as well as inform locally driven strategies. Strengthening the health

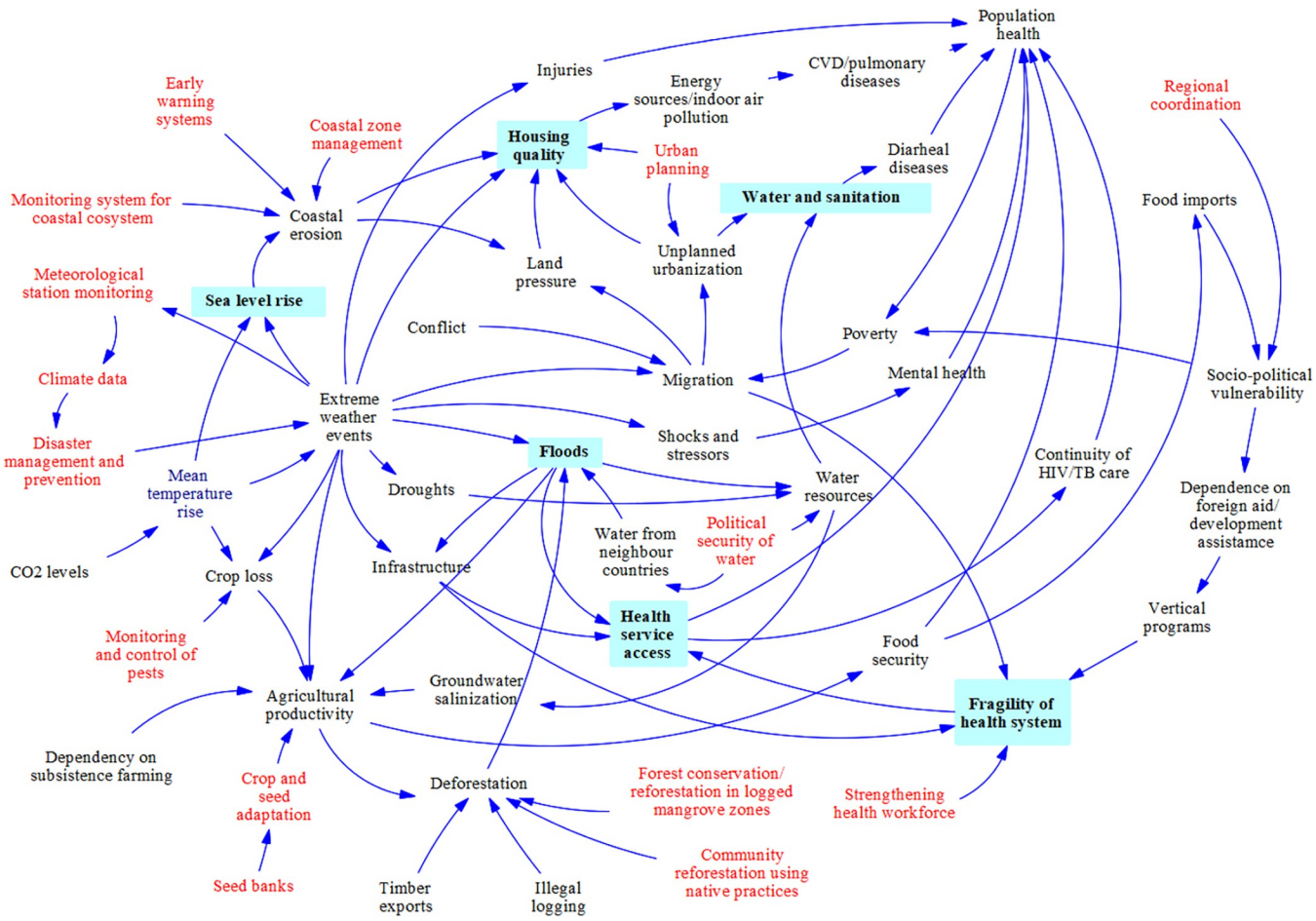

Fig 4. Mozambique causal loop analysis. Key pathways exacerbating threat considered in the workshop flagged in light blue; potential foci of adaptation and resilience shown in red.

https://doi.org/10.1371/journal.pclm.0000184.g004

system–in terms of preparedness, capacity and resilience of infrastructure–was also identified as a key focus for action if the impacts of climate change were to be moderated.

Lebanon case study

Country profile. Lebanon is located on the eastern basin of the Mediterranean Sea. It is a LMIC with a population of approximately 6 million people [35]. In recent years, Lebanon has witnessed political instability, sectarian division, economic crises and recurring civil unrest [36] which has affected its ability to build consensus on political issues and develop equitable and effective policies. The World Bank characterises Lebanon as exhibiting high institutional and social fragility [15]. Even before considering the significant impacts of climate change, the stressors experienced by the country are substantive, including the need to accommodate the highest number of Syrian refugees per capita post 2011 [37], progressive economic collapse precipitated by high levels of unrest and limited economic growth [38, 39], and the devastating impacts of the August 4th 2020 explosion [40].

Lebanon struggles with an increased burden of NCD (including mental health) needs, precipitated by the fragility-related risks it has navigated over time. These have limited the country's capacity to deliver primary care and related NCD services through its network of primary

health centres [35, 41, 42]. Current circumstances underscore the need to identify effective and affordable primary care-based services which can be sustainably financed by the diverse stakeholders active in Lebanon (e.g., Ministry of Health, World Bank, and UNHCR).

Dominated by mountains, 67% of the country's total land is arable and 24% is forest and other wooded lands. The economy is dominated by the service sector, which contributes 45% of the country's GDP. Degraded sandy soils contribute to dust and sandstorms, which are hazardous to both humans and livestock. Signs of water shortages are evident due to increased demand from agriculture and industry. Weak institutional structures, policies and legislations, limited access to new technologies, skills and technical resources all hamper Lebanon's ability to address the current challenges, especially in relation to water, agriculture, forests, and management of coastal areas [35].

In 2013 Lebanon identified Nationally Appropriate Mitigation Actions (NAMAs) articulating voluntary emission reduction proposals, and established working groups on the transport, energy, waste, forestry, and industry sectors. Lebanon signed the Paris Agreement in 2016 and submitted an update to its initial NDC in 2020 [43]. The country's most recent WHO Health and Climate Change Country Profile [44] particularly highlights health risks due to heat stress, food safety and security, and water quantity and quality. Associated risks due to air pollution are also noted, with recent data indicating annual mean $PM_{2.5}$ levels for major cities over five times greater than the WHO guideline value of 5 $\mu g/m^3$.

Emerging themes and strategies. A core focus of workshop discussion was the complex dynamics related to the environment and agricultural production which mediated between climate and health (see Fig 5). Such variables were not initially included in the CLD but were highlighted by participants during the workshop. Harvesting of pine nuts, for example, is one of a number of important sources of livelihood threatened by changing climatic conditions. Irrigation to sustain horticulture through changing seasonal conditions is placing a strain on insecure water sources. Extension of dairy and cattle farming to meet local demand for food supply is further taxing water resources, as well as contributing to greenhouse gas emissions.

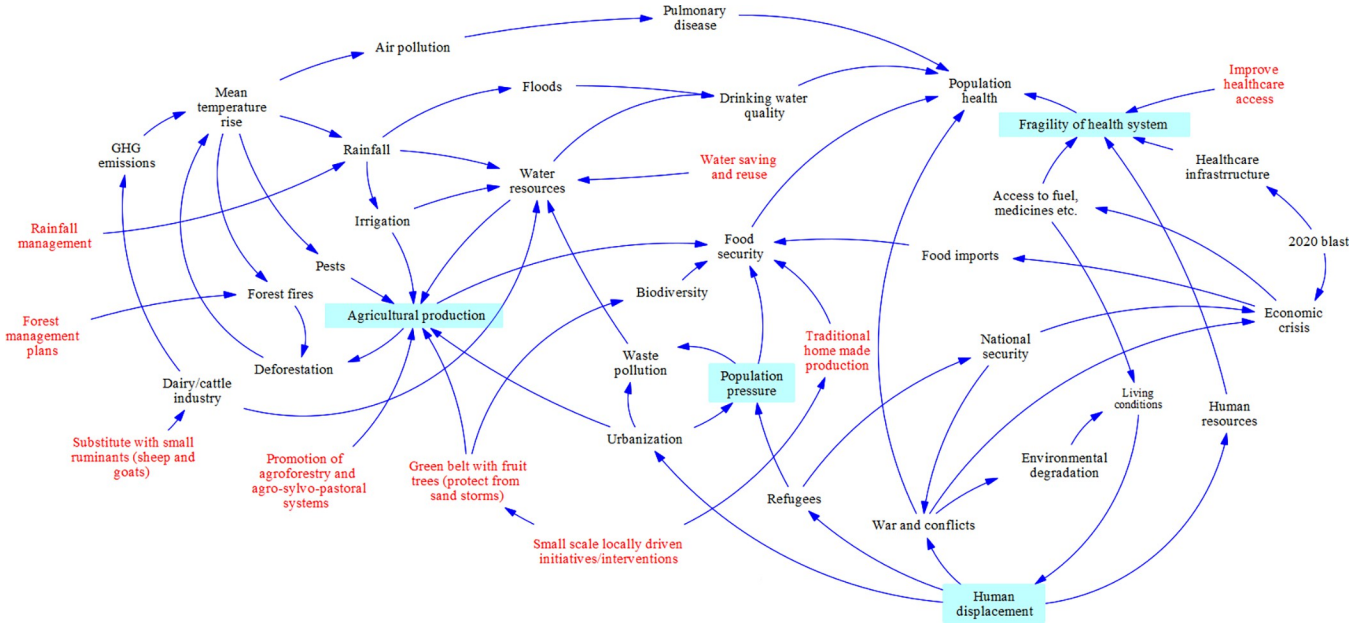

Fig 5. Lebanon causal loop analysis. Key pathways exacerbating threat considered in the workshop flagged in light blue; potential foci of adaptation and resilience shown in red.

https://doi.org/10.1371/journal.pclm.0000184.g005

All these dynamics impact population health (e.g., through food security or availability of water) as well as upon household livelihoods and environmental conditions.

Human displacement and population pressure were other factors considered to be shaping the dynamics of climate and health. War and conflict in the region have driven a cycle of environmental degradation and population movement. The influx of refugees has exacerbated pressure on land, urban settlements, food and water, adding to the direct impacts of climate change. The political and economic crisis facing the country drives further dynamics eroding population health and the capacity to moderate climate impacts. There are implications for food security and the sustainability of agricultural production. Economic conditions are also restricting access to vital commodities to support the operation of the health system. Together with population displacement involving outward migration of health workers, these trends are contributing to greater fragility of the health system, with major implications for population health.

Potential adaptation strategies addressed include strengthening sustainable agricultural solutions (such as climate smart agriculture, agroforestry and greater use of small ruminants such as local goats and sheep) and developing sustainable water services. Although government policy can facilitate development, given the economic and governance challenges in the country, local community-based initiatives were considered crucial. Conflict- and climate-sensitive approaches were viewed as vital to sustain access to health services enabling universal health coverage (UHC). Greater cross-sectoral collaboration is required to ensure public health safety and disaster risk reduction are integrated into national health plans.

Costa Rica case study

Country profile. Costa Rica, situated between Nicaragua and Panama, has moderate poverty rates in comparison with other states within Latin America and the Caribbean. However, fiscal challenges and increasing income inequality are persistent pressing issues [45], with the Fragile State Index (FSI) noting escalating concerns on issues of security and resource distribution [15]. The country is characterised by high rates of migration from across Central America, being one of the top ten countries in the world to receive asylum requests [46]. Evidence from 2015 suggests that the average disposable income of the 10% richest households was 32 times higher than that of the poorest 10% (c.f. OECD average of 9.6) [47].

The threat of economic recession leaves the Costa Rican population open to health-related risk. While UHC is formally guaranteed, more than one-third of the assets of the *Caja Costarricense de Seguro Social* (social security and health insurance agency) are owed to it by the State [48], itself struggling to raise revenues given rapid increases in unemployment, informal employment [49] and effects of COVID-19. The country's disease profile is dominated by a high NCD burden, typically addressed by high-cost treatments at the level of secondary care.

The country has a varied topography that includes coastal plains separated by rugged mountains, including over 100 volcanic cones. Even though Costa Rica constitutes less than 0.05 percent of the total Earth surface, its habitats represent around 5 percent of the planet's biodiversity. Costa Rica is known worldwide for its conservation efforts and is a 'hot spot' for eco-tourism, with more than 26 percent of its land under protection.

However, due to a combination of geographic and economic factors, Costa Rica is highly vulnerable to extreme climate events and natural hazards. Part of this vulnerability is a result of the presence of populations in areas prone to volcanic eruptions and in unstable lands, degraded by widespread cattle ranching, or in poorly planned settlements prone to landslides and flooding. Costa Rica's National Climate Change Strategy (ENCC) and its Plan of Action, as well as advances in the Framework Law on Climate Change, frame policy objectives in this area. The ENCC prioritizes action on mitigation, adaptation, technology, education and

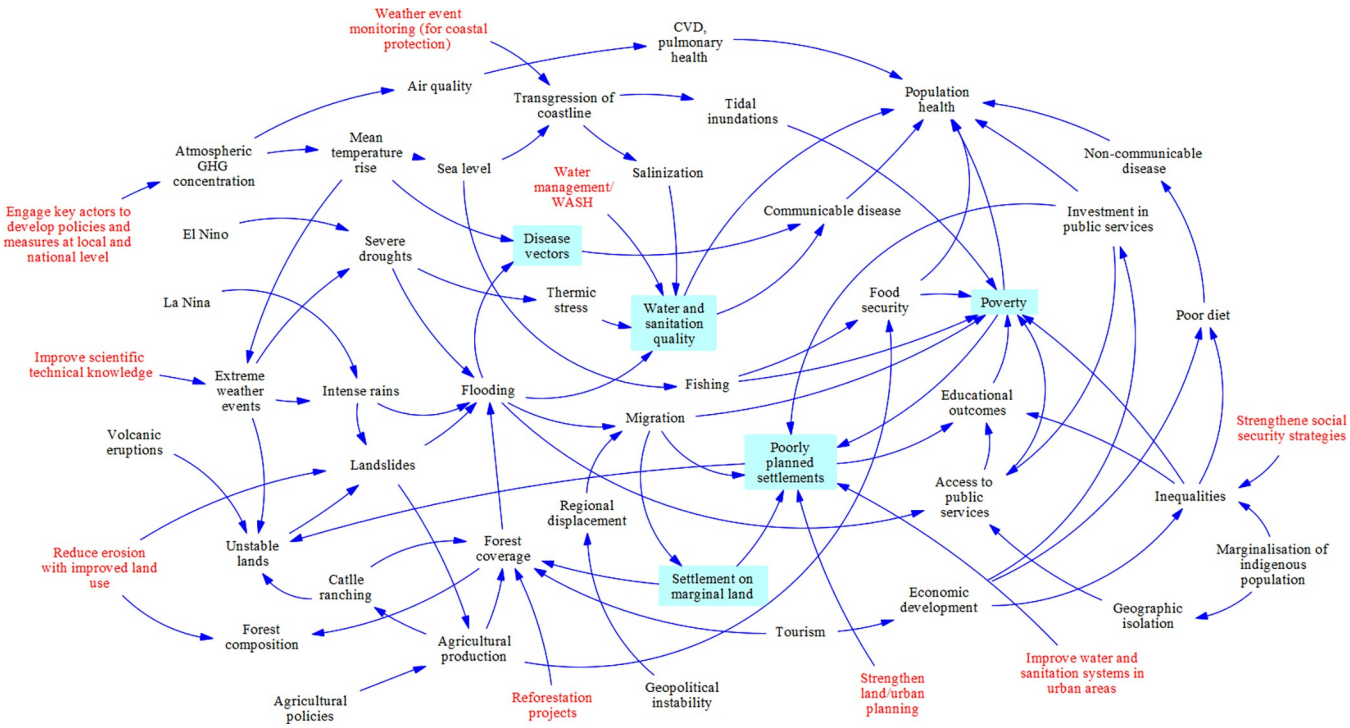

Fig 6. Costa Rica causal loop analysis. Key pathways exacerbating threat considered in the workshop flagged in light blue; potential foci of adaptation and resilience shown in red.

https://doi.org/10.1371/journal.pclm.0000184.g006

finance with the goal to integrate climate change policy with the long-term competitiveness of the country and a strategy of sustainable development. The National Adaptation Policy (2018–2030), the National Decarbonization Plan (2018–2050), and the country's NDC [50] all affirm the country priorities and commitment to tackle climate change. The National Adaptation Plan to Climate Change 2022–2026 [51] makes a clear reference to the links between climate change and health, noting marked increases in the prevalence of infectious diseases such as Zika, malaria, dengue, and chikungunya. It also emphasises the increasing vulnerabilities of indigenous communities, women, and the elderly to climate change stressors.

Emerging themes and strategies. With important changes in patterns of rainfall, a major focus of discussion amongst participants were the dynamics influencing water resources, whether directly through droughts, floods and salinization of aquifers or indirectly through the impact of forestry and agricultural practices (see Fig 6). A lack of safe water was seen as impacting economic growth (due to water cuts and rationing) and as a major contribution to compromised hygiene and increased risk of diarrhoeal disease. Floods contaminate freshwater supplies, heighten the risk of water-borne diseases, and create breeding grounds for disease vectors, for many of which climate change was lengthening the transmission season and geographic range.

Another major focus of discussion was the role of settlement on marginal land, poorly planned settlements and, more broadly, poverty and inequality on mediating the influences of climate change. Areas where there was significant population pressure on land and public infrastructure had poorer access to public services, which data confirmed affected both health and educational outcomes. These variables and associated pathways were elaborated during the workshop. Economic development which addressed deep inequalities was viewed as important to confront these sources of vulnerability.

Potential adaptation strategies discussed included the need to tackle the direct impacts of climate change via surveillance, monitoring and early warning systems. Strengthened social security strategies were considered of significance in reducing the multiple risks linked to poverty. Health systems need to expand traditional systems of healthcare delivery by integrating climate change considerations (e.g. control of climate-sensitive diseases), improving management of environmental determinants of health (such as water and sanitation, nutrition, and air quality), and establish emergency preparedness plans for extreme events. Urban and housing planning in marginal lands, coastal or flood-risk areas was also considered a key area of intervention.

Integrative analysis. Causal loop analysis identified complex dynamics reflecting the unique characteristics of each setting. Modelling served a valuable function in collating evidence from multiple sources, convening consultations from researchers of varied disciplines, and identifying actions—and interactions—of relevance across multiple sectors. This approach to mapping the linkage of climate change, health, and other human systems such as agriculture, settlement, and livelihoods is thus perhaps best suited to local, contextual engagement of actors in identifying key leverage points for adaption strategy. However, while the causal loop analyses across these four settings reflect the unique characteristics of each setting, they also suggest some dynamics that are shared across these contexts.

The causal loop diagram (Fig 7) seeks to represent some of the recurrent features from the country system dynamics. In all settings, mean temperature rise is leading to an increased frequent and intensity of extreme weather events that–whether through the means of floods, droughts, heatwaves etc.–expose populations to health risks. These risks exacerbate disease

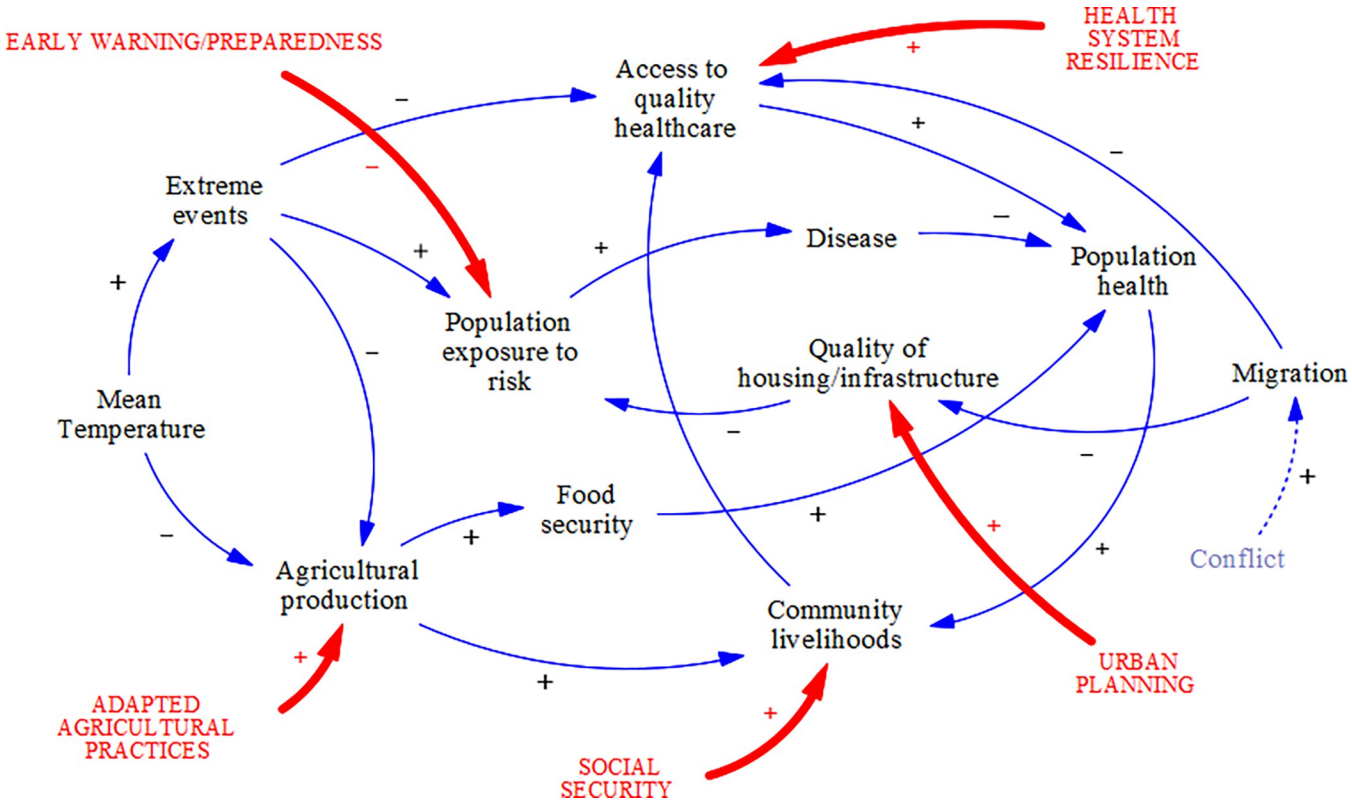

Fig 7. Causal loop diagram showing common dynamics across the four settings. Key foci of adaptation strategy indicated in red.

https://doi.org/10.1371/journal.pclm.0000184.g007

burden and undermine population health. This pathway of climate impact on population health is complemented by a pathway mediated by loss of agricultural production and reduced food security. Additional dynamics influencing the degree of impact of climate change are commonly mediated by the economic livelihoods of communities; migration (often related to conflict) and the resulting pressures on housing and infrastructure; and access to quality healthcare.

There may–as illustrated in the country case studies—be multiple factors linking these pathways, and this figure is not presented as an exhaustive analysis. Such interlinkage may be crucial in determining appropriate foci for local adaptation policy and practice (e.g. impact of government investment in healthcare on functional service access). However, the pathways highlighted in Fig 7 serve to signal broad classes of adaptation strategy operating with respect to factors highlighted in this integrative analysis.

The five strategies are focused on i) early warning/preparedness regarding extreme events (thus mitigating exposure to risk); ii) adapted agricultural practices (to sustain food security and community livelihoods in changing environmental conditions); iii) urban planning (to strengthen the quality of housing and infrastructure and thus reduce population exposure to risks); iv) health systems resilience (to maintain access to quality healthcare both for the treatment of disease associated with increased risk exposure and for other conditions for which access may be disrupted by extreme events); and v) social security (supporting the livelihoods of communities vulnerable through the impact of climate change or otherwise) enabling their access to public services, including healthcare.

Identification of key leverage points for intervention within a complex system of interactions is a valuable outcome of system dynamics analyses and an increasingly important focus of inter-disciplinary research focus [13, 52].

Discussion

Climate change represents a significant threat globally, but particularly for LMIC and fragile settings. Linkages with health are increasingly recognised and becoming prioritised in the global health agenda [53]. While the Sharm-El-Sheikh Adaptation Agenda [12] does not list health as one of the 'impact systems' targeted for adaptation, its recognition of the importance that 'actors across several sectors see . . . their actions and progress mutually reinforce to overcome obstacles, break silos, enhance synergies and create catalytic action' has clear implications for acknowledging the linkage of climate, health and other human systems. Indeed, the analyses presented illustrate how the 'impact systems' defined within the Sharm-El-Sheikh Adaptation Agenda –food and agriculture; water and nature; human settlement; coastal and ocean systems; infrastructure; planning; and finance–in practice richly interact with each other in shaping well-being.

This research thus aimed to contribute to understanding by providing country specific findings and recommendation and by developing further the adoption of system thinking methodologies for use for climate and health research. We used a case study approach based on system dynamic modelling to identify adaptation strategies in four settings that present different fragility features. The aim is ultimately to sustain the development of climate-resilient health systems, in line with the WHO operational framework [54]. The findings also speak directly to the interventions outlined in the WHO guidance for climate resilient and environmentally sustainable healthcare facilities [55] in providing evidence of the amplification of impacts through the interconnectedness of the challenges. This not only informs adaptation and mitigation measures required but also signals the co-benefits of investments in, for example, solar power, where transition from fossil fuels reduces carbon emissions, mitigates the

destabilising effects of energy systems facing outages because of adverse climate events, and reduces health risks through cleaner air.

The causal loop diagrams presented in this paper act as useful starting points to identify fragility and leverage points that can support the policy development process. The use of system thinking has been recognised to be a key element to unpack climate change and build resilient health systems. Systems thinking, which stems from complexity theory, analyses the interactions between systems' components to explain how and why they give rise to observed system outcomes and behaviours [56]. System thinking is particularly useful to support multi-sectoral collaboration through a shared understanding of the nexus between climate change and health and to foster political action by identifying effective strategies. For instance, the four models developed for this study highlighted the need to build surveillance and early warning systems. Key steps to reach these goals would include establishing key indicators [57], such as the ones suggested by The Lancet Countdown on health and climate change (e.g., risk exposures, vulnerability factors, adaptation, planning, and resilience; mitigation and health co-benefits; economics; and political engagement) [58]. In this regard, risk assessment and health impact assessments should be integrated in routine assessments to quantify climate-driven health impacts. A system thinking approach to climate change and its impact on health is well suited to support health in all policy (HiAP) approach. HiAP is required to develop a comprehensive response to the risks presented by short-term climate variability and long-term climate change [59] and to define the health components of National Health Adaptation Plans (NHAPs) under the UN Framework Convention on Climate Change (UNFCCC). By identifying vulnerabilities in the health system as well as opportunities to increase the resilience of health systems to climate change, countries will be making important steps to achieve Universal Health Care (UHC). Climate-driven health outcomes should be included in the essential health services coverage by way of workforce training on climate–health relationships, financing, and increasing resilience of health care service delivery which may be disrupted during climate-related events (e.g., storms, and flooding). These can bolster UHC to address context-specific climate-driven health effects that are already being experienced and expected to worsen over time.

Overall, more research and action are required to avoid the effects of climate change aggravating even further global health inequalities. A more profound question of justice is at play, whereby climate change interacts with existing social and economic disparities and exacerbates longstanding trends within and between countries. Finally, it is essential to incorporate different types of knowledge and an indigenous lens into the conceptualisation and implementation of planetary health [60].

Limitations

To our knowledge, this is the first study that presented country case studies on the link between climate change and health using system thinking. Even though we used a robust methodological approach, some limitations need to be noted. Given the qualitative nature of the approach, we acknowledge that researcher perspectives may have influenced the work and findings; however, researchers from diverse backgrounds and from local contexts collaborated on the synthesis of the CLDs, bringing in diverse positions and perspectives.

Conclusions

Our research highlights five important lessons. First, system dynamics modelling methods, such as participatory group model building, provide a useful mechanism for convening actors across multiple sectors to consider the development of adaptation strategies. Consultations at national and local levels using approaches informed by systems dynamics should be used to

identify linkages that can promote–or, unattended, would undermine—coherent, cross-sectoral action in support of adaptation.

Second, in line with the OECD multi-dimensional analysis of fragility [61], climate-related environmental risks need to be increasingly factored into appraisal of state and regional fragility, alongside issues of security and social, economic and political risks.

Third, our modelling has highlighted how pathways of impact of climate change can disproportionally affect those with lower household incomes, exacerbating inequalities. Adaptation strategies need to consider *a priori* investments which prioritise social security of vulnerable communities and populations.

Fourth, strategies focused on strengthening health systems resilience need to consider the relevant influences not only of national preparedness and early warning systems, but also of evolving agricultural (and wider livelihood) practices and patterns of settlement.

Finally, fifth, effective data monitoring systems need to be prioritised at national level to integrate information from all relevant sectors, with datasets and analyses shared across all ministries.

We consider these lessons to have important implications for conceptualizing adaptation both nationally and globally. In terms of the former, we have shared findings with governmental partners regarding national climate adaptation strategy and, in Mozambique, are working with the National Institute for Health on a major prospective study of community adaptation measures in three locations at particular risk for extreme weather events. In terms of the latter, the lessons have been shared in a range of fora, ranging from fringe meetings in the context of CoP26 in Scotland to the multi-stakeholder policy forum of the 2023 Prince Mahidol Award Conference in Bangkok focused on 'Setting a New Health Agenda: at the Nexus of Climate Change, Environment and Biodiversity'. By such means we aim for findings to foster the adoption of systems thinking in the formulation of adaptation strategies reflecting the dynamic linkages between climate change, health, and other human systems.

Supporting information

S1 Table. Search terms and inclusion criteria for literature review.
(DOCX)

S2 Table. Extraction template/matrix for literature review.
(DOCX)

S3 Table. List of included studies.
(DOCX)

Acknowledgments

We are deeply grateful to our workshops participants who provided their knowledge, time and expertise to develop the case studies. These include: Dr Maia Uchaneishvili, Research Unit Director, Curatio International Foundation; Dr Nia Giuashvili, Environmental Health Expert, Advisor of the National Center for Disease Control and Public Health General Director on Environmental Health; Dr Mariam Maglakelidze, Head, Department of Institutional Culture Development, Petre Shotadze Tbilisi Medical Academy; Affiliate Scholar, Institute for Advanced Sustainability Studies, Potsdam, Germany; Ina Girard, Climate Change and Human Health Expert, WHO Focal Point on the Environmental Health Issues at the National Environmental Agency; Dr Tamar Kashibadze, Public Health Specialist, NCD Department, National Center for Disease Control and Public Health; Dr Tatiana Marrufo, Instituto Nacional de Saúde (INS), National Health Observatory Technical Secretariat, Program Lead of

Environmental Health; Dr Fady Asmar, Forestry Expert, Lebanon; D.E.A. Pascal Girot, Head of the School of Geography, Universidad de Costa Rica; Dr Valeria Lentini, Lecturer, School of Economics, Universidad de Costa Rica; Dr Juan Robalino, Head of the Economics Research Institute, Universidad de Costa Rica; Dr Yanira Xirinachs-Salazar, Associate Professor, School of Economics, Universidad de Costa Rica; and Dr Paola Zúñiga-Brenes, Associate Professor, School of Economics, Universidad de Costa Rica.

Author Contributions

Conceptualization: Giulia Loffreda, Liz Grant, Alastair Ager.

Data curation: Giulia Loffreda, Ivdity Chikovani, Ana O. Mocumbi, Michele Kosremelli Asmar, Laura C. Blanco.

Formal analysis: Giulia Loffreda, Alastair Ager.

Funding acquisition: Liz Grant, Alastair Ager.

Investigation: Giulia Loffreda, Ivdity Chikovani, Ana O. Mocumbi, Michele Kosremelli Asmar, Laura C. Blanco, Alastair Ager.

Methodology: Giulia Loffreda, Alastair Ager.

Project administration: Alastair Ager.

Resources: Ivdity Chikovani, Ana O. Mocumbi, Michele Kosremelli Asmar, Laura C. Blanco.

Software: Giulia Loffreda.

Supervision: Alastair Ager.

Validation: Ivdity Chikovani, Ana O. Mocumbi, Michele Kosremelli Asmar, Laura C. Blanco.

Writing – original draft: Giulia Loffreda.

Writing – review & editing: Giulia Loffreda, Ivdity Chikovani, Ana O. Mocumbi, Michele Kosremelli Asmar, Laura C. Blanco, Liz Grant, Alastair Ager.

References

1. United Nations Framework Convention on Climate Change. Copenhagen Accord. 2009. Available from: https://unfccc.int/resource/docs/2009/cop15/eng/l07.pdf
2. World Meteorological Organisation. State of the Climate in Africa. Avail. 2020. Available from: https://library.wmo.int/doc_num.php?explnum_id=10421
3. Whitmee S, Haines A, Beyrer C, Boltz A., Capon A G, de Souza Dias B F et al. Safeguarding human health in the anthropocene epoch: Report of The Rockefeller Foundation–Lancet Commission on Planetary Health. Lancet, 2015; 386:1973–2028 https://doi.org/10.1016/S0140-6736(15)60901-1 PMID: 26188744
4. Berry H L, Waite T D, Dear K B G., Capon A G and Murray V. The case for systems thinking about climate change and mental health. Nature Climate Change. 2018; 8, 282–290. https://doi.org/10.1038/s41558-018-0102-4
5. Romanello M., Di Napoli C, 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. Lancet, 2022; 400:1619–1654. https://doi.org/10.1016/S0140-6736(22)01540-9 PMID: 36306815
6. European Observatory on Health Systems and Policies, Thomas S, Sagan A, Larkin J, Cylus J. et al. Strengthening health systems resilience: key concepts and strategies. World Health Organization, Regional Office for Europe. 2020. Available from: https://apps.who.int/iris/handle/10665/332441
7. El-Sayed A M and Galea S Systems Science and Population Health. OUP: Oxford; 2017.
8. Jamal Z, Alameddine M, Diaconu K, Lough G, Witter S, Ager A et al. Health system resilience in the face of crisis: analysing the challenges, strategies and capacities for UNRWA in Syria, Health Policy and Planning, 2020; 35 (1), 26–35. https://doi.org/10.1093/heapol/czz129 PMID: 31625558

9. Blanchet K, Nam SL, Ramalingam B, Pozo-Martin F. Governance and Capacity to Manage Resilience of Health Systems: Towards a New Conceptual Framework. Int J Health Policy Manag. 2017; 6 (8):431–435. https://doi.org/10.15171/ijhpm.2017.36 PMID: 28812842; PMCID: PMC5553211.

10. Guzmán CAF, Aguirre AA, Astle B, Barros E, Bayles B, Chimbari M, et al. A framework to guide planetary health education. Lancet Planet Health. 2021 May; 5(5):e253–e255. https://doi.org/10.1016/S2542-5196(21)00110-8 Epub 2021 Apr 21. PMID: 33894134.

11. UNFCCC Report of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement on its third session, held in Glasgow from 31 October to 13 November 2021. Available from: https://unfccc.int/sites/default/files/resource/cma2021_10_add1_adv.pdf

12. Sharm-El-Sheikh Adaptation Agenda: The global transformations towards adaptive and resilient development. 2022. Available from: https://climatechampions.unfccc.int/wp-content/uploads/2022/11/SeS-Adaptation-Agenda_Complete-Report-COP27_FINAL-1.pdf

13. Proust K, Newell B, Brown H, Capon A, Browne C, Burton A, et al. Human health and climate change: leverage points for adaptation in urban environments. Int J Environ Res Public Health. 2012; 9 (6):2134–58. https://doi.org/10.3390/ijerph9062134 Epub 2012 Jun 6. PMID: 22829795; PMCID: PMC3397369.

14. Ager A, Saleh S, Wurie H, Witter S. Health systems research in fragile settings. WHO Bulletin, 2020, https://doi.org/http%3A//dx.doi.org/10.2471/BLT.19.233965 PMID: 31210671

15. OECD. States of Fragility 2022. OECD Publishing, Paris, 2022. Available from: https://doi.org/10.1787/c7fedf5e-en

16. De Garine-Wichatitsky M, Binot A, Ward J, Caron A, Perrotton A, Ross H, et al. "Health in" and "Health of" Social-Ecological Systems: A Practical Framework for the Management of Healthy and Resilient Agricultural and Natural Ecosystems. Front. Public Health 2021; 8:616328. https://doi.org/10.3389/fpubh.2020.616328 PMID: 33585387

17. Benjaminsen T A, Svarstad H. Political ecology. In: Encyclopedia of Ecology, 2nd ed. Volume 4. Elsevier; 2019.

18. United Nations Climate Change. Introduction to Gender and Climate Change. UNFCCC; 2020. Available from: https://unfccc.int/gender

19. Markedonov, Sergey M., and Suchkov M. A. Russia and the United States in the Caucasus: cooperation and competition. Caucasus Survey. 2020; 8.2: 179–195. https://doi.org/10.1080/23761199.2020.1732101

20. Rukhadze T. An overview of the health care system in Georgia: expert recommendations in the context of predictive, preventive and personalised medicine. EPMA J. 2013; 4(1):8. https://doi.org/10.1186/1878-5085-4-8 PMID: 23442219; PMCID: PMC3621519.

21. The Fund for Peace. Fragile States Index Report. 2021. Available from: https://fragilestatesindex.org/wp-content/uploads/2021/05/fsi2021-report.pdf

22. World Health Organization. Regional Office for Europe, European Observatory on Health Systems and Policies. Georgia: health system review. World Health Organization. Regional Office for Europe, 2017.

23. World Health Organization. Regional Office for Europe, European Observatory on Health Systems and Policies, Gamkrelidze A, Atun R, Gotsadze G. et al. Health care systems in transition: Georgia. WHO, Regional Office for Europe; 2002. Available from: https://apps.who.int/iris/handle/10665/107402

24. Goginashvili K, Nadareishvili M, Habicht T. Can people afford to pay for health care? New evidence on financial protection in Georgia. Copenhagen: WHO Regional Office for Europe; 2021.

25. USAID. Climate risk profile Georgia, Factsheet, 2017. Available from: https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID%20ATLAS_Climate%20Change%20Risk%20Profile%20-%20Georgia.pdf

26. Fourth National Communication of Georgia under the UNFCCC, 2021. Available from: https://unfccc.int/sites/default/files/resource/4%20Final%20Report%20-%20English%202020%2030.03_0.pdf

27. Georgia's 2030 Climate Change Strategy and Action Plan. Government of Georgia. Available from: https://mepa.gov.ge/En/Files/ViewFile/50123

28. Batley R, Bjørnestad L, Cumbi A. Joint Evaluation of General Budget Support 1994–2004: Mozambique Country Report. International Development Department School of Public Policy University of Birmingham. 2006. Available from: https://www.oecd.org/countries/mozambique/43867765.pdf

29. Anselmi L, Lagarde M, Hanson K. Health service availability and health seeking behaviour in resource poor settings: evidence from Mozambique. Health Econ Rev. 2015; 5(1):62. https://doi.org/10.1186/s13561-015-0062-6 Epub 2015 Sep 2. PMID: 26329425; PMCID: PMC4556719.

30. World Bank. The World Bank in Mozambique [Internet] Accessed 24 June 2022. Available from: https://www.worldbank.org/en/country/mozambique/overview

31. Bukhman G, Mocumbi AO, Atun R, Becker AE, Bhutta Z, Binagwaho A et al. Lancet NCDI Poverty Commission Study Group. The Lancet NCDI Poverty Commission: bridging a gap in universal health coverage for the poorest billion. Lancet. 2020; 3; 396(10256):991–1044. https://doi.org/10.1016/S0140-6736(20)31907-3 Epub 2020 Sep 14. PMID: 32941823; PMCID: PMC7489932.

32. Mozambique. [internet] Institute for Health Metrics and Evaluation, Global Burden of Disease. Accessed 10 November 2022. Available from https://www.healthdata.org/mozambique

33. Update of the First Nationally Determined Contribution to the United Nations Framework Convention on Climate Change Mozambique Period: 2020–2025. Republic of Mozambique. 2021. Available from https://unfccc.int/sites/default/files/NDC/2022-06/NDC_EN_Final.pdf

34. Clim-Health Africa. Health vulnerability and adaptation to climate change assessment conducted in Mozambique. May 2020. Available from: https://climhealthafrica.org/news-mozambique-vulnerability-and-adaptation-assessment

35. World Health Organization and the United Nations Framework Convention on Climate Change. Lebanon Health and Climate Change Country Profile. WHO/UNFCCC, 2021.

36. Government of Lebanon and United Nations, Lebanon Crisis Response Plan 2017–2020: 2020 Update. Available from: https://lebanon.un.org/sites/default/files/2021-02/LCRP2020%20update_EN_Full_180122-035824.pdf

37. United Nation Refugee Agency (UNHCR). UNHCR Global Appeal, 2015 Update. Available from: https://www.unhcr.org/uk/publications/fundraising/5461e5ec3c/unhcr-global-appeal-2015-update-populations-concern-unhcr.html

38. Masri S., Srour I. Assessment of the impact of Syrian refugees in Lebanon and their employment profile. International Labour Organization. Geneva, 2014. Available from: https://www.ilo.org/beirut/publications/WCMS_240134/lang—en/index.htm

39. Situation Syria Regional Refugee Response [internet] United Nation Refugee Agency (UNHCR). Accessed: 16 August 2021. Available from: https://data.unhcr.org/en/situations/syria

40. Devi S. Lebanon faces humanitarian emergency after blast. Lancet. 2020; 396(10249): 456. https://doi.org/10.1016/S0140-6736(20)31750-5 PMID: 32798477

41. Naja F., Shatila H., El Koussa M, Lokman M, Ghandour L, Saleh S. Burden of non-communicable diseases among Syrian refugees: a scoping review. BMC Public Health, 2019; 19, 637. https://doi.org/10.1186/s12889-019-6977-9 PMID: 31126261

42. Noubani A, Diaconu K, Loffreda G, et al. Readiness to deliver person-focused care in a fragile situation: the case of Mental Health Services in Lebanon. Int J Ment Health Syst. 2021 15, 21. https://doi.org/10.1186/s13033-021-00446-2 PMID: 33653392

43. Lebanon's Nationally Determined Contribution Updated 2020 Version. Government of Lebanon; 2020.

44. Lebanon: WHO Health and Climate Change Country Profile 2021. WHO/UNFCCC; 2021. Available from: https://www.who.int/publications/i/item/WHO-HEP-ECH-CCH-21.01.09

45. Costa Rica [Internet] The World Bank. Accessed 10 November 2022. Available from: https://data.worldbank.org/country/CR

46. Costa Rica. [Internet] United Nations Refugee Agency (UNHCR). Accessed 10 November 2022. Available from: https://www.unhcr.org/uk/costa-rica.html

47. OECD Costa Rica Policy Brief: Inequity. February 2016. Available from: https://www.oecd.org/policy-briefs/costa-rica-towards-a-more-inclusive-society.pdf

48. Caja Costarricense de Seguro Social. Estados financieros: Seguro de salud, San José: CCSS. Gerencia Financiera; 2020.

49. National Institute of Statistics and Census. Continuous Survey on Employment for the first quarter of 2020. General Results. San José: INEC; 2020.

50. Contribución Nacionalmente Determinada de Costa Rica. [Internet] Accessed 10 November 2022. Available: https://cambioclimatico.go.cr/contribucion-nacionalmente-determinada-ndc-de-costa-rica/

51. Dirección de Cambio Climático; Ministerio de Ambiente y Energía. Plan Nacional de Adaptación al Cambio Climático de Costa Rica, 2022–2026. San José, Costa Rica, 2022.

52. Schnitter R. and Berry P. The Climate Change, Food Security and Human Health Nexus in Canada: A Framework to Protect Population Health. International Journal of Environmental Research and Public Health 16(14):2531. https://doi.org/10.3390/ijerph16142531 PMID: 31315172

53. The 2022 Global Report of the Lancet Countdown: Tracking Progress on Health and Climate Change. Available from: https://www.lancetcountdown.org/2022-report/

54. Operational framework for building climate resilient health systems, WHO, 2015. Available from: https://www.who.int/publications/i/item/9789241565073

55. WHO guidance for climate-resilient and environmentally sustainable health care facilities. Geneva: World Health Organization, 2020.

56. Kwamie A, Ha S, Ghaffar A. Applied systems thinking: unlocking theory, evidence and practice for health policy and systems research, Health Policy and Planning. 2021; 36 (10), 1715–1717. https://doi.org/10.1093/heapol/czab062 PMID: 34131699

57. World Health Organization. WHO Guidance to Protect Health from Climate Change through Health Adaptation Planning; World Health Organization: Geneva, Switzerland, 2015.

58. Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Beagley J. Belesova K. et al. The 2020 report of The Lancet Countdown on health and climate change: Responding to converging crises. Lancet 2020, 396, 129–170.

59. Pongsiri M J and Bassi A M. A Systems understanding underpins actions at the climate and health nexus. Int. J. Environ. Res. Public Health 2021, 18, 2398. https://doi.org/10.3390/ijerph18052398 PMID: 33804531

60. Redvers N, Celidwen Y, Schultz C, Horn O, Githaiga C, Vera M et al. The determinants of planetary health: an Indigenous consensus perspective. Lancet Planet Health. 2022 Feb; 6(2):e156–e163. https://doi.org/10.1016/S2542-5196(21)00354-5 PMID: 35150624.

61. Diaconu K, Falconer J, Vidal N, O'May F, Azasi E, Elimian K et al. Understanding fragility: implications for global health research and practice, Health Policy and Planning, 2020; 35 (2) 235–243. https://doi.org/10.1093/heapol/czz142 PMID: 31821487