Anticipation Hub

WORKING PAPER

Applying anticipatory action ahead of disease outbreaks and epidemics: a conceptual framework for the International Red Cross and Red Crescent Movement

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Acronyms and abbreviations

CBS	community-based surveillance
CDC	Centers for Disease Control and Prevention
CERF	Central Emergency Response Fund
DREF	Disaster Response Emergency Fund
EAP	early action protocol
GIDEON	Global Infectious Diseases and Epidemiology Online Network
IFRC	International Federation of Red Cross and Red Crescent Societies
IPCC	Intergovernmental Panel on Climate Change
km/h	kilometres per hour
MSF	Médecins sans Frontières
REAP	Risk-informed Early Action Partnership
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
UNICEF	United Nations Children's Fund
UNISDR	United Nations International Strategy for Disaster Reduction
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
WASH	water, sanitation and hygiene
WHO	World Health Organization
WMO	World Meteorological Organization

1. Background

1.1 The Red Cross Red Crescent Working Group on Anticipatory Action and Health

The Red Cross Red Crescent Working Group on Anticipatory Action and Health, established under the Anticipation Hub, seeks to advance the work being done by the International Red Cross Red Crescent Movement (the Movement) on anticipating and preventing, or mitigating, the negative health outcomes and impacts for people at risk. As defined in its terms of reference, the working group aims to:

- strengthen, in a more systematic way, the Movement's knowledge exchange, practice and tools on anticipating and mitigating negative health outcomes and malnutrition
- foster more effective collaboration within the Movement to achieve these objectives
- build practical experience and evidence, based on effective anticipatory action for health and nutrition, with the ambition to develop early action protocols (EAPs)[1] for specific health risks.

The working group draws on the valuable work being done by many National Red Cross and Red Crescent Societies (National Societies) worldwide, particularly in terms of epidemic preparedness and response, while seeking to identify and capitalize on the opportunities provided by the anticipatory action approach to prevent adverse health outcomes and reduce human suffering.

Information on anticipatory action is drawn from a number of key Movement documents, including: the *Forecast-based Financing Practitioners Manual* (**Red Cross Red Crescent Climate Centre, IFRC and German Red Cross nd**), the *Glossary of Early Action Terms: 2022 Edition* (**Knox Clarke and REAP Secretariat 2022**), papers on *Connections between National Society Preparedness for Effective Response and Forecast-based Financing* (**IFRC 2019a**) and *Anticipatory Action & National Society Preparedness* (**IFRC 2023**), as well as existing EAPs that include health-related actions.

To develop the conceptual understanding of anticipatory action and health, and the operationalization of this approach, the Red Cross Red Crescent Working Group on Anticipatory Action and Health maintains close contact with the Interagency Working Group on Anticipatory Action and Health, which comprises diverse health actors including Médecins sans Frontières (MSF) and the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA). Outcomes and lessons learnt through this external collaboration have also informed this paper.

While the primary audience for this working paper is National Societies, many of the findings and recommendations are applicable for other organizations working on, or interested in, anticipatory action for epidemics.

1.2 Purpose of this working paper

Within the broader aims of the working group, this working paper specifically contributes to building a common understanding of the concept of **anticipatory action for disease outbreaks and epidemics**[2] across the Movement. It offers a useful synthesis of the current theory to guide National Societies wishing to apply anticipatory action for epidemics. The methodological applications of anticipatory action for epidemics are evolving, hence this working paper reflects the present status of discussions and will require updates as knowledge and practice improve.

1 EAPs are the frameworks used by the Movement to set out how anticipatory actions ahead of a hazard (or hazards) will be implemented, once the trigger thresholds are reached. They also set out the pre-arranged financing in place for those actions.

2 A disease outbreak is the occurrence of cases of a disease in excess of what would normally be expected in a defined community, geographical area or season (**WHO 2024a**). It is synonymous with 'epidemic' (**WHO 2022**) but typically used to describe the initial phases of an epidemic.

2. Introduction

While anticipatory action initiatives to date have largely focused on extreme climate and weather events, opportunities are emerging to look beyond these and act ahead of other hazards. These include disease outbreaks and epidemics, which are drivers of immense human suffering and loss, and have major socio-economic impacts.

2.1 What is anticipatory action?

Anticipatory action is an approach in which humanitarian actors implement "actions to prevent or mitigate potential disaster impacts before a shock or before acute impacts are felt" (**IFRC 2020a, p. 351**). Although its operationalization depends on the implementing organization, anticipatory action initiatives share three common features:

1. The actions happen in advance of a hazard (both the actions, and who will implement them, are agreed in advance).
2. The aim is to prevent or mitigate the expected impacts of a hazard.
3. The actions are implemented based on forecasts of when and where a hazard will occur, with pre-agreed funding mechanisms which allow the action plan to be implemented once forecast thresholds or agreed triggers are met (**Anticipation Hub 2022**).

Anticipatory action closes the gap between longer-term preparedness and humanitarian response by striving to mitigate the risk that has not (yet) been reduced by these longer-term efforts (Figure 1). As it is complementary to a National Society's other preparedness and response efforts, services and cross-cutting programmes, it should be part of the broader strategy to manage risk, rather than considered as a stand-alone method.

Box 1. Infectious disease epidemics

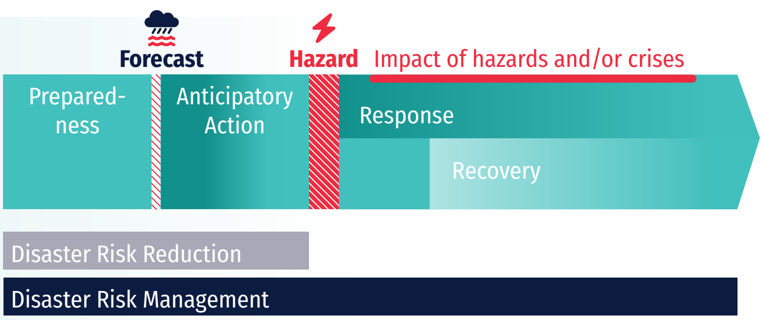
Infectious diseases are caused by pathogens such as bacteria, viruses, fungi and parasites, and can be spread directly or indirectly from person to person or animal to person. Over half of the infectious diseases confronting humanity are likely to be aggravated by climate change (**Mora, McKenzie, Gaw et al. 2022**). Rising health and climate risks threaten to undo years of development gains, strain already overburdened health systems, and further stretch limited humanitarian resources.

Diseases occur at varying levels in a given population. Some diseases occur infrequently or irregularly and outbreaks are characterized as sporadic (**CDC 2012**). Other diseases have a constant presence and/or usual prevalence in a population within a geographic area, and are referred to as endemic or hyperendemic if they have persistently high levels of disease occurrence (Ibid.).

A disease outbreak is the occurrence of cases of a disease in excess of what would normally be expected in a defined community, geographical area or season (**WHO 2024a**). It is synonymous with 'epidemic' (WHO 2022) but typically used to describe the initial phases of an epidemic.

Figure 1.
Anticipatory action within the disaster-risk-management continuum

Source: Anticipation Hub



2.2 Funding mechanisms for anticipatory action

Within the Movement, there are two key mechanisms that enable National Societies to access funding for anticipatory action:[3] (1) EAPs, both full and simplified; and (2) imminent Disaster Response Emergency Fund (DREF) requests (Table 1).

There are several sources of financing for anticipatory action outside of the Movement, such as the United Nation's Central Emergency Response Fund (CERF) and the Start Fund, which is managed by Start Network.

2.3 What is the added value of anticipatory action for epidemic preparedness and response?

Anticipatory action can provide an avenue to support National Societies' ongoing disaster preparedness, readiness and response activities, as outlined in the IFRC's white paper, *Global Health Security* (**IFRC 2021a**). It is also directly linked to the Movement's resolution to tackle epidemics and pandemics together (**IFRC 2019b**), situated within the second pillar of the Movement's ambitions to address the climate crisis (**IFRC 2020b**), and in line with the Movement's efforts to reduce the health and water, sanitation and hygiene (WASH) impacts of climate change (**IFRC 2021b**).

While the ultimate goal of anticipatory action for epidemics is to prevent an outbreak from occurring, this is very difficult to achieve, given that disease transmission is driven by a complex interaction of climate, environmental, socio-behavioural and physiological drivers. Yet anticipatory action can add value to epidemic preparedness and response in several ways. For example, it can help to:

- **identify in advance** when climatic and environmental conditions may be suitable for increased disease transmission in a particular region
- **identify in advance** which regions might be mainly affected by a disease outbreak
- **improve the timeliness** of action on outbreaks by formalizing the triggering of 'early' or 'on time' actions, based on surveillance data through pre-agreed plans and funding
- **inform decisions** about when and where to implement specific actions in order to contain the spread of an outbreak
- **improve early detection** of cases through enhanced (community-based) surveillance based on forecasting models
- **better understand and predict the onset or cessation** of transmission seasons – including the potential surpassing of

Table 1. Funding mechanisms for anticipatory action within the International Red Cross and Red Crescent Movement

EAPs and Simplified EAPs	Imminent DREF
EAPs and Simplified EAPs (**IFRC 2022**) are funded by the DREF. Detailed information and guidance are provided in the *Forecast-Based Financing Practitioners Manual* (**Red Cross Red Crescent Climate Centre, IFRC and German Red Cross nd**). Both types of framework outline precisely what a National Society will do when a hazard forecast exceeds the defined trigger threshold, and explains how the target communities will be selected. They also provide justifications for the selected anticipatory actions based on analysis of previous events. Once an EAP or Simplified EAP has been validated, the IFRC automatically provides pre-agreed funding to the National Society when it is notified that the trigger(s) have been reached. In addition to funding for anticipatory actions, EAPs and Simplified EAPs can provide funding for readiness and pre-positioning costs, such as staff costs, training, procurement and warehousing, so that National Societies are ready to act when the trigger is reached.	If there is no EAP or Simplified EAP for a hazard that is forecast to be imminent, National Societies can finance anticipatory actions by submitting a request for an imminent DREF disbursement. These requests allow National Societies to access funding up to four months before the onset or peak of a slow-onset hazard, or one month before an anticipated rapid-onset hazard. If the event does not materialize, the National Society must return the funds. The IFRC provides guidance to National Societies on using the DREF for anticipatory humanitarian action, which provides a comparison between the imminent DREF request and other funding modalities for anticipatory action, with additional information on using the DREF for an imminent crisis (**IFRC 2021c**).

3 Within the Movement, this approach is also sometimes referred to as forecast-based financing or forecast-based action.

the epidemic threshold – in endemic areas, based on climate-risk information and forecasting

- **provide an indication of the magnitude** of the predicted epidemic curve, based on evidence-based risk information
- **identify and react to changes in spatial transmission patterns,** based on outbreak risk-prediction models
- **improve the coordination and clarification of responsibilities** among relevant authorities and stakeholders as part of the development of pre-agreed action plans
- **enable mobilization and reduce delays in response** to outbreaks due to pre-agreed funding mechanisms
- **strengthen advocacy efforts around epidemic risk** and the importance of epidemic preparedness in national disaster plans.

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 and other organizations throughout the world, continue to be relevant and applied; see, for example, the IFRC's 'Epidemic Control Toolkit' (**IFRC nd**).

It is important to foster and encourage an **anticipatory mindset** that allows National Societies and other organizations to plan ahead and use the tools that help with decision-making across timescales, regardless of whether a formal anticipatory action programme can be developed in a given context. Anticipatory action is one tool, within the broader anticipatory mindset, that offers a mechanism, based on pre-agreed plans and funding, to help inform whether disease prevention and control actions could be implemented earlier than through normal response activities, and thus more effectively reduce disease risk and transmission.

Box 2. Climate-sensitive infectious diseases

Disease development is complex and climatic variables interact with multiple other drivers to shape disease dynamics. Importantly, for 'climate-sensitive' infectious diseases, climatic variables (e.g., temperature, precipitation, humidity) have a strong influence on the ecology and transmission. For example, these diseases tend to: show strong seasonality; have interannual variation in incidence (including epidemics); and have associations with hydrometeorological extremes (e.g., floods, droughts) and global climate phenomena such as the El Niño-Southern Oscillation and the Indian Ocean Dipole.

They may also be geographically bound within climatic zones, for example dengue in the tropics (**Bhatt, Gething, Brady et al. 2013**) or meningitis in the 'meningitis belt' (Lapeyssonnie 1963; **Molesworth, Thomson, Connor et al. 2002**). Climate change is already influencing climate-sensitive infectious diseases directly, and in ways we can potentially quantify and predict. Climate change is also likely to have an indirect and cascading influence on other infectious diseases, which may not be so evidently 'climate sensitive' in their ecology.

We have created a reference list of infectious diseases (Annex 2)[4] from the Centers for Disease Control and Prevention (CDC) and the Global Infectious Diseases and Epidemiology Online Network (GIDEON) (retrieved from **Mora, McKenzie, Gaw et al. 2022**). We have also reviewed and collated the substantial body of literature on the various pathways by which climate influences disease transmission and how climatic variables (e.g., temperature, humidity, rainfall) could be used as 'amplifying factors' during trigger development for cholera, dengue and malaria (Annex 3).

4 This research was undertaken by Sarina Chandaria and Danhue J. Kim, with the support of Tilly Alcayna.

3. Approaches to anticipatory action for disease outbreaks and epidemics

There are three main approaches within the current conceptual framework for anticipatory action for epidemics. Table 2 provides a description of these, examples of existing practice, and notes on the triggers, lead times, certainty, requirements and further considerations. It is highly recommended that anticipatory action programmes – whether for epidemics, other health outcomes or natural hazards – are, from the outset, developed with relevant ministries (e.g., the ministry of health) in a country.

Table 2. Approaches to anticipatory action for disease outbreaks and epidemics

	Approach A: Identification of health impacts linked to hydrometeorological hazards	**Approach B:** Real-time surveillance data and amplifying factors	**Approach C:** Outbreak risk-prediction models
Description	Weather forecasts are used to predict extreme weather events or hydrometeorological extremes. These have formed the basis of most anticipatory action initiatives developed from early 2010s to date. If historical data in a given context indicates that hydrometeorological events (e.g., floods, cyclones) are linked to previous disease outbreaks or increases in endemic diseases, anticipatory actions that focus on mitigating the health impacts of these hazards should be included in an EAP (or similar framework for anticipatory action). Depending on the data and information available, it may be possible to conduct statistical analysis to quantify this relationship. In many circumstances, however, it may be a qualitative relationship without statistical analysis that is used.	Decisions to intervene in public health emergencies are typically taken based on a combination of risk factors. Therefore, this approach combines different indicators, including surveillance data on the disease of interest, as well as other known drivers of disease transmission, such as seasonal trends or population factors (in the guidance for a Simplified EAP for cholera, these are termed 'amplifying factors'). Together, these create a composite trigger, or multi-step approach, which helps to coordinate actions with increasing certainty of the impacts. For example, the first step could be readiness activities initiated prior to the trigger; next, a first trigger activates low-cost actions; then, a second trigger (e.g., once there is higher certainty of the impact) activates the full range of pre-agreed anticipatory actions.	Although not yet used by National Societies, substantial progress is being made in academia to combine climate and epidemiological data, for climate-sensitive infectious diseases, in statistical models to predict the probability of a future outbreak in a given country or location.
Example	The EAP for cyclones in Mozambique, which was approved in March 2019, aims to prevent water-borne illnesses due to the destruction and/or pollution of water sources in coastal communities. Anticipatory actions include the distribution of chlorine tablets and buckets, as well as hygiene messaging. Funding is released based on forecast windspeeds of 120km/h or above at landfall. The lead time is 72 hours. This EAP was activated once, on 27 December 2020, ahead of Tropical Storm Chalane.	Several existing EAPs for drought use a composite, multi-step triggering approach. An EAP to prevent and reduce the impacts of cholera outbreaks is currently being developed by National Societies in several cholera-endemic countries. The approach includes epidemiological factors (e.g., suspected and confirmed cases in neighbouring districts/countries), monitoring of other health indicators (e.g., malnutrition) and environmental or social factors (e.g., population movement or hydrometeorological events). Countries currently working on an EAP or Simplified EAP for cholera include Cameroon, Ethiopia and Zambia. The anticipatory action framework for cholera in the Democratic Republic of the Congo, facilitated by UNOCHA, includes three scenarios to get ahead of large outbreaks. Each scenario can independently activate the framework, releasing funding from the CERF to the United Nations Children's Fund (UNICEF) and the World Health Organization (WHO) for life-saving WASH and health activities. Scenarios 1 and 3 are based on observed epidemiological data: if cholera cases or deaths exceed a predefined threshold over a three-week period in endemic (scenario 1) or non-endemic (scenario 3) provinces, this indicates a heightened risk level for a large outbreak and the framework is activated. Scenario 2 accounts for the increased risk of cholera outbreaks posed by external shocks, such as hydrometeorological hazards (see Approach A); whenever such an event occurs and the CERF makes a rapid response allocation for a province where the disease is endemic, this also activates the framework.	A prototype early warning system for dengue was developed in partnership with the Barbados Meteorological Services, the Barbados Ministry of Health, the French Red Cross, the Red Cross Red Crescent Climate Centre and the London School of Hygiene & Tropical Medicine. The climate-informed early warning model creates a probabilistic risk output of a dengue outbreak months in advance. If an above-average dengue transmission season is predicted several months in advance, there is an opportunity to implement preventative public-health actions, such as vector control activities. MSF's malaria anticipation project has been piloting an early warning system for malaria in Jonglei State, South Sudan. The ensemble models that underpin the system use epidemiological data and climate and environmental indicators as inputs, with the weekly number of malaria-positive outpatients expected in the MSF hospital as the output. Should the model predictions reach a defined threshold, this triggers one or more anticipatory actions, which MSF splits into four pillars for malaria: (1) implementing preventive measures (i.e., vector control, chemoprevention); (2) increasing the clinical capacity to diagnose and treat malaria cases; (3) advocating for other actors to intervene; or (4) sharing this information with communities who could implement community-led responses.
Trigger	Triggers will depend on the hydrometeorological hazard in question and the weather forecast model(s) available.	Readiness actions and first triggers may be set based on amplifying factors known to drive disease transmission, such as displacement (which may lead to overcrowding and susceptible populations mixing with populations in which a disease is circulating) or forecasts of weather conditions. Second triggers may be based on surveillance data (e.g., suspected or confirmed cases).	The trigger can be formulated as the probability of a specific caseload threshold being exceeded.

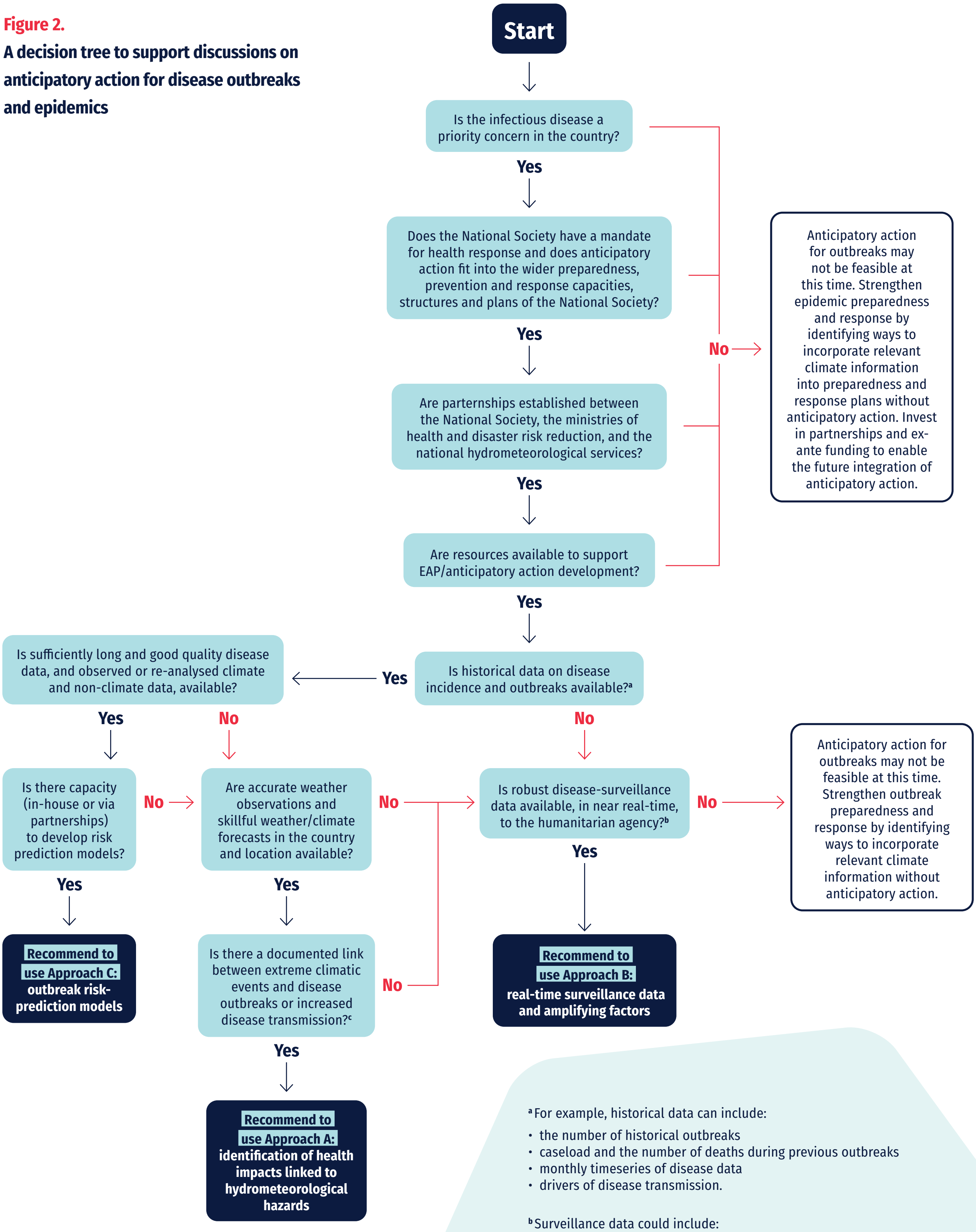
	Approach A: Identification of health impacts linked to hydrometeorological hazards	**Approach B:** Real-time surveillance data and amplifying factors	**Approach C:** Outbreak risk-prediction models
Lead time	The lead time will depend on the prediction of the respective hydrometeorological hazard. Flood triggers allow 3 to 10 days of lead time, whereas most cyclones have a lead time of 2 to 3 days. For National Societies, the trigger mechanism should follow standard practice, as outlined in the *Forecast-Based Financing Practitioners Manual.*	Lead times depend on the combination of triggers and relevant amplifying factors in the context.	The lead time is potentially weeks to months, depending on the statistical associations found as part of the analysis and model development.
Requirements	As the trigger in this scenario is based on hydrometeorological forecasts, this approach requires the availability and analysis of skilful weather forecasts (i.e., the accuracy of these forecasts). National Societies and partners will need access to historic information on the aftermath of extreme weather events and health outcomes: specifically, whether and where there was a disease outbreak. Publicly available information on health outcomes and impacts can be found in emergency appeals, situation reports, project documentations and in databases.	National Societies and other organizations need access to the data being reported to disease surveillance systems, and in as close to real time as possible. A triggering mechanism based on disease surveillance systems should not be developed if there are big delays (e.g., a week or more) between when the diseases are reported to the system and when this information becomes available to the National Society (or similar). To access data from a disease surveillance system operated by a ministry of health, it may be necessary to develop a memorandum of understanding with the ministry at the national or local level. An alternative source of data is community-based surveillance (known as CBS), which has become a flagship intervention for the Movement. Anticipatory action can build on this expertise and systems to formalize early action based on pre-agreed surveillance triggers linked to specified and pre-agreed funding mechanisms.	**Epidemiological data** The longest available timeseries of epidemiological data at the highest spatial resolution available, ideally a minimum of 10 years of notified cases (confirmed and/or suspected) aggregated at the monthly level. **Climate information** Daily or monthly meteorological records for climate variables of relevance to the disease (e.g., temperature, precipitation, humidity, windspeed) from as many meteorological stations in the study area (e.g., country) as possible. The timeseries of the climate data should match or be longer than the timeseries of the epidemiological data. **Demographic information** This could include: population size per district; proportional access to sanitation, water supply and other administrative-level services; and factors relating to income, housing, education and the accessibility of healthcare. **Environmental information** This could include: land cover classification; land use data; or topography/altitude. This approach also requires access to sufficient real-time data going forward, and skills and resources being available for the maintenance of the system and for regular calibration of the model.
Certainty	This approach does not rely on analysing statistical associations between hydrometeorological events (e.g., floods or cyclones) and disease outbreaks. Therefore, it is not certain, in quantifiable means, that a disease outbreak would occur in the aftermath. For disease-mitigating anticipatory actions to be approved, the EAP (or similar framework) should provide evidence that disasters caused by the hydrometeorological hazard in question have been linked to disease outbreaks in the past.	Certainty increases from the pre-trigger phase to the first trigger and then the second trigger.	The mathematical models have tested statistical associations between climatic conditions and disease risk, and can provide quanitifed probabilistic risk-prediction statements depending on the type of model developed. However, models are not able to predict disease outbreaks associated with newly emerging patterns, as they are trained with data from the past.
Considerations	National Societies and other organizations should consider the connections and complementarity between hydrometeorological hazards and infectious disease hazards, and their capacity to respond to both simultaneously. Close collaboration between all relevant sectors or departments within the National Society or similar organization (e.g., disaster management, health, WASH) is required for planning and implementing this approach.	Potential amplifying factors to consider include: • heavy/extreme rainfall • below-average rainfall • early/delayed onset of the rainy season • extreme temperatures (heat waves) • flooding • compound extremes (e.g., flooding in a conflict setting or refugee camp) • conflict/violence • displacement/migration • damage to health facilities • damage to critical infrastructure. For surveillance data, it will need to be decided if the trigger is based on suspected, probable or confirmed cases.	To support the operationalization of these tools, National Societies and other organizations should seek partnerships with academics and ministries of health that are already working on disease outbreak risk-prediction models. Despite the number of disease prediction models in existence, most do not support decision-making processes that could turn a warning into anticipatory action (**Ryan, Lippi, Caplan et al. 2023**). Sustainability challenges also persist, in which models are too costly to maintain and, moving forward, data is not available to update and calibrate the model.

4. A decision tree to support discussions on anticipatory action for disease outbreaks and epidemics

This decision tree (Figure 2) is intended to help National Societies and other organizations think through whether anticipatory action for epidemics is appropriate in a given context and, if so, which trigger mechanism may be most appropriate. Working through the decision tree can also help to determine which of the three approaches (see Section 3) might be most successful in their context, depending on the disease of interest and the availability of data, and partners (e.g., in the ministry of health or in academia) that may already be working on early warnings for disease outbreaks.

Table 3 lists further useful resources to consult when identifying historical disease trends or impact data.

Figure 2.
A decision tree to support discussions on anticipatory action for disease outbreaks and epidemics



[a] For example, historical data can include:

- the number of historical outbreaks
- caseload and the number of deaths during previous outbreaks
- monthly timeseries of disease data
- drivers of disease transmission.

[b] Surveillance data could include:

- community-based surveillance (CBS)
- regional/district-level surveillance data from the ministry of health, the Public Health Institute, WHO, the Pan American Health Organization and other organizations or non-governmental organizations.

[c] The link between extreme climatic events and infectious disease outbreaks varies by country and disease. At a minimum, there is strong evidence from outbreak investigations, academic papers and past reports that certain climatic events have previously triggered outbreaks.

Table 3. Useful resources to access information and data on disease trends or impacts

Resource	Organization	Description	Link
Climahealth	WHO and WMO	One-stop shop for publications and resources on climate and health, searchable by specific countries or topics of interest.	www.climahealth.info
Data Collections	WHO	Key health-data products and resources, from across WHO, on global health and well-being.	www.who.int/data/collections
Disease Outbreak News	WHO	The latest WHO news on disease outbreaks, providing information on confirmed acute public-health events or potential events of concern.	www.who.int/emergencies/disease-outbreak-news
Epidemic Preparedness Toolkit	IFRC	Helpful tools and resources about epidemic and pandemic preparedness, on topics ranging from disease control to community engagement and accountability.	www.ifrc.org/our-work/health-and-care/emergency-health/epidemic-and-pandemic-preparedness/epidemic-preparedness
Global Infectious Disease and Epidemiology Network (GIDEON)	GIDEON	Behind a paywall, although it is sometimes possible to access it via an academic affiliation login. A one-stop resource for data on infectious diseases for research, education and diagnostics.	www.gideononline.com
Global Cholera and Acute Watery Diarrhea Dashboard	WHO	Public dashboard on cholera outbreaks worldwide.	https://who-global-cholera-and-awd-dashboard-1-who.hub.arcgis.com/
Global Health Observatory	WHO	A repository of global health data, although data are sometimes not as up to date as needed at the country level. This includes the Global Health Observatory Data Repository.	https://www.who.int/data/gho https://apps.who.int/gho/data/node.main
Global Health Security Index	Johns Hopkins University and the Nuclear Threat Initiative	This is the first comprehensive assessment and benchmarking of health security and related capabilities across the 195 countries that make up the States Parties to the International Health Regulations.	www.ghsindex.org
Global Public Health Intelligence Network	Canadian government	This open-source, signal-detection repository on epidemic intelligence has a similar function to ProMed. It is available, with a login request, to field-epidemiology training programmes and institutions that support health surveillance and responses to outbreaks.	www.canada.ca/en/public-health/corporate/mandate/about-agency/external-advisory-bodies/list/independent-review-global-public-health-intelligence-network/final-report.html
Humanitarian Data Exchange	UNOCHA	Not health specific, but a place to find, share and use humanitarian data, all in one place.	https://data.humdata.org/
Institute for Health Metrics and Evaluation	University of Washington	Repository of health data and reports that are searchable by theme. This includes Global Burden of Disease visualizations.	www.healthdata.org https://vizhub.healthdata.org/gbd-compare/
ProMed	International Society for Infectious Diseases	Currently only providing 30-day historic information on unverified disease alerts/signals globally.	www.promedmail.org
WHO Hub for Pandemic and Epidemic Intelligence	WHO	This was set up to improve countries' abilities to detect, monitor and manage public health threats, and to inform decision-making on broader policy issues to mitigate these threats.	https://pandemichub.who.int/
World Animal Health Information System	World Organisation for Animal Health	With free access to animal health data around the world, this provides internet users with several computer-based tools designed to answer specific user needs. The portal provides easy access to these tools, allowing for more accurate results while searching for information on animal health worldwide.	www.woah.org/en/what-we-do/animal-health-and-welfare/disease-data-collection/world-animal-health-information-system/

5. Concluding remarks

National Red Cross and Red Crescent Societies have a long history of effective and successful epidemic preparedness and response. The concepts provided in this working paper aim to strengthen these efforts by supporting future discussions on which approaches might be most appropriate for anticipatory action for disease outbreaks and epidemics in different contexts.

The theoretical value that anticipatory action can add to epidemic preparedness and response activities will need to be tested and evaluated in the coming years, as anticipatory action for disease outbreaks and epidemics is put into operation.

This working paper is an important starting point to ensure the Movement, and others active in this field, have a common understanding of the potential types of triggering approaches and investments needed to build successful programmes to act in anticipation of epidemics and disease outbreaks.

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Annex 1. Glossary

Table A1. Glossary of terms used in this working paper

Term	Definition
Adaptation	The process of adjustment in systems, processes, practices and structures to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities (**IPCC 2022**).
Anticipatory action	Anticipatory action is an approach in which humanitarian actors implement "actions to prevent or mitigate potential disaster impacts before a shock or before acute impacts are felt" (**IFRC 2020a**, p. 351). Although operationalization depends on the implementing organization, anticipatory action programmes share three common features: 1. The actions happen in advance of a hazard (both the actions, and who will implement them, are agreed in advance). 2. The aim is to prevent or mitigate the expected impacts of a hazard. 3. The actions are implemented based on forecasts of when and where a hazard will occur, with pre-agreed funding mechanisms which allow the action plan to be implemented once forecast thresholds or agreed triggers are met (**Anticipation Hub 2022**).
Anticipatory mindset	A mindset which is proactively identifying risks and thinking of ways to reduce and prevent risk. This may entail horizon-scanning, the development of contingency plans, and the establishment of roles and responsibilities during scenario planning (definition by the authors of this working paper).
Climate	"In a narrow sense, climate is usually defined as the average weather – or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities – over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system" (**IPCC 2022**, p. 2902).
Climate change	Anthropogenic climate change refers to long-term shifts in temperatures and weather patterns as a result of the emissions of greenhouse gases (notably carbon dioxide and methane) over the past 200 years (**UN nd**).
Climate variability	Climate variability refers to variations in the mean state and other statistics (e.g., standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events (**IPCC 2012**).
Disaster risk reduction	The substantial reduction of disaster risk and losses in lives, livelihoods and health, and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries (**UNDRR nd a**). It denotes both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing exposure, hazard or vulnerability; and improving resilience (**IPCC 2022**).
Disease outbreak	A disease outbreak is the occurrence of cases of a disease in excess of what would normally be expected in a defined community, geographical area or season (**WHO 2024a**). It is synonymous with 'epidemic' (**WHO 2022**) but typically used to describe the initial phases of an epidemic.
Early action	Anticipatory action is the overall approach that links early warnings to early actions. Early actions are the set of actions implemented based on the early warning that aim to prevent or reduce the impacts of a hazardous event before they fully unfold, predicated on a forecast or credible risk analysis of when and where a hazardous event will occur (**Knox Clarke and REAP 2022**).
Early response	Early response refers to actions that are undertaken right after a disaster occurs. Anticipatory (or early) action is different from early response insofar as the former begins before the hazard and/or threat strikes, whereas the latter begins after it has struck. In contrast to anticipatory action, early response is based on an evidenced hazard/threat and observable, rather than forecast, needs; furthermore, it does not require pre-agreed implementation plans.
Early warning	The provision of timely and effective information, through identified institutions, that allows individuals, responders and decision-makers exposed to a hazard to take action to avoid or reduce risks and prepare for an effective response (**UNISDR 2004**).
Early warning system	An integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, and communication and preparedness activities, systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events (**UNDRR 2015**).
Epidemic	The occurrence of more cases of a particular type of disease, chronic condition or injury than expected in a given area, or among a specific group of people, over a particular time interval (**WHO 2022**).

Term	Definition
Forecast	A statement of expected meteorological and environmental conditions for a specified time or period, and for a specified area. Forecasts are often divided into short-term weather forecasts (less than 10 days), sub-seasonal forecasts (20-40 days) and seasonal forecasts (3-6 months) (**Red Cross Red Crescent Climate Centre, IFRC and German Red Cross nd**).
Lead time	The time from when the forecast is issued until the occurrence of the event that is forecast to happen. For example, a forecast issued on a Monday for a storm that makes landfall on a Friday has a four-day lead time (**Red Cross Red Crescent Climate Centre, IFRC and German Red Cross nd**).
Preparedness	The knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters (**UNDRR nd b**).
Prevention	Disaster prevention expresses the concept and intention to completely avoid the potential adverse impacts of hazardous events. While certain disaster risks cannot be eliminated, prevention aims to reduce vulnerability and exposure in such contexts where, as a result, the risk of disaster is removed (**UNDRR nd c**). "Disease prevention, understood as specific, population-based and individual-based interventions for primary and secondary (early detection) prevention, aiming to minimize the burden of diseases and associated risk factors" (**WHO 2024b**).
Slow-onset disaster	Slow-onset disasters, such as drought, can be predicted much further in advance and unfold over months or even years.
Trigger	A trigger is a predetermined criterion that, when met, is used to initiate actions (**Knox Clarke and REAP 2022**).
Weather	The state of the atmosphere at a particular time, as defined by the various meteorological elements (**WMO 1992**). Weather describes short-term natural events – such as fog, rain, snow, blizzards, wind, thunderstorms, tropical cyclones, etc. – in a specific place and time (**WMO 2024**).

Annex 2. The links between climate and weather and specific infectious diseases of humanitarian importance

Disclaimer: Table A2 is based on a rapid review in 2023 of the literature[5] concerning a subset of climate-sensitive infectious diseases, taken from the supplementary material of Mora, McKenzie, Gaw et al. (**2022**). It is not an exhaustive or systematic analysis of the links; therefore, some of the information may not be accurate or applicable in every setting. Instead, it is a summary table for general guidance only, as the specific disease dynamics will differ from context to context, depending on a number of other factors. This information can be used as a starting point to think through the relevant climate and weather links for a given infectious disease in a specific context. In many circumstances temperature, precipitation and humidity have non-linear effects and opposing extreme weather events (e.g., floods and droughts) may sometimes both increase infection risk.

5 Links to the literature, where available, can be found in the reference list.

Table A2. The links between climate, weather and infectious disease incidence

Disease	Transmission	Optimal ecological conditions	Climate and weather links to disease incidence	Hotspot areas
Cholera	Water- or food-borne	The best environmental conditions for *V. cholerae* are 30°C water temperature, 15% salinity, and almost alkaline environments (pH = 8.5) (Asadgol, Mohammadi, Kermani et al. 2019).	Mean monthly flooded area, mean monthly air temperature, and monthly cumulative rainfall, and the use of unsafe or contaminated water sources (e.g., lakes, wells, ponds), which may arise because of droughts and flooding, are linked with increased cholera incidence (Griffith, Kelly-Hope and Miller 2006; Rebaudet, Sudre, Faucher et al. 2013; Moore, Eisen, Monaghan et al. 2014; Adamou 2022; Perez-Saez, Lessler, Lee et al. 2022). Several studies have shown a significant correlation between cholera incidence and either high or low rainfall, which can affect the concentration of bacteria and incidence of cholera cases (Asadgol, Mohammadi, Kermani et al. 2019). Increasing temperatures are expected to expand the range and increase the prevalence of cholera both geographically and temporally (Funari, Manganelli and Sinisi 2012). Warmer aquatic temperatures linked with climate change have been found to increase the growth rate of *V. cholerae* and induce outbreaks (Paz 2009; Cann, Thomas, Salmon et al. 2013).	Countries in sub-Saharan Africa (e.g., Democratic Republic of the Congo, Mozambique, Zambia). Bangladesh, India, Pakistan, Philippines, Syrian Arab Republic and Yemen. Broad areas of concern include: western Africa; South-East Asia; parts of the Middle East; parts of eastern and southern Africa.
Dengue	Vector-borne	The optimal temperature for *Aedes aegypti*, the mosquito that is the vector for dengue, is 26-30°C and 70-80% humidity (Mourya, Yadav and Mishra 2004).	Climatic factors influence dengue ecology, both directly and indirectly, by affecting mosquito-growth dynamics, virus replication and mosquito–human interactions (Tran, Tseng, Chen et al. 2020). Specifically, temperature and humidity are highly influential (Bhatt, Gething, Brady et al. 2013). Weekly minimum ambient temperature increases the risk of dengue epidemics (Chien and Yu 2014). High annual rainfall and high annual temperature were found to be the strongest predictors of dengue (Hales, De Wet, Maindonald et al. 2002). However, in certain contexts, low precipitation and drought could affect the spread of dengue due to the reduced population sizes of mosquito predators/competitors, and increased water-storage vessels providing larval habitats (Beebe, Cooper, Mottram et al. 2009; Brown, Medlock and Murray 2014). Climate change will affect virus incubation times (Naish, Dale, Mackenzie et al. 2014) and is likely to lead to a geographic expansion of dengue (Barcellos and Lowe 2014).	The disease is endemic in more than 100 countries in Africa, the Americas, the eastern Mediterranean, South-East Asia and Western Pacific. Asia represents about 70% of the global disease burden, mainly in Bangladesh, Malaysia, Philippines and Viet Nam. Increasing temperatures in temperate regions could increase the probability of *A. Aegypti* mosquitos invading/colonizing temperate regions (Yang, Macoris, Galvani et al. 2009).
Diarrhoea	Water- or food-borne	Diarrhoea can be caused by a number of different pathogens, for example *Cryptosporidium spp., E. coli*-producing heat stable toxin (an enterotoxigenic *E. coli*), typical enteropathogenic *E. coli,* rotavirus and Shigella. It is therefore important to understand the specific ecological conditions of different pathogens.	Higher temperatures are associated with elevated rates of diarrhoea (moderate/high confidence). Associations between temperature and diarrhoea vary by the taxonomic category of diarrheal disease agent (high confidence). Heavy rainfall events are associated with elevated rates of diarrhoea (moderate confidence). Heavy rainfall following dry periods are also associated with elevated rates of diarrhoea (moderate confidence). Flooding is associated with elevated rates of diarrhoea (moderate confidence). Drought is associated with an increase in diarrheal diseases (low confidence) (all from Levy, Woster, Goldstein et al. 2016).	The highest mortality from diarrhoeal diseases is in sub-Saharan Africa and South Asia (Farthing, Salam, Lindberg et al. 2013).
Leishmaniasis	Vector-borne	Sandflies, the vector for Leishmaniasis, generally live in warmer (tropical/subtropical) regions. They require high temperatures for their development and survival (Koch, Kochman, Klimpel et al. 2017) and sufficient rainfall is needed to maintain moisture levels for egg survival (Ibid.).	Increases in temperature towards an ecological optimum increase sandfly populations and may increase transmission risk (Koch, Kochman, Klimpel et al. 2017). Heavy rainfall can restrict flight activity and kill immature flies (Ibid.). Global heating may result in the emergence of leishmaniasis in previously non-endemic regions (Ibid.).	Visceral leishmaniasis: Brazil, East Africa, India. Cutaneous leishmaniasis: Americas, Mediterranean basin, Middle East, Central Asia. Mucocutaneous leishmaniasis: Bolivia, Brazil, Ethiopia, Peru.
Leptospirosis	Water-borne	Leptospires have an optimum growth temperature of 28-30°C (Levett 2001). The optimal ecological conditions for leptospirosis are found in tropical and subtropical areas with high rainfall (i.e., warm and humid areas) (Levett 2001; WHO 2003).	Flooding and heavy rainfall have been associated with outbreaks of leptospirosis (Lau, Smythe, Craig et al. 2010) as bacteria, and the animal hosts of the bacteria, are brought into closer contact with humans; for example, bacteria in soil can be washed into freshwater sources. Leptospira (the bacteria) are also able to survive for longer periods in higher temperatures and more humid environments (Ibid.). This means that climate change resulting in temperature increases can lengthen the season and expand the geographical range for the optimal survival and transmission of leptospires.	Areas with the highest impact include Oceania, the Caribbean, parts of Latin America, sub-Saharan Africa, East Asia and parts of South-East Asia. Countries that are especially affected include Chad, Ecuador, Ethiopia, Guyana, Indonesia, Kenya, Papua New Guinea, Rwanda, Sri Lanka and Uganda (Torgerson, Hagan, Costa et al. 2015).

Disease	Transmission	Optimal ecological conditions	Climate and weather links to disease incidence	Hotspot areas
Malaria	Vector-borne	Optimal malaria transmission is at 25°C (Mordecai, Paaijmans, Johnson et al. 2013). The optimal rates of development for *Plasmodium falciparum* and *Plasmodium vivax*[6] 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 and Anttila-Hughes 2017). The minimum temperatures required for the development of *P. falciparum* and *P. vivax* are approximately 18°C and 15°C, respectively (Patz and Olson 2006). Adequate precipitation is required to maintain breeding sites (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).	Transmission decreases at temperatures above 28°C (Mordecai, Paaijmans, Johnson et al. 2013). At temperatures below 20°C, *P. falciparum* cannot complete its growth cycle and cannot be transmitted (CDC 2024). Rainfall may increase malaria cases in areas dependent only on rain for surface water (Hoshen and Morse 2004).	Sub-Saharan Africa has the largest malaria burden (McCord and Anttila-Hughes 2017). Four African countries accounted for just over half of all malaria deaths worldwide: Nigeria (31.3%), the Democratic Republic of the Congo (12.6%), the United Republic of Tanzania (4.1%) and Niger (3.9%) (WHO 2023a). Some malaria transmission occurs in South and Central America, as well as in the Middle East and Asia.
Measles	Droplet	The virulence and survival of the measles virus in air are mainly influenced by temperature and relative humidity. The virus is temperature-sensitive and a study performed in the laboratory shows that the survival of the measles virus at 15°C is slightly better than at 20°C (Yang, Xu, Wang et al. 2014). Survival of the measles virus is mostly dependent on relative humidity, and the virus thrives at low relative humidity (Yerdessov, Abbay, Makhammajanov et al. 2023).	Both hot and cold temperatures result in decreases in the incidence of measles (Yang, Xu, Wang et al. 2014). An increased number of measles cases might occur before and after a cold spell (Ibid.). Measles transmission increases during the late winter and early spring in temperate climates, and after the rainy season in tropical climates (Gutu, Bekele, Seid et al. 2020).	Measles is still common in many lower-income countries, particularly in parts of Africa and Asia. The overwhelming majority (more than 95%) of measles deaths occur in countries with low per-capita incomes and weak health infrastructures (WHO 2023b). The countries with the highest burdens are Afghanistan, Cameroon, the Democratic Republic of the Congo, Ethiopia, India, Indonesia, Nigeria, Pakistan, Somalia and Yemen (Minta, Ferrari, Antoni et al. 2023).
Meningitis/ Meningococcal	Droplet	It replicates best at temperatures of 35-37°C (Bai, Hu, Yan et al. 2017). Research in the meningitis belt have found that the optimal climate for transmission of the disease is the savannah climate south of the Sahel, with an annual precipitation index of 300-1,100mm: extremely dry but warm winter seasons and a relatively abrupt onset of the rainy season (Palmgren 2009).	The spatial distribution, intensity and seasonality of meningococcal (epidemic) meningitis appear to be strongly linked to climatic and environmental factors (IPCC 2023). High temperatures and sunshine, low rainfall, low relative and absolute humidity, and dry Harmattan winter winds with airborne dust were significantly associated with meningitis in the meningitis belt (Sultan, Labadi, Guégan et al. 2005; Yaka, Sultan, Broutin et al. 2008; Jusot, Neill, Waters et al. 2017; Akanwake, Atinga and Boafo 2022). In all countries of the African meningitis belt (between 5°N and 20°N), the seasonal timing of bacterial meningitis was situated in February to March, during the dry season (Paireau, Chen, Broutin et al. 2016). There is a rapid decline of meningitis cases with the onset of rains (García-Pando, Stanton, Diggle et al. 2014).	The highest burden of the disease is in the African meningitis belt, which is in sub-Saharan Africa and runs across the continent from Senegal to Ethiopia.
Plague	Zoonotic	Optimal conditions vary according to the sensitivity of the hosts and vectors to meteorological conditions (which vary with geographic location). Spring temperature is relevant because fleas are only active when the air temperature is above 10°C (Stenseth, Samia, Viljugrein et al. 2006).	Temperature, rainfall and relative humidity have direct effects on development and survival, as well as the behaviour and reproduction, of fleas and their populations (Ben-Ari, Neerinckx, Gage et al. 2011). In Madagascar, cases of bubonic plague are reported nearly every year during the epidemic season; this is between September and April, which coincides with the hot and rainy season in the agricultural highlands (WHO nd a). Higher temperatures and increased precipitation during the cold and dry season in Madagascar are likely to increase flea survival rates and shorten flea development time (Kreppel, Caminade, Telfer et al. 2014).	Currently, the three most endemic countries are the Democratic Republic of the Congo, Madagascar and Peru (WHO nd a). Natural foci are found globally, except in Oceania.

6 These are the parasites that cause malaria and are often abbreviated to *P. falciparum* and *P. vivax*.

Disease	Transmission	Optimal ecological conditions	Climate and weather links to disease incidence	Hotspot areas
Rift Valley fever	Vector-borne	*Aedes sp., Mansoni sp.,* and *Culex sp.* are thought to be the most important for virus transmission to livestock and people (WHO nd b).	The availability of seasonally varying water bodies and ambient temperatures dictate when the mosquito vector populations will persist (Lo Iacono, Cunningham, Bett et al. 2018). The *Aedes* mosquito's reproductive cycle in particular is highly dependent on rainfall patterns: eggs need to be flooded to hatch, meaning that heavy rainfall results in an increase in vector populations. Once infection has been amplified in livestock, secondary vectors – such as *Culex*, which breed in semi-permanent pools of water – become involved in the transmission of the virus (Martin, Chevalier, Ceccato et al. 2008). This is more common in outbreaks occurring in areas of sub-Saharan, eastern and southern Africa. In western Africa and the Arabian Peninsula, there is an association with other species of mosquito with a preference for permanent bodies of water (e.g., reservoirs) (Pepin, Bouloy, Bird et al. 2010). In eastern Africa, Saudi Arabia and Yemen, Rift Valley fever outbreaks are closely associated with periods of above-average rainfall (WHO nd b). Outbreaks in East Africa are closely associated with the heavy rainfall that occurs during the warm phase of the El Niño-Southern Oscillation phenomenon (Redding, Tiedt, Lo Iacono et al. 2017; WHO nd b).	The disease is found on the African continent (particularly Egypt, Kenya, Madagascar, Mauritania, Niger, South Africa and Sudan), Indian Ocean nations and in the Middle East. It first expanded its range outside Africa in 2000, when it caused major outbreaks on the Arabian Peninsula (Bron, Strimbu, Cecilia et al. 2021).
Schistosomiasis	Zoonotic	The optimal temperature range for the transmission of schistosomiasis is 22-27°C (Kalinda, Chimbari, Mukaratirwa et al. 2017). For schistosoma mansoni, transmission risk peaks at 21.7°C (Nguyen, Boersch-Supan, Hartman et al. 2021).	As the temperature increases, parasite development within the snails (the hosts) increases, up to a maximum thermal limit (31°C), beyond which the snails die and infection reduces (Kalinda, Chimbari, Mukaratirwa et al. 2017). Heavy rainfall/flooding can establish snail populations in new, non-endemic areas, increasing the transmission range. Fast-flowing waters can, however, eliminate the snails (Ibid.). Drought and heat waves can increase human contact with snail-infested waters. However, it can also reduce snail abundance and, therefore, transmission (during and following extreme heat) (Ibid.).	Across sub-Saharan Africa (the majority of cases). Some South American countries (including Brazil, Suriname, Venezuela) and the Caribbean. Asia (Cambodia, Indonesia, Lao People's Democratic Republic, parts of China). Tropical and subtropical areas.
Typhoid fever	Water-borne	Salmonellae are adapted to life in the animal gut and their optimal growth temperature is 37°C.	Seasonal variability of typhoid is more pronounced further from the equator (Saad, Lynch, Antillón et al. 2018). Globally, there are positive associations between temperature and typhoid fever incidence (Ibid.). However, very high temperatures negatively affect bacterial survival and reproduction (Thindwa, Chipeta, Henrion et al. 2019). Incidence of typhoid fever is generally found to be higher in the rainy season, but very heavy rains can flush out and reduce the environmental reservoir of the bacteria (Ibid.).	The highest incidence and highest total number of cases are in South Asia (71.8%); South-East Asia, East Asia and Oceania accounted for 14.1% of cases; and sub-Saharan Africa for 12.1% of cases (Stanaway, Reiner, Blacker et al. 2019).
Yellow fever	Vector-borne	Increases in disease incidence are associated with higher temperature and rainfall, due to their impacts on mosquito (*Aedes* or *Haemagogus* spp.) life cycles and viral replication in the mosquito; interaction between the two is important (Hamlet, Jean, Perea et al. 2018).	Increased temperature, high relative humidity (but less than 75%) and increased rainfall associated with rainy seasons can increase the mosquito population and increase infection risk (Moreno and Barata 2012; da Cruz Ferreira, Degener, de Almeida Marques-Toledo et al. 2017; Hamlet, Jean, Perea et al. 2018).	The virus is endemic in tropical areas of Africa and Central and South America, with approximately 90% of cases occurring in Africa. With climate change, annual mortality is projected to increase, although heterogeneously across regions, requiring context-based future research (Hamlet, Jean, Perea et al. 2018)
Zika	Vector-borne	At constant temperatures, *Ae. aegypti* transmission peaks at 29.1°C, and *Ae. albopictus* transmission peaks at 26.4°C (Tesla, Demakovsky, Mordecai et al. 2018). Zika virus transmission was optimized at 29°C and had a thermal range of 22.7-34.7°C (also the predicted thermal minimum for Zika transmission, and 5°C warmer than that of dengue) (Ibid.).	Higher average humidity, higher total rainfall and rainy seasons, higher maximum temperature and El Niño have all been associated with Zika virus (Paz and Semanza 2016; Chien, Lin, Liao et al. 2018). Drought changes human behaviour, leading to more water storage in household containers, which are exploited as breeding sites and may indirectly expand the mosquitoes' range and therefore increase transmission risk (Paz and Semanza 2016).	Zika virus causes substantially more burden in the Americas but, due to climate change, it can spread north and into longer seasons (Tesla, Demakovsky, Mordecai et al. 2018; Puntasecca, King and LeBeaud 2021).

Annex 3. Possible amplifying factors for outbreaks of cholera, dengue and malaria

Disclaimer: Table A3 provides a summary of some of the possible amplifying factors for cholera, dengue and malaria. It can help guide thinking on which amplifying factors to explore for cholera, dengue and malaria in a given context, but amplifying factors should always be relevant to disease dynamics in the target context.

Table A3. Possible amplifying factors for outbreaks of cholera, dengue and malaria

Disease	Amplifying factors
Cholera	• Dry conditions followed by heavy rainfall. • Heavy rainfall during existing floods. • High temperatures and heat waves. • Flooding which affects critical WASH infrastructure. • Persistent low rainfall and damaged water infrastructure, including for watering crops. • Violence and conflict, which damage infrastructure or displace populations, leading to overcrowding in unhygienic conditions. • Malnutrition. • Waning immunity. • Proximity to fishing communities in which cholera is endemic. • Increased trade from an endemic area. • Increased salinity of water bodies. Sources: Rieckmann, Tamason, Gurley et al. 2018; Wu, Yunus, Ali et al. 2018; Jones, Bouzid, Few et al. 2020; Charnley, Kelman, Green et al. 2021; Alcayna, Fletcher, Gibb et al. 2022.
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 activities. • Population movement or displacement. Sources: Lowe, Stewart-Ibarra, Petrova et al. 2017; Lowe, Gasparrini, Van Meerbeeck et al. 2018; Gutu, Bekele, Seid et al. 2021; Mekuriaw, Kinde, Kindu et al. 2022.
Malaria	• Increased rainfall tends to be a predictor of increased malaria up to several months in advance. This has a levelling-off effect: after a certain threshold of rainfall, more malaria is not observed. • Increased temperature is a predictor of increased malaria, potentially 1-2 months prior (but each context should be analysed). Maximum and minimum temperature increases and occurrences during the rainy or dry season need to be carefully investigated. For example, minimum temperature in some contexts has the strongest correlation with increased malaria several months later. • The combination of rainfall and temperature, their sequencing and also other contextual factors (e.g., topography, vegetation cover, altitude) must be considered. • Humidity may also modulate the effects of rainfall and temperature. • Low rainfall in drought-affected areas. • The 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. Sources: Abeku, Van Oortmarssen, Borsboom et al. 2003; Zhou, Minawaka, Githeko et al. 2004; Ceccato, Ghebremeskel, Jaiteh et al. 2007; Loha and Lindtjørn 2010; Midekisa, Senay, Henebry et al. 2012; Karuri and Snow 2016; Ergete, Sorsa, Loha et al. 2018; Kibret, Glenn Wilson, Ryder et al. 2019; Dabaro, Birhanu, Negash et al. 2021.

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