Anticipatory Action for climate-sensitive infectious diseases:

East Africa 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 and acronyms list

AA	Anticipatory Action
BORT	branch outreach response team
CBS	community-based surveillance
CDC	Centers for Disease Control and Prevention
CMIP6	Coupled Model Intercomparison Project Phase 6
DHIS2	district health information system 2
DREF	Disaster Response Emergency Fund
DRM	disaster risk management
EAC	East African Community
EAP	Early Action Protocol
EM-DAT	international disaster database
ENSO	El Niño–Southern Oscillation
EPIDEMIA	Epidemic Prognosis Incorporating Disease and Environmental Monitoring for Integrated Assessment
ERCS	Ethiopian Red Cross Society
EPHI	Ethiopian Public Health Institute
EWARS	Early Warning and Response System
EWS	early warning systems
ICPAC	Intergovernmental Authority on Development Climate Prediction and Application Centre
IDPs	internally displaced people
IDSR	Integrated Diseases Surveillance and Response
IGAD	Intergovernmental Authority on Development
IOD	Indian Ocean Dipole
IFRC	International Federation of Red Cross and Red Crescent Societies
IPCC	Intergovernmental Panel on Climate Change
KEMRI	Kenya Medical Research Institute
KRCS	Kenya Red Cross Society
KII	key informant interview
mm	millimetres
MoH	Ministry of Health
MoU	Memorandum of Understanding
MSF	Médecins Sans Frontières
MVIP	Malaria Vaccine Implementation Programme
NMEP	National Malaria Elimination Program
NGOs	non-governmental organizations
NS	National Society
OND	October, November, December
PHEM	Public Health Emergency Management
PMI	(US) President's Malaria Initiative
PNS	Partner National Society
RCRC	Red Cross Red Crescent
RVF	Rift Valley Fever
sEAP	Simplified Early Action Protocol
ToR	Terms of Reference
USAID	United States Agency for International Development
WASH	water, sanitation and hygiene
WHO	World Health Organization

Executive summary

The East African region – here comprising Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan, Tanzania and Uganda – is home to approximately 370 million people, with some countries facing significant poverty and vulnerability to climate change. The region is facing various humanitarian challenges, compounded by the impacts of climate change, poverty, conflict and political instability. Extreme weather events, including droughts, floods, heatwaves and tropical cyclones are occurring with increased frequency and intensity, resulting in acute food insecurity and compromised water security for millions of people.

Infectious diseases, such as cholera, dengue, malaria, measles, meningitis, Rift Valley fever, schistosomiasis and yellow fever pose significant health threats, particularly as they are highly sensitive to climatic conditions. Anticipatory Action is emerging as a crucial approach to preventing epidemics of climate-sensitive infectious diseases, offering the potential to implement preventive measures earlier and more effectively reduce disease transmission.

This regional assessment identifies malaria, dengue and cholera as priority diseases, emphasizing the need for prioritized Anticipatory Action for these diseases. Despite existing Early Action Protocols (EAPs) and simplified EAPs (sEAPs) for floods or droughts, there are currently no operational EAPs for climate-sensitive infectious diseases in East Africa. This is partly related to a lack of systematic digital disease data collection, sectoral silos, insufficient coordination between health and disaster management agencies, and limited access to public health services, particularly in conflict-affected regions.

The assessment suggests focusing on the development of specific sEAPs for cholera, malaria and dengue in Ethiopia and Kenya within the next 1–3 years, leveraging these countries' robust infrastructure, strong health ministries and sufficient climate and disease data. Partnerships with research institutions and academics, both local and international, are crucial for analysing climate and health data for trigger development as well as mathematical modelling to predict outbreak risks.

In addition, National Societies and Partner National Societies should advocate for the inclusion of health and water, sanitation and hygiene (WASH) early actions in future or updated hydrometeorological EAPs and sEAPs. In Somalia, South Sudan and Tanzania, discussions are underway regarding the development of sEAPs for floods and droughts, providing an opportunity for National Societies to integrate robust health prevention measures into the sEAPS/EAPs from their initial stages. In countries currently lacking the development of EAPs, such as Eritrea and Sudan, support is recommended for conducting workshops and training on Anticipatory Action for epidemics and the connections between climate change and health.

Improvements in epidemic preparedness coordination can be achieved through the establishment of national preparedness task forces and cross-border dialogues between National Societies and partners.

These recommendations can serve as a starting point to tackling the increased risks posed by climate-sensitive infectious diseases in East Africa and highlight the need for cross-sector and widespread collaboration between National Societies, Partner National Societies and stakeholders, including government authorities and agencies, and research institutes. They should help National Societies and Partner National Societies in East Africa to advance epidemic preparedness in the region and mitigate the health impacts from climate-sensitive infectious diseases.

1 Introduction

1.1 Background

Anticipatory Action, a crucial component of the disaster risk management cycle, formalizes the connection between early warning and early action based on forecasted hazards. It is an approach that operates on various scales, shaped by organizational mandates, local contexts, specific hazards and available forecasts. Key parameters include a focus on mitigating forecastable hazard impacts, designing actions based on predictive analyses, and implementing interventions before the hazard's impact or its most acute effects are felt. In recent years, growing attention has been given to developing Anticipatory Action for epidemics.

The Anticipatory Action and Health Working Group, launched in January 2022, has developed a working paper on Guidance for Anticipatory Action for Epidemics (Alcayna and Kellerhaus, in prep.). The guidance is intended to contribute to a common understanding of Anticipatory Action for epidemics across the Red Cross Red Crescent (RCRC) Movement and act as a useful theoretical guide for National Societies who wish to engage in such interventions.

The Anticipatory and Health Working Group has identified three main anticipatory approaches to develop triggers for epidemics:

1. **Trigger Approach 1:** identification of health impacts linked to hydrometeorological hazards
2. **Trigger Approach 2:** multi-stepped composite (surveillance data and amplifying factors)
3. **Trigger Approach 3:** epidemiological mathematical models.

To complement the working paper on guidance for Anticipatory Action for epidemics, regional assessments are being produced. This assessment focuses on the East African region, including Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan, Tanzania and Uganda (see Section 1.3), where climate-sensitive infectious diseases are of high concern. Kenya and Ethiopia have been selected as country case studies to update and build on the climate change impact assessments in Kenya and Ethiopia conducted in 2020. Both countries are characterized by mountain regions and high geographic diversity that provide ecological conditions for various infectious diseases.

This report attempts to provide a guide on evaluating the different factors to assess and implement Anticipatory Action for climate-sensitive infectious diseases in East Africa, particularly Ethiopia (Annex A) and Kenya (Annex B).

We focus on climate change in the region, identify priority climate-sensitive infectious diseases, and investigate potential mechanisms on how climate and non-climate drivers can affect climate-sensitive infectious disease transmission and outbreaks. Furthermore, we analyse existing preparedness and prevention activities in the region, determine the feasibility of Anticipatory Action to support epidemic preparedness and prevention, and give recommendations for potential Anticipatory Action for priority climate-sensitive infectious diseases in East Africa, Ethiopia and Kenya.

1.2 Objectives

This report has the following objectives:

- map historical and future climate change in the region, and in Kenya and Ethiopia specifically
- identify the priority climate-sensitive infectious diseases in the East African region, and in Kenya and Ethiopia specifically
- map existing preparedness activities in the region including disease surveillance systems, outbreak risk prediction models, and early warning systems (EWS) for epidemics
- identify the main barriers and challenges for not taking early action for the priority infectious diseases
- analyse which (if any) of the three Anticipatory Action approaches may be most feasible to pursue for a given infectious disease
- provide evidence-based relevant and feasible early action activities to be put in place by RCRC National Societies in the region and Ethiopia and Kenya specifically for the priority infectious diseases and provide recommendations on moving forward with RCRC National Societies in supporting Anticipatory Action for epidemics.

1.3 East Africa context

For this report, the East African region comprises Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan, Tanzania and Uganda. The region is home to around 370 million people (World Bank, 2023d) and some of the region's countries are among Africa's poorest and the most vulnerable to climate change (see Section 3). The region is facing various humanitarian challenges and compound impacts of climate change (in particular, droughts, floods and cyclones), poverty, conflict and political instability.

As a consequence of war, conflicts and environmental degradation, the region is facing significant displacement within and across borders, making it a leading region for refugees and internally displaced people (IDPs) worldwide. About 8.5 million forcibly displaced people – including over 6 million IDPs and around 2.5 million refugees and asylum seekers – have been hosted in Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and South Sudan in 2020 (Noack, 2020). Displacement, informal settlements, lack of adequate water and sanitation infrastructure, overcrowding and increasing population density, complex humanitarian emergencies occurring cross-borders, in addition to climatic and environmental shocks and stresses, are exacerbating health risks.

In April 2023 conflict broke out in Sudan, and clashes erupted between the Sudanese Armed Forces (SAF) and the Rapid Support Forces (RSF) in multiple areas. In May 2023, 24.7 million people (more than 50 per cent of the country's population) were in need of humanitarian assistance (ACAPS, 2023b). Inside the country shortages of water and fuel, limited communications and electricity, and very high prices for essential items made the situation critical (UNHCR, 2023b). The conflict has destroyed key infrastructure, such as WASH facilities and hospitals, the capacity of which was already previously overstretched. Furthermore, there are severe shortages of medicines and vital supplies. The conflict displaced almost 4.3 million people within Sudan by October and drove over 1.1 million people into five neighbouring countries: the Central African Republic, Chad, Egypt, Ethiopia and South Sudan (UNHCR, 2023b).

In South Sudan, the humanitarian situation remains serious. After outbreaks of civil war in 2013 and 2016, the country has faced droughts, floods and low economic development impacts from the conflict in Sudan. In 2023, 76 per cent of the population was estimated to need humanitarian assistance (World Bank, 2023b).

In Somalia, the humanitarian situation is fragile, and the adverse impacts of climate change are worsened by conflict and instability. Al-Shabaab is a militant group that has been fighting against the Somali Government since its founding in 2006. In August 2022, the President of Somalia declared a ‘total war’ against Al-Shabaab, leading to escalated fighting and territorial shifts (ACAPS, 2023a). As of February 2023, 8.25 million people in Somalia needed humanitarian assistance, with nearly 5 million experiencing acute food insecurity between January and March 2023 (ACAPS, 2023a).

With a population of approximately 123 million people (2022), Ethiopia ranks as the second most populous nation in Africa. The country exhibits one of the region’s fastest-growing economies, experiencing an estimated growth rate of 6.4 per cent in 2021/22. Despite this economic momentum, Ethiopia continues to grapple with high poverty rates, reflected in a per capita gross national income of 1,020 US dollars. The nation aspires to attain lower-middle-income status by the year 2025 (World Bank, 2023a). However, the political situation is fragile. In November 2020, fighting erupted between the Ethiopian Government and the Tigray People’s Liberation Front (TPLF) rebel group, causing deaths and displacements. After two years, a peace deal was signed in November 2022. Yet, millions still urgently require humanitarian aid and protection. Approximately 9 million people in conflict-affected areas, including Tigray, Afar and Amhara, face insufficient access to food. In Tigray, almost 40 per cent of the population experiences severe food shortages. Beyond food insecurity, gender-based violence has risen significantly, yet women and children lack proper access to healthcare, social welfare and justice services (UNHCR, 2023a).

Around 54 million people are living in Kenya (World Bank, 2023d). Kenya has maintained relative political stability, with ongoing economic development initiatives. Regional collaborations, such as the East African Community (EAC), aim to foster economic integration and cooperation among member states. The EAC is a regional intergovernmental organization of seven Partner States: the Republic of Burundi, the Democratic Republic of the Congo, the Republic of Kenya, the Republic of Rwanda, the Republic of South Sudan, the Republic of Uganda and the United Republic of Tanzania, with its headquarters in Arusha, Tanzania.

2 Methodology

2.1 Study region

We focus on nine countries (Eritrea, Ethiopia, Djibouti, Somalia, Kenya, Sudan, South Sudan, Uganda and Tanzania) in the East African region within the Greater Horn of Africa (see Figure 1). Within the report, reference to East Africa encompasses these nine countries. Two case studies have been conducted for Ethiopia and Kenya providing in-depth information. Ethiopia and Kenya are crossed by the East African Rift and have a diverse geography including highland areas (Figure 1). Mount Kenya is the second highest peak of Africa, and the Ethiopian Highlands stretch across the country from north to south.

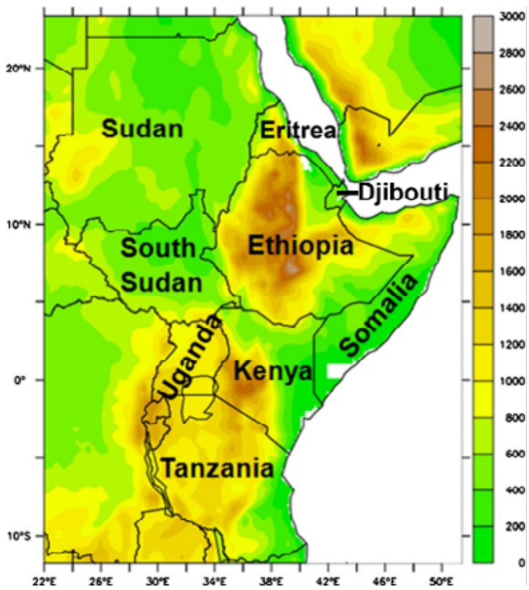

Figure 1. *Topography map of East African countries adapted from Osima et al., 2018. The colour scale indicates elevation in metres. Note that in this study we focus on Ethiopia, Eritrea, Djibouti, Somalia, Kenya, Sudan, South Sudan, Uganda and Tanzania.*

2.2 Current and future climate

The descriptions of current climate and future projections are based on the IPCC Working Group 1 Assessment Report (IPCC, 2021) and corresponding data provided in the Interactive Scaling Atlas from the IPCC IPCC WGI Interactive Atlas. Furthermore, we included results from regional projections (Osima *et al.*, 2018) as well as climate and hazard data from the countries' profiles on the World Bank Climate Change Knowledge Portal (World Bank, 2021c). The future projections for Ethiopia and Kenya are based on the SSP2–4.5 Shared Socio-economic Pathway – a middle of the road emissions scenario provided in the World Bank portal. While not the worst-case emissions scenario, SSP2–4.5 assumes that the Paris Agreement commitments are not achieved and 2°C global warming is not avoided.

2.3 Disease data collection and analysis

Disease development is complex and climatic variables interact with multiple other drivers to shape disease transmission. Importantly, for climate-sensitive infectious diseases, the relative influence that climatic variables (temperature, rainfall and humidity) have in driving infectious disease ecology and transmission is higher as compared to other drivers. These diseases tend to show strong seasonality; interannual variation in incidence (including epidemics); and associations with hydrometeorological extremes (e.g., floods and droughts) as well as global climate phenomena, such as the El Niño–Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). Furthermore, these diseases may be geographically bounded within climate zones, for example, dengue in the tropics (Bhatt *et al*., 2013) or meningitis in the 'meningitis belt' (Lapeyssonnie, 1963; Molesworth *et al*., 2003). However, to date, there is no definitive list of climate-sensitive infectious diseases.

To determine priority climate-sensitive infectious diseases in the region, we conducted a desk review, collating existing estimates of disease prevalence and known climate drivers in disease incidence and transmission. Since data availability on many of the climate-sensitive infectious diseases in the region is limited, multiple data sources and metrics were used, generating an overall, yet incomplete, picture with a likely underestimation of burden. Data was derived from ReliefWeb disaster alerts (ReliefWeb, 2024), disaster outbreaks news (DONs) from the World Health Organization (WHO) (World Health Organization, 2021), Our World in Data (Roser & Ritchie, 2019) and multiple WHO reports. Additional estimates were collected from peer-reviewed studies and reports from respected sources (e.g., UN reports or Centers for Disease Control and Prevention (CDC)). Information on climate-sensitivity was collected using peer-reviewed studies. Furthermore, while we identified priority diseases, the order in the list is no ultimate ranking. To validate the compiled list, interviews were conducted with stakeholders from the ERCS, KRCS and stakeholders in the region. Lists were also shared with the National Societies in Ethiopia and Kenya during an initial findings workshop, and one consolidated list per country was produced.

2.4 Mapping existing epidemic preparedness activities

We reviewed online sources and conducted key informant interviews (KIIs) to map surveillance systems, risk prediction models, EWS and existing programmes for the identified climate-sensitive infectious diseases. KIIs were held with stakeholders from the ERCS, KRCS and the region to learn more about existing epidemic preparedness activities as well as challenges to better prepare for climate-sensitive infectious disease outbreaks.

3 Regional climate profile and projections

3.1 Historical climate and extreme weather

The climate in the East African region has a strong seasonality. The northern region, encompassing northern Ethiopia, Eritrea, South Sudan, Djibouti and northern Uganda, predominantly receives rainfall from June to September (JJAS). In the equatorial part of eastern Africa, there are two distinct rainy seasons: the 'long rains' occurring from March to May (MAM) and the 'short rains' from October to December (OND) (Endris *et al*., 2019). The year-to-year rainfall variability is very high, in particular the variability in short rains (OND) is linked to large-scale circulation patterns in tropical oceans (Philippon *et al*., 2002).

- **Temperature:** East Africa has experienced a faster increase in surface temperatures compared to the global average (IPCC, 2021). Hot extremes and heatwaves have increased in the recent past (1995–2014) whereas cold extremes have decreased (IPCC, 2021).

- **Droughts:** In recent decades, a significant portion of Eastern Africa, specifically the Horn of Africa has encountered a rise in drought frequency and a reduction in overall rainfall during the long-rains season (Tierney *et al*., 2015). This has had major consequences for regional food security, where agriculture is mainly rainfed. The 2020–2023 drought in Ethiopia, Kenya and Somalia has surpassed the severe droughts of 2010–2011 and 2016–2017 (UN OCHA, 2023). Since late 2020, Somalia, and parts of Ethiopia and Kenya have been hit by the worst drought in the region in 40 years with more than 36 million people affected (The New Humanitarian, 2023). Parts of Somalia, Djibouti, Ethiopia and Kenya experienced their driest and hottest conditions on record in 2022 (NASA Earth Observatory, 2022; UNEP, 2022).

- **Floods:** The region is regularly affected by flooding caused by extreme rainfall that is partly related to ENSO and tropical cyclones in the coastal regions. In addition, coastal regions are exposed to sea level rise that contributes to increases in the frequency and severity of coastal flooding in low-lying areas as well as to coastal erosion along most sandy coasts (high confidence) (IPCC, 2021).

- **Tropical cyclones:** Tropical cyclones occur regularly in the northern and southern Indian Ocean, affecting the coastal regions of East Africa such as Somalia, Kenya and Tanzania. Prolonged heavy rainfall from tropical cyclones can cause severe flooding, damaging houses and critical infrastructure; causing sewers to overflow; destroying agricultural lands and crops; and displacing families (Floodlist, 2016; ReliefWeb, 2021).

3.2 Climate projections

Climate change will be associated with an increase in extreme events and devastating impacts.

- **Temperature:** Mean and extreme temperatures in East Africa are projected to further increase throughout the 21st century (see Figure A1 in the appendix). Notably, both maximum and minimum temperatures will increase indicating a warming of hot extremes during the day and at night in already hot regions (IPCC, 2021). The highest temperature increases are projected for Sudan and northern parts of Ethiopia; whilst the coastal belt of Tanzania will experience the least warming (Osima *et al.*, 2018).

- **Precipitation:** Precipitation projections are less clear and show stronger regional variability (see Figure A1 in the appendix). There is a tendency for drying in Sudan and South Sudan and wettening in Somalia, Djibouti, Ethiopia, Eritrea, Kenya and Tanzania (low confidence) (IPCC, 2021). Average rainfall will likely increase over the Ethiopian highlands and is projected to decrease over central and northern parts of Ethiopia (Osima *et al.*, 2018). Extreme rainfall will increase in the whole region, associated with pluvial flooding (IPCC, 2021).

- In southern East Africa, in particular Tanzania, average **tropical cyclone** wind speeds are projected to increase while their frequency is projected to decrease (medium confidence). This will be associated with heavy precipitation and more intense tropical cyclones (Category 4–5).

4 Priority climate-sensitive infectious diseases in East Africa

- The following diseases were identified as priority (based on prevalence, historic epidemics and link to a changing climate) in East Africa. The priority diseases are not in an objective rank order as there are significant challenges with under-reporting of diseases, inconsistent use of or changing case definitions affecting disease reporting, and limited data on country-specific distribution, burden and deaths. The disease presence by country is summarized in Figure 2. According to interviews with actors in the region, malaria, dengue and cholera are the top three diseases of concern.

Priority diseases

- **Malaria (vector-borne):** The malaria burden in East Africa is high with an average incidence of 136 cases per 1,000 people and an average death rate of 21.6 per 100,000 people per year between 2010–2020 (likely underestimates due to surveillance and reporting challenges) (Roser & Ritchie, 2019). Malaria is endemic in all of the nine countries under study (Roser & Ritchie, 2019). The invasive mosquito species *Anopheles stephensi*, is now detected in seven countries in Africa including Djibouti, Ethiopia, Sudan, Somalia and Kenya. Although the overall contribution of *Anopheles stephensi* to malaria transmission in the region remains unclear, the vector has the ability to transmit two malaria parasites (*Plasmodium falciparum* and *P. vivax*), thrives in urban and rural environments and consequently poses a significant threat to malaria control and elimination in East Africa (World Health Organization, 2023e).

- **Dengue (vector-borne):** Under-reporting of dengue makes it challenging to assess regional incidence and prevalence. Epidemics have been recorded in Djibouti, Eritrea, Ethiopia, Kenya and Sudan between 2013 and 2021 (Degife *et al.*, 2019; ReliefWeb, 2022; Usman *et al.*, 2016; World Health Organization, 2016, 2021).

- **Cholera (water-borne):** Cholera is endemic in many of the countries and there are numerous outbreaks in East Africa across the years. Figures are likely underestimated due to unreported cases, inadequate reporting systems, failure to seek medical attention, or other unknown barriers.

Disease of high concern

- **Yellow fever (vector-borne):** Endemic in Ethiopia, South Sudan, Sudan, Tanzania and Uganda (World Health Organization, 2023a)

- **Rift Valley fever (zoonotic, vector-borne):** No clear evidence on the burden of RVF is available for East Africa and other information is limited. The few reported outbreaks occurred in Kenya, Somalia, Sudan, Tanzania and Uganda (EM-DAT, 2023; World Health Organization, 2016, 2023a).

- **Schistosomiasis (zoonotic, vector-borne):** No official data on schistosomiasis was available, but it is estimated that Africa carries at least 90 per cent of all schistosomiasis burden and that a minimum of 218 million people required treatment while only 66.5 million received it as of 2015 (World Health Organization, 2023f).

- **Leishmaniasis (visceral and cutaneous) (zoonotic, vector-borne):** Visceral leishmaniasis hotspots are in the endemic countries Ethiopia, Kenya, Somalia, South Sudan, Sudan and Uganda (World Health Organization, 2020). Tanzania is considered endemic additionally (World Health Organization, 2023a). Cutaneous leishmaniasis is endemic in Eritrea, Ethiopia, Kenya and Uganda in East Africa (World Health Organization, 2023a).

- **Onchocerciasis (zoonotic, vector-borne):** Onchocerciasis is not well reported. 99 per cent of all cases occur in 31 countries sub-Saharan Africa of which six are located in East Africa (Ethiopia, Kenya, South Sudan, Sudan, Uganda and Tanzania) (World Health Organization, 2022).

- **Typhoid fever (water-borne):** Sub-Saharan Africa is estimated to account for 12.1 per cent of the global typhoid and paratyphoid burden, with incidences ranging between 100–200 per 100,000 people per year in East Africa (Stanaway *et al.*, 2019).

- **Rotavirus (water-borne):** Rotavirus is a substantial burden in East Africa with mortality rates ranging from more than 100 per 100,000 children under five years old in Uganda and South Sudan, to 50–100 per 100,000 children under five years old in Djibouti and Somalia, and 10–49 per 100,000 children under five years old for the rest of East Africa (IVAC, 2022). Additionally, 40–45 per cent of diarrhoeal-related childhood deaths can be attributed to rotavirus infections in the region (Tate *et al.*, 2016).

- **Influenza (air-borne):** While much is unknown, the burden of influenza in the East Africa region is high, with disproportionately higher mortality and hospitalization rates, compared to other world regions (Troeger *et al.*, 2019).

- **Measles (air-borne):** Limited data for East Africa specifically (beyond a high burden in sub-Saharan Africa) exists.

- **Meningitis (person-to-person droplets transmission):** Many countries of the East African region are part of the 'meningitis belt' (see Figure 6) with hyperendemicity in parts of Sudan, South Sudan, Eritrea, Ethiopia, Kenya and Uganda as well as increased risk in Tanzania (not part of the belt) (CDC, 2023). Epidemics at large scale occur every 5–12 years, but yearly epidemics occur during dry seasons reaching incidences of 1,000 cases per 100,000 people (*ibid*). East Africa carries the second highest burden across all world regions after West Africa, with an incidence rate of 165.7 in 1990–2019 (Chen *et al.*, 2023).

Specific risk groups, climatic and non-climatic drivers and projected changes in disease trends of the identified priority diseases are summarized in Table 1. We highlighted diseases that are highly climate-sensitive (dark green) and likely to exhibit a future increase in transmission based on climate projections for environmental suitability (dark blue).

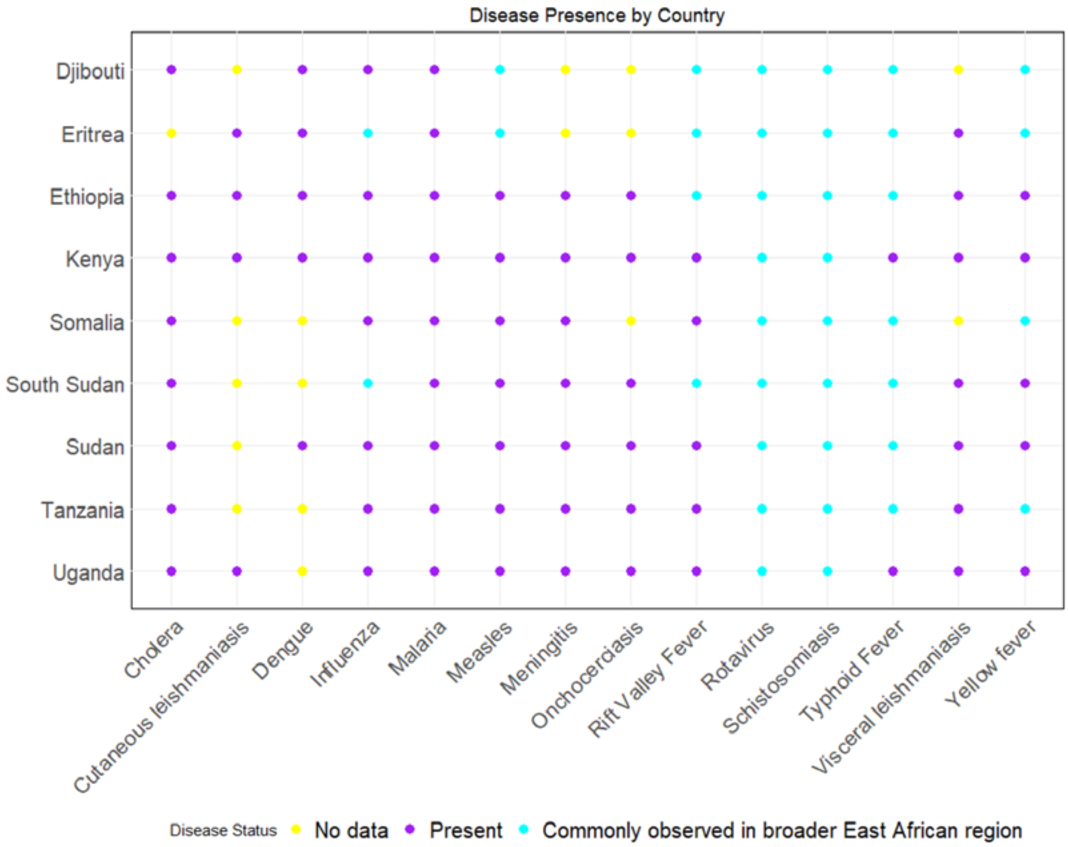

Figure 2. *The figure displays the presence of climate-sensitive infectious diseases across the different countries in the East African region. Each country is represented on the Y-axis, while climate-sensitive diseases are listed on the X-axis. Purple dots indicate the presence of these diseases in the respective countries, while yellow dots indicate no data availability. Cyan dots indicate acknowledgment of existence of the disease in the wider East African region, without country-specific data available.*

Disease	At-risk groups	Non-climatic drivers	Climatic drivers and seasonality	Projected changes in transmission pathways
Malaria	Populations with lower immunity, including highland populations, HIV infected individuals, children and pregnant women.	Population movements towards endemic areas (possibly connected to climatic drivers), proximity to vector breeding sites (artificial e.g., plastic water containers and natural e.g. ponds), drug resistant malaria, insecticide resistance and lack of vector control.	Malaria is transmitted by the bite of female mosquitoes of certain Anopheles species that carry the Plasmodium parasite. Both Anopheles mosquitoes and the parasite are sensitive to changes in temperature. Temperature has a non-linear relationship with vector and pathogen survival. The optimal rates of development for ***Plasmodium falciparum*** and ***Plasmodium vivax*** occur at 23–24°C, whereas the development rates begin to decrease beyond 31°C for ***P. falciparum*** and 29.8°C for ***P. vivax*** (McCord & Anttila-Hughes, 2017). The minimum temperature required for the development of ***P. falciparum*** and ***P. vivax*** is approximately 18°C and 15°C, respectively (Patz & Olson, 2006). Adequate rainfall is needed to maintain breeding sites (pools of water) (McCord, 2016). Adult mosquitoes are also dependent on specific moisture content in the air and will desiccate if the climate is too dry. Therefore, adequate humidity is also an important environmental condition (Stresman, 2010). Malaria exhibits strong seasonality, but seasonal patterns are highly location specific. In the East African highlands, increased prevalence and epidemics have been associated with rainfall and temperature changes as well as ENSO (Kulkarni *et al.*, 2022).	Transmission areas and season are already increasing and shifting e.g. towards highlands. Moreover, an increase in suitable areas and transmission months are expected in almost the entire East African region under every emission scenario.
Dengue	Multiple infections with different serotypes of dengue virus heighten the risk of developing severe dengue.	Proximity to vector breeding sites (artificial and natural), lack of vector control, urban residence and population movements to endemic areas.	Dengue is a viral infection of the dengue virus (DENV) transmitted by the bite of infected ***Aedes*** mosquitoes. There are several serotypes of dengue virus (DENV1, 2, 3 and 4). The optimal temperature for ***Aedes aegypti*** is 26–30°C and 70–80 per cent humidity (Mourya *et al.*, 2004). Dengue also exhibits non-linear associations with rainfall and temperature. High rainfall in combination with high temperatures (especially the weekly minimum temperature) tends to be a strong predictor for increased dengue transmission (Hales *et al.*, 2002; Chien & Yu, 2014). Above-normal temperatures and drought followed by extreme rainfall leads to dengue outbreaks 3–5 months later in certain contexts (studies not conducted in East Africa) (Lowe *et al.*, 2016).	Areas suitable for transmission have increased in most countries in East Africa. Transmission scenarios predict a future increase in basic reproduction rates for most countries in East Africa. Areas with moderate to high suitability for transmission are predicted to shift to central, eastern and south-eastern Africa by 2050 (Sintayehu *et al.*, 2020).
Cholera	Young children, especially when experiencing nutritional deficits.	Most drivers relate to WASH. Moreover, population movements and displacement drive disease into new areas.	Cholera is caused by ingesting food or water contaminated with the bacterium ***Vibro cholerae serotypes*** O1 or O132. Cholera outbreaks are largely due to the presence of the pathogen and broken WASH infrastructure, but temperature is known to positively influence bacterial growth, and heavy rainfall can mobilize the bacteria from a source resulting in the contamination of water. There is an increase of cholera cases between July and October for the Sahel region while the rest of the East African region (southern from Sahel), shows only weaker influences of seasonal patterns with slightly higher peak between December and January (Perez-Saez *et al.*, 2022). Cholera risk has historically increased during El Niño years (Moore *et al.*, 2017), and has place-specific interactions with drought and flooding (Charnley *et al.*, 2022).	No studies on future projections of cholera are available. However heavy rainfall and flooding are projected to increase in East Africa (IPCC, 2021) and may facilitate the spread of disease outbreaks.

Disease	At-risk groups	Non-climatic drivers	Climatic drivers and seasonality	Projected changes in transmission pathways
Yellow Fever	Risk groups include unvaccinated population groups (vaccine recommendation excludes pregnant women, children < 9 months and people with immunodeficiency). (WHO, 2023h)	Lack of vaccination, proximity to vector breeding sites (artificial and natural) and lack of vector control.	Yellow fever is a viral infection transmitted by infected, day-biting *Aedes* and *Haemagogus* mosquitoes. Increase in disease incidence is associated with higher temperatures and rainfall, due to their impacts on the mosquito lifecycle and viral replication in the mosquito (Hamlet *et al.*, 2018; Adekiya *et al.*, 2020). Seasonality is country specific but predominantly occurs in September and October, with a secondary peak in spring/early summer across all regions, suggesting that there are two periods of heightened transmission annually (da Cruz Ferreira *et al.*, 2017; Hamlet *et al.*, 2018).	The incidence rate per year is expected to increase with climate change.
Rift Valley Fever	Occupational groups handling animal products (blood or organs of infected animals) especially pastoralists. Traditionally, men are more often involved in these activities.	Flat areas below 500 metres above sea level, proximity to vector breeding sites (artificial and natural) and lack of vector control.	Rift Valley Fever primarily affects domesticated animals but can spread to humans via the bite of an infected mosquito or fly, or the handling of infected animal products. Increase in disease transmission risk is associated with increased ecological suitability for vectors, including sustained higher rainfall (leading to flooding) and increased vegetative coverage (Nanyingi *et al.*, 2015; WHO, 2021; Redding *et al.*, 2017).	Future outbreaks are expected to occur primarily in the rift valley and expanding towards the surrounding highland in each emission scenario (Taylor *et al.*, 2016).
Schistosomiasis	Individuals exposed to infested water relating to agricultural, domestic and occupational work and swimming (primarily children). Rural and economically disadvantaged areas, specifically those reliant on fishing.	Population movements towards endemic areas as well as population movements from endemic to non-endemic areas, population growth, urbanization, and related water demand and environmental modifications.	Schistosomiasis is caused by a parasitic worm that typically lives in freshwater snails. The larval stage of the worm lives in freshwater and can penetrate the skin and infect humans who enter the water. Increased rainfall and flooding can expand infested freshwater habitats (leading to contamination of other water bodies) increasing disease transmission risk (Adekiya et. al,2020). Ideal ecological conditions for human transmission are 16–18°C in calm water and 20–25°C in flowing waters (Adekiya *et al.*, 2020). Prolonged drought (9+ months) can reduce the occurrence of schistosomiasis (*ibid*). Higher temperatures can reduce the development rates of parasitic larvae and worms (*ibid*). Climatic interactions on snail and parasite development are complex and context specific.	No information specific for East Africa.
Leishmaniasis (Visceral and Cutaneous)	Populations with low immunity in previously non-endemic areas, HIV-positive individuals, children and young adults. Agricultural workers, traditionally men.	Intense agricultural practices, population movements, close proximity to vector reservoir and shared living with domestic animals.	Leishmaniasis is a parasitic infection caused by the bite of infected female *Phlebotomine* sandflies. The sandflies thrive between 19–30°C with a relative humidity above 30 per cent. Biting behaviour is highest between 20–30°C. Above 30°C, and with low relative humidity, sandfly populations decrease (Valero & Uriarte, 2020).	No information for the region but expected shift in distribution towards highlands in Ethiopia.

Disease	At-risk groups	Non-climatic drivers	Climatic drivers and seasonality	Projected changes in transmission pathways
Onchocerciasis	Remote, rural agricultural areas close to rapidly flowing waters (WHO, 2022).	Lack of vector control (in connection with cross-border collaboration) (Nakkazi, 2020)	Commonly known as "river blindness", onchocerciasis is caused by the parasitic worm *Onchocerca volvulus*. It is transmitted to humans through exposure to repeated bites of infected blackflies of the genus *Simulium* (WHO). Temperature influences both blackfly and worm ecology; however, evidence is limited to West Africa (Blum *et al.*, 2014; Cheke *et al.*, 2015). Different *Simulium* species thrive best at different maximal temperatures (Cheke *et al.*, 2015).	No information.
Typhoid fever	Young children and the elderly. Due to the close connection to WASH, population without access in rural settings and urban population in informal settlements (Kim *et al.*, 2022).	Lack of basic epidemiological evidence for African context. Typhoid risk relates to WASH access and safe drinking water. This might relate to unplanned urbanization. Drug resistant typhoid is an increasing problem in Africa (Kim *et al.*, 2022).	Typhoid fever is caused by a bacteria. Evidence on climatic drivers is limited. Seasonality varies greatly between geographical areas; strong global evidence identifies temperature and rainfall as strong drivers.	No information.
Rotavirus	Children below the age of 2 are at the highest risk of severe outcomes, with children below 12 months at even higher risk. Malnutrition exacerbates risk for all children (WHO, 2023e).	Low vaccination rates are a major driver of infections. Due to occurrence of rotavirus across income levels globally, WASH is unlikely to have substantial influence of transmissions (WHO, 2023e).	East Africa-specific evidence is lacking. Global studies identified temperature, rainfall and humidity as climatic predictors.	No information.

Disease	At-risk groups	Non-climatic drivers	Climatic drivers and seasonality	Projected changes in transmission pathways
Influenza	Risk population for severe outcomes include pregnant women, HIV infected individuals, individuals with chronic conditions (e.g., pulmonary-, cardiac-, or metabolic diseases) and age groups at both ends of the spectrum (WHO, 2023g)	Much of transmission dynamics is unknown in the African context. Transmission happens in crowded spaces such as schools and nursing homes (WHO, 2023g)	Global findings are contradicting pointing towards high context specificity. Rainfall, temperature and humidity have been studied, but no clear evidence can be found for the direction of associations between the climatic drivers and incidence of influenza, with some studies finding positive, some negative or no associations (Lane *et al.*, 2022).	No information.
Measles	Highly mobile populations and other hard to reach populations lack vaccination access. Overcrowded living situations. Malnourished children are at particular risk of severe outcomes.	Lack of routine immunization, population movements and fragility of the healthcare system are main drivers and can be exacerbated by drought.	Measles is caused by a virus that spreads easily between people. Childhood vaccination against measles is stalling in sub–Saharan African countries during drought periods due to population behaviour changes (e.g., migration or avoidance of vaccination due to other illness) (Nagata *et al.*, 2021). Drought in some contexts is associated with malnourishment of children, making them more susceptible to measle infections (WHO, 2023d).	No information.
Meningitis	Individuals with preconditions relating to immune deficiencies (e.g., HIV) are particularly vulnerable. Different age groups are vulnerable to different pathogens.	High density of people living together, e.g., in overcrowded housing or refugee camps promote spread as well as mass gatherings.	Meningitis can be caused by a viral or bacterial infection. Meningitis infection appears to be influenced by temperature, rainfall, wind speed and air pollution. Research from the Sahel region highlights that increased temperature and high concentration of airborne dust are associated with increased risk of meningitis infection and mortality (Jusot *et al.*, 2017). Temperature variability appears to have the largest effect on meningitis at a global scale, but when this is downscaled to countries the patterns are not definitive (Chen *et al.*, 2023).	Future emission scenarios indicate an increase in incidence globally under each emission scenario (Chen *et al.*, 2023).

Table 1. *Priority diseases for East Africa, their specific at-risk groups, (non) climatic drivers and transmission pathways, where available. The colour code indicates the climate sensitivity of diseases. Green indicates regional climate sensitivity.*
Deep dark green = climate sensitive with strong global and regional evidence.
Dark green = climate sensitive with regional evidence but limited global evidence.
Light green = climate sensitive with strong global evidence but limited regional evidence.

Grey = limited regional and global evidence. Blue = projected changes in future transmissions.
Dark blue = projections of transmission for each country in East Africa exists.
Light blue = evidence for some countries.

References for the detailed information are provided in written text; additional sources not mentioned in the text are referenced direct.

5 Existing epidemic preparedness activities

5.1 Mapping epidemic preparedness activities

In the East African region, various epidemic preparedness activities are in place.

The East African Community, an intergovernmental organization headquartered in Tanzania, has several disease prevention strategies, projects and programmes that emphasize collaboration across East Africa to improve health emergency preparedness:

- Public Health Laboratory Networking Project: establishing laboratories for the diagnosis and surveillance of tuberculosis and other communicable diseases (East African Community, 2023b).

- Pandemic Preparedness Project: contributes to regional contingency plans to implement regional risk and crisis communication strategies (East African Community, 2023d).

- Cross-Border Field Simulations: a form of practicing and training for emergency situations in which functional capacity is monitored and evaluated (East African Community, 2023a).

Additionally, the WHO's Health Emergency Preparedness, Response and Resilience Programme (HEPR) aims to enhance health security and system capacity by fostering collaboration across sectors, strengthening operational systems and securing finance for preparedness initiatives (WHO, 2023b).

5.2 Surveillance systems

Health surveillance systems in East Africa are responsible for monitoring public health concerns, including the tracking of diseases, outbreaks and other health-related events.

- The East African Integrated Disease Surveillance Network (EAIDS Net) primarily enhances disease surveillance systems, while facilitating the exchange of information and knowledge (East African Community, 2023c). Connecting Organizations for Regional Disease Surveillance (CORDS) has worked to improve capacity with EAIDS Net by aiding the continuous exchange of information within the region (CORDS, 2023).

- EAC Regional Knowledge Management Portal for Health: A health portal that shares knowledge from different regional health programmes of the East African Community.

- Africa Centres for Disease Control Event-Based Surveillance (EBS): EBS is used to monitor and report unusual or unexpected health events and is essential for early detection of emerging diseases and health threats (Africa CDC, 2023a).

- Regional Integrated Surveillance and Laboratory Network (RISLNET): A network of laboratories in place for disease testing and surveillance. This initiative aids in the early detection and confirmation of diseases (Africa CDC, 2023b).

Since 2017, the IFRC has been implementing the Community Epidemic and Pandemic Preparedness Programme, that started in seven countries including Kenya and Uganda (IFRC, 2023a). The IFRC is working with public authorities and key stakeholders with an emphasis on the One Health approach. Consequently, a strong focus is put on zoonotic diseases. Community-based surveillance depends on volunteers that report diseases to the branch level of the National Society (NS) that reports back to regional and national level and relevant government authorities. The trained volunteers use community-case definitions with alerts that are associated with diseases or specific symptoms (KII 1). In Kenya, a focus is put on the One Health approach and thus zoonotic diseases. The alerts include human disease (acute water diarrhoea, measles, polio, Covid-19, viral haemorrhagic fevers, unusual illnesses or deaths of people) and animal diseases (anthrax, Rift Valley fever, rabies or a cluster of unusual animal deaths). However, the system is not directly reporting vector-borne diseases such as malaria, dengue and cholera as these are indirectly detected when diarrhoea symptoms are recorded.

The Norwegian Red Cross is supporting community-based surveillance and developed a custom software platform for data collection, called Nyss (Norwegian Red Cross, 2023). The programme is active in ten countries including Kenya, Somalia, South Sudan and Uganda. Volunteers are equipped with training to identify signs of epidemic-prone diseases and use basic phones to report health risks via short, coded SMS. Nyss receives, aggregates and studies these reports, sharing the data with platform users and issuing real-time alerts to supervisors and health authorities.

Through the ECHO-funded Pilot Programmatic Partnership (PPP) and with support from the IFRC network, the South Sudan Red Cross is supporting communities to detect disease outbreaks, preparedness and response (KII 11).

Furthermore, countries have surveillance systems at the national level, mostly hosted by the Ministry of Health. The national health ministries often provide weekly or monthly bulletins with information about current outbreaks, alerts etc.

The East African region has high quality regional climate information for the East African region provided by the Intergovernmental Authority on Development (IGAD) Climate Prediction and Application Centre (ICPAC) – a regional climate centre of the World Meteorological Organization (ICPAC, 2023).

5.3 Disease risk prediction models

In 2016, Taylor *et al.*, (2016) used the Liverpool Rift Valley Fever model, driven by climate data, to assess the risk of RVF outbreaks in East Africa under different climate scenarios, emphasizing the need for vigilance, EWS and socio-economic interventions to mitigate future impacts. The results of this academic endeavour emphasized the need for investment in surveillance and EWS throughout East Africa.

Multiple risk prediction models have been also developed for Ethiopia, Kenya, Tanzania and Uganda with a focus on malaria, also including dengue, RVF and cholera, but have not been operationalized and linked to EAPs (see Table A1 in the appendix).

5.4 Early warning systems

To date, there are several sEAPs for floods or droughts but no operational sEAPs for climate-sensitive infectious diseases in the East Africa region (see Table 2). The existing drought and flood sEAPs do not focus on preparedness activities for epidemics (Anticipation Hub, 2022). IFRC is currently in the planning phase of a cholera sEAP in Cameroon, Democratic Republic of the Congo, Ethiopia, Malawi, Mozambique, Nigeria, Zambia and Zimbabwe (KII 14).

Table 2. Overview of existing sEAPs for hydrometeorological hazards, sEAPs for infectious diseases and other EWS for infectious diseases.

Country	Existing hydrometeorological hazard EAP	sEAP for infectious diseases under development	Other anticipatory activities for infectious diseases
Djibouti	Flood sEAP	None	
Eritrea	None	None	
Ethiopia	Drought EAP Flood EAP	Cholera sEAP in planning (IFRC)	The NS is using an EWS for malaria that was implemented by 510.org and is based on a weather-based trigger. The NS has access to the impact-based forecasting portal and sends alerts to different districts (Woreda). Preventive actions are taken; mainly the distribution of mosquito nets. However, the skill has to be assessed as the system tends to predict too many outbreaks (KII 8)
Kenya	Drought EAP Flood EAP	None	The IFRC is in discussions with NS for the development of an sEAP for cholera. The Danish Red Cross is interested in supporting an sEAP for an infectious disease (target disease not yet decided).
Somalia	None	None	
South Sudan	None (under discussion: IFRC Anticipatory Action programme to develop an sEAP for floods)	None	
Sudan	None (development of a flood EAP has been terminated as of December 2023)	None	
Tanzania	None (under discussion: IFRC Anticipatory Action programme to develop an sEAP for floods)	None	
Uganda	Flood EAP Drought EAP under development	None	Currently in the planning phase is the "Improving early warning and control of mosquito-borne disease outbreaks caused by extreme weather in Uganda" funded by the UK National Institute for Health and Care Research with Uganda Red Cross Society, Uganda Virus Research Institute, Malaria Consortium UK (lead), Erasmus Medical Centre (Netherlands) and 510 (KII 8).

The WHO's Neglected Tropical Diseases unit (WHO/NTD) alongside the Special Programme for Research and Training in Tropical Diseases (TDR) developed an Early Warning and Response System (EWARS) for dengue outbreaks in 2017. This was introduced to 71 countries including Ethiopia (KII 12; WHO, 2017). The tool was developed for epidemiological surveillance and response activities; however, it can be used for outbreak modelling too.

In 2019, training on the 'EWARS in a box' tool to improve disease outbreak detection in emergency settings, such as in countries in conflict or following climate-related disasters, was held (WHO, 2019). 'EWARS in a box' has been operational in Ethiopia and South Sudan. In Ethiopia, two key actions were to establish sentinel sites across the country, and to develop a decision support tool to model and forecast climate-sensitive diseases in key areas during peak seasons, enabling targeted public health interventions and health system preparedness. The decision support tool uses a statistical outbreak prediction model and is applied to model outbreaks of vector-borne and water-borne diseases such as malaria, yellow fever, cholera and meningitis in Ethiopia (KII 12). However, a thorough assessment of the tool is outstanding.

6 Challenges and barriers to Anticipatory Action for epidemics

In the region, we identified the following major challenges and barriers to Anticipatory Action for epidemics.

Data collection, synchronization and maintenance: Data often remains fragmented across various sources without systematic transfer into a unified nationwide database (KII 9). Digitization requires significant effort and resources which are not available. Harmonization of diverse datasets poses additional barriers, as standardizing formats and protocols across disparate systems is challenging. Surveillance systems often suffer delays due to healthcare underutilization or incompleteness due to unreported outbreaks, undermining the effectiveness of early detection. Challenges with data sharing among different entities impede timely analyses and responses to emerging health threats.

Existing silos and coordination gaps: Communication and coordination among diverse stakeholders pose persistent challenges (KII 13). There is a notable lack of cross-sectoral collaboration between health, Anticipatory Action and disaster risk management stakeholders. Coordination gaps persist not only between ministries and non-governmental organizations (NGOs), but also within the NS and regional activities involving various local and international NGOs. Within the NS, engagement between thematic departments (e.g., health and disaster management) can be challenging. Furthermore, coordination between national, sub-national and local authorities/NS branches remains challenging (KII 17).

Alert systems rarely lead to action: Despite partly active surveillance and alert systems, there is a lack of systematic public health actions initiated that go beyond the sending of alerts.

Public health concerns: Health infrastructure is highly limited in certain countries and inadequate financial resources impede the overall healthcare system. The absence of advanced laboratory facilities creates delays in disease testing and identification. During epidemics, the absence of sufficient health infrastructure and funding hampers the containment efforts. Furthermore, the lack of access to medications can exacerbate the impact of diseases. The lack of awareness regarding disease transmission from animals to humans, coupled with the absence of health tests for animals, poses a significant public health risk. Finally, the restricted access to healthcare facilities in remote areas, worsened by conflicts in the regions, further complicates efforts to implement preventive strategies, making the population vulnerable to infectious diseases.

Political instability and conflict: Political instability and conflict significantly contribute to the challenges faced by health systems in the East African region. The occurrence of simultaneous emergencies overwhelms health systems. Ongoing conflicts in the region exacerbate the difficulties in accessing health services and hinder the distribution of medical resources. The displacement of populations in conflict zones is high and is a known outbreak risk factor. Cross-border movement poses a significant challenge to disease monitoring and response efforts, necessitating strong regional coordination.

Knowledge and capacity: There is limited knowledge on disease transmission, how Anticipatory Action could be used to reduce or prevent epidemics, and what data analysis may be needed (KII 12, KII 13). Furthermore, National Societies do not have the technical capacity to investigate the links between climate and disease outbreaks and to establish evidence-based amplifying factors. As such, external technical support will be needed, at least in the establishment of operational systems and again periodically to make system improvements over time.

Finance: There is a lack of sustained funding for long-term projects and personnel, both within National Societies and ministries, specifically geared toward prioritizing health and Anticipatory Action. The Anticipatory Pillar of the Disaster Response Emergency Fund (DREF), while an important resource for operationalizing AA systems, has specific limitations, including not being able to fund government actors to undertake action, caps on spending, and caps on the frequency of activation. Limitations of funds for continuous monitoring may be particularly limiting for AA for epidemics systems as compared to systems targeting directly a hydrometeorological hazard, which benefit from a set of largely automated forecasting tools.

7 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 throughout the world, will continue to be relevant (see Epidemic Control Toolkit, IFRC, 2023b). Rather, Anticipatory Action offers a mechanism to help inform whether disease prevention and control actions could be implemented earlier than the normal response and thus more effectively reduce disease transmission.

The Anticipatory and Health Working Group has identified three main anticipatory approaches to develop triggers for epidemics:

Trigger Approach 1: identification of health impacts linked to hydrometeorological hazards

Trigger Approac 2: multi-stepped composite (surveillance and amplifying factors)

Trigger Approac 3: outbreak risk prediction mathematical models.

7.1 Anticipatory Action priorities in next 1–3 years

Recommendation 1

Recommendation 1: Partner National Societies to support National Societies in East Africa in the development of sEAPs for cholera, malaria and dengue using Trigger Approach 2.

For Ethiopia and Kenya, the development of sEAPs for dengue, cholera and malaria seem to be feasible as these countries have strong National Societies, governmental institutions and the availability of both disease and meteorological data. Moreover, these diseases represent high regional as well as country priorities and are strategic within global frameworks (e.g., the Roadmap 2030 to end Cholera by 2023 (Global Taskforce on Cholera Control, 2017)). Trigger Approach 2 necessitates strong surveillance data. In both of these contexts, surveillance data is strong enough for regular access to data (pending a Memorandum of Understanding with the Ministry of Health (MoH) in each country). The precise combination of 'amplifying factors' – hydrometeorological, socio-economic, or other – that will determine the trigger will depend on the country and the disease. Discussions on amplifying factors should be held between National Societies, MoH, researchers, disaster risk management, and hydrometeorological services. Partner National Societies (PNS) could support a series of in-country workshops to determine the most feasible and accurate 'amplifying factors' to be used in combination with surveillance data. The development of sEAPs would follow good practice outlined in the Forecast-based Financing (FbF) Practitioners Manual.

Identifying evidence-based 'amplifying factors'

Amplifying factors include: (1) known climatic and weather drivers of infectious disease, as identified in academic research papers (whether from statistical analysis or laboratory-based experiments); (2) known socio-politico-economic drivers of disease transmission risk such as displacement and overcrowding, which may be linked with violence and conflict; (3) destruction or damage to critical infrastructure, which can have long-term consequences; (4) other underlying health conditions, such as an increase in malnutrition rates for specific diseases. These amplifying factors should be carefully researched to ensure the proposed pathways by which these amplifying factors may influence disease transmission risk are correct for the specific context.

In order to work on sEAPs for epidemics, we recommend to: 1) reach out and connect with relevant stakeholders in the country/region and, if necessary, formalize relationships through an MoU; 2) hold a workshop with the MoH and relevant stakeholders to agree which diseases to focus on first based on level of concern, existing data, models and activities; 3) provide technical support for trigger development and the assessment of existing models and activities – the decision tree developed by the Anticipatory and Health Working Group might be a useful tool to identify if trigger development is feasible for the selected disease; 4) pool resources and funding from large-scale projects (e.g., IFRC Anticipatory Action in Africa); and 5) make use of existing programmes and task forces, and support the evaluation of activities.

We recommend focusing on Trigger Approach 2, pending further discussions on data access and partnerships for Trigger Approach 3 (which requires mathematical modelling and appropriate academic partnerships).

Table 3. Overview of indicative list of amplifying factors to investigate and feasible early actions for the priority climate-sensitive infectious diseases.

Disease	Amplifying factors to investigate	Feasible early actions to explore
Malaria	▪ Increased rainfall tends to be a predictor of increased malaria up to 3 months in advance in Ethiopia, Kenya, Eritrea, Uganda and Sudan. This has a levelling-off affect: after a certain threshold of rainfall more malaria is not observed. ▪ Increased temperature is a predictor of increased malaria, usually 1–2 months in advance in Ethiopia and Kenya. Maximum and minimum temperature increase and occurrence during the rainy or dry season needs to be carefully investigated. For example, minimum temperature has the strongest correlation with increased malaria several months later, with especially pronounced effects in highland areas. ▪ Combination of rainfall and temperature, their sequencing and also other contextual factors (topography, vegetation cover, altitude) must be considered. ▪ Humidity may also modulate the effects of rainfall and temperature. ▪ High rainfall in lowlands. ▪ Low rainfall in drought affected areas. ▪ Indian Ocean Dipole and El Niño–Southern Oscillation may influence malaria incidence. ▪ Population displacement. ▪ Level of infections in the previous year (or transmission season where bimodal seasons are present) or waning immunity. ▪ Interventions used in previous seasons. ▪ Anti-malarial resistance increase. ▪ Changes in socio-economic status or economic crisis (Abeku *et al.*, 2004; Ceccato *et al.*, 2007; Dabaro *et al.*, 2021; Ergete *et al.*, 2018; Karuri & Snow, 2016; Kibret *et al.*, 2019; Loha *et al.*, 2012; Midekisa *et al.*, 2012; Zhou *et al.*, 2004)	Note that many of the early actions for malaria will have co-benefits for dengue prevention and vice versa. ▪ Community-based awareness-raising on transmission risk and good protective behaviours. ▪ Support to the MoH in raising awareness, training volunteers on case referrals, case definition and prompt identification. ▪ Provision of window screens to be installed at health centres or schools lacking them to prevent mosquitoes from entering. ▪ Distribution of mosquito repellents to evening workers. ▪ Environmental management i.e., removal of vector breeding sites. ▪ Fumigation session (timing of these will be important) and discussions on the impact on the environment of such a method. ▪ Essential items could be distributed to the community, including long-lasting insecticidal nets (per family), community cleaning kits with tools and gloves, and repellents (per family). ▪ Support to the MoH – assistance can be provided to the MoH for vector control, including fumigation, larviciding, collecting samples and raising awareness.

Disease	Amplifying factors to investigate	Feasible early actions to explore
Dengue	▪ Higher temperatures (to a thermal limit). ▪ Rainfall has context-specific effects: in arid areas it may create the only source of standing water; in urban areas it may result in the creation of pools of water suitable for breeding in human-made containers; in agricultural areas it may wash away larvae where water sources are abundant year-round. The effect of rainfall is modified by local topography, hydrology and altitude. ▪ Dynamics of drought followed by rainfall. ▪ El Niño–Southern Oscillation phenomena. ▪ Interventions in previous seasons. ▪ Population behaviour with regards to the storage of water or outdoor activity. ▪ Population movement. (Gutu *et al.*, 2021; Lowe *et al.*, 2016, 2018; Mekuriaw *et al.*, 2022)	Note that many of the early actions for malaria will have co-benefits for dengue prevention and vice versa. ▪ Conduct awareness-raising sessions at the community level, including in schools, to promote community-based disease control and health awareness. These sessions could include communicating critical messages on dengue prevention during community clean-up activities. ▪ Environmental management i.e., removal of vector breeding sites during community mobilization days. ▪ Distribution of mosquito repellents to outdoor daytime workers. ▪ Provision of mosquito nets to public buildings to prevent the entry of mosquitoes. ▪ Essential items could be distributed to the community, including long-lasting insecticidal nets (per family), community cleaning kits with tools and gloves, and repellents (per family). ▪ Support to the MoH: assistance can be provided to the MoH for vector control, including fumigation, larviciding, collecting samples and raising awareness.
Cholera	▪ Dry conditions followed by heavy rainfall. ▪ Heavy rainfall during existing floods. ▪ High temperatures and heatwaves. ▪ Flooding which affects critical WASH infrastructure. ▪ Persistent low rainfall and damaged water infrastructure, including for watering crops. ▪ Violence and conflict which damages infrastructure or displaces populations leading to overcrowding in unhygienic conditions. ▪ Prescence of open defecation. ▪ Malnutrition. ▪ Waning immunity. ▪ Proximity to fishing communities in which cholera is endemic. ▪ Increased trade from an endemic area. ▪ Increased salinity of water bodies. (Alcayna *et al.*, 2022; Charnley *et al.*, 2021; Jones *et al.*, 2020; Rieckmann *et al.*, 2018; Wu *et al.*, 2018)	▪ Support to the MoH in raising awareness, training volunteers on case referrals, case definition and prompt identification. ▪ Community-based surveillance. ▪ Awareness-raising on good hygiene promotion, especially hand washing and washing of food in safe drinking water. ▪ Distribution of chlorination tablets. ▪ Oral cholera vaccination campaign (if there is sufficient lead time). ▪ Distribution of safe water storage containers.

Recommendation 2

Recommendation 2: Advocate for the inclusion of health or WASH early actions in future or updated hydrometeorological EAPs and sEAPs

In countries of the region where EAPs and sEAPs for climate-related hazards are in place (Djibouti, Uganda), we recommend fostering interventions (during the next validation cycle) for climate-sensitive infectious diseases and WASH activities in these existing (s)EAPs to strengthen health early actions in current interventions. Discussions have begun between IFRC and National Societies in Sudan, South Sudan and Tanzania on developing (s)EAPs likely for hydrometeorological hazards. PNS can support these discussions and advocate for the inclusion of health impacts in the feasibility study as well as the inclusion of health early actions (where appropriate) to help reduce disease outbreak risk. There are currently no planned discussions for Anticipatory Action in Eritrea or Somalia. A Terms of Reference (ToR) document was begun but never finalized by the German Red Cross for operational research on climate-sensitive infectious diseases in Somalia. PNS could reach out to German Red Cross to pick up this ToR again and discuss challenges.

For countries with less advanced health infrastructure, such as Djibouti, Eritrea, Somalia, South Sudan and Sudan, emphasis should be placed on supporting the improvement of surveillance mechanisms, increasing access to public healthcare, supporting the scale-up and roll out of preemptive vaccination campaigns, distribution of mosquito nets and improvement of WASH.

Special care is needed to select health or WASH activities that are suitable for the specific health impacts to be addressed (e.g., chosen with an understanding of the range of pathways in which contaminated water is ingested), right-sized (e.g., a sufficient supply of chlorine for the period of elevated risk and considering the limited shelf-life of cholerine as the powder loses 50 per cent efficacy after 4–5 months) and evidence-based. Continual monitoring around the effectiveness of health and WASH activities as early actions will help build the evidence-base and refine best practices.

7.2 Climate and health knowledge and awareness

Recommendation 3

Recommendation 3: In countries with no existing EAPs, Partner National Societies can support National Societies to hold workshops and training on Anticipatory Action for epidemics and climate change along with health linkages.

The understanding of climate-sensitive infectious diseases (e.g., links between climate change and infectious diseases, and possible prevention) can be strengthened at the regional, national and local levels, leveraging existing knowledge within the RCRC Movement.

- **Regional** workshops with relevant actors (including researchers) that are working on climate-sensitive infectious diseases should be conducted by National Societies and partners from the RCRC Movement in collaboration with regional platforms such as the East and South Africa Regional Cholera Platform and the Dengue Alliance. In this context, collaboration between IFRC, PNS and countries' NS would be helpful to promote the discussion on Anticipatory Action for health and to align them with national and international policies.

- We recommend countries' NS join existing **national** working groups on disease surveillance and climate-sensitive infectious diseases to advocate for the inclusion of Anticipatory Action across different sectors.

- At the **local level**, we encourage active measures to be taken by PNS and the NS to improve the health literacy of volunteers and communities by implementing targeted initiatives to enhance understanding of disease-related information. This includes organizing educational training or events, distributing materials in local languages and leveraging community leaders to disseminate crucial health warnings and/or messages. Emphasis should be placed on preventative measures, such as vaccination and hygiene practices, particularly for vulnerable communities. The NS branches can facilitate training (with local volunteers) and make the proposed activities feasible.

- **Some useful resources and tools** from the RCRC Movement and beyond that can be used are:

  - Epidemic Control for Volunteers (IFRC) – https://www.ifrc.org/document/epidemic-control-volunteers-toolkit

  - Learning resources about Anticipatory Action (Anticipation Hub) – https://www.anticipation-hub.org/learn/learning-resources

  - Epidemic preparedness tool (IFRC) – https://www.ifrc.org/our-work/disasters-climate-and-crises/what-disaster/epidemics-and-pandemics

  - Data readiness tool (Global Disaster Preparedness Center) – https://preparecenter.org/toolkit/data-readiness-toolkit/

  - Alliance for Transformative Action on Climate and Health (a WHO-hosted network) – https://www.atachcommunity.com/

  - Overview of climate-sensitive infectious diseases (WHO) –https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

  - Operational Cholera Toolkit (Action Contre la Faim) – Operational cholera toolkit

  - Guidelines for malaria (WHO) – https://app.magicapp.org/#/guideline/7661

7.3 Partnerships

Recommendation 4

Recommendation 4: Develop partnerships with research institutions and academics in-country and internationally for analysis of climate and health data for trigger development (Trigger Approach 2 and 3) and evaluation.

NS and PNS can: (1) capitalize on the research capacities of high-calibre universities in the region; and (2) facilitate international partnerships with other universities and research groups to support the analysis of climate and weather data as well as epidemiological modelling. In countries like Ethiopia, where disease and meteorological data are available, such collaborations could enable the utilization of historical data for model development. NS and PNS could bring together representatives from meteorological agencies and health ministries as well as regional and international disease modelling researchers in a seminar (series) to share their knowledge on disease surveillance and epidemiological modelling. We recommend coordination with the following institutes:

- **Ethiopia:** Ethiopian Public Health Institute (EPHI); National Meteorology Agency, Integrated Sector Oriented Meteorological Service, Meteorological Forecast and Early Warning Research.
- **Kenya:** University of Nairobi, Department of Clinical Medicine and Therapeutics; Kenya Meteorological Department; Kenyan Medical Research Institute (KEMRI).
- **Uganda:** Makerere University, School of Public Health; Uganda Virus Research Institute.
- **Regional:** Intergovernmental Authority on Development Climate Prediction and Application Centre (ICPAC).
- **International:** Malaria Consortium; London School of Hygiene and Tropical Medicine regarding Barbados dengue early warning system; Médecins Sans Frontières (MSF).

Early discussions between the NS, MoH and partners should focus on evaluating Anticipatory Action for epidemics programmes in East Africa so that lessons can be drawn from the pilots. The Anticipatory Action and Health Working Group has prioritized the development of evaluation frameworks for 2024–2025 – all relevant health and MEAL (monitoring, evaluation, accountability and learning) staff can support the co-development of this work. Existing preparedness activities and interventions should be evaluated on their effectiveness and these evaluations could be codesigned with experts from research institutions and other partnerships. As an additional form of support, National Societies globally are encouraged to join the Anticipation Hub Working Group on Anticipatory Action for Health to discuss how to design evaluations. This work can be supported by the Working Group on Monitoring, Evaluation and Learning.

Recommendation 5

7.4 Advocacy

Recommendation 5: National Societies and partners to continue advocating for the strengthening of climate resilient healthcare systems in the region.

The strength of the health system and people's access to timely healthcare is critical for effective disease prevention and control. If mandated to do so, National Societies can advocate for the bolstering of testing facilities for diseases; ensuring the efficient distribution of medicines; and enhancing immunization programmes as well as mass drug distribution efforts. By increasing access to healthcare services in remote and conflict-affected areas, epidemic preparedness can be enhanced. NS can also advocate for a One Health approach[1] with regards to zoonotic diseases, and generally be involved in improving the climate and health knowledge of communities and partners.

7.5 Coordination

Recommendation 6

Recommendation 6: Improve coordination through the development of national and/or regional Anticipatory Action Task Forces

We recommend that National Societies in the region advocate with Governments to create national task forces on Anticipatory Action and health and/or join existing national working groups to advocate for the inclusion of Anticipatory Action across different sectors (i.e., within National Health Security plans). This could foster political commitment and secure allocated budgets for proactive measures. The members of the task forces should include government authorities (Ministry of Health, national weather service), research institutes, local and international NGOs, National Societies and Partner National Societies. The national task forces could:

- **Promote Anticipatory Action in National Health Security Plans:** Develop and formalize strategies that can be implemented at the national level on preparing for, protecting from and responding to adverse health effects for health emergencies.

- **Enhance the positioning of health in Climate Change Action and Adaptation Plans:** It would be beneficial to advocate for the integration of climate-sensitive disease outbreaks in discussions on climate-related disaster management, particularly with national weather services.

- **Provide annual workshops for knowledge-sharing among technical working groups:** Organize and conduct annual workshops to share successes and lessons learned among technical working groups. Include relevant stakeholders, experts and institutions.

- **Provide capacity building and training programmes:** Develop programmes to enhance capacity and skills, particularly around disease surveillance and anticipatory aid deployment and delivery.

1 "Unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes that the health of humans, domestic and wild animals, plants and the wider environment (including ecosystems) are closely linked and interdependent." (WHO, 2024).

- **Develop annual reports documenting evidence of collaboration and coordination:** A report documenting the successes and challenges of task force collaboration and goals for future collaboration should be published annually.

Recommendation 7

Recommendation 7: Establish cross-border dialogues between National Societies and partners for Anticipatory Action and epidemics, and ensure regular communication with existing initiatives.

Coordination and peer-to-peer learning from epidemic preparedness activities and operationalized sEAPs for infectious diseases should be supported across the region in the next 1–5 years. In addition, PNS and IFRC should ensure consistent coordination and regular updates on the expanding Anticipatory Action projects in the East Africa region. For cholera there is the East and South Africa Regional Cholera Platform – a regional network from the multi-sectoral global Cholera Platform supported by the European Civil Protection and Humanitarian Aid Operations (ECHO), UK Department for International Development, UNICEF and the CDC. The platform aims to better understand where and why cholera epidemics take place (Cholera Platform, 2023). The topic of Anticipatory Action and the development of (s)EAPs for cholera could be discussed in this context.

The Dengue Alliance, conceived by the Drugs for Neglected Diseases initiative (DNDi), was launched in 2022 to develop affordable and accessible treatments for dengue. The Alliance also focuses on raising funds and mobilizing resources while openly sharing research knowledge. In addition, all East African countries considered here – apart from Tanzania – are members of IGAD, whose mission is to assist and complement the efforts of its member states in areas of peace, security, agriculture, environment, economic cooperation and social development. The IGAD Climate Prediction and Applications Centre (ICPAC), as the regional climate centre, provides medium-range and extended climate forecasts for the region. Strong collaboration with ICPAC and national weather services is encouraged. A regional technical working group on Anticipatory Action could be led by IGAD/ICPAC.

Lastly, the regional and sub-regional Dialogue Platforms on Anticipatory Humanitarian Action offer an opportunity for cross-border discussion and learning. These annual events bring together stakeholders from the humanitarian sector, academia, donors and governments. Sessions and networking events specifically on Anticipatory Action for epidemics could be included in each dialogue.

8 Conclusion

Our analysis reveals that the development of sEAPs is most promising for cholera, dengue and malaria in Ethiopia and Kenya within the next 1–3 years. Ethiopia and Kenya are countries with robust infrastructure and strong health ministries as well as sufficient climate and disease data; and can, therefore, focus on developing (s)EAPs for cholera, dengue and malaria. Cholera is a priority disease in all countries and monitoring and surveillance systems are in place. In addition, work on Anticipatory Action for cholera has a high priority in the global Anticipatory Action network as well as the RCRC Movement. This is a promising opportunity for National Societies to leverage work on cholera (s)EAPs in their countries. Moreover, dengue and malaria are highly climate-sensitive and of high priority in East Africa. Dengue is increasing geographically and seasonally across many regions in Africa. Furthermore, malaria is endemic in many regions but traditionally non-endemic regions experience malaria outbreaks and a new mosquito (*Anopheles stephensi*) is spreading in the East African region. In order to develop sEAPs, robust, evidence-based triggers for malaria and dengue need to be developed in collaboration with technical specialists (EPHI, KEMRI, University of Nairobi, Makerere University, Uganda Virus Research Institute, London School of Hygiene and Tropical Medicine, Climate Centre, etc.).

During the course of this study, the authors and funder gained insights which can help inform institutional learning for the development of Anticipatory Action for epidemics and how to support national partners in this sector. Multiple forms of support have been outlined in the recommendations section of this report – most notably for partner national societies is to support National Societies to develop (s)EAPs. The structures around Anticipatory Action systems, including the extremity of events that are considered, its financing, the efficacy actions and triggers, and so forth, have been shaped by the hydrometeorological hazards that have been the foundations of the Anticipatory Action sector – floods, droughts, cyclones and, increasingly, temperature extremes. On a practical level, Anticipatory Action for epidemics differs substantially from Anticipatory Action for hydrometeorological hazards. There are far fewer available operational early warning products for epidemics and in most cases a dearth of data, as compared to the available models and historical data for floods, droughts and temperature extremes. It is essential to check the feasibility of developing an Anticipatory Action for epidemics system before committing significant funds, as it may well be the case that a reliable early warning system is not achievable with the presently available data, surveillance capacities or early warning product for a specific context. In those cases, it is advisable to make investments in system strengthening. Thankfully, there have been significant investments in surveillance and resources devoted to understanding the relationship between disease outbreaks and weather parameters in both Kenya and Ethiopia. As such, there are multiple viable options to pursue.

Further, the resources available to support National Societies to develop Anticipatory Action systems and institutional knowledge around Anticipatory Action is heavily skewed towards hydrometeorological hazards. This is understandable given the vast experience among Red Cross Red Crescent actors in operationalizin gAnticipatory Action for the impacts of floods and droughts. National Societies seeking to develop Anticipatory Action for epidemics have fewer examples to look to, less written guidance, and less familiarity in which to develop these systems, which are barriers more acutely felt in the initial stages. Institutions seeking to support National Societies to begin Anticipatory Action for epidemics will need to lean in during these early stages and ensure there is sufficient staff resource – for both National Society staff and technical experts – especially for the establishment of triggers, targeting criteria and identification of evidence-based higher impact actions. During the study it was clear that there was interest in establishing such systems, and often funding from different sources to make progress, but it remained challenging to make decisions around system design. It can be very discouraging for National Society staff to only be given tasks, such as identifying available datasets for health impacts, without being empowered to co-develop the analysis. National Societies will need partners to be working closely with them at crucial stages of the project – ideally in the spirit of a co-design, rather than simply technical guidance that a National Society must then grapple with to make the final decisions on actions, targeting, triggers, lead times etc.

Anticipatory Action for epidemics may also require more cross-departmental collaboration as compared to Anticipatory Action for hydrometeorological hazards, which in many cases can be led and delivered primarily by the disaster management department of a National Society. In contrast, Anticipatory Action for epidemics will most likely need substantial buy-in and involvement of both the disaster management and health departments, but also ideally MEAL to support the establishment of evidence around health early actions, as well as psycho-social support where relevant, and preparedness/disaster risk reduction to embed Anticipatory Action for epidemics in ongoing initiatives including surveillance, vector control, education etc. This also increases the requirements around time, guidance, coordination, etc., which need to be considered during the early set-up of a project.

In closing, during this study, National Societies and health partners in both Kenya and Ethiopia have had the opportunity to connect and begin discussions on operationalizing sEAPs for the prioritized climate-sensitive infectious diseases. New connections have been made, and old ones revived, which has created a sense of momentum. For the first time, several stakeholders have clarity around what such a system could look like in their context, and others are reaching out for materials and other forms of support. There is greater awareness around, and willingness to engage with, regional and national workshop groups for Anticipatory Action generally. It is crucial to take advantage of this momentum to support the National Societies and partner stakeholders to progress in establishing operational sEAPs for epidemics in the region.

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Annex A

Ethiopia: Climate-sensitive infectious disease country assessment

This case study is part of the East Africa regional assessment on Anticipatory Action for climate-sensitive infectious diseases. Additional information and recommendations for the region can be found in the regional assessment.

1. Objectives

The objectives of this case study are to:

1. Summarize the geography and climate of Ethiopia as these influence disease distribution
2. Provide information on the climatic and non-climatic drivers of priority infectious diseases in Ethiopia
3. Summarize the ongoing epidemic preparedness activities in Ethiopia, highlighting challenges
4. Provide recommendations on moving forward with the National Society of the Ethiopian Red Cross and partners in supporting the development of frameworks and (s)EAPs for infectious diseases.

2. Background

With a population of approximately 123 million people (World Bank, 2023a), Ethiopia ranks as the second most populous nation in Africa. Although the country exhibits one of the region's fastest-growing economies, poverty rates are high (per capita gross national income of 1,020 US dollars) (World Bank, 2023a). Ethiopia's health conditions are generally poor. The country ranks the fifth highest in the 54 African nations for overall global health security; however, there are only eight doctors per 100,000 people (GHS Index, 2021a).

Maternal mortality and acute malnutrition rates remain high and infectious diseases (waterborne, airborne and vector-borne) are highly prevalent. Additionally, access to healthcare services is difficult; particularly in conflict- and flooding-affected regions. Most of the population still lacks proper sanitation infrastructure and access to clean water. Together with inadequate personal hygiene, these factors are leading causes for diarrhoeal diseases. 70 million people are at risk of cholera in Ethiopia (IFRC, 2021a).

Vector-borne diseases – including chikungunya, dengue fever, leishmaniasis, malaria and yellow fever – pose significant health impacts in Ethiopia and are highly sensitive to changing climatic conditions such as temperature, precipitation and humidity. Furthermore, approximately 9 million people in conflict-affected areas, including in Afar, Amhara and Tigray, face insufficient access to food. In Tigray, almost 40 per cent of the population experiences severe food shortages.

Beyond food insecurity, gender-based violence has risen significantly, yet women and children lack proper access to healthcare, social welfare and justice services (UNHCR, 2023a).

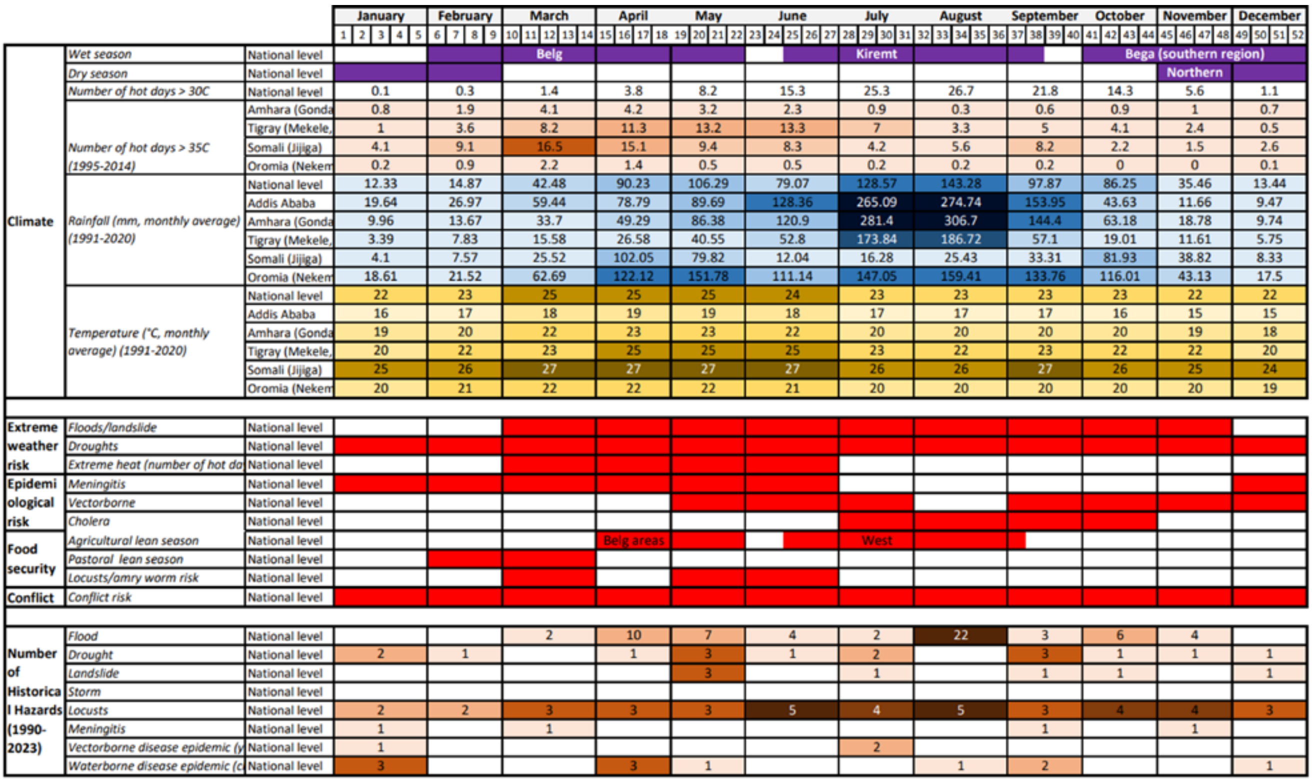
3. Geography and climate

Ethiopia is large, land-locked and highly geographically diverse. This results in diverse rainfall, temperature and climate patterns across the country. Equatorial rainforests in the south and south-west experience high rainfall and humidity. Afro-alpine (high altitude mountainous) areas and certain lowlands exhibit desert-like conditions. The central and northern highlands have cooler climates, while the east is arid with minimal rainfall. Temperature variations span from -15°C in the highlands to above 25°C in the lowlands (World Bank, 2021).

Seasonal rainfall, primarily influenced by the Inter-Tropical Convergence Zone (ITCZ), shows significant inter-annual variability. Ethiopia observes three rainfall seasons: *Kiremt* (mid-June to mid-September), contributing 50–80 per cent of annual rainfall; *Belg* (February to May), a sporadic secondary wet season in central and northern regions; and two distinct wet seasons in the southern regions – *Belg* (February to May) and *Bega* (October to December) with drier and colder conditions. Annual rainfall distribution ranges from approximately 2,000 millimetres (mm) in the south-west highlands to less than 300 mm in the south-east and north-east lowlands.

Ethiopia experiences extreme weather events such as major flooding (that have historically affected millions of people) and widespread devastating droughts (that have historically affected 10–36 million people), especially in the water deficit regions of Afar, Somali and Tigray (World Bank, 2021a).

Seasonal patterns of climate, extreme weather, health threats, food security and conflict are summarized in the seasonal emergency calendar (Figure 3).



			January	February	March	April	May	June	July	August	September	October	November	December
Climate	Wet season	National level			Belg				Kiremt			Bega (southern region)		
	Dry season	National level											Northern	
	Number of hot days > 30C	National level	0.1	0.3	1.4	3.8	8.2	15.3	25.3	26.7	21.8	14.3	5.6	1.1
	Number of hot days > 35C (1995-2014)	Amhara (Gonda	0.8	1.9	4.1	4.2	3.2	2.3	0.9	0.3	0.6	0.9	1	0.7
		Tigray (Mekele,	1	3.6	8.2	11.3	13.2	13.3	7	3.3	5	4.1	2.4	0.5
		Somali (Jijiga)	4.1	9.1	16.5	15.1	9.4	8.3	4.2	5.6	8.2	2.2	1.5	2.6
		Oromia (Nekem	0.2	0.9	2.2	1.4	0.5	0.5	0.2	0.2	0.2	0	0	0.1
	Rainfall (mm, monthly average) (1991-2020)	National level	12.33	14.87	42.48	90.23	106.29	79.07	128.57	143.28	97.87	86.25	35.46	13.44
		Addis Ababa	19.64	26.97	59.44	78.79	89.69	128.36	265.09	274.74	153.95	43.63	11.66	9.47
		Amhara (Gonda	9.96	13.67	33.7	49.29	86.38	120.9	281.4	306.7	144.4	63.18	18.78	9.74
		Tigray (Mekele,	3.39	7.83	15.58	26.58	40.55	52.8	173.84	186.72	57.1	19.01	11.61	5.75
		Somali (Jijiga)	4.1	7.57	25.52	102.05	79.82	12.04	16.28	25.43	33.31	81.93	38.82	8.33
		Oromia (Nekem	18.61	21.52	62.69	122.12	151.78	111.14	147.05	159.41	133.76	116.01	43.13	17.5
	Temperature (°C, monthly average) (1991-2020)	National level	22	23	25	25	25	24	23	23	23	23	22	22
		Addis Ababa	16	17	18	19	19	18	17	17	17	16	15	15
		Amhara (Gonda	19	20	22	23	23	22	20	20	20	20	19	18
		Tigray (Mekele,	20	22	23	25	25	25	23	22	23	22	22	20
		Somali (Jijiga)	25	26	27	27	27	27	26	26	27	26	25	24
		Oromia (Nekem	20	21	22	22	22	21	20	20	20	20	20	19
Extreme weather risk	Floods/landslide	National level												
	Droughts	National level												
	Extreme heat (number of hot da	National level												
Epidemiological risk	Meningitis	National level												
	Vectorborne	National level												
	Cholera	National level												
Food security	Agricultural lean season	National level				Belg areas			West					
	Pastoral lean season	National level												
	Locusts/amry worm risk	National level												
Conflict	Conflict risk	National level												
Number of Historical Hazards (1990-2023)	Flood	National level			2	10	7	4	2	22	3	6	4	
	Drought	National level	2	1		1	3	1	2		3	1	1	1
	Landslide	National level					3		1		1	1		1
	Storm	National level												
	Locusts	National level	2	2	3	3	3	5	4	5	3	4	4	3
	Meningitis	National level	1		1						1		1	
	Vectorborne disease epidemic (y	National level	1						2					
	Waterborne disease epidemic (c	National level	3			3	1			1	2			1

Figure 3. *Seasonal emergency calendar for Ethiopia summarizing average monthly climate, extreme weather, epidemiological, food security, and conflict risk based on (ACLED, 2024; Ahmed, 2012; Alemu & Wimberly, 2020; EM-DAT, 2023; FEWS NET, 2024; Perez-Saez et al., 2022; World Bank, 2023a).*

According to climate projections,[2] national average temperatures are projected to increase (~1.3°C by 2050) with the strongest seasonal increase in mean temperature between March to May (during the *Belg* rainy season). The number of 'hot' days (i.e., above 35°C) is expected to continue increasing; already many lowland regions experience more than 30 'hot' days per year.[3] The changes in rainfall will not be experienced uniformly across the country and across the seasons due to Ethiopia's large land area and diverse topography. Average rainfall is projected to increase in the Ethiopian highlands (IPCC, 2021). Western regions are projected to be drier in the *Belg* rainy season (Amhara, Benishangul–Gumuz and the Southern Nations, Nationalities and Peoples Region), which is associated with an increase in dry days. No changes in rainfall in the *Belg* rainy season are projected for Oromia and Tigray. Afar, Somali and Gambela may receive slightly more rainfall in the *Belg* rainy season. The northern regions of Afar, Amhara and Tigray may experience slightly higher average rainfall (5–15 per cent more) during the *Kiremt* rainy season. In the Somali region, rainfall during the *Bega* wet season may be about 10 per cent wetter than the recent past.

4. Priority climate-sensitive infectious diseases

Based on available evidence concerning the incidence, prevalence and historic epidemics, and triangulated via discussions with Ethiopian stakeholders (National Society, EPHI and the Ministry of Health), cholera, dengue, diarrhoeal disease, leishmaniasis (visceral and cutaneous), malaria, measles, meningitis, schistosomiasis, yellow fever and zika were determined to be the priority climate-sensitive infectious diseases.

Climate-sensitive infectious diseases

Climate-sensitive infectious diseases are diseases in which climatic variables (temperature, humidity and rainfall) strongly influence the ecology and thus lifecycle and transmission risk of an infectious disease. Other factors (such as population immune status, land-use change, urbanization and environmental degradation) also influence disease transmission risk. However, the delayed influence that climatic factors have on disease transmission risk can be capitalized on to build Anticipatory Action systems, which is why climate-sensitive infectious diseases are of focus in this report.

2 The results are based on projections from the SSP2–4.5 Shared Socio-economic Pathway of the Coupled Model Intercomparison Project Phase 6 (CMIP6) multi model ensemble used by the Intergovernmental Panel on Climate Change (Eyring *et al.*, 2016).

3 The eastern regions of Somali and Afar may experience 15–16 additional days above 35°C by 2050; this means around 60 hot days per year in Somali and around 44 hot days per year in Afar. The central areas including the highlands may experience an increase of 6–9 days hot days. In the southwestern region of Benishangul–Gumuz, the number of hot days increases by 15 days (to 51 days) per year by 2050 and in Gambela by an additional 11 days (to 74 days) hot days per year.

Table 4. Overview of priority climate-sensitive infectious diseases in Ethiopia, climatic, non-climatic drivers and existing preventions and preparedness programmes.

Disease	Climatic drivers	Non-climatic drivers	Existing prevention and preparedness programs
Malaria (endemic in lowland areas)	Rainfall, humidity and temperature have non-linear effects on mosquito survival, reproduction and biting rate, as well as parasite survival and replication. Proximity to breeding sites (stagnant water). ENSO and particularly El Niño years (Leal Filho *et al.*, 2023; Woyessa *et al.*, 2023).	Population immunity. Highly susceptible populations are in highland areas (Vajda & Webb, 2017). Population growth and behaviour (e.g., water storage habits)	Reported on a weekly basis. National Malaria Elimination Program (NMEP) aims for a 50 per cent reduction in malaria mortality and morbidity by 2025. Through the US President's Malaria Initiative (PMI), USAID in collaboration with the NMEP, is actively working to enhance malaria prevention and treatment efforts (USAID, 2023). The project supports the Ethiopian Government in collecting and analyzing data on malaria cases for Public Health Emergency Management (PHEM), deaths and interventions to inform decision-making and improve the effectiveness of malaria control efforts. In particular, PMI will increase support for weekly malaria data reported in PHEM used for the Epidemic Prognosis Incorporating Disease and Environmental Monitoring for Integrated Assessment (EPIDEMIA) tool which uses epidemiological and climate data to estimate potential future outbreaks (PMI, 2024). The National Meteorological Agency distributes monthly and seasonal climate information tailored for the health sector, focusing on malaria prediction (Ethiopia National Meteorology Agency, 2023). In 2017, in a WHO-led initiative, the WHO developed an early warning, alert and response system (EWARS) tool that is now used by the EPHI to predict malaria outbreaks (KII 12). In 2021, 510 developed a model to predict the environmental suitability for malaria-carrying mosquitos, based on monthly rainfall and temperature (KII 8). The tool was developed in an ad hoc project without involving ministries or other national stakeholders. It is used by the ERCS but not linked to a standardized response mechanism. The Health Cluster is assisting in the surveillance, prevention and control of outbreaks of communicable diseases, including malaria, and publishes health bulletins several times a year (Health Cluster, 2023).
Cholera	Seasonal differences between north and south Ethiopia, historically associated with extreme flooding (Perez-Saez *et al.*, 2022; Simane *et al.*, 2016). Drought periods, high temperatures, and changes in the pH and salinity of water bodies have been identified as risk factors for cholera in the sub-Saharan African region (Charnley *et al.*, 2021).	Poor WASH infrastructure often linked with poverty, human behaviours and knowledge.	Immediately notifiable to MoH. Reported on a daily basis at sentinel sites and transferred to EPHI. In 2017, in a WHO-led initiative, the WHO developed an EWARS tool that is now used by the EPHI to predict cholera outbreaks (KII 12). The National Cholera Elimination Plan aims to achieve zero cholera cases in hotspot areas for the disease by 2028. In response to a 2019 outbreak, Ethiopia developed an Emergency Plan of Action (EPoA) which highlights several WASH practices to reduce cholera risk. Ongoing discussions to develop an sEAP on cholera with IFRC. The Health Cluster is assisting in the surveillance, prevention, and control of outbreaks of communicable diseases, including cholera, and publishes health bulletins several times a year (Health Cluster, 2023).

Disease	Climatic drivers	Non-climatic drivers	Existing prevention and preparedness programs
Diarrhoeal disease	Increased risk during dry seasons or drought, increased incidence linked to rising temperatures and variable rainfall patterns (Alemayehu *et al.*, 2020a, Challa *et al.*, 2022).	Poor WASH infrastructure, human behaviorus and knowledge; close proximity to domestic animals in Ethiopia (Alemayehu *et al.*, 2020b).	Reported on a weekly basis.
Measles	Positively correlated with the dry season and negatively with the rainy season, but these patterns and peaks are likely driven by human behaviour, e.g., schooling year (Gutu *et al.*, 2020).	Low vaccination rates of hard-to-reach populations (Gutu *et al.*, 2020; WHO, 2023e). Human seasonal movement or displacement, especially if resulting in overcrowded conditions.	Immediately notifiable to MoH. Reported daily at sentinel sites and transferred to EPHI. The Health Cluster is assisting in the surveillance, prevention, and control of outbreaks of communicable diseases, including measles, and publishes health bulletins several times a year (Health Cluster, 2023).
Yellow Fever	Changes in temperature positively influence transmission intensity; rainfall often seems to mitigate transmission. Under certain conditions, high temperatures and rainfall can compound, resulting in increased transmission compared to temperature increase alone (Adekiya *et al*, 2020).	Close proximity to breeding sites and specific plant species, and outdoor activity during biting times in the morning and evening. (Lilay *et al.*, 2017; Mulchandani *et al.*, 2019; Waldetensai *et al.*, 2023).	Immediately notifiable to MoH. Reported daily at sentinel sites and transferred to EPHI. In 2017, in a WHO-led initiative, the WHO developed an EWARS tool, which is now used by the EPHI to predict yellow fever outbreaks (KII 12).
Meningitis	Mostly occurs during the dry season (December to June) across the meningitis belt (Figure 4) (Simane *et al.*, 2016). In Ethiopia, this lasts from December to February. High temperatures in the Sahel region and the high concentration of airborne dust are associated with the increased risk of meningitis infection and mortality (Xu *et al.*, 2022).	Overcrowded living and work environments, and mass gatherings (WHO, 2023f).	Immediately notifiable to MoH. Reported daily at sentinel sites and transferred to EPHI. In 2017, in a WHO-led initiative, the WHO developed an EWARS tool, which is now used by the EPHI to predict meningitis outbreaks with accuracy of 65 per cent (KII 12).
Dengue	In Africa, minimum temperature of the coldest month, annual temperature range, rainfall in the wettest month and rainfall in the driest month have significant influence (Nosrat *et al.*, 2021; Sintayehu *et al.*, 2020). Increased incidence of post-heavy rainfall occurs with temperature and humidity, influencing transmission (Mekuriaw *et al.*, 2022).	Human behaviour, including water storage in uncovered containers creating breeding sites, lack of awareness (Degife *et al.*, 2019; Mekuriaw *et al.*, 2022; Mesfin *et al.*, 2022).	Immediately notifiable to MoH. Reported daily at sentinel sites and transferred to EPHI. In 2017, in a WHO-led initiative, the WHO developed an EWARS tool, which is now used by the EPHI to predict dengue outbreaks (KII 12).

Disease	Climatic drivers	Non-climatic drivers	Existing prevention and preparedness programs
Schistosomiasis	Complex climate dynamics: temperature in the range of 17.9–29.8 °C, rainfall from 1,400–1,898 mm, and drought positively influence transmission and possibly compound individual effect (Ponpetch *et al.*, 2021).	Population streams; rapid, unplanned urbanization; occupational exposure to infested water (WHO, 2023f).	Not reported.
Leishmaniasis (visceral and cutaneous)	Temperature changes (range 17.2–23.8°C), rainfall (903.4–1,715.8 mm) and humidity influence vector (sandfly) distribution (Seid *et al.*, 2014; Simane *et al.*, 2016; WHO, 2020). Biting behaviour is suspected to occur at 20–30°C (Valero & Uriarte, 2020).	Intense agricultural practices and close living proximity to natural sandfly reservoirs (Assefa, 2018; Jones & Welburn, 2021).	Not reported.

5. Epidemic prevention and preparedness: opportunities and challenge

Disease surveillance

The MoH introduced the Public Health Emergency Management Centre in 2009 led by the EPHI. Data is reported through the PHEM, and EPHI holds the mandate for disease surveillance and early warning along with collecting and maintaining health data at the national level (KII 9). The MoH has prioritized 36 diseases, 22 immediately reported (such as cholera, dengue and yellow fever) and 14 weekly (such as malaria and meningitis) (KII 12). Disease surveillance is carried out at sentinel sites (KII 12) with data reported at a health facility transferred via the woreda, zone, region and finally to the EPHI either by paper, telephone or email (KII 9). As part of the PHEM, a digital data entry platform – district health information system 2 (DHIS2) – has been introduced.

Alongside the development of DHIS2, five days' training has been delivered to 30 participants and technical assistance has been given to the reporting sites (KII 9). The digital disease surveillance data is publicly available to download on request to the EPHI.

Nonetheless, there are currently only 14 sentinel sites, which may not be sufficient to comprehensively monitor and track diseases across the country (KII 12). Additionally, the digitization process – particularly the implementation of DHIS2 – is progressing slowly (KII 9). The country is encountering hurdles in terms of infrastructure as well as a lack of essential components, such as computers and servers, which are crucial for the effective operation of a digital health information system. These challenges highlight the need for increased investment and strategic planning to enhance the technological capabilities of disease surveillance in Ethiopia.

Disease risk prediction models

In Ethiopia multiple malaria models are in place, that could be useful for trigger development; however their thorough assessment is needed.

- The EWARS is based on a statistical outbreak prediction model and forecasts outbreaks of vector-borne and waterborne diseases such as cholera, malaria, meningitis and yellow fever (Trigger Approach 3) (KII 12). The EWARS decision support tool was introduced with help from the WHO and is used by the EPHI (KII 12). However, there are no automated response mechanisms linked to the EWARS tool.

- The EPIDEMIA tool (Merkord *et al.*, 2017), supported by USAID through the PMI, is used by the PHEM system, using epidemiological data and climate data to predict outbreaks of malaria (Trigger Approach 3) (PMI, 2024).

- The malaria model form the Ethiopian National Meteorology Agency predicts malaria outbreaks based on temperature and humidity to assess suitable mosquito breeding areas (Trigger Approach 1) and publishes the maps in monthly bulletins (National Meteorology Agency, 2023).

- The malaria model from 510 – also based on vector suitability – is available on the impact-based forecast platform and is accessible by the ERCS (Trigger Approach 1).

Coordination

In 2020, the MoH established a multi-sectoral technical working group for climate-sensitive disease surveillance (KII 12). The group is led by the Department of Early Warning of the EPHI. Members of the group include different directorates of the EPHI, Ministry of Agriculture, Environment Protection Authority, MoH, Ministry of Water and Energy, Ministry of Transport and Logistics, Ethiopian Investment Commission, Ministry of Innovation and Technology, Ethiopian Meteorology Institute, Addis Ababa University, Ethiopian Public Health Association, National Disaster Risk Management Commission and the WHO (KII 12). The ERCS is "welcome to join the group" but is not yet a member (KII 12).

Furthermore, the EPHI's Early Warning and Information System Management Directorate is reportedly not aware of the Anticipatory Action possible within IFRC's DREF (KII 12). Consequently, knowledge-sharing would be useful to develop standardized preparedness activities such as EAPs.

At the national scale of ERCS, there is no dedicated health department; instead, there is a health and WASH division under the Disaster Risk Management (DRM) department. Having a dedicated health department and focal point for health could enhance epidemic preparedness (KII 10).

Policy and capacity

Ethiopia established a National Action Plan for Health Security 2019–2023. The prioritization of epidemic preparedness along with coordinated communication are two key components of the National Action Plan. However, a lack of dedicated resources for epidemic preparedness poses a significant challenge to health security efforts. Health security assessments have revealed that a breakdown in communication between different sectors has impeded potential progress that could have been achieved through multi-sectoral coordination (Prevent Epidemics, 2022). Moreover, the shortage of dedicated staff at both the national and sub-national levels, particularly acute at the sub-national level, exacerbates the situation (KII 12). A focused approach on climate change and health is needed, emphasizing the need for dedicated personnel to address these critical issues at various administrative levels.

6. Recommendations

We recommend focusing Anticipatory Action efforts in the short- to medium-term (1–5 years) on cholera, dengue and malaria as these diseases are highly climate-sensitive, represent strong priorities for Ethiopia, and ongoing activities are likely to make the development of sEAPs feasible.

Recommendation 1

Recommendation 1: PNS can coordinate efforts with ERCS and IFRC, and support the development of an sEAP for cholera in 2024.

The IFRC is in discussion with the ERCS to develop a cholera sEAP in 2024, based on existing guidance, to build a composite trigger (surveillance data and amplifying factors such as population displacement, dry conditions or extremely heavy rainfall in a cholera endemic area) in Ethiopia (KII 15). A phased approach is suggested by IFRC with a first trigger (more than 10 cases of diarrhoeal disease in the same community within one week) linked to the establishment of a branch outreach response team (BORT) to interrupt the transmission chain, distribute disinfection spray, and provide advice and public health messages. With a second trigger (cholera is declared at the local level), oral rehydration points (ORP) and possibly cholera treatment units will be needed to treat mild cases. The third trigger (more than 100 cases with more than 1 per cent mortality) leads to a concluding of the prevention activities proposed in the sEAP and an emergency appeal will be submitted (imminent DREF). Next steps on sEAP development would follow good practice outlined in the Forecast-based Financing (FbF) Practitioners Manual.

Opportunities for action:

1. The PNS contacts the Head of the Disaster Management Department of the ERCS as well as representatives from IFRC to receive updates on plans. Furthermore, the British Red Cross is coordinating a joint BORT Training of Trainers programme alongside issuing guidance on cascading further training for the ERCS in the second and third quarters of 2024.

2. ERCS may need support in accessing data (knowing what to ask for at which scale of granularity) and in analysing the data to identify historical patterns and the development of a meaningful trigger along with evidence-based amplifying factors (Trigger Approach 2). Additional support may include conducting a thorough analysis of historical data to identify patterns related to cholera outbreaks, followed by a workshop to identify potential triggers for cholera outbreaks based on the analysis findings. Therefore discussions should be fostered between with IFRC, MoH, EPHI, PNS, academics and ERCS. PNS could possibly organize a Movement-wide workshop series on cholera triggers and amplifying factors (see Recommendation 1 in the main report), the Anticipatory Action and Health Working Group could support this.

3. The ERCS contacts the Senior Advisor to the Minister (lead on Public Health in Emergencies, Ministry of Health) to get involved in the sEAP discussion and ensure alignment of the sEAP with the National Cholera Plan (Strategic Objective 1) (Ministry of Health Ethiopia, 2022).

4. The ERCS together with PNS facilitates a joint meeting with the IFRC, MoH, EPHI and Health Cluster, Ethiopia (East Africa Cholera Platform and ERCS to discuss the next steps, milestones and timeline). Specifically, discussion should include joint exploration of the possible feasible early actions. Meetings can be followed up by writing workshops to coproduce an sEAP that is ready for the approval process.

Recommendation 2

Recommendation 2: ERCS with support from partners to help advocate for Anticipatory Action for epidemics

Opportunities for action:

1. The ERCS joins the multi-sectoral technical working group for climate-sensitive disease surveillance. The ERCS can contact the Early Warning Department at EPHI. The ERCS together with partners from the RCRC Movement, such as IFRC and PNS, could organize workshops on Anticipatory Action, the importance of sEAPs and the IFRC DREF.

2. ERCS together with PNS considers facilitating the creation of a national technical working group on Anticipatory Action.

3. ERCS and PNS advocate for Anticipatory Action by supporting the integration of Anticipatory Action into the National Action Plan for Health Security. ERCS can contact the Senior Advisor to the Minister to do so.

4. The introduction of a focal point for health at the ERCS national level would be beneficial for national coordination.

5. ERCS branches facilitate training for and with volunteers and communities on Anticipatory Action and climate-sensitive infectious diseases.

Possible stakeholders for task force:

MoH (Senior Advisor to the Minister, lead on Public Health in Emergencies); EPHI, PHEM, Early Warning and Information System Management Directorate; Ethiopia National Meteorology Agency, Integrated Sector Oriented Meteorological Service, Meteorological Forecast and Early Warning Research; Addis Ababa University, School of Public Health; PNS such as the Danish Red Cross, British Red Cross and IFRC; USAID.

Recommendation 3

Recommendation 3: ERCS and PNS to explore the development of an (s)EAP for either dengue or malaria in the next 1–3 years.

Both diseases have high priority in Ethiopia and the development of an sEAP for either one of them might be feasible. The development of an sEAP for malaria may yield potential co-benefits for dengue prevention and, conversely, the establishment of an sEAP for dengue could have benefits for malaria prevention. This is because prevention measures can be similar, for example, through the distribution of mosquito nets and mosquito repellent. Although the Ethiopian Government works towards malaria elimination, malaria cases have been increasing in recent years and 3.2 million cases were reported in 2023 (ReliefWeb, 2023). This is partially attributed to the inadequate and underfunded execution of vector control measures, interruptions in interventions due to conflicts, as well as mosquito resistance to pyrethroid insecticides and the introduction of *Anopheles stephensi* (PMI, 2024).

Opportunities for action:

1. ERCS with PNS facilitates meetings with stakeholders – in particular the MoH and Ethiopian National Meteorology Agency – to decide on a dengue or malaria sEAP. Dengue has been given less attention while cases are increasing in Africa. However, digital retrospective data for dengue might not be available (KII 12), which can make trigger development more challenging. A dengue sEAP might be beneficial for most at-risk groups, such as women, children and the elderly, because treatment is not available. For malaria, digital surveillance data is available via DHIS2 data platform (KII 12).

2. ERCS with PNS facilitates and coordinates trigger development to be aligned within the different agencies as, for example, multiple malaria models are in use (see Section 7, Recommendation 4 of the main report). The decision tree developed by the Anticipatory and Health Working Group might be a useful tool to identify the appropriate trigger approach for the selected disease. In addition, the Uganda Virus Research Institute is currently working on early warning for malaria in Uganda and MSF is working on a malaria EWS for South Sudan. Both organizations could be contacted regarding trigger development.

3. ERCS identifies possible sources of funding while PNS supports the preparation of proposals

4. ERCS together with IFRC develops monitoring and evaluation criteria for sEAPs along with preventive measures to assess if suggested activities have been effective.

Funding opportunities:

The Pandemic Fund will offer a second round of funding, focusing on epidemic and pandemic preparedness (World Bank, 2023c). Applications began in early 2024 and IGAD, together with IFRC, is currently developing a proposal for East Africa. NS and PNS can contact IFRC to get involved and updated on this.

Furthermore, in January 2024, KRCS together with NS from Ethiopia, Tanzania and Uganda submitted a proposal for funding to the Epidemic Science Leadership and Innovation Networks of the Science for Africa Foundation.

In addition, ERCS and PNS should reach out to USAID to evaluate if a potential sEAP for malaria could be supported by the PMI in Ethiopia.

Annex B

Kenya:
Climate-sensitive infectious disease country assessment

This case study is part of East Africa regional assessment on Anticipatory Action for climate-sensitive infectious diseases. Additional information and recommendations for the region can be found in the regional assessment.

1. Objectives

The objectives of this case study are to:

1. Summarize the geography and climate of Kenya, as this influences disease distribution

2. Provide information on the climatic and non-climatic drivers of priority infectious diseases in Kenya

3. Summarize the ongoing epidemic preparedness activities in Kenya, highlighting challenges

4. Provide recommendations on moving forward with the National Society of the Kenya Red Cross and partners in supporting the development of frameworks and (s)EAPs for infectious diseases.

2. Background

Kenya is home to approximately 54 million people (World Bank, 2023d). In recent years, the country has sustained a notable degree of political stability alongside ongoing economic development initiatives. Kenya's health system follows a decentralized model encompassing both the public and private healthcare sectors.

Despite being ranked third out of 54 African countries in terms of overall health security (GHS Index, 2021b), there is a shortage of health workers with only 16 doctors per 100,000 people.

The rapid infrastructural development in Kenya, especially in urban areas, has resulted in unmatched investments in WASH infrastructure. This is one of the causes of sustained overflows, bursts of sanitation systems and contamination of water systems (KII 12).

Challenges such as flooding and conflict disrupt access to healthcare as well as safe drinking water and affect health facilities. This can lead to an increased risk of diarrhoeal disease and cholera outbreaks.

The country faces significant health impacts from vector-borne diseases such as chikungunya, dengue, leishmaniasis, malaria and yellow fever. These diseases are highly sensitive to changing climatic conditions such as temperature, rainfall and humidity. In addition, waterborne diseases like cholera remain a major public health problem.

However, recently, the Government recognized the importance of cross-sectoral collaboration to address climate-sensitive infectious diseases and their impact on vulnerable populations in the Kenya Climate Change and Health Strategy 2023–2027, launched at the UN Climate Change Conference in Dubai in 2023 (Ministry of Health, 2023).

3. Geography and climate

Kenya's varied topography and proximity to the Indian Ocean result in a range of climatic zones (World Bank, 2021b). Coastal areas along the Indian Ocean have a tropical climate, while eastern Kenya is arid or semi-arid. The eastern edge of the Rift Valley includes a highland plateau with a more temperate climate. The mountains in this area generally receive substantial rainfall, though there are dry areas throughout the valley. Western Kenya, along Lake Victoria, is generally wet, while the northern and northeastern areas, including Lake Turkana, are arid. Most parts of the country have two rainy seasons: the long rains (*Masika*) from March to May and the short rains (*Vuli*) from October to December.

Kenya has historically been affected by flooding and droughts, and is influenced by El Niño (World Bank, 2021b; FloodList, 2023). Kenya faced five consecutive rainy seasons with below-average precipitation until 2023, resulting in the longest and most severe drought in recent history (Humanitarian Action, 2023). This has led to a significant increase in humanitarian needs across the arid and semi-arid lands (ASAL) region.

Seasonal patterns of natural hazards and health threats, food security and conflict are summarized in the seasonal emergency calendar (Figure 4).

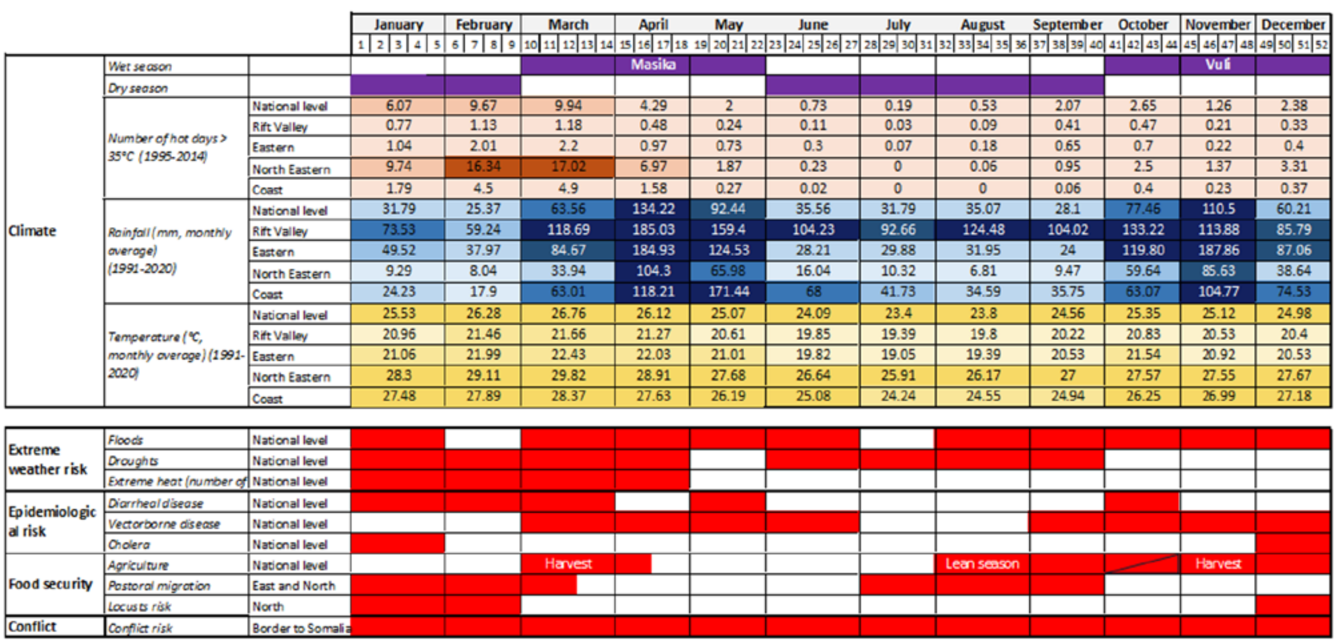


Figure 4. *Seasonal emergency calendar for Kenya summarizing average monthly climate, extreme weather, epidemiological, food security, and conflict risks based on (ACAPS, 2024; EM-DAT, 2023; MacLeod et al., 2021; Tornheim et al., 2010; World Bank, 2021b; WRBU, 2021).*

According to climate projections,[4] national average temperatures are projected to increase by around 1.2°C by 2050 with the strongest seasonal increase between May and June, at the end of the first rainy season. By 2050, 'hot days' (i.e., above 40°C) are projected to increase from 10 to 14 'hot days' in February and March and 2 to 6 'hot days' in September and October, before the onset of the rainy seasons. The strongest increase in hot days is projected in the northern regions of Turkana and Marsabit, followed by the eastern regions of Mandera, Wajir, Garissa, Isiolo and the Tana River. Rainfall variability remains high, and projections of rainfall show large uncertainties. However, there is a tendency for an increase in rainfall at the beginning of the first rainy season and during the second rainy season. Furthermore, extreme rainfall will increase across the country and can be associated with pluvial flooding (high confidence) (IPCC, 2021).

4. Priority climate-sensitive infectious diseases

Based on available evidence on incidence, prevalence and historic epidemics, and triangulated via discussions with Kenyan stakeholders (NS, PNS, IFRC, MoH), chikungunya, cholera, dengue, diarrhoeal disease, malaria, measles, Rift Valley fever, schistosomiasis and yellow fever were determined to be the priority climate-sensitive infectious diseases.

Climate-sensitive infectious diseases

Climate-sensitive infectious diseases are diseases in which climatic variables (temperature, humidity, rainfall) strongly influence the ecology and, therefore, the lifecycle and transmission risk of an infectious disease. Other factors (such as population immune status, land-use change, urbanization, environmental degradation) also influence disease transmission risk. However, the delayed influence that climatic factors have on disease transmission risk can be capitalized on to build Anticipatory Action systems, which is why climate-sensitive infectious diseases are the focus of this report.

4 This is based on projections from the SSP2–4.5 Shared Socio-economic Pathway of the Coupled Model Intercomparison Project Phase 6 (CMIP6) multi model ensemble used by the Intergovernmental Panel on Climate Change (Eyring *et al.*, 2016).

Table 5. Overview of priority climate-sensitive infectious diseases in Kenya, climatic and non-climatic drivers, and existing preventions and preparedness programmes.

Disease	Climatic drivers	Non-climatic drivers	Existing prevention and preparedness programmes
Malaria (endemic in Lake Victoria region) Malaria has been reported in recent years in northeastern countries (arid areas), where malaria is non-endemic (Marsabit, Isiolok, Mandera, Wajir, Garissa and Turkana) and that are classified as low transmission zones (KII 2).	Wet and warm climates related to El Niño and IOD drive transmission. Rainfall especially, but regional differences need to be considered (Gopal *et al.*, 2019; IFRC, 2021b)	Proximity to water bodies, drug resistance, changes in livelihoods and demographics (Gopal *et al.*, 2019; Niang *et al.*, 2018). Movement of people and livestock is likely to increase spread of the invasive vector ***Anopheles stephensi*** (Sinka *et al.*, 2020)	The Kenya Malaria Strategy (2019–2023) aimed to reduce malaria incidences and deaths by 75 per cent by 2023 compared to 2016. In 2019, the WHO introduced the RTS,S/AS01 vaccine in as part of its Malaria Vaccine Implementation Programme (MVIP), but its roll-out has to be expanded. The KRCS has not been involved in the MVIP (KII 2). In a collaboration between the Kenya Meteorological Department, Kenya Medical Research Institute (KEMRI) and the Ministry of Health (MoH), an outbreak prediction model was developed with a few months' lead time (KII 16). The model is operationally in place for three counties (Kakamega, Nandi, Kisii) in the highlands where malaria has traditionally not been endemic. A monthly bulletin with an output from the malaria epidemics early prediction system for the western Kenya highland is sent to county directors of meteorological services to disseminate to health actors at the county level. No early action protocol is linked to this EWS. A number of models and digital tools for malaria have been developed but are not in operational use. Malaria is part of the Integrated Diseases Surveillance and Response (IDSR) Programme and reported weekly. Reporting is also done at sub-county level, if resources in place. (Ministry of Health, Kenya, 2013).
Cholera	Rainfall is positively or negatively correlated with cholera, depending on the time of the year and region (Perez-Saez *et al.*, 2022; Stoltzfus *et al.*, 2014). Drought periods, high temperatures, and changes in the pH and salinity of water bodies have been identified as risk factors for cholera in the sub-Saharan African region (Charnley *et al.*, 2021, 2022).	Insufficient availability of health equipment, rapid urbanization stretching social services and infrastructure, WASH-related hazards, internal population movements (Charnley *et al.*, 2021, 2022; Paye *et al.*, 2021; Stoltzfus *et al.*, 2014).	A community-based surveillance system is consistently reporting across four of the 47 counties (KII 1, KII 2). Cholera is indirectly detected when diarrhoea symptoms are recorded. Volunteers undergo training centred on community case definitions rather than specific disease definitions. Cholera is part of the IDSR Programme and reported within 24 hours. Reporting is also done at sub-county level, if resources in place. (Ministry of Health Kenya, 2013)
Diarrhoeal disease	Influenced by heavy rainfall, dependency on mean temperature ranging 15–25°C (Kemajou, 2022; Powers *et al.*, 2023).	Insufficient availability of health equipment, WASH-related hazards, internal population movements (Charnley *et al.*, 2021, 2022; Paye *et al.*, 2021; Stoltzfus *et al.*, 2014).	A community-based surveillance system is consistently reporting across four of the 47 counties (KII 1, KII 2). Cholera is indirectly detected when diarrhoea symptoms are recorded. Volunteers undergo training centred on community case definitions, rather than specific disease definitions.

Disease	Climatic drivers	Non-climatic drivers	Existing prevention and preparedness programmes
Measles	Increased cases during colder months (May to September) and reverse trends during dry periods (December to February). Outbreaks and severity, e.g., due to malnourishment and population movement, can be exacerbated by drought and the absence of vaccination. Displacement (e.g., due to flooding) and consequent crowding can increase cases. (Nganga & Ngugi, 2013; WHO, 2023a).	Outbreaks are driven by population movement including cross-border movement, overcrowding linked to displacement and school year trends (ReliefWeb, 2016).	Measles is part of the IDSR Programme and reported within 24 hours. Reporting is also done at sub-county level, if resources in place (Ministry of Health Kenya, 2013). Vaccination for children who are malnourished (UNICEF, 2024)
Yellow Fever	Changes in temperature positively influence transmission intensity, rainfall often seems to mitigate transmission. Under certain conditions, high temperatures and rainfall can compound, resulting in increased transmission compared to temperature increase alone (Gaythorpe *et al.*, 2020).	Close proximity to breeding sites, including water storage and unplanned urbanization (Agha *et al.*, 2017).	Yello fever is part of the IDSR Programme and reported within 24 hours. Reporting is also done at sub-county level, if resources in place (Ministry of Health Kenya, 2013).
Dengue	Unusually wet months are followed by increased mosquito (*A. aegypti*) occurrence. Regional studies in Africa show dependence on the minimum temperature of the coldest month, annual temperature range, rainfall in the wettest month, rainfall in the driest month (Nosrat *et al.*, 2021; Sintayehu *et al.*, 2020).	Lacking vector control, (rapid) unplanned urbanization and travel (Mwanyika *et al.*, 2021). Close proximity to breeding sites including water storage (Agha *et al.*, 2017).	Severe dengue is part of the IDSR Programme and reported within 24 hours. Reporting is also done at sub-county level, if resources in place (Ministry of Health Kenya, 2013).
Rift Valley fever	Closely tied to periods of above-average rainfall, often associated with El Niño in the East African region, (Anyamba *et al.*, 2009; WHO, 2018).	Interaction and occupational work with infected animals and livestock trade, especially in low-altitude regions (Gerken *et al.*, 2022; Nanyingi *et al.*, 2015).	A community-based surveillance system is consistently reporting across four of the 47 counties (KII 1, KII 2). Viral haemorrhagic fevers caused by, e.g., Rift Valley fever, are part of the IDSR Programme and reported within 24 hours. Reporting is also done at sub-county level, if resources in place (Ministry of Health Kenya, 2013).
Chikungunya	Linked to abnormally warm and dry conditions in coastal areas, but recent data and publications are scarce (Sergon *et al.*, 2007).	Close proximity to breeding sites, including water storage (Sergon *et al.*, 2007).	Not reported.

Disease	Climatic drivers	Non-climatic drivers	Existing prevention and preparedness programmes
Schistosomiasis	Ideal temperatures for human transmission at 16–18°C in calm water and 20–25°C in flowing waters in the wider East African region have been identified (Adekiya *et al.*, 2020).	Population streams; rapid, unplanned urbanization; (occupational) exposure to infested water (WHO, 2023f).	Not reported.
Leishmaniasis (visceral and cutaneous)	Limited evidence of climatic influence. Occurrence correlates with seasonal water pathways. Peaks were observed at the end of the first and start of the last quarter annually, coinciding with reduced precipitation and higher temperatures in the region (Abdullahi *et al.*, 2022).	Close proximity to breeding sites and animal shelters (Ngere *et al.*, 2020). Population growth and increased movements are suspected drivers, amplified by social conflict (Ouma & Mulambalah, 2021).	Not reported.

5. Epidemic prevention and preparedness: opportunities and challenges

Disease surveillance: Parallel surveillance systems exist, from the KRCS and the Government.

The KRCS has established a community-based surveillance system in the context of the Community Epidemic and Pandemic Preparedness Programme (CP3) funded by USAID. The system is in place in four of the 47 counties (West Pokot, Narok, Bomet, Tharaka-Nithi) (KII 1, KII 2), integrating the One Health approach by covering public and animal health (KII 2). The alerts include human disease (acute water diarrhoea, measles, polio, Covid-19, viral haemorrhagic fevers, unusual illnesses or deaths of people) and animal diseases (anthrax, Rift Valley fever, rabies, cluster of unusual animal deaths). Cholera is indirectly detected when diarrhoeal symptoms are recorded; malaria is not reported as it is not present in the four counties. Volunteers undergo training based on community case definitions. The data is partly collected in a digital system (Nyss) developed by the Norwegian Red Cross in partnership with IFRC and the Belgian Red Cross; however, it is not integrated in governmental data collection (Norwegian Red Cross, 2023).

The Government has also established an event-based community surveillance system. However, despite Government efforts to implement event-based surveillance in seven out of 47 counties, only two consistently report, with four reporting intermittently and one county entirely non-compliant (KII 2). The parallel systems and mixed level of adherence to reporting protocols underscores the need for continued efforts to strengthen surveillance systems across all counties, including aligned digital data collection coordinated with the Ministry of Health.

Encouragingly, the IDSR is in place as a health facility-based system, where medial staff report cases of disease with national coverage.

Disease risk prediction models: For malaria, the Malaria Epidemic Early Prediction System for Western Kenya Highland exists that could be useful for the trigger development of a malaria sEAP. It has been developed in a collaborative effort between the Kenya Meteorological Department and KEMRI (KII 16). The model is operationally in place for three counties (Kakamega, Nandi, Kisii) in the Kenyan highlands where malaria has traditionally not been endemic. A monthly bulletin is sent to county directors of meteorological services to disseminate to health actors at the county level. Several other models and digital tools for malaria in particular have been developed for different regions in Kenya, but are not in operational use. A comprehensive evaluation would be required to assess the skills of the models.

Malaria vaccination: In 2019, the WHO introduced the RTS,S/AS01 malaria vaccine in parts of Kenya through a programme known as the WHO MVIP. The vaccine programme targets children and proved to be safe and effective during the pilot period (WHO, 2023c). While the vaccine has been rolled out, it is yet to be scaled-up. The KRCS is not focusing on malaria and has not been involved in the programme (KII 2). In addition, the MoH plans to distribute 18.3 million Long Lasting Insecticidal Nets (LLINs) in 28 targeted counties (one net for every two household members) in 2024 to prevent malaria transmission (Ministry of Health Kenya, 2023).

Coordination: In Kenya, national technical working groups exist where the topic of Anticipatory Action for epidemics could be prioritized. For instance, a Technical Working Group for Anticipatory Action exists, led by the National Disasters Operation Centre and co-chaired by the KRCS. The MoH, Ministry of Agriculture and Livestock Development, Ministry of Water, Sanitation and Irrigation, and Ministry of Education are members of the task force alongside institutions such as the Kenya National Bureau of Statistics, Kenya Meteorological Department, UN bodies, ICPAC, Regional Centre for Mapping of Resources for Development and the University of Reading, King's College London and the University of Sussex. The University of Nairobi and Jomo Kenyatta University of Agriculture and Technology participated at the beginning and should rejoin the group soon. In December 2023, the United Nations Development Programme (UNDP) funded a workshop to develop a workplan for the Technical Working Group (KII 16).

The health sector El-Niño Taskforce was founded in mid-2023 and is chaired by a representative of the State Department for Public Health and Professional Standards of the Ministry of Health. Members include representatives from different departments of the MoH and the National Disaster Operations Centre as well as UNICEF, United Nations Population Fund (UNFPA) and the KRCS. They meet on a weekly basis with members reporting disease outbreaks as well as health prevention and response in relation to ENSO (KII 2).

In addition, a new national Disease Surveillance and Response Technical Working Group is being established under the leadership of the Disease Surveillance and Epidemic Response Department of the Directorate of Public Health, Ministry of Health, and the KRCS is in the process of seeking membership (KII 2). Furthermore, a Technical Working Group on Climate Change in the Environmental Health Department of the Directorate of Public Health, Ministry of Health is about to be formed. Again, the KRCS will be represented (KII 12).

6. Recommendations

The assessment suggests focusing on Anticipatory Action in the short- to medium-term (1–5 years) for cholera, dengue and malaria, as these diseases are highly climate-sensitive, represent strong priorities for Kenya, and ongoing activities are likely to make the development of sEAPs feasible.

Recommendation 1

Recommendation 1: KRCS with support from PNS can coordinate efforts and advocate for Anticipatory Action for epidemics in existing taskforces.

Opportunities for action:

1. NS and PNS promotes Anticipatory Action for climate-sensitive infectious diseases, particularly for health stakeholders in the national Technical Working Group for Anticipatory Action, the new national Disease Surveillance and Response Technical Working Group as well as the Climate Change Technical Working Group.

2. The KRCS introduces the topic of Anticipatory Action for epidemics into the revised workplan of the working group for Anticipatory Action; providing an overview of existing activities on climate-sensitive infectious diseases from the RCRC Movement and facilitating discussion on the development of sEAPs for epidemics.

3. In addition, the national Disease Surveillance and Response as well as the Climate Change Technical Working Groups under the leadership of the MoH are currently being set up (KII 12) where KRCS could foster early discussions on Anticipatory Action and epidemic preparedness and potentially suggest new members from PNS.

4. Furthermore, the KRCS together with its partners (e.g., British Red Cross, Danish Red Cross, Finnish Red Cross, Netherlands Red Cross, Norwegian Red Cross, IFRC) could organize sessions for the working groups, presenting lessons learnt from the work on climate-sensitive infectious diseases and promoting the development of sEAPs for cholera, dengue and malaria.

Recommendation 2

Recommendation 2: KRCS and PNS to explore the development of an (s)EAP for cholera, dengue or malaria in the next 1–3 years.

Cholera, dengue and malaria are priority diseases for Kenya and the development of an sEAP might be feasible. An sEAP for cholera might be promising as it is a priority of the RCRC Movement and the IFRC is currently planning to develop sEAPs for cholera in African countries. Discussions in Kenya are at an early stage and KRCS could explore the possibility of working on sEAPs for cholera as IFRC is planning its development in Ethiopia (Trigger Approach 2: combining surveillance data and 'amplifying factors', including hydrometeorological indicators, see Recommendation 1 for Ethiopia). Consequently, the KRCS could work with the ERCS in sharing lessons on the development of the sEAP and facilitate the collaboration across the two countries (see Recommendation 4 and 7 in the main report).

An sEAP for malaria could be beneficial in light of the spread of the invasive vector *Anopheles stephensi*. The development of an sEAP for malaria may yield potential co-benefits for dengue prevention too. Conversely, the establishment of an sEAP for dengue could have co-benefits for malaria prevention. This is because prevention measures can be similar, for example, through the distribution of mosquito nets and mosquito repellent.

The decision tree developed by the Anticipatory and Health Working Group might be a useful tool to identify the appropriate trigger approach for the selected disease.

Opportunities for action:

1. KRCS with PNS coordinates plans with IFRC, the Technical Working Group for Anticipatory Action, the Disease Surveillance and Response Working Group and other relevant stakeholders to decide on the disease for the sEAP.

2. KRCS with PNS facilitates technical support to trigger development (see Recommendation 3).

3. KRCS identifies possible sources of funding while PNS support the preparation of proposals.

4. KRCS and PNS together with IFRC develops monitoring and evaluation criteria for sEAPs and preventive measures to assess if suggested activities and interventions have been effective.

Funding opportunities:

The Danish Red Cross is considering developing an sEAP for epidemics (undecided on the specific disease) in Kenya and could be a potential donor.

The Pandemic Fund will offer a second round of funding, focusing on epidemic and pandemic preparedness (World Bank, 2023c). Applications begin in early 2024 and IGAD, together with IFRC, will develop a proposal on cross-border epidemic preparedness for East Africa. The NS and PNS can contact the Regional Public Health in Emergencies Coordinator from the IFRC Africa Regional Office to get involved and updated on this.

KRCS is currently considering applying for the EU's Innovative digital health solutions for sub-Saharan Africa programme to work on sEAPs for epidemics. Furthermore, KRCS together with NS from Ethiopia, Tanzania and Uganda submitted a proposal in January 2024 to the Epidemic Science Leadership and Innovation Networks of the Science for Africa Foundation.

Recommendation 3

Recommendation 3: KRC and PNS can preemptively reach out to research institutes to foster partnerships with academics to improve triggers.

Opportunities for action:

Evidence-based, robust triggers and amplifying factors are key to the development of meaningful (s)EAPs. Therefore, NS and PNS could focus on facilitation and support for trigger development. KRCS with PNS could:

1. Working with researchers, initiate an assessment of the Malaria Epidemic Early Prediction System for Western Kenya Highland developed by KEMRI along with other existing disease risk prediction models to identify malaria triggers. In addition, the Uganda Virus Research Institute is currently working on early warning for malaria in Uganda, while MSF work on a malaria early warning system for South Sudan could be useful regarding trigger development. Findings from the assessment should be shared with relevant stakeholders and (cross-border) task forces (see Recommendation 4 and 7 in main report).

2. Enable technical support for the identification of evidence-based amplifying factors by analyzing the relationship between the amplifying factors and health outcomes.

3. Liaise with local and regional researchers with the RCRC Movement, international research groups and initiatives.

Relevant institutes, organizations and government authorities:

KEMRI; University of Nairobi, Unit of Clinical Infectious Diseases, Department of Clinical Medicine and Therapeutics; Kenya Meteorological Department; Ministry of Health (disease prevention); Makerere University, School of Public Health; Uganda Virus Research Institute (for malaria); Malaria Consortium; EPHI, PHEM, Early Warning and Information System Management Directorate; MSF (regarding malaria early warning system for South Sudan).

Annex C

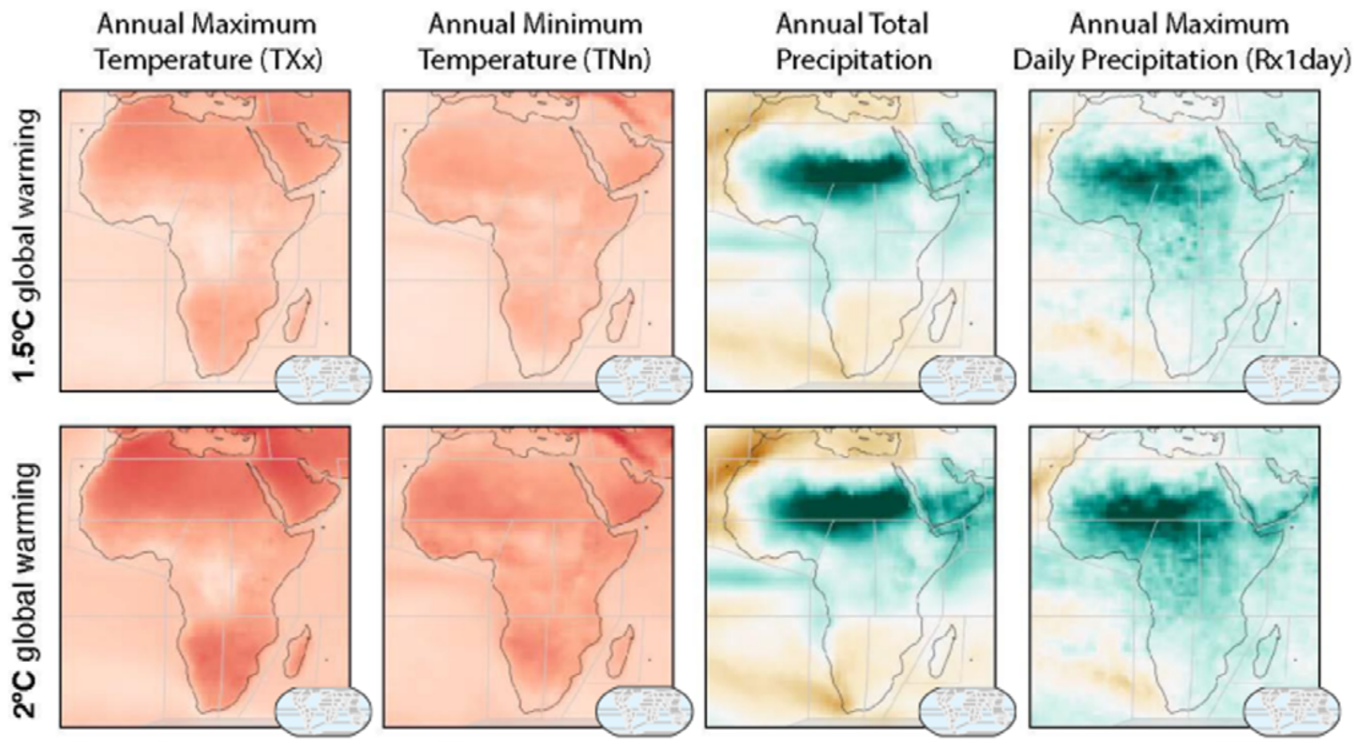


Figure 5:. *Future projections of annual maximum temerpature, annual minimum temprature, total precipiation and daily maximxum precipitaiton for Africa for 1.5°C (top) and 2°C (bottom) global warming compraed to the recent past (1995–20214) adapted from IPCC, 2021*

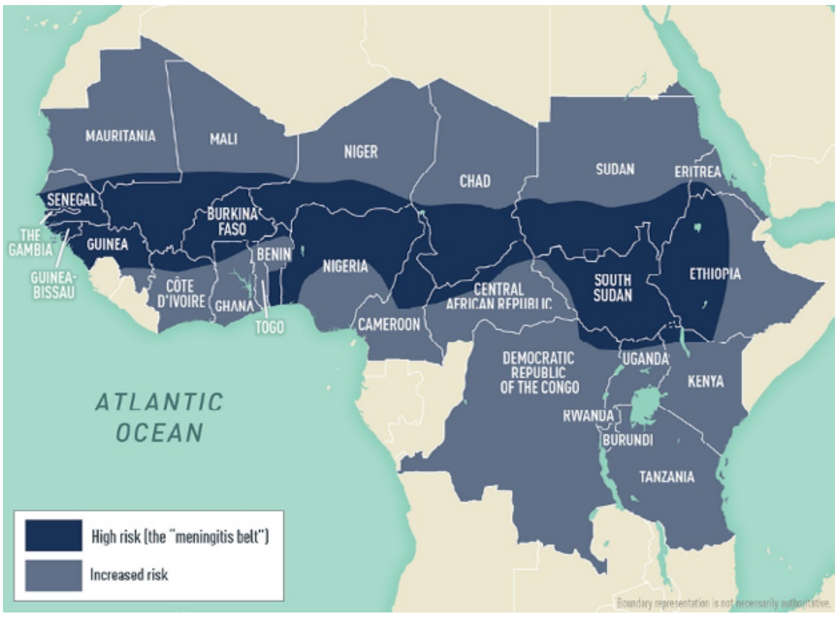


Figure 6. *Meningitis Belt adapted from Centers for Disease Control and Prevention (CDC), 2023 and Meningococcal Disease, CDC Yellow Book, 2024. Dark blue indicates areas of the Meningitis Belt; light blue indicates areas with increased risk of meningitis.*

Table 6. Overview of disease prediction models in East Africa based on digital tools database (Ryan *et al.*, 2023)).

Country	Disease	Title	Description	Tool Name	Reference
Ethiopia, Amhara region	Malaria	Integrating malaria surveillance with climate data for outbreak detection and forecasting: the EPIDEMIA system.	Integration of epidemiological data uploaded weekly by the Amhara Regional Health Bureau with remotely sensed environmental data freely available from online archives. Software was developed to implement a public health interface for data upload and download, harmonize the epidemiological and environmental data into a unified database, automatically update time series forecasting models, and generate formatted reports.	Epidemic Prognosis Incorporating Disease and Environmental Monitoring for Integrated Assessment (EPIDEMIA)	Merkord *et al.*, 2017
Ethiopia, Koka Reservoir	Malaria	Prevention of malaria transmission around reservoirs: an observational and modelling study on the effect of wind direction and village location.	Spatially explicit mechanistic malaria transmission model for the Koka Reservoir.	Hydrology, Entomology and Malaria Transmission Simulator (HYDREMATS)	Endo & Eltahir, 2018
Kenya	Malaria	Testing a multi-malaria-model ensemble against 30 years of data in the Kenyan highlands.	Used a four-malaria-model ensemble to assess the impact of climatic changes on malaria in western Kenya, explaining 32–38 per cent of malaria variance, with temperature trends and drug resistance playing significant roles.	Four models (MAC, AM, WCT, ABP)	Ruiz *et al.*, 2014
Kenya	Malaria	Analyzing the generality of spatially predictive mosquito habitat models.	Developed 24 mosquito habitat models using data from six time periods and four modeling approaches, achieving reasonable predictive performance across different time periods, offering a flexible architecture for future research.	Biomapper: A GIS-toolkit to model ecological niche and habitat sustainability. Spatial Econometrics Toolbox.	Li *et al.*, 2011
Kenya	Malaria	Simulation of malaria epidemiology and control in the highlands of western Kenya.	Used mathematical models to simulate malaria dynamics in low-transmission areas of western Kenya, emphasizing the importance of indoor spraying, detection methods and the need for accurate parameterization to inform malaria control strategies.	OpenMalaria platform	Stuckey *et al.*, 2012
Kenya	Malaria	Temporal and micro-spatial heterogeneity in the distribution of Anopheles vectors of malaria along the Kenyan coast.	Used polynomial distributed lag generalized linear mixed models to analyze how both short-term climate changes and micro-spatial factors influence the distribution of Anopheles mosquitoes in Kenya, with implications for targeted malaria interventions.	Polynomial Distributed Lag Generalized Linear Mixed Models (PDL GLMMs)	Walker *et al.*, 2013
Kenya	Malaria	Raised temperatures over the Kericho tea estates: revisiting the climate in the East African highlands malaria debate.	Observed a significant warming trend of approximately 0.2°C per decade in the Kenyan Highlands over 30 years, which may contribute to increased malaria incidence, although other factors such as land use changes and drug resistance also play a role.	RHtestV3	Omumbo *et al.*, 2011

Country	Disease	Title	Description	Tool Name	Reference
Kenya	Dengue	Mosquito habitat and dengue risk potential in Kenya: alternative methods to traditional risk mapping techniques.	Used geospatial analysis to identify high- and low-risk areas for dengue fever in Kenya by combining environmental factors and geographical information systems, validated with reported epidemic cases.	Similarity Search	Attaway *et al.*, 2014
Kenya	Malaria	Predicting the direct and indirect impacts of climate change on malaria in coastal Kenya.	Investigated the combined effects of climate change on malaria dynamics in a rural region of Kenya, revealing that elevated atmospheric CO2 and temperature changes can indirectly increase malaria risk by impacting mosquito larval habitats and parasite development.	SLIM	Le *et al.*, 2019)
Kenya	Malaria	Stochastic lattice-based modelling of malaria dynamics.	Developed a model that combines mosquito dispersal and epidemiological factors to better predict malaria dynamics in heterogeneous environments, with a case study in Kilifi county, Kenya.	Stochastic lattice-based integrated malaria model	Le *et al.*, 2018
Kenya	Malaria	Uncertainty in malaria simulations in the highlands of Kenya: Relative contributions of model parameter setting, driving climate and initial condition errors.	Experimented with a genetic algorithm to assess the impact of model, initial conditions and climate uncertainties on malaria transmission simulations, highlighting the dominance of spatial representativeness uncertainty in climate data, particularly temperature, for high-altitude regions near the transmission threshold.	VECTRI	Tompkins & Thomson, 2018
Kenya	Malaria	Predicting malaria epidemics in the Kenyan highlands using climate data: A tool for decision makers	Argued that malaria epidemics in the Kenyan highlands depend on permissive climatic conditions, particularly an increase in maximum temperatures, with a prediction model developed based on the association between temperature anomalies and malaria cases.	Epidemic prediction model	Githeko & Ndegwa, 2001
Kenya	Malaria	The use of driving endonuclease genes to suppress mosquito vectors of malaria in temporally variable environments.	Investigated the impact of seasonal and random rainfall patterns on the spread of a gene drive system aimed at controlling malaria vectors, showing that release timing in response to varying population densities due to rainfall can improve mosquito suppression or extinction in different climates.	Rainfall model fitter	Lambert *et al.*, 2018
Tanzania, Kilombero Valley	Rift Valley fever	Rift Valley fever: An open-source transmission dynamics simulation model.	Model to simulate the transmission dynamics of RVF. The model was calibrated using data collected in the Kilombero Valley in Tanzania with people and cattle as host species and Aedes mcintoshi, Aedes ægypti and two Culex species as vectors.	open-source transmission dynamics simulation model	Sumaye *et al.*, 2019
Tanzania, Ngorongoro District	Rift Valley fever	Simulation modelling of population dynamics of mosquito vectors for Rift Valley fever virus in a disease epidemic setting.	Implementation of time-varying distributed delays (TVDD) and multi-way functional response equations to simulate mosquito vectors and hosts developmental stages and to establish interactions between stages and phases of mosquito vectors in relation to vertebrate hosts for infection introduction in compartmental phases.	Rift Valley fever plug-in simulator.	Mweya *et al.*, 2014

Country	Disease	Title	Description	Tool Name	Reference
Tanzania, Dar es Salaam	Cholera	Machine learning model for imbalanced cholera dataset in Tanzania.	Machine learning approaches have been tested to model cholera epidemics and XGBoost classifier was selected to be the best approach.	XGBoost	Leo *et al.*, 2019
Uganda	Malaria	To what extent does climate explain variations in reported malaria cases in early 20th century Uganda?	A dynamical malaria model was driven with available precipitation and temperature data from 1926 to 1960 for five stations located across a range of environments in Uganda.	Vector borne Disease Community Model from ICTP	Tompkins *et al.*, 2016
Uganda, Jinja, Kanungu and Mubende	Malaria	Dynamical malaria forecasts are skillful at regional and local scales in Uganda up to four months ahead.	A pilot preoperational forecasting system is introduced in which the European Centre for Medium Range Weather Forecasts ensemble prediction system and seasonal climate forecasts of temperature and rainfall are used to drive the uncalibrated dynamical malaria model VECTRI to predict anomalies in transmission intensity four months ahead	VECTRI	Tompkins *et al.*, 2019

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