Anticipatory action for climate-sensitive infectious diseases:

Latin America Regional Assessment

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The views in this report are the authors' alone and not those of the Red Cross Red Crescent Climate Centre, the IFRC, ICRC or any National Society.

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Abbreviations

DREF	Disaster Response Emergency Fund
EAP	Early Action Protocols
ECR	Ethiopian Red Cross Society
EWS	Early warning systems
FbF	Forecast-based financing
IPCC	Intergovernmental Panel on Climate Change
WHO	World Health Organization
PAHO	Pan-American Health Organization
MMR	Maternal mortality ratio
LAC	Latin America and the Caribbean
ENSO	El Niño-Southern Oscillation
WASH	Water sanitation and hygiene

Executive summary

Climate hazards can play a pivotal role in the transmission of disease. Extreme temperatures, floods, droughts, storms and other climatic hazards can directly and indirectly influence the spread of infectious diseases. For example, rising temperatures can expand the geographical range of disease vectors like mosquitoes, enabling the transmission of diseases like malaria and dengue in new areas. Flooding can contaminate water sources, while droughts can reduce access to clean water and sanitation, increasing the risk of waterborne disease. Moreover, extreme weather events often disrupt healthcare systems, infrastructure and supply chains, making accessing healthcare and essential medicines for infectious diseases challenging for affected populations.

The Red Cross Red Crescent working group on anticipatory action and health seeks to advance the work on anticipating and preventing adverse health outcomes within the Red Cross Red Crescent Movement ("the Movement"). Many anticipatory action initiatives have focused on extreme climate and weather events. But there are still increasing opportunities to look beyond these and act ahead of other hazards, including disease outbreaks and epidemics.

This report complements the working paper on anticipatory action for epidemics, which is intended to contribute to a common understanding of the concept of anticipatory action for epidemics across the Movement.

This assessment is valuable guidance for National Societies in Latin America and the Caribbean (LAC) who wish to engage in anticipatory action for epidemics. It aims to provide evidence for deciding which infectious-disease risks should be prioritized for early warning and early action initiatives, and recommendations on next steps.

Malaria and dengue are infectious diseases for which developing anticipatory action approaches is feasible. They can be pursued in the following priority countries (alphabetically): Barbados, Brazil, Colombia, Ecuador, Guatemala, Guyana, Haiti, Honduras, and Peru. Cholera is also a priority disease for Haiti and Mexico. This prioritization does not preclude the development of anticipatory action for other diseases in other countries; however, based on the analysis, these are the most viable options for the next few years.

1 Introduction

1.1 Background

The anticipatory action and health working group, launched in January 2022, has developed guidance for epidemics intended to contribute to a common understanding across the Movement, especially among National Societies wishing to engage in such interventions. Regional assessments are being produced to complement the working paper on guidance for anticipatory action for epidemics in the LAC region.

This report provides a guide to assessing and implementing anticipatory action for climate-sensitive infectious diseases in the LAC region, accounting for both climatic and non-climatic factors, population at risk, and existing activities. It will identify which climate-sensitive infectious diseases are the most relevant and suitable. The working group on anticipatory action and health has identified three main anticipatory approaches to develop triggers for epidemics:

1. **Identification of health impacts linked to hydro-meteorological hazards**
2. **Multi-stepped composite analysis (based on surveillance and amplifying factors)**
3. **Mathematical models for predicting the risk of outbreaks.**

1.2 Objectives

To develop anticipatory action for climate-sensitive infectious diseases with National Societies, IFRC regional offices and National Societies, it is essential to have evidence-based information about such diseases as well as existing approaches and challenges.

This report focuses on generating a climate profile and climate change projects in the LAC region, climate-sensitive infectious diseases, and the mechanisms by which climate and non-climate drivers affect them. We analysed existing preparedness activities and give recommendations for possible anticipatory action in LAC, focusing on the following issues:

- Which climatic hazards are relevant for anticipatory action and epidemics, and how do they vary?
- Which infectious diseases are climate-sensitive, and what are the climate drivers of transmission?
- What are the different transmission pathways that could be affected by climate hazards? How can we define the level of risk in the population? Are other drivers aggravating and interacting with climate drivers affecting this risk?
- What early warning systems are being designed or actually implemented?
- Based on the literature, which triggers, and lead times could be defined for anticipatory action in health?

- What are the key components to be considered in developing frameworks for anticipatory action and health for infectious diseases?

1.3 Latin America regional context

The LAC region comprises 33 countries and territories and faces various humanitarian challenges. According to the World Bank,[1] the region has a significant income inequality gap, with over 30 per cent of its population living in poverty. Additionally, natural hazards like hurricanes, earthquakes, and volcanic eruptions are relatively common, causing significant humanitarian crises, as seen in the devastating 2010 earthquake in Haiti. High crime rates in some LAC countries contribute to safety concerns and challenges in providing adequate healthcare and education.

Additionally, displacement due to conflict and violence in countries such as Venezuela has led to one of the most significant refugee crises in the world. The UNHCR reports that by 2021, at least 5.6 million Venezuelans had left their country. Humanitarian organizations and governments continue to address these complex challenges and try to improve living conditions for vulnerable populations. National Societies play a vital role in providing humanitarian assistance, disaster relief, and community support, working tirelessly to alleviate the suffering of those affected by emergencies and disasters.

The LAC region has made notable strides in improving health care for its population, as evidenced by the significant reduction in maternal mortality. In 2016, the region reported a maternal mortality ratio (MMR) of 60.8 maternal deaths per 100,000 live births (Pan American Health Organization and World Health Organization, 2016), representing approximately a 17 per cent reduction between 1990 and 2015 (Pan American Health Organization, 2023). Nevertheless, LAC stands out as one of the world's most unequal regions. Despite notable economic advances, the top 10 per cent of people possess just over 70 per cent of total wealth.5,6 Such income inequality hinders access to quality healthcare services for vulnerable or socially marginalized groups.

The region has grappled with many socio-economic and geopolitical challenges, including violence and political instability associated with drug trafficking. Additionally, there is general insecurity stemming from political and socio-economic instability and food insecurity from declining agriculture. Factors like displacement, urbanization, and the marginalization of indigenous people have also compounded these issues.[2]

2 Methodology

2.1 Study region

In this report, the LAC region comprises 33 countries: Antigua and Barbuda, Argentina, Bahamas, Barbados, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay and Venezuela. Three country case studies – Barbados, Brazil, and Colombia – provide a more in-depth analysis of the existing efforts to scale up anticipatory action for epidemics.

2.2 Current and future climate

We performed a review to create a baseline and describe the distribution and historical dynamics of the different climate hazards in the region (floods, droughts, landslides, storms, hurricanes, and fires). This review, combined with a data analysis using the EM-DAT database, will help determine which climate hazard should be prioritized for our project and identify projected changes in climate hazards (future) and climate variables, their seasonality, and spatial patterns relevant to climate-sensitive infectious diseases and anticipatory action.

2.3 Disease data collection and analysis

Based on expert knowledge and data collected from PLISA, the open data portal of the Pan American Health Organization (PAHO/WHO)), we can map the disease's presence and absence in different regions. In addition, we will calculate a measure of their disease burden and the mortality related to those diseases in the region. With these results, we will identify possible climate drivers and triggers for infectious disease outbreaks, identify non-climatic factors driving infectious disease transmission, and understand their interactions with the climate drivers.

Combining expert knowledge and the existing literature on climate and disease, we will create a table summarizing the relationships between the climate hazards and diseases identified above. We will include criteria such as the type of pathogens, the optimal ecological conditions, country or specific locations, the population at risk, regional climatic drivers/ climate variables, non-climatic drivers (socio-economic factors, behaviour), and a description of the effect on transmission.

2.4 Mapping existing epidemic preparedness activities

By reviewing the existing literature connecting climate hazards, extreme climate, and extreme climate events with epidemiology, we can identify existing surveillance systems and risk prediction models for the identified diseases and their applications. We will focus on understanding which tools or models are available (methods used) and, from these tools, what are the triggers used, lead times, early action activities in place, observed trends in burden (decrease/increase/no change/no evidence) and projected changes in identified climatic drivers. In addition, we will monitor whether surveillance systems are in place, identify their advantages and limitations, and investigate if they could be transferred to other regions.

2.5 Developing recommendations

We will review existing Early Action Protocols (EAPs) and conclude practical anticipatory action approaches for the different identified infectious diseases depending on region, population groups, seasons and time horizon. Finally, we will have consultations and key informant interviews with relevant stakeholders in the three country case studies (Colombia, Brazil and Barbados); based on this information, we will prepare recommendations on evidence-based, relevant and feasible early action activities to be implemented by National Red Cross and Red Crescent Societies.

3 Regional climate profile and projections

3.1 Historical climate and extreme weather

The Latin America region has several climate zones, stretching from above the Tropic of Cancer to near the Antarctic Circle. Moreover, the region comprises a vast topographical variety, ranging from small island states to countries at high elevations with mountainous terrain. As such, there are different temperature profiles, rainfall patterns, and risks of floods, heatwaves, hurricanes, and droughts across the 51 countries and territories in the region – of which there are 33 official countries.

Floods are the most common natural hazard in the region and are a function of the climate (e.g., extreme rainfall, hurricanes, tropical storms, El Niño phenomenon), hydrology (e.g., flash floods in very steep areas, lower parts of largest drainage systems) and soil characteristics. Mexico, Central America, and the Caribbean are in the pathways of hurricanes and tropical storms in the western Atlantic and eastern Pacific. In 2021, **extreme rainfall** in north-eastern Brazil resulted in landslides that killed hundreds, destroyed tens of thousands of homes, and displaced hundreds of thousands of people. The economic damage associated with these events is estimated at US$ 3.1 billion.[3]

Seasonal droughts occur in climates with well-defined annual rainy and dry seasons, such as arid and cold climatic zones. In these areas, the risk of desertification is also high. Wildfires are associated with the dry season, drought conditions, and human intervention.[4] Chile is experiencing a mega-drought, entering its 13th consecutive year, the longest recorded in at least 1,000 years.[5]

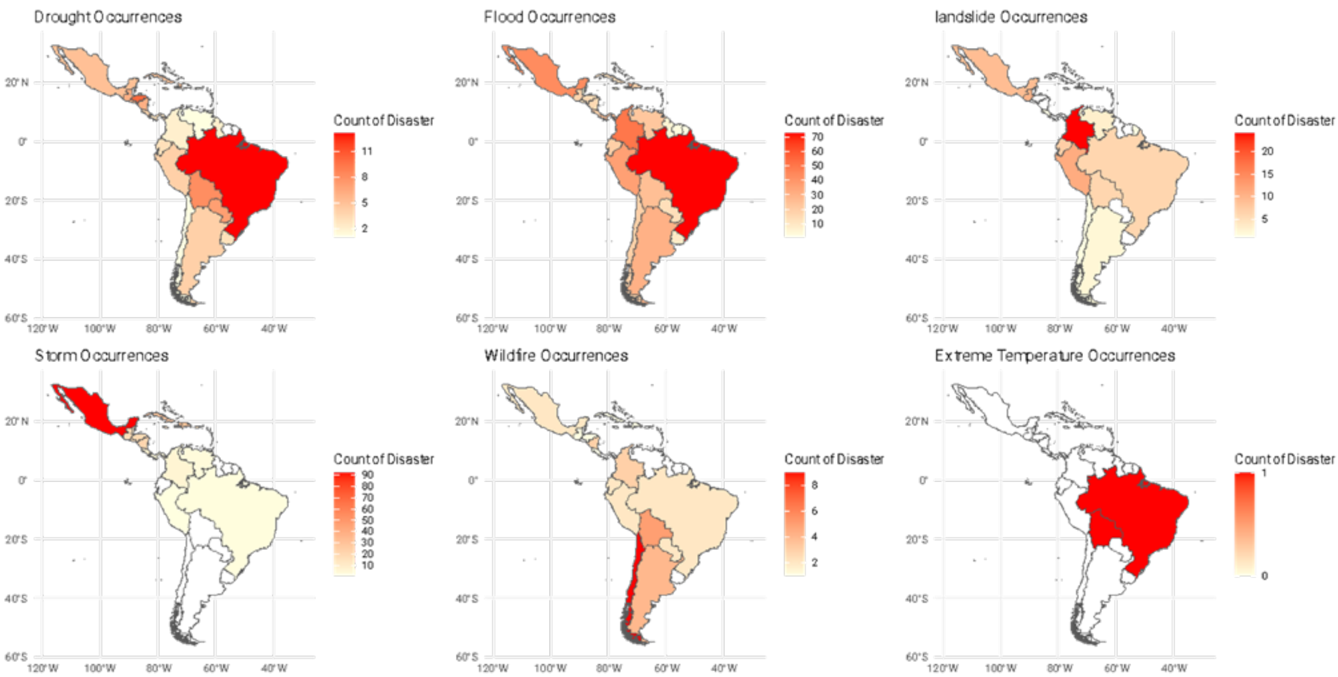


Figure 1. Climate hazards frequency distribution in LATAM mapped using EM-DAT database from 1991-2002.

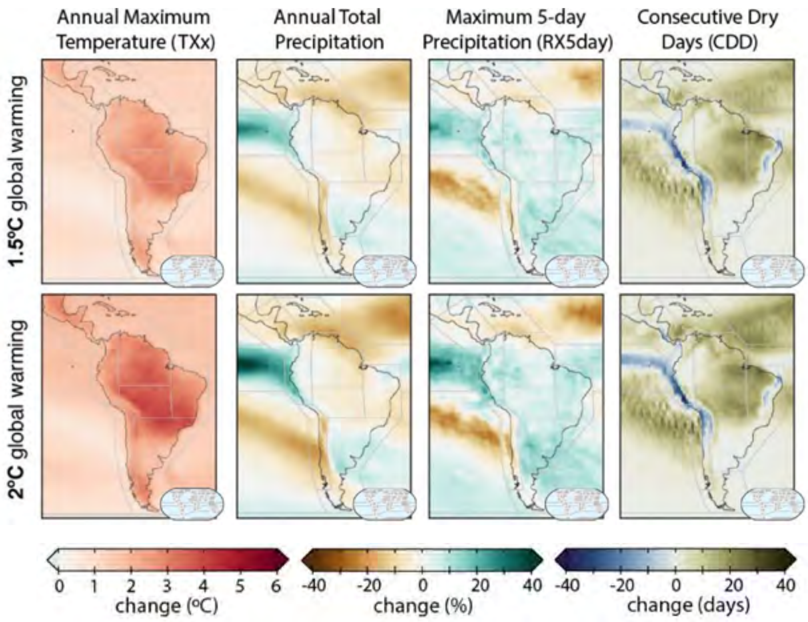
Heatwaves in LAC are becoming more frequent and severe, posing significant challenges to the region. Rising temperatures linked to climate change have led to prolonged periods of extreme heat. These heatwaves can have dire consequences, including heat-related illnesses, strain on healthcare systems, and negative impacts on agriculture. Vulnerable populations, such as the elderly and impoverished communities, are particularly at risk. In recent years, cities like Buenos Aires, Santiago, and Rio de Janeiro have experienced record-breaking heat waves, prompting governments and local authorities to implement heat action plans and public awareness campaigns. As climate change intensifies, addressing the impacts of heatwaves will be a crucial concern for LAC nations, requiring sustainable strategies to mitigate extreme weather events and protect their populations.

Based on the EM-DAT database, natural hazards and their impacts are unevenly distributed across the region's countries. Between 1990 and 2019, according to the CEPALSTAT database (https://estadisticas.cepal.org/), Latin American countries registered 1,220 events (90 per cent of the total). Mexico, Brazil and Colombia stand out, perhaps due to their locations, extensive territories, diversity of natural landscapes, large population contingents and the concentration in these countries of the region's largest economies and goods (Figure 1).

3.2 Climate projections

According to the IPCC Working Group 1 Assessment Report (IPCC, 2021), climate change leads to shifting rainfall patterns and rising temperatures. Some areas are experiencing changes in the frequency and severity of weather extremes, such as heavy rains. In Latin America, mean temperatures will continue to increase at rates greater than the global average (high confidence). Average rainfall is projected to change, with increases in North-West South America and South-East South America (high confidence). It decreases in North-East South America and South-West South America (medium confidence). The rise in relative sea level is extremely likely to continue in the oceans around Central and South America, contributing to increased coastal flooding in low-lying areas (high confidence) and shoreline retreat along most sandy coasts (high confidence).

Figure 2. Adapted from IPCC, 2021. Projected changes in annual mean temperature (T), annual total precipitation, annual maximum 5-day precipitation (RX5day) and annual consecutive dry days (CDD) at 1.5°C, and 2°C global warming relative to 1850– 1900.



4 Climate sensitive infectious diseases: burden and trends

4.1 Overview of diseases in the region

The region grapples with a heavy burden of infectious diseases, with high rates of communicable diseases, including HIV/AIDS, tuberculosis, water-borne diseases (cholera and other diarrheal diseases), and mosquito-borne diseases, including malaria, dengue, yellow fever, Zika, and others. Of the estimated worldwide burden of 56.6 million disability-adjusted life years (DALYs) caused by neglected tropical diseases (NTD), the LAC region shoulders 8.8 per cent of this burden.[6] The high burden of NTDs in the region is closely intertwined with poverty and inequality. Apart from nearly eradicating onchocerciasis (river blindness), there have been limited notable improvements in public health regarding NTDs.

While there have been some advances in the control of malaria, *trichuriasis*, and, to some extent, *ascariasis* across the region (except for Venezuela), the prevalence of hookworm diseases has only slightly decreased. Moreover, the prevalence of Chagas disease and *cysticercosis* has risen, with Chagas now endemic in 21 countries across the Americas, affecting an estimated 6 to 8 million people. *Leishmaniasis* has seen a significant increase in incident cases, and the emergence of Zika virus infection is a recent concern. It is crucial to emphasize that the LAC region appears to be stagnating in its efforts to control these diseases, making it a global “hotspot” for NTDs. Waterborne diseases exert a significant public health burden in the LAC region, with several major diseases contributing to this challenge. Cholera, for instance, remains a serious concern, with periodic outbreaks affecting the region. In 2010, the largest cholera outbreak in recent history erupted in Haiti, subsequently spreading to the Dominican Republic and other countries in LAC. Furthermore, predominantly caused by contaminated water sources, diarrheal diseases continue to cause morbidity and mortality in the region. According to the WHO, over 20 per cent of child deaths under five in LAC are attributed to diarrheal diseases, with an estimated annual death toll of around 30,000 children in this age group. Typhoid fever, dysentery, and other waterborne illnesses contribute to the region’s disease burden.

4.2 Priority climate-sensitive infectious diseases based on surveillance data

The distribution of climate-sensitive infectious diseases in the LAC region is characterized by considerable spatial heterogeneity. Certain countries report significantly more climate-sensitive infectious diseases than others. Notably, Brazil, Colombia, and Venezuela have high disease burdens. Figure 2 displays the spatial distribution of climate-sensitive diseases across different countries in the Latin American region. Each country is represented on the Y-axis, while climate-sensitive diseases are listed on the X-axis. Yellow dots indicate the presence of these diseases in the respective countries, while purple dots represent countries where these diseases are absent or where data is unavailable.

There are 12 climate-sensitive infectious diseases identified as highly concerning in LAC: Chagas, chikungunya, cholera, dengue, *leishmaniasis*, *lymphatic filariasis*, malaria, *onchocerciasis*, plague, *schistosomiasis*, yellow fever, and Zika. Dengue, Zika, and chikungunya, transmitted by the *Aedes* mosquito, have caused substantial outbreaks across most countries.

In contrast, diseases with significant disease burdens, such as malaria and *leishmaniasis*, exhibit a more localized distribution. While these diseases exhibit varying degrees of prevalence, it is worth noting that the **northern part of South American and Caribbean countries bear the brunt of the disease burden** (Figure 3, Figure 1 and Annex 1).

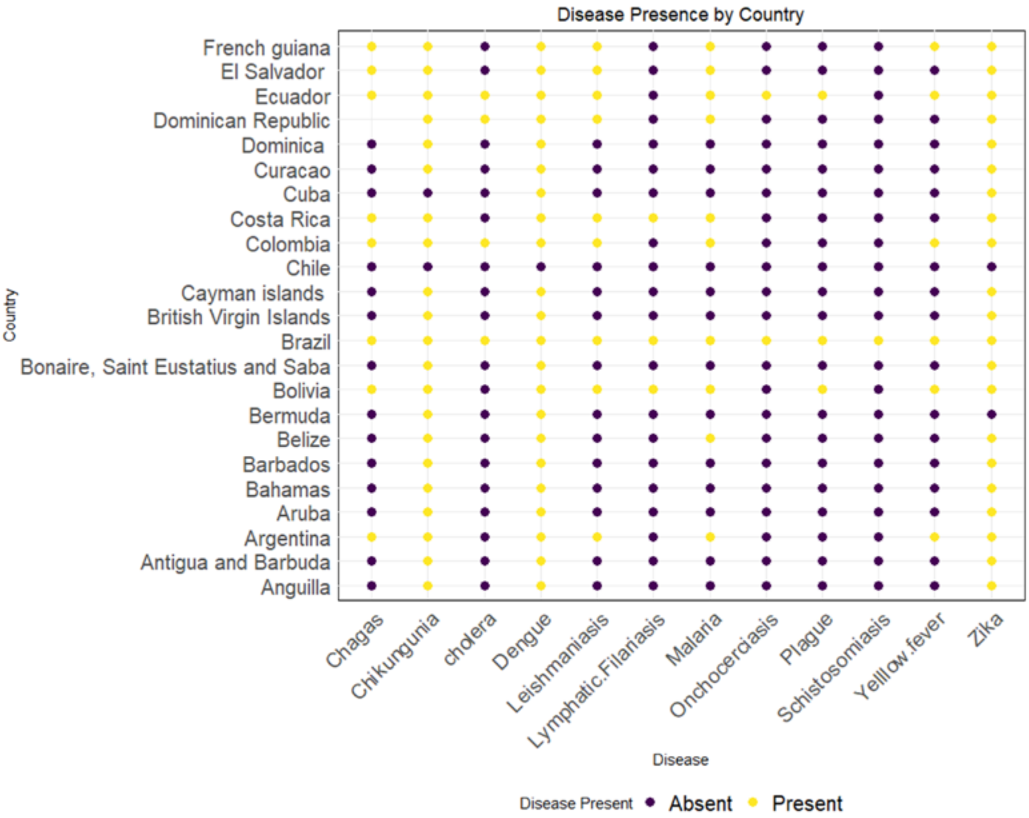
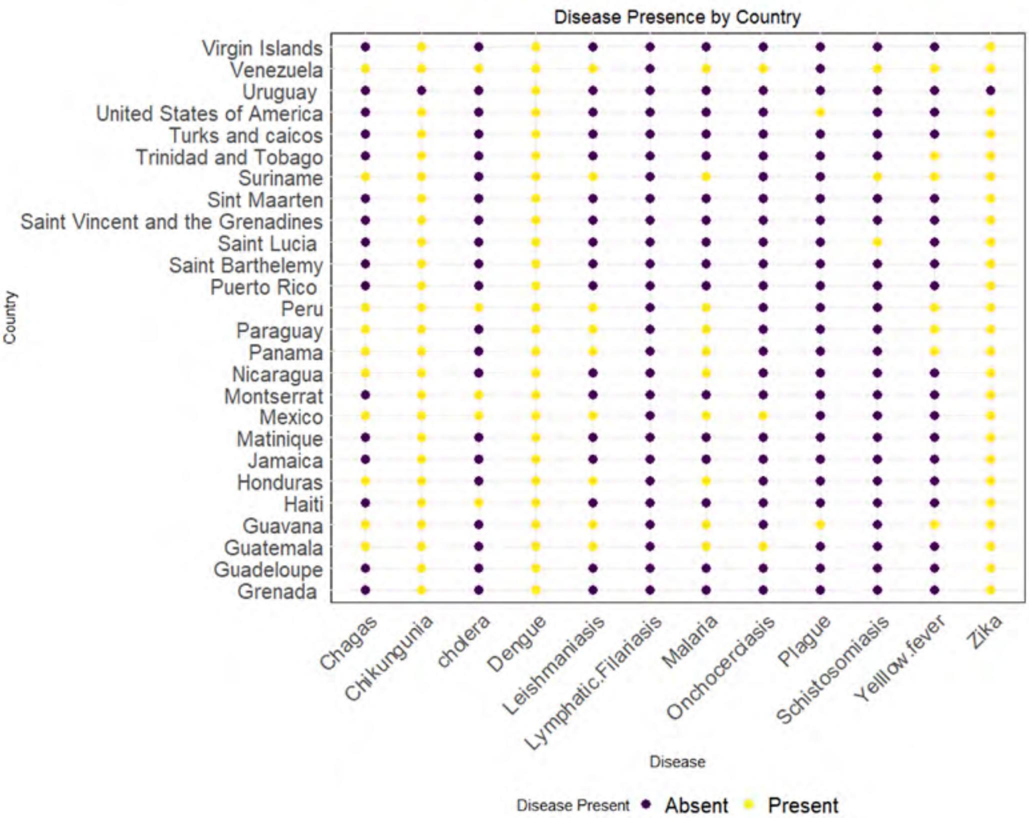


Figure 3. The figure displays the spatial distribution of climate-sensitive diseases across different countries in the region. Each country is represented on the Y-axis, while climate-sensitive diseases are listed on the X-axis. Yellow dots indicate the presence of these diseases in the respective countries, while purple dots represent countries where these diseases are absent.



The priority diseases in terms of prevalence include:

1. **Malaria:** In 2016, Brazil, Colombia, Peru and Venezuela collectively accounted for 80 per cent of the 875,000 malaria cases reported. Colombia experienced an increase in Plasmodium falciparum infections after the cessation of the World Malaria Programme in 2015. Despite past success, Brazil saw a resurgence in malaria cases in 2017. Peru witnessed a decline in malaria cases during a funded control programme from 2005-2010, but cases rose again by 2017. In Venezuela, following ongoing political and financial crises, malaria cases soared to 300,189 by the end of 2017.[6]

2. **Arboviruses (dengue,Zika and chikungunya):** Approximately 500 million people in the Americas are currently at risk of dengue, with the incidence increasing from 16.4 cases per 100,000 in the 1980s to 218.3 per 100,000 during the 2000-2010 decade.

3. **Leishmaniasis:** Another disease with a high prevalence in the region is *leishmaniasis*, which has three clinical forms: cutaneous, mucosal, and visceral. Cutaneous *leishmaniasis*, the most common form, affects 18 countries in the region, with Brazil, Colombia, Peru, Nicaragua, and Bolivia reporting 54,000 cases annually. Mucosal *leishmaniasis*, although rare, causes severe deformities. Visceral *leishmaniasis* is endemic in 13 countries, primarily Brazil, with around 3,500 cases per year[2] (Pan American Health Organization, 2022).

4. **Cholera:** Cholera prevalence in Latin America varies, and some countries are at a higher risk of outbreaks due to several factors. Haiti, the Dominican Republic and Mexico experience a higher risk of cholera. This heightened risk is often associated with inadequate sanitation, limited access to clean drinking water and population density. Cholera outbreaks can occur periodically, primarily in areas with contaminated water sources and limited access to healthcare services. Efforts to reduce the risk of cholera in Latin America have included improving sanitation infrastructure, ensuring access to clean water and public health education.

Given the high disease burden in the region and its strong correlation with climatic factors, addressing these diseases becomes a top priority.

4.3 Priority disease transmission pathways in connection with climatic and non-climatic hazards

The relationship between climate and health is complex, with climate being a critical determinant in disease emergence, distribution, and intensity. Understanding how climate hazards affect disease transmission in the region is crucial for developing effective public health strategies and mitigating the adverse effects of climate change on vulnerable populations. Our emphasis has been on diseases with the highest burden in LAC, such as vector-borne and water-borne diseases. These diseases reflect the critical public health issues facing the region and serve as instructive examples of how ecological mechanisms can significantly impact disease transmission, particularly under the influence of extreme climate events.

Climate variations contribute to the prevalence and distribution of vector-borne diseases in Latin America, a region known for its vulnerability to the impacts of climate change. Rising temperatures, changing rainfall patterns, and altered humidity levels create ideal conditions for disease vectors like mosquitoes and ticks to proliferate, spreading diseases such as dengue, Zika, Chikungunya, malaria, *leishmaniasis*, and yellow fever, mainly transmitted by *Aedes*, Anopheles, and sandfly vectors. The expansion of vector habitats to new altitudes and latitudes previously considered unsuitable exposes hitherto unaffected populations to the risk of infection. Additionally, extreme weather events, such as hurricanes and flooding, can disrupt water storage and sanitation systems, increasing breeding sites for disease vectors. Scientific research underscores these intricate relationships, emphasizing the need for proactive climate adaptation measures and robust vector control strategies to mitigate the impact of vector-borne diseases in Latin America.[7, 8, 9]

Climate change also substantially influences the prevalence and distribution of waterborne diseases. Altered rainfall patterns, increased temperatures and extreme weather events can significantly impact the availability and quality of water sources. Waterborne diseases, like for instance, cholera, leptospirosis and gastrointestinal infections, are closely tied to these climate variations. Extreme rainfall can overwhelm drainage infrastructure, exposing populations to contaminated water where diseases thrive.[10, 11]

Zoonotic diseases in Latin America are increasingly impacted by climate change. Climate-related shifts, such as altered precipitation patterns and rising temperatures, can significantly influence the distribution and behaviour of disease vectors and animal hosts, leading to changes in the prevalence and geographic range of zoonotic diseases. For example, vector-borne diseases, including dengue and Chagas disease, have expanded their transmission zones due to these climate-related alterations (Kovats *et al.*, 2003; Gubler, 2004). Climate change can also contribute to ecological disturbances, such as deforestation and habitat destruction, which bring humans closer to wildlife and potentially increase the risk of zoonotic disease spillover (Daszak *et al.*, 2001). Addressing the complex nexus between climate change and zoonotic diseases in Latin America requires a multi-disciplinary approach incorporating climate adaptation strategies, improved disease surveillance and public health interventions.

Our comprehensive review has identified dengue, malaria, yellow fever, and *leishmaniasis* – the climate-sensitive diseases with the highest-burden – as LAC's most significant vector-transmitted diseases. Additionally, cholera has emerged as a notable issue in specific Caribbean countries such as Haiti, Mexico, and Dominican Republic. This assessment is further corroborated by insights obtained during interviews, where 80 per cent of respondents cited dengue and malaria as their top priorities. These findings underscore the urgency and consensus surrounding the need for targeted interventions and strategic planning to address these prevalent health challenges. The collective acknowledgment of these priorities strengthens our commitment to developing effective measures to combat the spread of these diseases and promoting more resilient and healthier communities in the LAC region.

Box 1: Climatic drivers of malaria transmission

Extreme temperatures have a significant impact on malaria transmission dynamics. It has been shown that elevated temperatures facilitate the development and transmission of the malaria parasite, Plasmodium, within Anopheles mosquito vector.[12] The literature show a shorter incubation periods and an increased likelihood of successful transmission to humans are dependent on the temperature. Warmer temperatures also extend the mosquito's lifespan and enhance its feeding frequency, leading to higher malaria transmission rates[13] (Mordecai *et al.*, 2013). Conversely, extreme cold temperatures can limit malaria transmission by hindering mosquito survival and activity. In Latin America, regions with tropical climates, such as the Amazon Basin, have experienced heightened malaria transmission due to the conducive environment created by rising temperatures.[14] In contrast, high-altitude areas, including the Andes, have traditionally experienced lower malaria transmission, partly due to cooler temperatures restricting mosquito activity.[15] However, changing climate patterns, exemplified in highland regions of South America, can expand the areas suitable for malaria transmission.[16]

Flooding events notably impact malaria transmission, especially in regions prone to heavy rainfall and malaria vectors. Flooding can exacerbate malaria transmission dynamics through several mechanisms. Stagnant water bodies serve as ideal breeding sites for Anopheles mosquitoes, the primary vectors of malaria.[17] Prolonged water accumulation after floods provides abundant opportunities for mosquito breeding, increasing vector populations. Furthermore, floods often lead to population displacement, causing overcrowding in temporary shelters or settlements, where people may lack access to effective malaria prevention measures, such as insecticide-treated bed nets or proper housing.[18] These conditions can contribute to a rapid increase in malaria transmission. Following flooding events in Peru, Colombia and Brazil, malaria transmission soared. The floods led to the expansion of mosquito breeding sites and increased population movement, resulting in a surge of reported malaria cases.[19,20] Recognizing the interplay between flooding and malaria transmission is essential for the timely implementation of public health responses and mitigation strategies in flood-prone areas.

Droughts, characterised by extended periods of water scarcity, also affect malaria transmission. While excessive rainfall often promotes the breeding of malaria vectors, droughts affect the dynamics of the disease. During droughts, reducing standing water availability can limit Anopheles mosquitoes' breeding habitats, potentially decreasing vector populations.[21] However, the impact of droughts on malaria transmission is more complex. Reduced water resources may force communities to store water in containers, and if not adequately covered or treated, these containers can become ideal breeding sites for mosquitoes.[22] In Latin America, regions such as the semi-arid areas of northeast Brazil, have experienced fluctuations in malaria transmission during drought periods. In these areas, limited rainfall can lead to decreased vector breeding sites. Yet, storing water in containers during droughts can inadvertently increase local mosquito populations and the risk of malaria transmission.[23]

Box 2: Climatic drivers of arboviral diseases (dengue, Zika, Chikungunya)

Extreme temperatures play a critical role in the transmission dynamics of the dengue virus, a mosquito-borne arbovirus that poses a significant public health threat. Higher temperatures, often associated with climate change, can accelerate the life cycle of *Aedes aegypti* and *Aedes albopictus* mosquitoes, the primary vectors of dengue. Elevated temperatures promote faster mosquito development, shorter virus incubation periods and increased mosquito activity, which collectively lead to more efficient dengue transmission.[24] In Latin America, where dengue is endemic, countries like Brazil, Mexico and Colombia have experienced intensified dengue outbreaks during periods of extreme heat, highlighting the influence of temperature on disease dynamics.[25,26,27,28] Rising temperatures due to climate change have expanded the geographical range of *Aedes* mosquitoes and have increased dengue incidence in previously unaffected regions, underscoring the importance of temperature as a key driver of dengue transmission.[29] Elevated temperatures can enhance the mosquito's reproductive rates and shorten the extrinsic incubation period, potentially leading to increased viral replication and transmission.[30] In Latin America, where yellow fever remains a concern, temperature fluctuations can have significant effects on disease dynamics. For example, during periods of extreme heat and drought, regions in Brazil, particularly in the Amazon basin, have experienced more intense yellow fever outbreaks.[31] The expectation of an increase in extreme precipitation events because of global warming poses significant implications for infectious diseases. In particular, we know that heavy rainfall has an impact on infectious diseases, and that outbreaks of certain vector-borne diseases are often associated with flooding. Despite this understanding, the relationships between flooding and vector-borne diseases remain contentious and require further clarification.[32,33]

Higher temperatures can accelerate the reproductive and feeding rates of these mosquito vectors, leading to an increased potential for viral transmission.[34] In Latin America, regions with tropical and subtropical climates are particularly vulnerable to the effects of rising temperatures. For instance, during the outbreak of the Zika virus in Brazil in 2015 and 2016, elevated temperatures created favourable conditions for *Aedes* mosquitoes, contributing to the rapid spread of the virus.[35,36] Droughts, characterized by prolonged periods of water scarcity, can also influence the transmission of dengue, a mosquito-borne viral disease. While droughts often lead to reduced water availability, potentially limiting the breeding sites for *Aedes aegypt*i mosquitoes (the primary vectors of dengue) can also have unintended consequences. Drought-induced water storage practices, such as the collection of water in containers, often create new breeding sites for mosquitoes in and around households.[37] In Latin America, countries like Brazil and Mexico have witnessed dengue outbreaks in regions affected by droughts due to these container-breeding mosquitoes, which can thrive even during water scarcity.[38,39,40] Flooding events can have a substantial impact on the transmission of dengue, a mosquito-borne viral disease. These events also create optimal conditions for the proliferation of the other dengue vector *Aedes albopictus* mosquitoes, as they provide abundant breeding sites in the form of stagnant water pools outside of the households in parks and residuals abandoned on the streets. Prolonged flooding can also lead to displacement and crowded temporary shelters or settlements with inadequate sanitation, creating ideal environments for dengue transmission.[41] In Latin America, countries like Brazil and Mexico, have witnessed dengue outbreaks following severe flooding events. For instance, heavy rainfall and subsequent flooding in the north-eastern region of Brazil have increased dengue cases due to the expansion of mosquito breeding sites.[42]

Box 3: Climatic drivers of *leishmaniasis*

Extreme heat, often associated with climate change, can impact the transmission of *leishmaniasis*, a vector-borne disease caused by Leishmania parasites and transmitted by sandflies. Elevated temperatures can directly affect the sandfly vectors' life cycle, development and activity, potentially accelerating disease transmission.[43] In Latin America, where *leishmaniasis* is endemic, regions with high temperatures have been linked to increased disease incidence. For example, in the arid regions of northeastern Brazil, rising temperatures have expanded the geographic range of sandflies, leading to higher *leishmaniasis* transmission.[44,45]

Floods can significantly influence the transmission of *leishmaniasis*, a parasitic disease transmitted by sandfly vectors. The inundation of habitats during floods can lead to the displacement and migration of human and animal reservoir hosts, bringing them closer to sandfly breeding sites.[46] This increased interaction can facilitate the transmission of Leishmania parasites from reservoir hosts to sandflies and subsequently to humans. In Latin America, countries such as Brazil and Peru, have reported higher rates of *leishmaniasis* following flood events. For example, in the Amazon region of Brazil, the flooding of riverbanks and increased human displacement during extreme rainfall events have been associated with higher *leishmaniasis* incidence.[47]

Box 4: Climatic drivers of Cholera

Extreme heat events can exacerbate the growth of Vibrio cholerae, the bacterium responsible for cholera, in aquatic environments. Warmer temperatures can increase the abundance of these pathogens, making it more likely for cholera to spread through contaminated water sources.[48] While not as extensively documented as flooding-related cholera outbreaks, the risk of heat-related cholera cases are growing. As temperatures rise due to climate change, especially in regions with inadequate sanitation and access to clean water, the risk of cholera transmission may increase.[49]

The association between droughts and cholera in Latin America is a pressing concern influenced by climate variability and its effects on water and sanitation systems. Prolonged droughts can lead to water scarcity and reduced water quality, increasing the risk of cholera outbreaks. A notable example is the case of the drought in Haiti in 2015, followed by a surge in cholera cases due to inadequate access to clean water and proper sanitation facilities.[50] Droughts can also force communities to rely on unsafe water sources, further amplifying the risk. Mechanisms involve compromised water quality and the concentration of Vibrio cholerae 10.[50]

4.4 Definition of at-risk groups

By examining historical data, modeling disease vectors' behaviour, and assessing the environmental factors influencing disease prevalence, we sought to identify key drivers of disease transmission in the face of changing climate patterns. Our research was guided by the recognition that understanding these mechanistic relationships is pivotal for devising informed and effective strategies to mitigate the health impacts of climate change. Through our analysis, we uncovered critical insights that will advance our comprehension of these complex dynamics and inform future interventions aimed at safeguarding the health and well-being of communities across the region (Annex 2).

To facilitate a systematic examination of the intricate connections between climate hazards and disease transmission in Latin America, we created a comprehensive table. This table is valuable for identifying the potential relationships between climate hazards and disease transmission, highlighting the associated climate drivers, and elucidating the modulating non-climate factors. Through this structured approach, we aim to capture the multifaceted web of variables that influence the dynamics of climate-sensitive diseases, providing a clear framework for analyzing the interplay of environmental and socio-economic factors on disease transmission in the context of changing climate patterns. Table 1 (see below) shows a holistic understanding of these complex relationships, laying the groundwork for more targeted and effective regional public health strategies.

Disease	Vulnerable Populations	Optimal Ecological Conditions	Estimated Regional Burden (Year)	Non-Climatic Drivers	Reference
Malaria	Children under 5 years of age, pregnant women, low-income rural communities	High temperatures, rainfall, humidity	0.9 million cases (2019)	Socioeconomic factors, access to healthcare, policies	WHO *World malaria Report* 2020.
Dengue	Urban areas, low-income communities, population WASH services	Standing water in containers, high mosquito density	6.6 million cases (2009)	Rapid Urbanisation, travel and trade	First WHO report on neglected tropical diseases, 2010.
Zika	Pregnant women, areas with *Aedes* mosquitoes, low-income communities	Warm and humid conditions	Variable (e.g., 2015-2016)	Sexual transmission, travel-related cases	WHO Zika Virus factsheet, 2017.
Chikungunya	Regions with *Aedes* mosquitoes, travellers	Warm and humid conditions, *Aedes* presence	Variable (e.g., 2004, 2014)	Travel and trade, human movement	Weaver and Lecuit, 2015
Yellow Fever	Forested regions, non-immunized populations	*Aedes* or *Haemagogus* mosquitoes, forests	Variable (outbreaks)	Vaccination coverage, global health infrastructure	WHO Yellow Fever factsheet, 2017.
Leishmaniasis	Rural communities, immunocompromised	Sandy or loamy soils, sandfly vectors	104,445 cases (CL/ML + VL cases) (2016)	Socioeconomic factors, conflict, migration	WHO *Leismaniasis* factsheet. PAHO/WHO. *Leishmaniasis Epidemiological Report of the Americas*, 2018.
Chagas disease	Rural and impoverished communities	Triatomine bugs, mud walls, thatched roofs	6 million cases (2017)	Housing condi-tions, vector con-trol, healthcare access	WHO Chagas disease fact sheet. PAHO/WHO. *Health in the Americas+, 2017 Edition.*
Cholera	Rural communities, periurban slums and refugee camps	Increased salinity of water, together with increased rainfall and poor sanitation	42,581 cases (2016)	Socioeconomic factors	WHO – Cholera Dashboard

Table 1. Summary table of risk factors for the most prevalent climate diseases in the LAC Region

Malaria, dengue, yellow fever, and *leishmaniasis* each present distinct risk profiles that can vary from urban to rural populations, as well as among non-immunized populations and those who are immunocompromised. For instance, malaria tends to be more prevalent in rural and resource-constrained settings, where populations may have limited access to preventive measures such as bed nets and antimalarial treatments. In contrast, dengue often thrives in urban areas due to the presence of the *Aedes* mosquito, which breeds in artificial containers found in densely populated regions. Yellow fever transmission occurs in urban and sylvatic cycles, posing risks to different populations. Finally, *leishmaniasis* is often associated with rural and forested environments, particularly affecting individuals with compromised immune systems. Understanding these diverse risk profiles is essential for effectively tailoring public health interventions and control strategies.

4.5 Possible future climate-sensitive infectious disease trends

Predicting how climate change will affect climate-sensitive infectious diseases is challenging, as many uncertainties exist. First, how the climate will change depends on the aggressiveness of human actions to reduce greenhouse gas emissions. Second, predictions will need to consider changes in non-climate drivers, which are highly uncertain. Based on available evidence in the literature, the following have been identified as possible future trends for the priority diseases identified:

- Climate change may play a role in the risk of pathogen spillover. Changing environmental conditions can alter species' range and density, leading to novel interactions between species and increasing the risk of zoonotic emergence.
- Climate change affects significantly more vulnerable and economically deprived communities, implying higher exposure and, ultimately, a risk of more pronounced outbreaks in countries with higher disparities, such as the LAC region.
- We expect climatic shifts to create a more favourable environment for the transmission of various infectious diseases, not only by directly influencing the biological characteristics of pathogens, such as their growth, survival, and virulence, but also by impacting the behaviour and distribution of disease vectors.
- Climate change will indirectly facilitate disease transmission through ecosystem alterations and human behaviour shifts. These multifaceted interactions underscore the complex and dynamic nature of the relationship between climate change and infectious diseases, requiring proactive strategies for disease surveillance, prevention, and adaptation to mitigate the evolving health risks associated with a changing climate.

5 Defining priorities for climate-sensitive infectious diseases based on interviews

Through our interviews with stakeholders, we discovered that while most activities within the climate-sensitive infectious diseases (CSID) initiative are geared towards tackling dengue, malaria, yellow fever and *leishmaniasis* in the LAC region, it is imperative to acknowledge the broader scope revealed in our studies (See Appendix 1). Our findings highlight specific diseases like leptospirosis in Argentina, cholera in Haiti and Chagas disease in Brazil as additional concerns. The recognition and proactive addressing of these diverse health challenges underscore the comprehensive nature of our efforts. By integrating a broader spectrum of diseases into our initiatives, our goal is to reinforce our approach to public health, ensuring a more holistic and effective response to the diverse infectious diseases prevalent in the region.

The interviews underscore the significance of vector-borne and waterborne diseases as paramount concerns in the LAC region. Particularly noteworthy is the high prevalence of dengue in both South America and the Caribbean. The interviews also revealed a consensus on the critical importance of addressing and mitigating the impact of dengue, prompting various concerted efforts across the region. Notably, there is a discernible focus on developing predictive frameworks for dengue, showcasing a proactive approach to anticipate and respond to potential outbreaks. These collaborative efforts demonstrate a collective commitment to advancing public health strategies aimed at curbing the spread of vector-borne diseases and enhancing preparedness for the associated challenges in the LAC region.

5.1 Challenges and limitations of early warning systems (EWS)

EWS implemented in the LAC region exhibit several limitations that impact their effectiveness:

1. These systems can sometimes only make predictions at small spatial units, hindering their precision at a local level, given the noise in the datasets.

2. The requirement for weekly data inputs for operational forecasting poses a challenge, making it less adaptable to real-time monitoring.

3. The pragmatic and helpful nature of the tool for detecting imminent outbreaks may be compromised by its susceptibility to inconsistent and missing data, particularly concerning entomological indices.

Existing predictive models heavily rely on a rich dataset of georeferenced case identifications, which needs regular updates, and adapting it requires pre-adjustments to the grid used in different geographical areas. Furthermore, these EWS are limited in scope, focusing primarily on climatic factors, and underreporting cases can compromise their accuracy. An extended data history is a prerequisite for evaluation, and a sophisticated analysis requires a skilled user. Factors, including population immunity and specific health interventions, may not adequately capture the temporal variability in case counts. Additionally, the unavailability of data at the district level and the lack of site-specific information poses significant challenges, limiting the system's granularity and applicability in addressing localized health threats effectively.

5.2 Potential triggers and lead times in the region

Methodological approaches in forecasting climate-sensitive diseases, dengue for example, use diverse datasets comprising surveillance data, hospital notifications, laboratory results and climatic variables. The integration of these datasets allows predictions of various disease dynamics, including transmission patterns, severity, and environmental impacts. Each dataset contributes unique insights, enhancing overall predictive capability. Predictions have varying lead times, with short-term forecasts informing immediate public health responses and longer-term projections aiding strategic resource planning. This comprehensive approach ensures a nuanced understanding of climate-disease interactions, facilitating effective and timely responses to mitigate the impact of climate-sensitive diseases.

5.2.1 Epidemiological data

The predominant data sources for epidemic forecasting, particularly concerning diseases such as dengue, include surveillance, hospital notification, and laboratory data. Surveillance data captures the overall disease trends and distribution within a population, while hospital notification data provides insights into the severity of cases and the impact on healthcare facilities. Laboratory data derived from diagnostic testing helps confirm cases and understand the specific strains of the virus. Integrating these diverse data types is crucial for developing comprehensive and accurate forecasting models, enhancing our ability to predict and respond to the dynamics of the epidemic effectively.

5.2.2 Climate predictors

Climate-sensitive disease models depend on various climatic predictors for accurate predictions. These include temperature data (minimum, maximum, mean), rainfall data, and humidity data. Commonly used drought indicators contribute to model precision, such as the *Standardized Precipitation Evapotranspiration Index* and the *Palmer Drought Severity Index*. The models also consider climate phenomena, for instance, El Niño and La Niña, incorporating indices such as the *Southern Oscillation Index* and the *Oceanic Niño Index*. This comprehensive integration of diverse climate predictors improves the understanding of the complex interplay between climate factors and disease transmission dynamics, ultimately elevating the accuracy of forecasting models.

5.2.3 Prediction targets (Triggers)

Various methodological approaches are employed to predict essential epidemiological quantities for a specific transmission season, typically spanning 12 months starting from the location-specific historical lowest incidence week. These approaches focus on forecasting the overall cases, outbreaks, and incidences and on crucial indicators that define the transmission season. Key targets include:

1. The timing of peak incidence, signifying the week during the transmission season when the highest incidence of dengue is expected to occur.

2. The maximum weekly incidence, representing the peak number of reported dengue cases in a single week.

3. The total number of cases in a transmission season, encompassing the cumulative count of dengue cases, whether confirmed or suspected, reported throughout the entire transmission season.

4. LTS stands for 'Length of Transmission Season,' representing the number of suitable transmission months per year for a particular infectious disease or vector-borne pathogen. This metric is crucial in understanding the temporal patterns of disease transmission. It is often used in epidemiological studies to assess the risk and prevalence of diseases influenced by climate and environmental factors.

5. PAR stands for "Potential Annual Recurrence" and represents the total population in a grid cell with at least one suitable month for disease transmission within the same year.

These targeted forecasts provide comprehensive insights into the dynamics and impact of the dengue transmission season, facilitating effective public health planning and response strategies.

5.3 Lead times experiences

Forecasting dengue outbreaks involves employing mathematical and time series models to provide predictions with lead times ranging from 2-3 weeks and up to 1-5 months. The shorter lead times offer a limited window for immediate reactive interventions, enabling local authorities to deploy timely responses to unavoidable outbreaks. On the other hand, longer lead times, such as predictors at 1-5 months lag, allow for a more extended forecast lead time. These methods usually involve statistical approaches that use climate predictors to generate predictions. This extended window enables local authorities to implement proactive measures to prevent or minimize the scale of an impending outbreak. Using different lead times in dengue forecasting supports various response options, contributing to more effective and targeted public health interventions.

5.4 Disease Risk Prediction Models

As part of the literature review to map the existing EWS in the region, 124 peer-reviewed studies were retrieved. Most studies focused on only a few countries in the LAC region. Brazil, the largest nation in the area, had 32 studies emphasizing its essential role in advancing the disease EWS. Mexico and Colombia follow closely behind with 15 and 13 studies, respectively, on vector-borne diseases, such as dengue, malaria, chikungunya, and Zika, as well as diseases attributable to *Aedes Aegypti*. We identified 20 studies that employed innovative prediction models and techniques. These findings suggest that these indicators can be used as triggers for anticipatory action mechanisms tailored for epidemic control and response. Notably, disease incidence was the most predicted variable (n=6), followed by the number of cases (n=3), geographical distribution (n=2), and disease transmission (n=2). A review of existing risk prediction models for climate-sensitive infectious diseases identified 29 products developed in LAC countries, focusing on vector-borne diseases such as malaria, dengue, yellow fever, Chagas, Zika, chikungunya, and *leishmaniasis*.

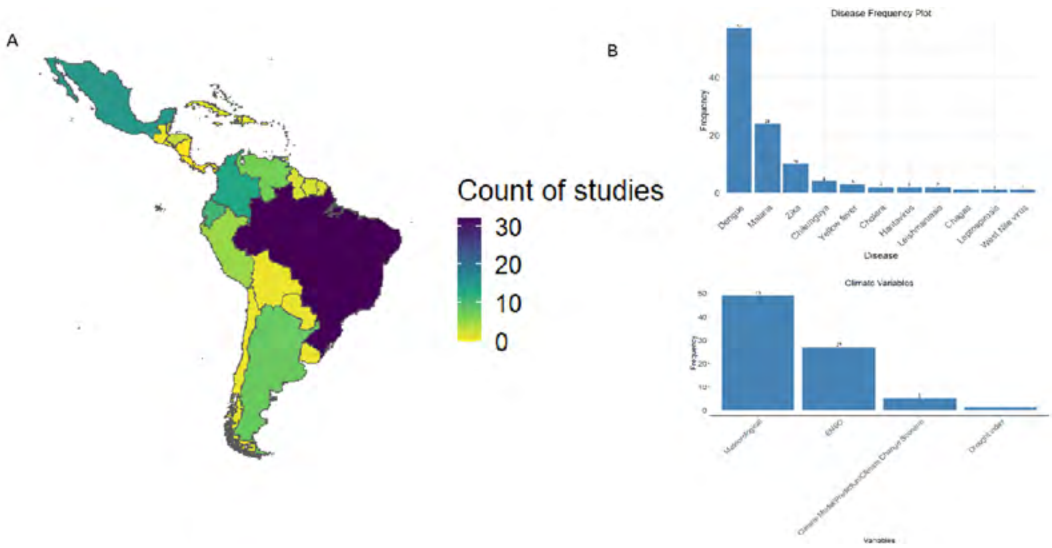


Figure 4. A) Geographic focus and climate variables in the systematic review. B) Top plot: distribution of studies by countries in the systematic review, highlighting the number of studies dedicated to each disease. Bottom plot depicts the climate variables employed in various studies to investigate disease outbreaks.

Figure 5. Geographic distribution of studies emphasizing the development of novel prediction models and methods. This figure displays the spatial distribution of studies that concentrate on developing new prediction models and methods, with geographical areas emphasized according to the number of relevant studies in each region.

6 Existing epidemic preparedness actions

6.1 Regional epidemic preparedness activities identification

Several regional health initiatives are addressing evolving health challenges. The Global Health Security Agenda is a global effort involving international organizations, non-governmental stakeholders, and over 50 countries, focusing on building capacity to prevent, detect and respond to infectious diseases. In 2019, Pan American Health Organization Member States approved the Disease Elimination Initiative, targeting over 30 infectious diseases in the Americas by 2030. HEARTS in the Americas integrates global best practices to prevent and control cardiovascular diseases, emphasizing primary health care. IMS-dengue is a management model that reduces morbidity, mortality, and the economic burden of dengue outbreaks. The WHO's Global Arbovirus Initiative, launched in 2022, aims to develop a risk monitoring tool for global risk assessment, strengthen vector control, and reduce arbovirus risk at local, regional, and national levels by reviewing spatial risk drivers.

We have identified countries with robust data and epidemic analytic capacities to anticipate and predict diseases. One notable example is Brazil, where institutions like Fiocruz host sophisticated systems such as Info Dengue and Info Gripe. These platforms demonstrate established analytics and prediction mechanisms to monitor and forecast disease trends. By leveraging advanced technologies and analytical frameworks, Brazil exemplifies a proactive stance in anticipating and responding to epidemics. This strategic approach, presented by Info Dengue and Info Gripe, reflects a commitment to harnessing data-driven insights for effective epidemic preparedness and management.

Several countries in LAC have established EWS to monitor and respond to disease outbreaks. In the Dominican Republic, Barbados, Colombia, Peru, Cuba, Ecuador, Brazil, Argentina, and Mexico, dedicated EWS have been implemented. These systems focus on diseases such as dengue, malaria, Chagas, and leptospirosis. By employing advanced surveillance and monitoring techniques, these countries aim to swiftly detect and address health threats, enhancing their capacity for early response and effective management of diseases. These proactive measures contribute to the overall health resilience of these nations and underscore their commitment to public health and community well-being.

All the countries mentioned above prioritized the establishment of EWS to address and manage disease outbreaks proactively. In the Dominican Republic and Barbados, dedicated EWS focused on dengue, while Colombia monitors malaria and dengue through its EWS. Peru similarly addresses malaria and dengue, while Cuba concentrates on dengue. Ecuador has implemented an early warning system specifically targeting malaria. Brazil stands out with a comprehensive approach, covering dengue, malaria, and Chagas in its early warning initiatives. Argentina's system is designed to detect and respond to leptospirosis and dengue, while Mexico focuses on dengue. These EWS collectively reflect the region's commitment to public health preparedness, emphasizing the importance of timely detection and intervention to mitigate the impact of infectious diseases.

Results from a study by Batista *et al.* (2023) suggest that climatic events strongly drive leptospirosis incidence, although the association was weaker in Santa Fe than in Entre Ríos. Furthermore, this study highlights how risk models could be used as prediction tools in an early warning system by utilizing the predictive power of long-lead ENSO predictors and short-lead local climate predictors to determine the risk of leptospirosis outbreaks.

6.2 Regional epidemic early action activities identification

6.2.1 Water sanitation and hygiene (WASH) and actions related to vector and waterborne diseases.

Based on our identified key informants and literature review, we have identified the following WASH and waterborne disease-related actions:

- identify potential water sources at evacuation sites and install community water points. E.g., "*In times of crisis, access to clean water is not just a necessity; it's a fundamental right that underpins the health and resilience of our communities.*"

- conduct community sensitization on water, sanitation, proper hygiene practices, and health to prevent waterborne diseases. E.g., "*Education is our first line of defense against waterborne diseases, and promoting awareness fosters a healthier and more resilient community (NS Honduras).*"

- Contribute to a thorough assessment of the WASH situation in designated communities. *"Given the local nature of the National Societies activities, we can provide invaluable insights that lead to a more accurate and comprehensive understanding of WASH challenges and importance (NS Ecuador)."*

- Promote training of the local population to use the selected purification method.

- Supply water resources, including jerry cans, water purification tablets, drinking water bottles, and soaps

- conduct educational sessions on the importance of purified water and the proper use of water-related tools. E.g., *"There is an urgency for empowering communities with knowledge on water purification and responsible water usage, which is key to fostering a healthier and more resilient population (NS Guatemala)."*

- operationalise the distribution of water filters to mitigate diseases caused by contaminated water

- appoint personnel (WASH officers) to oversee sanitation and hygiene activities in targeted communities, focusing on reducing disease risks. E.g., *"Having dedicated individuals focusing on these aspects is instrumental in reducing disease risks and promoting the overall health and well-being of the community (NS Argentina)."*

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6.2.2 Community-based actions for disease prevention and health promotion

Based on interviews and expert knowledge, the following actions have been identified to strengthen the control efforts for infectious diseases in the LAC region:

- conduct comprehensive community information sessions on vector control measures. e.g., *"Empowering communities with knowledge of effective vector control is paramount in safeguarding public health and fostering a proactive approach towards disease prevention (NS Honduras)."*

- design and disseminate informative materials for health promotion and vector control strategies, including crucial messages to combat waterborne and vector-borne diseases.

- train volunteers in the post-flood disease care protocol outlined in the Contingency Plan against Epidemics. *"I consider that equipping volunteers with specific protocols will ensure a swift and coordinated response, essential in mitigating the health impacts following floods and other emergencies NS Colombia."*

- evaluate household-level vector control methods, including repellent, mosquito nets, and fumigation. E.g., *"Given Central America's unique environmental and socio-economic cultural context, assessing the effectiveness of measures like repellents, mosquito nets, and fumigation at the household level is critical for tailoring interventions that resonate with the specific background in our communities."*

- conduct training sessions on vector control and prevention for various stakeholders engaged in Disaster Response Emergency Fund (DREF) activities

- carry out community-based clean-up campaigns to identify and eliminate potential breeding sites for disease vectors, focusing on collecting and removing items, such as plastic bottles, wrappers and open receptacles. E.g., *"A 30-second public service announcement could be broadcast on local television to convey essential messages on dengue, malaria, and cholera prevention."*

- organize educational sessions and communication campaigns for community leaders, adults and school children to raise awareness about dengue prevention

- include a comprehensive neighbourhood walk-through during Community Mobilization Days to spray insecticides and destroy mosquito breeding sites

- spread awareness through a social media campaign about preventing dengue and malaria (or other infectious diseases).

6.2.3 Operational risk actions related to diseases

Below is a set of operational risk actions related to diseases identified by key informants in Latin America and the Caribbean (LAC):

- strict use of personal protection equipment (such as impregnated mosquito nets and repellent) for volunteers and personnel supporting the operation
- distribute personal protective equipment to volunteers involved in the operation
- conduct community talks on biosecurity measures and distribute disease prevention kits including mosquito nets and repellents
- disseminate Information, education, and communication (IEC) materials focused on disease prevention and community-based epidemic control, emphasizing dengue and other vector-borne and waterborne diseases
- implement vector control measures by inspecting containers during home visits that could serve as mosquito breeding sites, with 16 per cent identified as positive and subsequently eliminated
- purchasing and distributing personal protection supplies, home vector control supplies, hygiene kits, drinking water, and water purification tablets
- produce and distribute promotional materials such as brochures, posters, and printed reusable bags, all carrying key infectious disease prevention messages. Billboards and public vehicle banners could also be utilized for dissemination.
- distribute essential items to communities, including long-lasting insecticidal nets (one per family), community cleaning kits with tools and gloves, and repellents (one per family).
- I. E.g., *" We should be able to effectively distribute brochures and infographics detailing the identification of dengue signs and symptoms and preventive measures could be proactively distributed to educate the community."*
- II. E.g *"WhatsApp stickers could be created for teachers to share with students, enhancing awareness at younger ages."*
- III. E.g., *"An 'Anti-Dengue School Kit' could be created and distributed to first and second graders. This kit should include critical messages and surveys to assess the level of risk in children's homes."*
- IV. E.g., *"Window screens could be supplied and installed at health centres lacking them to prevent mosquitoes from entering."*

- provide solid waste management kits to communities and at schools alongside dengue prevention events

- distribute kits to protect and prevent the spread of vector-borne diseases. E.g., *"We can increase the distribution of 'untadita kits' as part of the 'chlorine spread, tanks properly sealed' campaign to ensure the proper storage of water and prevent the spread of vector-related diseases."*

6.2.4 Surveillance systems

Many countries conduct disease surveillance to track high burdens, detect outbreaks, and monitor progress in controlling endemic diseases. In general, we found that the effectiveness of health surveillance systems varies within and between countries, requiring continuous efforts to strengthen these systems and address emerging health challenges. Below are more specific actions identified by our key informants:

- conduct disease surveillance to track high burdens, detect outbreaks, and monitor progress in controlling endemic diseases.

- define surveillance methods based on each country's unique infectious disease threats and response history

- deploy surveillance activities primarily run by disease control programmes, with varying levels of effectiveness and support. National Societies can contribute significantly to ensuring that surveillance remains interconnected and effective. Their assistance is vital in preventing the fragmentation of surveillance efforts. E.g., *"By actively collaborating with local health authorities, fostering information-sharing networks, and implementing standardised reporting protocols, National Societies play a key role in maintaining a cohesive surveillance system."*

- authorities, such as the Ministry of Health, institutes of health, and health secretaries, typically collect national infectious disease data. Encourage other institutions, the private sector, and NGOs to also conduct surveillance in the health sector, often with external donor support.

- deploy support from National Societies to detect cases using active surveillance during crises. Countries in Latin America, such as Brazil, Colombia, and Mexico, have established effective health surveillance systems known for robust infrastructure tracking infectious diseases, including Zika and dengue, but others would benefit from greater support from National Societies.

- strengthen epidemiological surveillance complemented by community-based surveillance actions for acute infectious diseases, including vector-borne diseases, diarrheal diseases, and respiratory febrile diseases. This comprehensive approach involves leveraging a volunteer network and targeting 61 per cent of the communities for intervention. This initiative aims to enhance the monitoring, detection, and response to infectious diseases, particularly those significantly impacting public health.

- continue carrying out fumigation sessions. Those sessions have been carried out with the collaborative support of community volunteers, health volunteers, and the naval base. They include disseminating crucial information on dengue prevention actions and educational materials addressing ways to reduce or eliminate vector-borne diseases.

6.2.5 Capacity Building:

- Health personnel training: First and second-level health personnel receive training in the clinical management of dengue to enhance their competence. E.g., *"Training our frontline healthcare providers is essential to enhance their competence in diagnosing and managing dengue cases effectively, ultimately improving patient outcomes and reducing the disease burden."*

- Community volunteer training: Health personnel and community volunteers are trained in timely case identification and referral. A community-based surveillance form is used to record personal data and larval indices.

- Support to the Ministry of Health: The Ministry of Health can receive assistance for vector control, including fumigation, larviciding, collecting samples, and raising awareness.

- Technical training can be provided to National Societies to identify vulnerable populations in hard-to-reach areas and provide treatment for suspected dengue cases.

- Explore regional training opportunities that the Climate Centre or IFRC offers on the intersection of climate and health and effectively integrate these aspects into operational pipelines.

7 Challenges and opportunities: anticipatory action for epidemics

7.1 Challenges and barriers

We interviewed key stakeholders from the different National Societies in Latin America and documented the results. The interviews aimed to characterize the main challenges, approaches and needs, providing insights into the challenges and barriers encountered while implementing various initiatives. Additionally, this process helped prioritize the actions already identified. Engaging with stakeholders in the field, we gathered valuable information and perspectives, contributing to a comprehensive understanding of the evolving landscape of health-related interventions and strategies in the region. It was a crucial step in our research, enabling us to refine our analysis and provide meaningful insights into Latin America's dynamic and evolving healthcare initiatives.

- A challenge in Latin America is the need for more adequate funding for projects and initiatives. The region requires increased resources to successfully implement comprehensive strategies and ensure the effectiveness of essential public health activities within constrained budgets.

- Another notable challenge in Latin America is the imperative to bolster collaboration with academia and regional partners, particularly Honduras. Strengthening these relationships is crucial for fostering knowledge exchange, promoting research initiatives, and innovating solutions that enhance epidemic preparedness.

- Indigenous communities encounter issues in accessing healthcare, leading to lower hospital discharge rates but elevated mortality rates from waterborne diseases. The impacts of changes, such as road construction, serve as natural experiments and provide opportunities to examine the epidemiology of diarrheal diseases in these populations.

- The broader LAC region anticipates various impacts, including food and water security challenges, changes in human settlements and infrastructure, and ecosystem shifts. These changes may lead to increased heat stress, altered disease distribution, air pollution, respiratory illnesses, and waterborne diseases.

- The absence of a formal surveillance mechanism leads to a reactive rather than proactive approach. Establishing formal mechanisms is crucial to ensure territorial presence and implement effective tools for community action.

- Communication and coordination among diverse stakeholders pose persistent challenges. Integrating epidemic management into existing preparedness and anticipatory action activities is essential for more effective outcomes.

- Close coordination and collaboration with the Pan American Health Organization, as well as being actively engaged with various Ministries of Health, are essential in responding to the dengue regional outbreak.

- Operationalizing existing malaria models for the LAC region poses a significant challenge, highlighting the importance of collaborative efforts between universities, research institutions, National Societies, and ministries. Developing triggers and risk prediction models for epidemics requires a concerted approach.

- Some countries have valuable expertise in researching, treating, and preventing tropical diseases, particularly vector-borne diseases. However, those experiences have yet to be extrapolated to new countries.

- The health sector has many responsibilities, from preventive and promotional strategies to diagnosing infectious diseases, livelihood approaches, and managing the national health systems network. These entail various requirements, including developing technical skills, non-formal training, and first aid education. Effectively navigating and fulfilling these multifaceted responsibilities is essential for a comprehensive and well-functioning health sector.

- Due to its fragmented nature across various sources, continuous challenges are evident in data collection, synchronization, and digitization. There is a pressing need for a more systematic tra of this data into a unified nationwide database to enhance coherence and accessibility.

8 Recommendations

Anticipatory action does not necessarily involve the development of new actions or methods to prevent or respond to epidemics. Well-established evidence-based interventions implemented by National Societies worldwide will continue to be relevant and applicable (see Epidemic Control Toolkit). Rather, anticipatory action offers a mechanism to help inform whether disease prevention and control actions could be implemented earlier than the normal response, thus reducing disease transmission more effectively. Outbreak preparedness encompasses rigorous surveillance of larvae, viruses, and vectors, establishing effective warning systems, providing an ample supply of diagnostic kits, formulating locally adapted integrated vector control measures, and fostering community awareness.

The working group on anticipatory action and health has identified three main anticipatory approaches to develop triggers for epidemics:

1. identification of health impacts linked to hydro-meteorological hazards
2. multi-stepped composite (surveillance and amplifying factors)
3. mathematical models for predicting the risk of outbreaks

8.1 Anticipatory action priorities in the next 1-3 years

Recommendation 1:

Malaria and dengue are feasible infectious diseases for developing anticipatory action approaches. They could be pursued in the following priority countries: Barbados, Brazil, Colombia, Ecuador, Guatemala, Guyana, Haiti, Honduras and Peru. Cholera is also a priority disease for Haiti and Mexico. This prioritisation does not preclude the development of anticipatory action approaches for other diseases in other countries; however, based on the analysis, these are the most viable options for the forthcoming years.

Recommendation 2:

IFRC and partner National Societies to support or continue to support National Societies in Barbados, Brazil and Colombia in their progress in developing anticipatory action for dengue. The Wellcome Trust funded IDExtremes project (2023-2026) in Barbados and Brazil can provide learning for other National Societies in the region, and regional activities should be shared widely and regularly.

8.2 Partnerships

Recommendation 3:

All National Societies in LAC, and especially Barbados, Brazil, Colombia, Ecuador, Guatemala, Guyana, Haiti, Honduras, Peru and Mexico, to proactively strengthen relationships with Ministries of Health and meteorology agencies to support future efforts for anticipatory action and health (with a focus in the short-term on epidemics). It will probably be necessary to share data in order to initiate discussions on data-sharing agreements. Wherever possible, look for data disaggregated by region. For example, temperature increases are not evenly distributed across Colombia, which has very different impacts on disease transmission.

Recommendation 4:

National Societies in LAC, IFRC and Climate Centre to proactively identify regional and international academic partners that could support the development of thresholds for "trigger approaches 2 and 3". Within these, investments should be made to help improve the technical capacity of National Societies to develop triggers, interpret t model outputs (if used) and understand the kind of data needed to perform different types of analysis. The potential of exploring and establishing more direct linkages between climate change trends and vector-borne diseases, such as dengue, Zika and chikungunya, is immense. This untapped opportunity for additional research in the LAC region can contribute to a deeper understanding of the intricate connections between climate dynamics and disease transmission. Such insights are invaluable for designing targeted interventions and adaptive strategies. A key focus is on constructing and monitoring indicators that assess the impact of climate change on insect species dispersion and disease transmission dynamics. This approach aims to enhance understanding and early detection of changes in vector behaviour, contributing to more effective and targeted interventions against climate-sensitive diseases.

Recommendation 5:

Establishing collaborative training programmes between the climate and health sectors is not just beneficial, it is vital. These programmes facilitate cooperation, enhance cross-sectoral understanding and collectively strengthen our ability to address health challenges influenced by climate factors. By building synergies between these sectors, we can adopt a more holistic approach to climate-related health issues, leading to comprehensive and effective responses.

Recommendation 6:

Formulating strategies for financing and sustaining implemented adaptation actions in the LAC region presents an opportunity. Involving the private sector in these efforts can enhance the financial sustainability of climate adaptation initiatives, fostering collaboration and resource mobilisation for effective long-term climate resilience.

8.3 Climate and health knowledge and awareness

Recommendation 7:

Institutional strengthening, a cornerstone of this approach, involves ongoing training for institutional and community staff, enhancing their skills in water, sanitation, and hygiene practices. Logistical support is provided to humanitarian response coordination branches, facilitating effective community-based actions and the implementation of WASH initiatives. These combined efforts underscore a holistic commitment to public health and community well-being.

Recommendation 8:

It is crucial to coordinate various local efforts related to WASH and community risk awareness communication in Eastern Central America. Establishing a network that facilitates the sharing of successful experiences is of utmost importance for effectively controlling climate-sensitive diseases. This collaborative approach promotes the exchange of valuable insights and best practices, and fosters a collective effort to improve the resilience of regional public health.

8.4 Addressing underlying causes of vulnerability.

Recommendation 9:

Ensure that social determinants of health are included in any decision on priority groups or feasibility study for climate-sensitive infectious diseases moving forward. Addressing underlying vulnerabilities to climate change, rooted in systemic racism, gender and economic oppression, is crucial to mitigate the inequitable impacts on human health. This involves recognising and addressing social determinants to ensure a more equitable and inclusive approach to climate resilience and adaptation.

8.5 Feasible early actions

Recommendation 10:

Explore potential funding opportunities within the movement itself. Establish a dedicated fund or allocate resources specifically for the expansion of e-surveillance. Engage with the Movement's stakeholders, including member municipalities and institutions, to contribute financially to the initiative.

Recommendation 11:

To enhance resource allocation effectiveness, it is imperative to ensure that resources are allocated at the right time, in the right place, and in the right quantity. Additionally, careful attention should be given to critical logistical aspects, including patient flow management and workforce availability, often overlooked in contingency plans. Addressing these considerations is essential to encompass a comprehensive range of decision variables, preventing potential bottlenecks or workforce shortages.

Recommendation 12:

A comprehensive vector control approach is essential to effectively prevent and manage vector-borne diseases like dengue. This involves using chemical and biological methods, such as larvicides and Bacillus thuringiensis israelensis, in fixed-water containers to control mosquito populations.

Recommendation 13:

Community-based campaigns are crucial to eliminate mosquito breeding sites in households and communal areas. Prioritizing the distribution of cleaning kits for water reservoirs ensures access to clean and safe water. Furthermore, tailored educational programmes are essential to promote preventive measures, especially for dengue. Lastly, providing 1,000-litre water tanks to families in high-priority areas significantly improves water storage and hygiene.

Below are suggestions of feasible early actions that could be implemented in collaboration with the government to assess the health situation and address immediate risks in the community, focusing on dengue prevention and control. These actions cover several key areas:

9 Case Studies

The working group on anticipatory action and health has identified three main anticipatory approaches to develop triggers for epidemics. Data availability is one of the primary considerations when choosing the most viable triggering approach for the development of anticipatory action:

1. **identification of health impacts linked to hydro-meteorological hazards.** Weather-based triggers if the forecast is sufficiently reliable and there is solid qualitative evidence of a link between a given extreme weather event and a health outcome.

2. **multi-stepped composite (surveillance and amplifying factors).** Based on the emergence of one case in a target area or a neighboring country.

3. **mathematical models for predicting the risk of outbreaks.** Typically, this involves the development of climate-informed EWS that use mathematical models to predict when an epidemic threshold may be surpassed. The development of these models requires substantial resources.

National Societies and partners should use the decision tree developed in the working paper to identify the most appropriate approach in their context. Based on existing discussions, the following countries could pursue the following strategies:

Climate Centre

Barbados

Triggering Approach 3 for dengue:

In 2017, the Barbados Ministry of Health and Wellness collaborated with a regional climate organization and international researchers to develop climate-informed disease forecast models, initially coordinated by the Caribbean Institute for Meteorology and Hydrology. With the early backing of the United States Agency for International Development, the project received subsequent support from the Red Cross Red Crescent Climate Centre. Ongoing collaboration involves team members from the Ministry of Health and Wellness, Barbados Meteorological Services, Caribbean Institute for Meteorology and Hydrology, Caribbean Public Health Agency, and academic researchers with diverse expertise.

Extreme hydrometeorological events, such as tropical storms, floods, and droughts, significantly impact the timing and intensity of climate-sensitive diseases. The risk of dengue was high in urban areas 3 to 5 months after experiencing extreme drought conditions. Conversely, extremely wet conditions were associated with an increased risk of dengue during the same month and up to three months following the wet period. These findings highlight the complex relationship between climatic extremes and dengue transmission dynamics, which calls for the development of an EWS tailored to the region's specific challenges. In Barbados, the MoH has developed an impact-based forecasting methodology, an interactive visualization platform, and training materials to empower local partners from the Barbados Meteorological Services and the Ministry of Health and Wellness. This collaboration enables local authorities to issue monthly probabilistic forecasts of dengue risk three months in advance, enhancing preparedness and response capabilities.

Based on the country's experiences, implementing EWS based on climate information has encountered numerous challenges. These challenges were identified during interviews with the modelers responsible for developing the effort and with officials from the Ministry of Health.

Challenges in EWS implementation:

- Lack of sustained funding poses a challenge for the transition from a pilot system to an operational EWS.
- Limited technological and procedural capacities, including Geographic Information Systems (GIS), software engineering, and statistical or modeling expertise, coupled with inadequate financial and human resources within the Ministry of Health and Wellness, hinder the implementation of an operational EWS.
- The absence of fine-scale climate data at a sub-national level linked to geo-referenced epidemiological information hampers the production of spatially resolved probabilistic forecasts for disease risk at the health district level.
- The need for dedicated personnel to curate and manage climate and health data limits effective real-time data sharing.
- The absence of a specific mandate to address climate health work in both the health and climate sectors leads to a lack of dedicated personnel and resources.
- Formalized partnerships, such as memoranda of understanding, between national-level climate and health communities are needed to establish joint work plans, data sharing, and modeling.
- Translating probabilistic forecasts of outbreaks into impact alerts with actionable response messages remains a challenge.

Brazil

Triggering approach 1 or 3 for dengue:

The InfoDengue system is an innovative dengue surveillance and monitoring approach. This system, implemented in 2015, was developed through a collaborative effort involving researchers from the Scientific Computing Programme at Fundação Oswaldo Cruz in Rio de Janeiro and the School of Applied Mathematics at Fundação Getúlio Vargas, among others. InfoDengue reached the national level with the support of the Brazilian Health Ministry in 2021, making it accessible to all municipalities in the country. Municipalities now receive weekly InfoDengue bulletins and state-level reports can be obtained through the state health secretariats. This semi-automated system collects and harmonizes data to generate vital epidemiological indicators related to dengue and other arboviruses at the municipal level. InfoDengue's user-friendly website is widely accessed and frequently utilized for various purposes, such as travel planning and other activities. Furthermore, the system has expanded its collaborative network, including international research groups and civil society organizations, fostering sharing experiences and methodologies to enhance arbovirus surveillance and innovation.

Based on interviews with key personnel from InfoDengue, including Flavio Coelho and Claudia Codeco, along with representatives from the Ministry of Health, we have identified the main challenges the system has managed to overcome in recent years.

Challenges in EWS implementation

- **Standardization and interoperability:** Ensure that the e-surveillance systems in different municipalities and countries adhere to common standards to facilitate interoperability. This will enable seamless data and information sharing across regions, fostering collaboration and a more comprehensive understanding of public health trends.
- **Data security and privacy:** Given the sensitive nature of healthcare data, prioritizing data security and privacy is crucial. Implement robust encryption and access controls to protect patient information and comply with relevant regulations. Clear guidelines and agreements should be established to govern the responsible use of the collected data.
- **Capacity building:** Provide training and capacity-building programmes for healthcare professionals and IT personnel in the new municipalities and countries. This will ensure that the personnel involved are well-equipped to manage and derive insights from the e-surveillance system effectively.
- **Engage stakeholders:** Collaborate closely with local health authorities, government agencies and other stakeholders in the target municipalities and countries. Their involvement is vital to successful implementation, as they can provide valuable insights, support and resources.
- **Public awareness and trust:** Communicate transparently to the public the purpose and benefits of e-surveillance. Building trust is essential for the success of such initiatives, and transparency can help address any concerns regarding data collection and use.
- **Scalability and flexibility:** Design the e-surveillance system with scalability in mind, allowing for future expansion and adapting to technological changes.
- **International collaboration:** Explore opportunities for collaboration with international health organizations and entities. Sharing best practices, research findings and experiences can improve public health surveillance strategies globally.
- **Evaluate and iterate:** Regularly assess the e-surveillance system's performance and gather feedback from users. Use this information to make any necessary improvements and upgrade the system to ensure it remains effective and relevant.

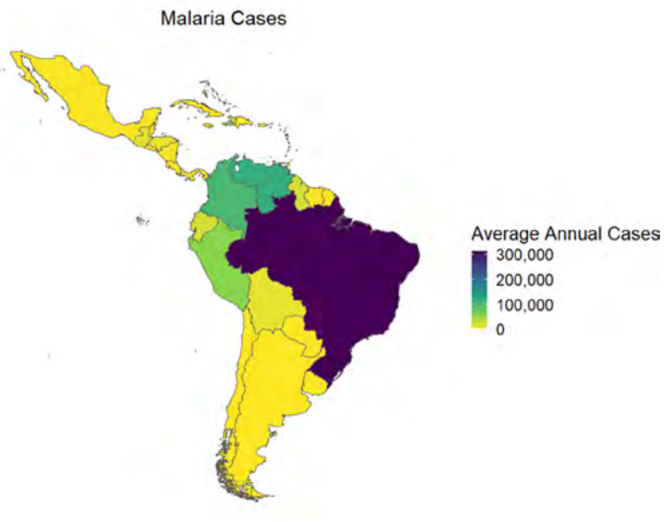
Colombia

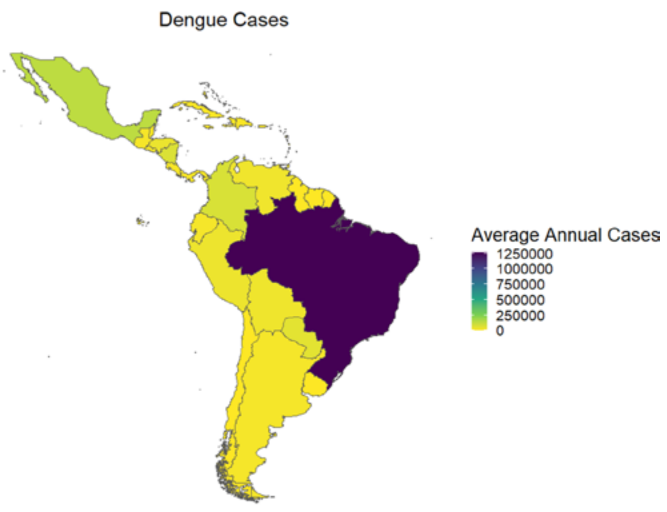
Trigger approach 2 or 3 for dengue

The Colombian Red Cross and its partners are currently working to establish an EAP specifically for dengue. This initiative is supported by the Ministry of Health, the Meteorological Office, and the National Institute of Health. The main objective of this case study is to develop a robust methodological approach capable of forecasting epidemiological triggers for climate hazards. The aim is to improve the region's preparedness and response mechanisms to dengue outbreaks.

Annex 1

Figure S1. The average annual number of cases in Latin America. This figure shows the average annual number of cases of climate-sensitive diseases in Latin America (LATAM) using data from PAHO. Please note that while data for most countries covers the period from 2014 to 2021, there might be slight variations in reporting years for specific countries. This visualization provides valuable insights into regional trends and patterns of occurrence of climate-sensitive diseases over time.





Annex 2

Vector-borne diseases

The transparency of the blue is related to climate sensitivity (according to current scientific knowledge). A less transparent (i.e., more opaque) blue means the disease is more climate-sensitive. The potential for developing forecast-based actions is color-coded green (likely feasible), orange (potentially feasible but may require significant investments), and red (not feasible or not recommended).

Disease	Dengue Fever	Malaria	Yellow Fever	Leishmaniasis
Pathogen	Dengue virus (DENV 1, 2, 3, 4) transmitted by *Aedes* mosquitoes	*Plasmodium falciparum* and *P. vivax* parasite transmitted by *Anopheles* mosquitoes.	The yellow fever pathogen is the yellow fever virus (YFV), a member of the *Flavivirus genus.* It is a single-stranded RNA virus transmitted to humans by mosquitoes, primarily the ***Aedes*** *aegypti* species.	*Leishmaniasis*, caused by parasites of the *genus Leishmania*, is transmitted to humans through bites of infected sandflies. The parasite's life cycle involves two hosts: mammals, including humans, and sandflies.
Endemicity	Endemic dengue regions in LAC include countries across the tropical and subtropical zones, where the ***Aedes aegypti*** mosquito thrives. (stable transmission)	Malaria- endemic regions in LAC include various countries with conditions suitable for malaria transmission, including parts of Central America, the Amazon Basin, and some Caribbean islands.	Yellow fever is endemic in parts of South America and Central America, affecting countries like Brazil, Colombia, Peru, and the Caribbean. These regions present favourable conditions for the transmission of the virus through *Aedes* and *Haemagogus* mosquitoes. Vaccination and surveillance are essential to manage and prevent periodic outbreaks.	
Association with weather and climate	Latin America and the Caribbean are highly sensitive to climate, and outbreaks are common during distinct seasons, with the rainy sea-son running from December to April in South America and from June to October in Central America. Cli-mate elements such as temperature, rainfall patterns, and extreme weather events, especially in the Caribbean, have a signifi-cant im-pact on the ecology of disease vectors. These climate-related fac-tors contrib-ute to fluctu-ations in the risk of outbreaks and the severity of epidemics in the region.	In Latin Amer-ica, vector-borne diseases that are highly sensi-tive to climate , such as malaria, are strongly correlated with temperature and rainfall. These climatic factors significantly influence vector ecology, impacting parameters like biting rate, larval recruitment, and parasite growth. In South America, the peak in malaria cases typically occurs after the rainy sea-son, underlining the complex relationship between climate patterns and disease dynamics in the region.	In South America, the seasonal pattern of diseases, particularly vector-borne diseases, is typically observed at the beginning of the year, from December to April. This period follows heavy rainfall and peak temperatures , creating favourable conditions for disease transmission	
Potential for forecast-based action	Establishing a climate-informed early warning system, such as a model for predicting the risk of a dengue outbreak requires substantial investments and collaboration with academic researchers, especially those skilled in modelling. Despite the challenges, this initiative can be a success if the right resources and partnerships are put in place.	In South America, including Peru, Ecuador, and Brazil, an early-warning system predicts malaria outbreaks up to 12 weeks ahead, using climate and epidemiological data for proactive public health interventions. Improved long-range forecasting, environmental monitoring, and case surveillance can enhance the system's sensitivity and specificity.	Limited information is available to predict yellow fever outbreaks. Studies on predicting yellow fever outbreaks are rare, perhaps because of the availability of vaccines against the disease.	Limited information is available to predict the presence of ***Leishmaniasis*** in Central America. While ***Leishmaniasis*** is prevalent in northern South America, its occurrence in Central America is less well-documented but remains a potential concern.
Potential priority regions	In the northern part of South America, in Brazil, and in Caribbean islands like Barbados, the Dominican Republic, Cuba, and Puerto Rico, efforts are underway to develop EWS exercises. These initiatives involve integrating climate data, epidemiological data and statistical approaches to enhance preparedness and response capabilities.	Prioritizing regions with a high disease burden is crucial. Peru, Colombia, Venezuela, and Brazil are areas facing significant malaria challenges, requiring targeted interventions. Additionally, Haiti, in the Caribbean, is identified as a priority for malaria-related initiatives.	In South America, the yellow fever virus is typically endemic in the Amazon region, which spans parts of Peru, Colombia, Venezuela, Guyana, Suriname, French Guiana, and Brazil.	Northern South America, including countries like Colombia, Peru, Ecuador, Venezuela, and Panama, should be a priority in efforts to address *Leishmaniasis*. These regions are known to have a higher incidence of the disease.

Vector-borne diseases

Disease	Diarrheal diseases	Cholera	Leptospirosis
Pathogen	Various		Leptospira bacteria carried by rodents
Endemicity	Endemic	.	Endemic
Association with weather and climate	Highly climate sensitive. Temperatures can influence the replication of pathogens. In addition, excess or lack of water affects the contamination of drinking water sources and can lead to transmission. The type of diarrheal disease (virus or bacterial) is affected by climate differently.	Highly climate sensitive. Transmission peaks during the wet season and is linked with severe flooding.	Heavy rainfall and flooding linked to increased transmission and outbreak risk.
Potential for forecast-based action	This should be a high priority area for National Societies as part of disaster risk management and overall resilience building. Improving WASH services is key to reducing overall risk. Forecasts of excessive rainfall or flood risk could act as a trigger for early action to prevent diarrheal disease. Addressing malnutrition can also reduce the severity and mortality rate associated with diarrheal disease, especially in children.	Potential for forecast-based action triggered by flood risk (pending a feasibility study). WASH services and infrastructure can reduce and control typhoid infection. A focus on prevention is needed as multi-drug resistant typhoid strains are of particular concern in Cambodia.	There is potential for anticipatory action approaches, but the scarcity of data may be an issue to study risk prediction models. Instead, forecast-based action linked to floods may be feasible.
Potential priority regions	Mexico and Haiti are priority regions for addressing diarrheal diseases, while Honduras has been identified as a potential risk site. These areas require targeted interventions and public health initiatives to prevent and control the spread of diarrheal illnesses.	Potential for forecast-based action triggered by flood risk (pending a feasibility study). WASH services and infrastructure can reduce and control typhoid infection. A focus on prevention is needed as multi-drug resistant typhoid strains are of particular concern in Cambodia.	Countries with a high prevalence of leptospirosis, such as Brazil, Nicaragua, and Ecuador, are prioritized for surveillance and intervention efforts.

Zoonotic diseases

Disease	Leptospirosis
Pathogen	*Leptospira* bacteria carried by rodents
Endemicity	Endemic
Association with weather and climate	Heavy rainfall and flooding linked to increased transmission and outbreak risk.
Potential for forecast-based action	There is potential for anticipatory action approaches, but the scarcity of data may be an issue to study risk prediction models. Instead, forecast-based action linked to floods may be feasible.
Potential priority regions	Countries with a high prevalence of leptospirosis, such as Brazil, Nicaragua, and Ecuador, are prioritized for surveillance and intervention efforts.

Annex 3

Interview reports from National Societies

Country	Entity	Challenges	Needs
Honduras	Cruz Roja Hondureña	Several challenges have been iden-tified in the context of epidemic preparedness and public health in Honduras and the region: - Limited funding: Securing adequate funding for projects and initiatives is a significant challenge. Additional resources must be provided to implement comprehensive strategies and limit the scope of essential public health activities. - Academic and partner collaboration: There is a need to strengthen collaboration with academia and partners in Honduras and the region. Stronger relationships can facilitate knowledge exchange, research initiatives and the development of innovative solutions for epidemic preparedness. - Coordination challenges: Coordinating efforts among various institutions is a key limitation. Improved coordination is essential to streamline resources, share information efficiently, and ensure a unified response to public health challenges. - Data availability: The need for more data poses a significant barrier. Comprehensive and timely data is crucial for informed decision-making, and efforts should be made to address gaps in data collection and dissemination . - Strengthening public health services: There is a pressing need to strengthen public health services, focusing on increasing the number of health facilities and improving the quality and safety of healthcare services. This includes investing in infrastructure, human resources, and continuous training. - Laboratory capacity: The laboratory confirmation of arboviruses is limited due to insufficient laboratory capacity and infrastructure. Enhancing these capabilities is essential for accurate and timely disease diagnosis, which is fundamental for ef-fective epidemic response and control.	- Prioritization of diseases for anticipatory action: It is crucial to prioritize diseases that are most suitable for anticipatory action. Conducting a comprehensive risk assessment and evaluating the potential impact of diseases in the region can guide strategic planning for proactive and target-ed interventions. - Technical support for trigger identification and design: Technical support in identifying and designing potential triggers is essential. Collaborating with experts in the field can help in developing practical triggers that signal the need for anticipatory actions, ensuring a timely and proactive response to emerging health threats. - Design and evaluation of community surveillance interventions: Designing and evaluating community surveil-lance interventions is key to improving the early detection of diseases. Developing effective community-based surveillance programmes requires careful planning, im-plementation and ongoing evaluation to ensure their impact and sustainability. - Joint training programmes: Joint training initiatives for the climate and health sectors are important to create national capacities for anticipatory action. These programmes can foster collaboration, improve cross-sectoral understanding, and enhance collective capacity to address climate-sensitive health challenges. Building synergies between these sectors is crucial for a holistic approach to climate-related health issues. - Concrete actions for volunteers during epidemics: It is essential to define concrete actions for volunteers. Volunteers play a pivotal role in response efforts. Giving them specific tasks and responsibilities ensures a coordinated and effective response at community-level. These actions should be well-defined, easily to implement, and aligned with public health strategies.

Country	Entity	Challenges	Needs
Panama	Cruz Roja Panameña	- Over the last three decades, research into infectious diseases in Panama has focused predominantly on protozoan, neglected and arthropod-borne diseases, with a particular emphasis on malaria, Chagas disease, and *leishmaniasis*, especially in the last dec-ade. - Research in Panama has focused on zoonotic infections transmitted by arthropods, in particularprotozoan pathogens transmitted by mosquitoes (*Anophelinae - Plasmodiu*m), sandflies (*Phlebotominae - Leishmania*), and kissing bugs (*Triatominae – Trypanosoma*). Malaria, Chagas disease and *leishmaniasis* have been studied in-depth due to their persistent prevalence in impoverished rural settings and isolated indigenous communities. - Ministries of Health and Agriculture in the LAC region recognize specific zoonoses, including Chagas disease and *leishmaniasis*, as endemic or emerging priorities. - Governmental agencies, such as MINSA and MIDA, have a low publication rate, indicating limited intersectoral research collaboration between academia and MINSA and MIDA in Panama over the last three decades. - The proposed solution involves a synergistic collaboration among SENACYT, MINSA, MIDA, and researchers from various Panamanian institutions with complementary research traditions and strengths. - The government of Panama is urged to establish funding instruments that encourage interinstitutional and intersectoral collaborations, as demonstrated by recent suc-cessful research sponsored by MINSA through SENACYT in Panama.	- Innovative strategies, such as releasing *Aedes aegypti* mosquitoes carrying the natural *Wolbachia* bacteria, are need-ed to reduce the ability of mosquitoes to transmit arboviruses. - Embracing the One Health approach is needed to address complex health challenges taking into account the interconnectedness of human, animal, and environmental health. - There is a need to recognize the importance of international collaborations, requiring sponsorship to enhance local competitiveness and develop technological capacity to bet-ter succeed in securing additional funding from foreign sources. - Give priority to developing the career of students, junior faculty, and independent researchers to strengthen the National Society's human resource base. - Actively promoting community engagement in collaborative problem-solving initiatives, fostering a sense of collective responsibility and inclusion. - Cultivating close cooperation with key international health organizations, specifically PA-HO and WHO, to benefit from shared expertise and resources.

Country	Entity	Challenges	Needs
Ecuador	Cruz Roja Ecuatoriana	- In Ecuador, challenges associated with anticipatory actions and diseases include significant data collection and harmonization. The lack of coordination between health and climate services complicates strategy development, while the scarcity of local information hinders planning and project execution. More projects addressing these challenges should be funded, emphasizing the need to enhance knowledge sharing at a regional scale. - Ecuador has ready-to-implement resources for local planning: COOTAD (Organic Code of Territorial Organization, Autonomy, and Decen-tralization) and “tools for integrating climate change criteria in territorial development and planning”. These resources can create an operational legislative framework and provide technical recommendations, including urban greenness plans in major cities. - The Sustainable Development Goals for water, sanitation, and hygiene in Ecuador reveal the high incidence of waterborne diseases among indigenous populations due to rural living, poor infrastructure and limited healthcare access. - Indigenous people face limitations in healthcare access, resulting in lower hospital discharge rates but higher mortality rates from waterborne diseases. Changes like road construction serve as natural experiments for examining the epidemiology of diarrheal disease. - Anticipated climate change impacts in Ecuador include food and water security challenges, altered human settlements, infrastructure issues, and ecosystem changes. This involves increased heat stress, altered disease distribution, air pollution, respiratory illnesses, and waterborne diseases. - Vulnerable populations on the Ecuadorian coast, in the Amazon, as well as parts of the Piedmont area in the Ecuadorian Andes, face heightened risks. For instance, El Niño events on the southern coast of Ecuador are associated with heavy rainfall, flooding, warmer temperatures, and mosquito-borne diseases like dengue fever. - A major flood in Machala caused damages in low-lying urban areas, followed by an increase in dengue fever cases several weeks later.	- Develop studies to define climate and health priorities in Ecuador and explore the possibilities of new EAPs or subsequent feasibility studies . - Additional research is necessary to establish more direct links between climate change trends and vector-borne diseases like dengue, Zika, and chikungunya. - Ecuador aims to set up a national surveillance system and early warning for vector control, focusing on diseases like dengue and yellow fever. - Data collected includes environmental and socioeconomic factors, supporting the development of mathematical models for assessing the risks associated with diseases like dengue, malaria, and *leishmaniasis*. - Monitoring indicators of the impact of climate change on insect species dispersion and disease transmission dynamics is a key priority. - Ecuador is committed to adapting the health sector by analysing climate risks to health infrastructure, developing policies to manage climate change impacts on health, implementing surveillance and early warning systems for diseases sensitive to climate, and enhancing institutional capacities for information generation and adaptation responses. - There is a need to improve climate projection coverage, spatial and temporal resolution, and vulnerability analyses. - Increase vulnerability studies with a national focus on key sectors encompassing rural and urban areas. - Formulate strategies for financing and sustaining the adaptation actions already implemented, and involve the private sector in these efforts. - Strengthen coordination capacities across sectors to enhance climate change preparation, adaptation, and mitigation efforts. - Move toward multi-hazard, multi-disease early warning systems integrating real-time climate, disaster, and health data streams. - Address underlying vulnerabilities to climate change, rooted in systemic racism, gender, and economic oppression, to mitigate inequitable impacts on human health.

Country	Entity	Challenges	Needs
Colombia	Cruz Roja Colombiana	- There is a need to continue addressing the impacts of climate change on communicable diseases, particularly vector- and waterborne diseases like malaria and dengue fever. - In Colombia, malaria transmission is highly sensitive to temperature and precipitation increases, with a doubling in the number of infectious mosquitoes observed with a two-degree Celsius temperature rise (World Bank 2011). - Demonstrate the impact of climate variability and severe weather shocks on waterborne disease transmission; the intermittent increase in infection rates remains a challenge in the country. - Dengue and malaria are identified as paramount health concerns , but there is still a need to understand their heterogeneous effects. - An effort is ongoing to construct an EAP addressing dengue and extreme events, demonstrating the importance of inter-institutional coordination. - Local institutions still need to acknowledge the intricate relationship between climate and health. - Governments can identify risk factors associated with climate variability. - It is possible to mitigate the impact of climate change on disease spread and reduce the vulnerability of potentially affected communities. - Climate variability and severe weather shocks impact the spread of various infectious diseases (e.g., malaria, dengue, cholera, and respiratory infections). - The meteorological service and the National Institute of Health reported significant progress in identifying and characterising the risk and association between climate and diseases. - Estimated consequences of climate change on temperature and precipitation in Colombia with a projected 17–31 per cent increase in malaria cases and a 63 per cent increase in dengue fever cases by the end of the century. - Funding issues are a threat to information flows as well as a bottleneck for investigating the role of climate on disease transmission.	- Identification of disproportionate impacts in Andean areas due to insufficient WASH infrastructure and variations in temperature and precipitation. - Immediate need of a health sector response to climate change, taking into account Colombia's geographical vulnerabilities that directly impact the health risks of its population. - Local interventions are needed to enhance climate change adaptation, considering the country's geographical and cultural diversity. - Disaggregated information supporting decision-making is crucial, as climate change scenarios predict uneven temperature increases across Colombia, particularly in departments like Arauca, Vichada, Vaupés and Norte de Santander. - Critical need to estimate the economic impact of climate change on health outcomes. - The necessity of accurate and up-to-date surveillance data to identify emerging health risks, allocate resources effectively, and develop evidence-based strategies for public health protection. - Early warning systems must be put in place to forecast and alert communities and healthcare providers about climate-related events, enabling timely preparedness and response. - Studies assessing the vulnerability and risks associated with climate change are necessary to understand which populations and regions are most at risk and require targeted interventions. - Studies aimed at showing the limitations of single interventions in addressing the complexities of climate change, emphasizing the adoption of a comprehensive strategy considering the broader context. - The necessity to disseminate and operationalise knowledge from specialized environmental agencies, promoting horizontal collaboration and mutually beneficial dialogue between society, producers and scientists to have tangible and positive impacts on climate change resilience.

Country	Entity	Challenges	Needs
Guatemala	Cruz Roja Guatemalteca	- The decline in health systems resulting from these vulnerability points are likely at the root of the minimal public health gains and reductions in NTDs seen over the last two decades. - Guatemala is situated in the Dry Corridor, a region in Central America characterised by crop failures and food insecurity resulting from unpredictable rainfall patterns leading to both droughts and floods. The impacts of climate change have exacerbated migration trends in the area. Between 2015 and 2018, many people left the region primarily due to the adverse effects of prolonged drought conditions. - Guatemala's geographical and social conditions expose its population to the risk of vector-borne diseases. Since 2003, the country has reported nearly 140,000 cases of dengue. In 2013, Chikungunya was introduced, followed by the appearance of the Zika virus in 2015. These diseases pose significant public health challenges in Guatemala. - Many rural and indigenous communities in Guatemala struggle with access to clean water, with some having limited or sparse access. Additionally, these communities often lack basic sanitation services in their homes. The lack of access to clean water and proper sanitation services leads to major health and hygiene issues, including the spread of waterborne diseases and poor living conditions, disproportionately affecting vulnerable populations.	- Indigenous populations are at disproportionate risk to NTDs due to lack of healthcare, extreme poverty, and the fact that their native lands are often exploited for mining and other causes of environmental degradation. - The dry corridor is believed to have developed and expanded due to Central America's disproportionate vulnerability to climate change [3], which can also promote susceptibility to vector-borne tropical diseases, particularly those transmitted by urbanized *Aedes aegypti* mosquitoes. It has been further noted that a mysterious form of kidney failure known as Mesoamerican nephropathy has emerged in the dry corridor, where it is sometimes known as global warming nephropathy.
Argentina	Cruz Roja Argentina	- Responsibilities in the health sector include preventive and promotional approaches, diagnosis of communicable diseases, livelihood approaches, and management of the national health systems network. From an educational perspective, it involves technical skills, non-formal training, and first aid training. - There is currently no formal mechanism for surveillance; it remains a reactive process. However, establishing formal mechanisms is of utmost importance to enable territorial presence and implement tools for community action. - Addressing veterinary aspects or urban fauna that may act as transmitters to other hosts is essential. This involves implementing measures to monitor, control and prevent diseases in animals that could potentially transmit infections to other hosts.	- These formal mechanisms should align with existing formal systems. Active case searching is a key component facilitated by the volunteer work of the Red Cross. This involves proactive engagement and collaboration with the community to actively seek and identify cases, contributing to a more effective surveillance and response system. - One of the Red Cross' primary goals is to harmonize communication strategies with governmental authorities. Coordinating and aligning efforts is key to ensuring a unified and practical approach to communication initiatives. These actions can significantly contribute to the effectiveness of the health sector's communication strategies in Argentina. - Working together in testing centres, in coordination with health authorities, is crucial. This collaboration involves joint efforts to ensure efficient and organized testing processes aligned with the directives and guidance of health authorities.

Country	Entity	Challenges	Needs
El Salvador	Cruz Roja Salvadoreña	- Ongoing challenges persist in collecting, synchronising, and digitising data as it remains fragmented across various sources, needing more systematic transfer into a unified nationwide database. - Additional barriers arise in ensuring control and harmonization of diverse datasets, with the standardization of formats and protocols across disparate systems proving challenging. - Challenges remain in communication and coordination among various stakeholders. Integrating epidemic management into existing preparedness and anticipatory action activities is crucial. - Essential funding is required to sustain ongoing and future collaborative and coordination efforts. - There is a need to strengthen regional exchanges on anticipatory action among National Societies, ministries and relevant stakeholders. This facilitates knowledge transfer, formulation of common strategies, and sharing lessons learned. - Collaborative efforts between universities, research institutions, National Societies and ministries are crucial in developing triggers and risk prediction models for epidemics. Although existing malaria models exist for Latin America and the Caribbean, implementing them remains a challenge. - The size of the current dengue outbreak in Central America, particularly in El Salvador, is unprecedented. Case numbers have surpassed those of previous years. - Close coordination and collaboration with PAHO, which is actively working with different Ministries of Health to respond to the regional dengue outbreak. - The country has valuable experience researching, treating and preventing tropical diseases, including vector-borne diseases. However, studies linking diseases like dengue to climate variables are limited.	- Country needs include the ability to access areas with limited operational capacity due to security concerns, particularly supporting the establishment of a referral mechanism for severe dengue cases. - Empowering communities is essential to reaching vulnerable individuals and households and reducing the dengue burden. Red Cross volunteers support government efforts, raise awareness, and leverage their experience combating diseases like Zika to enhance response capacity to dengue outbreaks. - The country needs to emphasize the importance of empowering communities to effectively reach the most vulnerable individuals and households, contributing to reducing the dengue burden. - Country needs involve monitoring climatic conditions based on bioclimatic forecasts for timely actions in strengthening prevention programmes and safeguarding the population. Strengthened mosquito control and surveillance, as well as valuable information, contribute to improving prediction models and warning systems. - With increasing climate-related displacement, the country needs to include strategies to address climate refugees who may carry diseases, including dengue. Preparedness for outbreaks in refugee camps is essential. - The country must promote a regional initiative supporting climate change and health research. This initiative should coordinate consolidated research teams across various disciplines and establish partnerships with different sectors. - The country should be involved in the analysis of the implications of changes in temperature, precipitation and demographic structure on climate and health studies. Greater attention should be paid to future trends and incorporating ecological niche modelling into vector-borne diseases research.

Endnotes

1 Hotez, PJ., Bottazzi, ME., Franco-Paredes, C., Ault, SK., Periago, MR. 'The Neglected Tropical Diseases of Latin America and the Caribbean: A Review of Disease Burden and Distribution and a Roadmap for Control and Elimination'. *PLoS Negl Trop Dis* 2008; **2**(9): e300.

2 UNHCR. 'Global Trends: Forced Displacement in 2015'. 2015.

3 World Bank Group. Climate Risk Country Profile: Brazil. T., 2021.

4 Charvériat, C. Natural Disasters in Latin America and the Caribbean: An Overview of Risk. *SSRN Electron J* 2000. DOI:10.2139/ssrn.1817233.

5 Garreaud, RD, Boisier, JP., Rondanelli R., Montecinos, A., Sepúlveda, HH., Veloso-Aguila D. The Central Chile Mega Drought (2010–2018): A climate dynamics perspective. *Int J Climatol* 2020; **40**: 421–39.

6 Espinosa, L., Mirinaviciute G. Health crisis in Venezuela: Status of communicable diseases and implications for the European Union and European Economic Area, May 2019. *Euro Surveill Bull Eur Sur Mal Transm Eur Commun Dis Bull* 2019; **24**: 1900308.

7 Patz JA., Campbell-Lendrum, D., Holloway, T., Foley, JA. Impact of regional climate change on human health. *Nature* 2005; **438**: 310–7.

8 Campbell-Lendrum, D., Manga, L., Bagayoko, M, Sommerfeld, J. Climate change and vector-borne diseases: what are the implications for public health research and policy? *Philos Trans R Soc B Biol Sci* 2015; **370**: 20130552.

9 Gage KL., Burkot, TR., Eisen, RJ., Hayes, EB. Climate and Vectorborne Diseases. *Am J Prev Med* 2008; 35: 436–50.

10 Checkley, W, Epstein, LD., Gilman, RH., *et al.* Effects of El Niño and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. *The Lancet* 2000; **355**: 442–50.

11 Cissé G. Food-borne and water-borne diseases under climate change in low- and middle-income countries: Further efforts needed for reducing environmental health exposure risks. *Acta Trop* 2019; **194**: 181–8.

12 Paaijmans, KP., Blanford, S., Bell, AS., Blanford JI., Read, AF., Thomas, MB. Influence of climate on malaria transmission depends on daily temperature variation. *Proc Natl Acad Sci* 2010; **107**: 15135–9.

13 Mordecai, EA., Paaijmans, KP., Johnson, LR, *et al.* Optimal temperature for malaria transmission is dramatically lower than previously predicted. *Ecol Lett* 2013; **16**: 22–30.

14 Gonzalez Daza W., Muylaert, RL., Sobral-Souza, T., Lemes Landeiro, V. Malaria Risk Drivers in the Brazilian Amazon: Land Use—Land Cover Interactions and Biological Diversity. *Int J Environ Res Public Health* 2023; **20**: 6497.

15 Gutiérrez LA., Naranjo, N., Jaramillo, LM., *et al.* Natural infectivity of Anopheles species from the Pacific and Atlantic Regions of Colombia. *Acta Trop* 2008; **107**: 99–105.

16 Caminade, C., Kovats, S., Rocklov, J., *et al.* Impact of climate change on global malaria distribution. Proc Natl *Acad Sci* 2014; **111**: 3286–91.

17 Stresman GH. Beyond temperature and precipitation: Ecological risk factors that modify malaria transmission. *Acta Trop* 2010; **116**: 167–72.

18 World Health Organization. Flooding and communicable diseases fact sheet. 2012.

19 Pina-Costa, AD., Brasil, P., Santi SMD., *et al.* Malaria in Brazil: what happens outside the Amazonian endemic region. *Mem Inst Oswaldo Cruz* 2014; **109**: 618–33.

20 Krieger, H., Durlacher, RR, Menezes, MJ., Camargo, EP., Silva, LHP., Alves FP. High prevalence of asymptomatic Plasmodium vivax and Plasmodium falciparum infections in native Amazonian populations. *Am J Trop Med Hyg* 2002; **66**: 641–8.

21 Nosrat, C, Altamirano, J., Anyamba, A., *et al.* Impact of recent climate extremes on mosquito-borne disease transmission in Kenya. *PLoS Negl Trop Dis* 2021; **15**: e0009182.

22 Depinay, J-MO., Mbogo, CM., Killeen, G, *et al.* A simulation model of African Anopheles ecology and population dynamics for the analysis of malaria transmission. *Malar J* 2004; **3**: 29.

23 Laporta GZ., Burattini, MN., Levy, D., *et al.* Plasmodium falciparum in the southeastern Atlantic forest: a challenge to the bromeliad-malaria paradigm? *Malar J* 2015; **14**: 181.

24 Hales, S, De Wet, N., Maindonald, J., Woodward, A. Potential effect of population and climate changes on global distribution of dengue fever: an empirical model. *The Lancet* 2002; **360**: 830–4.

25 Lowe, R., Bailey, TC., Stephenson, DB., *et al.* The development of an early warning system for climate-sensitive disease risk with a focus on dengue epidemics in Southeast Brazil. *Stat Med* 2013; **32**: 864–83.

26 Lowe, R., Lee, SA., O'Reilly, KM., *et al.* Combined effects of hydrometeorological hazards and urbanisation on dengue risk in Brazil: a spatiotemporal modelling study. *Lancet Planet Health* 2021; **5**: e209–19.

27 Lowe, R., Barcellos C., Coelho, CAS, *et al.* Dengue outlook for the World Cup in Brazil: an early warning model framework driven by real-time seasonal climate forecasts. *Lancet Infect Dis* 2014; **14**: 619–26.

28 Do Carmo, RF., Silva Júnior, JVJ., Pastor, AF., De Souza CDF. Spatiotemporal dynamics, risk areas and social determinants of dengue in Northeastern Brazil, 2014–2017: an ecological study. *Infect Dis Poverty* 2020; **9**: 153.

29 Morin, CW., Comrie, AC., Ernst, K. Climate and Dengue Transmission: Evidence and Implications. *Environ Health Perspect* 2013; **121**: 1264–72.

30 Monath, TP. Yellow fever: an update. *Lancet Infect Dis* 2001; **1**: 11–20.

31 Kaul, RB., Evans, MV., Murdock CC., Drake, JM. Spatio-temporal spillover risk of yellow fever in Brazil. *Parasit Vectors* 2018; **11**: 488.

32 Min, S-K., Zhang, X., Zwiers, FW., Hegerl, GC. Human contribution to more-intense precipitation extremes. *Nature* 2011; **470**: 378–81.

33 Ivers, LC, Ryan, ET. Infectious diseases of severe weather-related and flood-related natural disasters. *Curr Opin Infect Dis* 2006; **19**: 408–14.

34 McGregor BL., Connelly, CR. A Review of the Control of Aedes aegypti (Diptera: Culicidae) in the Continental United States. *J Med Entomol* 2020; : tjaa157.

35 Campos, GS., Bandeira AC., Sardi, SI. Zika Virus Outbreak, Bahia, Brazil. *Emerg Infect Dis* 2015; **21**: 1885–6.

36 Ryan, SJ., Carlson, CJ, Tesla, B., *et al.* Warming temperatures could expose more than 1.3 billion new people to Zika virus risk by 2050. *Glob Change Biol* 2021; **27**: 84–93.

37 Focks, DA., Brenner, RJ., Hayes, J., Daniels E. Transmission thresholds for dengue in terms of Aedes aegypti pupae per person with discussion of their utility in source reduction efforts. *Am J Trop Med Hyg* 2000; **62**: 11–8.

38 Barreto, ML., Teixeira, MG., Bastos, FI., Ximenes, RA., Barata, RB., Rodrigues, LC. Successes and failures in the control of infectious diseases in Brazil: social and environmental context, policies, interventions, and research needs. *The Lancet* 2011; **377**: 1877–89.

39 García-Rejón JE., Eisen, L., Flores-Flores, LF., *et al.* Mosquito Infestation and Dengue Virus Infection in Aedes aegypti Females in Schools in Mérida, México. *Am J Trop Med Hyg* 2011; **84**: 489–96.

40 Harris M., Caldwell, JM., Mordecai, EA. Climate drives spatial variation in Zika epidemics in Latin America. *Proc R Soc B Biol Sci* 2019; **286**: 20191578.

41 Chadee DD., Shivnauth, B, Rawlins SC, Chen AA. Climate, mosquito indices and the epidemiology of dengue fever in Trinidad (2002–2004). *Ann Trop Med Parasitol* 2007; **101**: 69–77.

42 Yee, SH., Yee, DA., De Jesus, Crespo R., Oczkowski, A, Bai, F., Friedman, S. Linking Water Quality to Aedes aegypti and Zika in Flood-Prone Neighborhoods. *EcoHealth* 2019; **16**: 191–209.

43 Cardenas, R., Sandoval, CM., Rodriguez-Morales, AJ, Vivas P. Zoonoses and Climate Variability: The Example of Leishmaniasis in Southern Departments of Colombia. *Ann N Y Acad Sci* 2008; **1149**: 326–30.

44 González C., Wang, O., Strutz, SE., González-Salazar, C., Sánchez-Cordero, V., Sarkar, S. Climate Change and Risk of Leishmaniasis in North America: Predictions from Ecological Niche Models of Vector and Reservoir Species. *PLoS Negl Trop Dis* 2010; **4**: e585.

45 González C., Paz, A., Ferro, C. Predicted altitudinal shifts and reduced spatial distribution of Leishmania infantum vector species under climate change scenarios in Colombia. *Acta Trop* 2014; **129**: 83–90.

46 Oliveira, CCG., Lacerda, HG., Martins, DRM., *et al.* Changing epidemiology of American cutaneous leishmaniasis (ACL) in Brazil: a disease of the urban–rural interface. *Acta Trop* 2004; **90**: 155–62.

47 Altamiranda-Saavedra, M., Gutiérrez, JD., Araque A., Valencia-Mazo, JD., Gutiérrez, R., Martínez-Vega, RA. Effect of El Niño Southern Oscillation cycle on the potential distribution of cutaneous leishmaniasis vector species in Colombia. *PLoS Negl Trop Dis* 2020; **14**: e0008324.

48 Lipp EK., Huq, A., Colwell, RR. Effects of Global Climate on Infectious Disease: the Cholera Model. *Clin Microbiol Rev* 2002; **15**: 757–70.

49 Escobar LE., Ryan, SJ., Stewart-Ibarra, AM., *et al.* A global map of suitability for coastal Vibrio cholerae under current and future climate conditions. *Acta Trop* 2015; **149**: 202–11.

50 Barzilay EJ., Schaad, N., Magloire, R., *et al.* Cholera Surveillance during the Haiti Epidemic — The First 2 Years. *N Engl J Med* 2013; **368**: 599–609.

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