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Early Warnings for All

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EW4ALL

Handbook on the use of Risk Knowledge for Multi-Hazard Early Warning Systems

2024

This publication has been developed as part of the Early Warning for All (EW4All) initiative of the United Nation's General Secretary, aiming to provide Early Warning Systems (EWS) for all by 2027, hence ensuring protection from weather and climate hazards. It particularly supports the initiative's first pillar - Disaster Risk Knowledge and Management - coordinated by the United Nations Office for Disaster Risk Reduction (UNDRR), that aims to increase risk knowledge globally so that everyone is equipped with adequate capacity and technical expertise to systematically collect, analyse, and disseminate risk information for use in EWS. UNDRR engaged CIMA Foundation to develop this deliverable.

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Acronyms

AA	Anticipatory Actions
AI	Artificial Intelligence
AMHEWAS	Africa Multi-hazard Early Warning and Action System
API	Application Programming Interfaces
ASEAN	Association of South-East Asian Nations
AUC-DRR	African Union Commission – Disaster Risk Reduction
BNPB	Indonesia - National Disaster Management Agency
BPS	Indonesia - National Statistics office
CAP	Common Alerting Protocol
CARE	Cooperative for Assistance and Relief Everywhere (Int'l NGO)
CB	Cell Broadcast,
CCRI-DRM	Children's Climate Risk Index - Disaster Risk Model (UNICEF)
CDEMA	Caribbean Disaster Emergency Management Agency
CDI	Combined Drought Index
CE	European Commission
CHE	Cataloguing of Hazardous Events
CIESIN	Centre for International Earth Science Information Network (Colombia)
CIMA	International Centre for Environmental Monitoring
COREQ	COnsolidated criteria for REporting Qualitative research
CRED	Centre for Research on the Epidemiology of Disasters
CRM	Comprehensive Risk Management
DLDT	Disaster Losses and Damages Tracking
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DRSF	Disaster-Related Statistics Framework
EA	Early Action(s)
EAP	Early Action Protocol (Kenya)
EM-DAT	Emergency Events Database
ERCC	Emergency Response and Coordination Centre
ESCAP	Economic and Social Commission for Asia and the Pacific
ET	Evapotranspiration
EW	Early Warning(s)
EW4All	Early Warning for All
EWC	Conference on Early Warning III (2006)
EWS	Early Warning System
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FAO	United Nation's Food and Agriculture Organisation
FbF	Forecast-based Financing
FCV	Fragile, Conflict and Violent contexts
FGD	Focus Group Discussion
GCA	Global Commission on Adaptation
GEO	GEOdatabase
GESEBL	Global Exposure Socio-Economic and Building Layer
GFDRR	Global Facility for Disaster Reduction and Recovery
GHSL	Global Humanitarian Settlement
GIS	Geographic Information System
GLAM	Global Agriculture Monitoring System
GLoFAS	Global Flood Awareness System
HDX	Humanitarian Data Exchange
HIPs	Hazard Information Profiles
HOT	Humanitarian OpenStreetMap Team
IBF	Impact-Based Forecast
IBW	Impact-Based Warning
IbEW	Impact-based Early Warning
I-CISK	Human Centred Climate Services
ICPAC	IGAD Climate Prediction and Applications Centre
IDPs	Internally Displaced People
IFAD	International Fund for Agriculture Development
IFRC	International Federation of the Red Cross

IGAD	Intergovernmental Authority on Development
IHE Delft	Institute for Water Education
IHME	University of Washington's Institute for Health Metrics and Evaluation
ILK	Indigenous and Local Knowledge
IM	Instant Messaging
IPCC	Inter-governmental Panel on Climate Change
IoT	Internet of Things
ITC	International Trade Centre
ITU	International Telecommunication Union
JRC	Joint Research Centre, the European Commission's science and knowledge service
KII	Key Informant Interview
LFI	Low Flow Index
LLM	Large Language Models
MBMS	Multimedia Broadcast/ Multicast Service
MHEWS	Model National Multi-Hazard Early Warning Systems
MISTRAL	Meteo Italian SupercompuTing PoRtAL (open data meteorological portal)
MMS	Multimedia Messaging Service
MoECCF	Ministry of Environment, Climate Change & Forestry (Kenya)
MOGREPS	Met Office Global and Regional Ensemble Prediction System
NCCAP	National Climate Change Action Plan (Kenya)
NDCP	Italian National Department of Civil Protection
NDMA	National Disaster Management Agencies
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organisation
NHMS	National Hydro-Meteorological Services
NLP	Natural Language Processing
NWP	Numerical Weather Predictions
OASIS	Organization for the Advancement of Structured Information Standards
OGC	Open Geospatial Consortium
OSGEO	Open Source for Geospatial
PPRD	Prevention, Preparedness and Response to natural and man-made Disasters
P&R	Preparedness and Response
PRA	Probabilistic Risk Assessment
RAG	Retrieval-Augmented Generation
RiX	UNDRR's Risk Information Exchange platform
SARCOF	Southern Africa Regional Climate Outlook Forum
SDI	Spatial Data Infrastructure
SGI	Standardised Groundwater level Index
SGDI	Subnational Gender Development Index
SHDI	Subnational Human Development Index
SIMEX	Simulation Exercise (Kenya)
SMS	SMS bulk messaging
SPEI	Standardised Precipitation Evapotranspiration Index
SPI	Standardised Precipitation Index
SRI	Standardised Runoff Index
SRSI	Standardised Reservoir Storage Index
SSWE	Standardised Snow Water Equivalent
TEC	UN Climate Change Technology Executive Committee
UN	United Nations
UNU-EHS	United Nations University – Institute for Environment and Human Security
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNICEF	United Nations Children's Funds
UNISDR	United Nations system for disaster risk reduction
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
USSD	Unstructured Supplementary Service Data
VCA	Vulnerability and Capacity Assessment
VHI	Vegetation Health Index
WMO	World Meteorological Organisation

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Introduction

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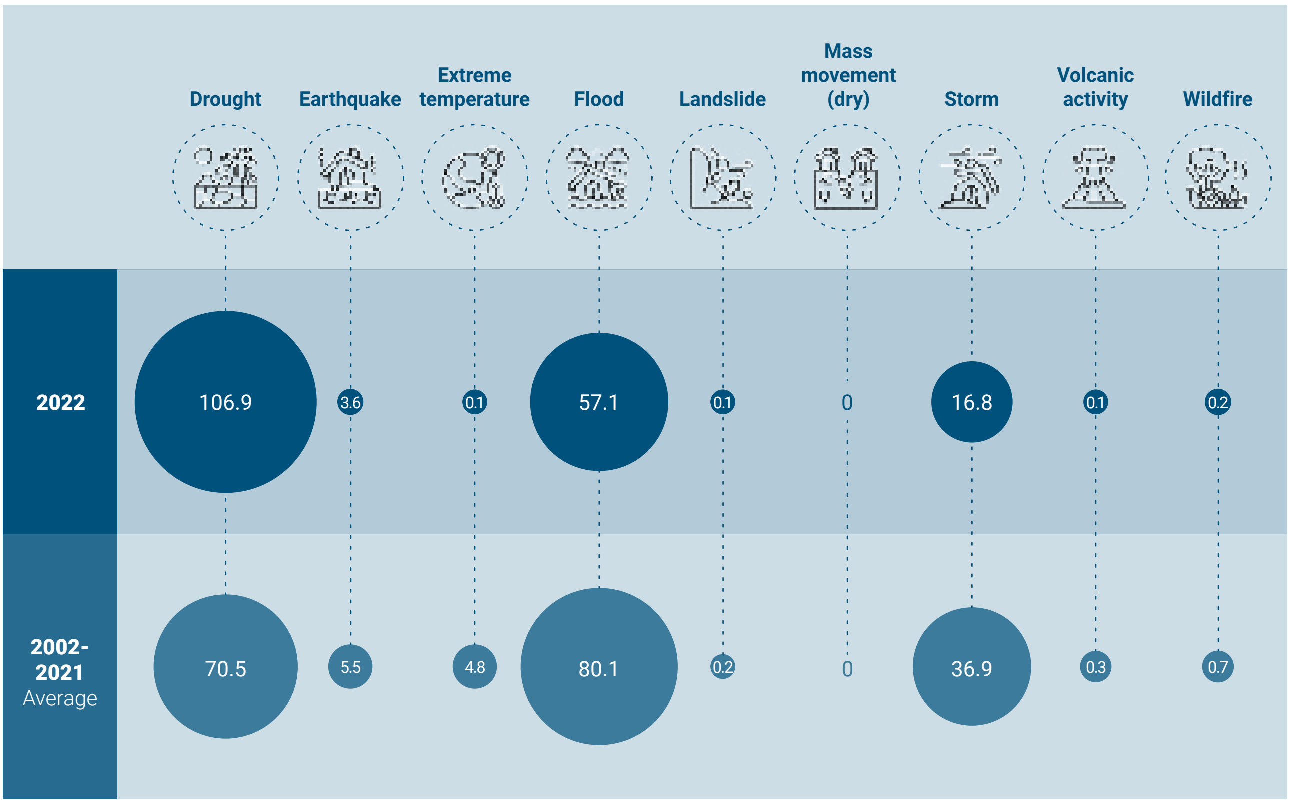
Introduction

1.1. General context

Natural hazards and disasters have devastating impacts on the lives and wellbeing of people and economies around the world. Between 2002 and 2022, the Emergency Events Database (EM-DAT) recorded about **7,800 disasters**, which caused an average annual death toll of 60,000, with some **200 million people affected** (Figure 1) and an estimated **US$190 billion of economic losses per year** (CRED, 2023). While the share of economic losses per continent is the greatest in the Americas, the populations most affected are disproportionately concentrated in developing countries, with the combined figures from Africa and Asia regularly exceeding 90% of the total. Climate change is increasing the frequency and intensity of natural hazards, such as floods, droughts, and heat waves, making future projections of disaster impacts even more daunting. The most common types of disasters related to natural hazards over the past two decades were **floods**, **storms**, **droughts**, and **earthquakes**, although the largest share of their impacts was caused by a few mega-disasters. For example, in 2004, the Indian Ocean tsunami killed over 230,000 people in 14 countries. In 2010, the Haiti earthquake killed over 220,000 people and displaced over 1.5 million people. In September 2023, heavy rainfall in North-Eastern Libya caused widespread flooding and the collapse of two dams. This resulted in an estimated death toll exceeding 11,000 people in the city of Derna alone, which is about twice the annual average number of deaths by floods globally.

Figure 1
Number of people affected (million) by disaster type: 2022 compared to the 2002-2021 annual average



1.2. EW4ALL context

The EW4All initiative is a global effort that aims to ensure that everyone on the Earth is protected from hazardous events by 2027 through life-saving EWS. The initiative is led by the UNDRR and the World Meteorological Organization (WMO), with support from the International Telecommunication Union (ITU), the International Federation of Red Cross and Red Crescent Societies (IFRC), and a wide range of partners from governments, international organisations, civil society, and the private sector. EWS are a critical adaptation measure for reducing disaster risk and saving lives.

Their usefulness is weighed considering their cost-effectiveness, with an average tenfold reduction in disaster impacts, compared to their cost of implementation, with figures varying according to specific hazards and regions of application (GCA, 2019; WMO and GFDRR, 2015). The EW4All initiative aims to strengthen EWS around the world, so that everyone has the information they need to stay safe and minimise impacts of hazardous events.

The initiative is developed around four main pillars:

- **Pillar 1**: disaster risk knowledge and management
- **Pillar 2**: detection, observation, monitoring, analysis and forecasting
- **Pillar 3**: warning dissemination and communication
- **Pillar 4**: preparedness and response capabilities

The EW4All initiative aims to:

- **ensure** that all countries have **multi-hazard EWS** in place by 2027
- **improve the quality** and **timeliness** of early warnings (EW)
- **increase the use of EW** by decision-makers and the public
- **build the capacity of countries** to manage EWS

1.3. Use of Risk Knowledge in EWS (Pillar 1)

EWS are essential for Disaster Risk Reduction (DRR), providing timely and accurate information to mitigate the impacts of natural hazards. Their effectiveness hinges on the integration of comprehensive risk information. This chapter explores how risk information feeds into EWS, considering the four pillars, as above.

Risk data and information underpin the pillars through two primary sources: historical disaster loss and damage information, and risk assessments. The continuous use of risk knowledge is vital in all phases of EWS implementation, as depicted in Figure 2, which illustrates how risk information contributes to the development of Impact-Based Forecasts (IBF), communication and advisory plans, as well as preparedness, anticipatory, and response actions.

Within Pillar 1, disaster loss data recording is crucial for developing credible risk information. It provides initial insights into the risk context and forms the basis for robust risk assessments. This data supports forensic research to refine risk assessments by informing hazard return periods and spatial correlations of events, enhancing prediction accuracy. It also supplies the necessary information to calibrate proper vulnerability models and serves as the primary data source for regulating and validating risk models used in comprehensive risk assessments.

Effective EWS design begins with detailed risk assessments that compile information on disasters and their impacts, covering both single hazard and multi-hazard evaluations. Data typically encompassed within a risk assessment include:

- frequency, magnitude, and spatial distribution of hazardous events
- multi-dimensional vulnerability assessments to gauge the susceptibility of various sectors, including physical, socio-economic, and environmental vulnerabilities
- information on population, buildings, infrastructure, and productive assets exposed to potential hazards
- coping capacities such as resilience, response capabilities, and redundancy

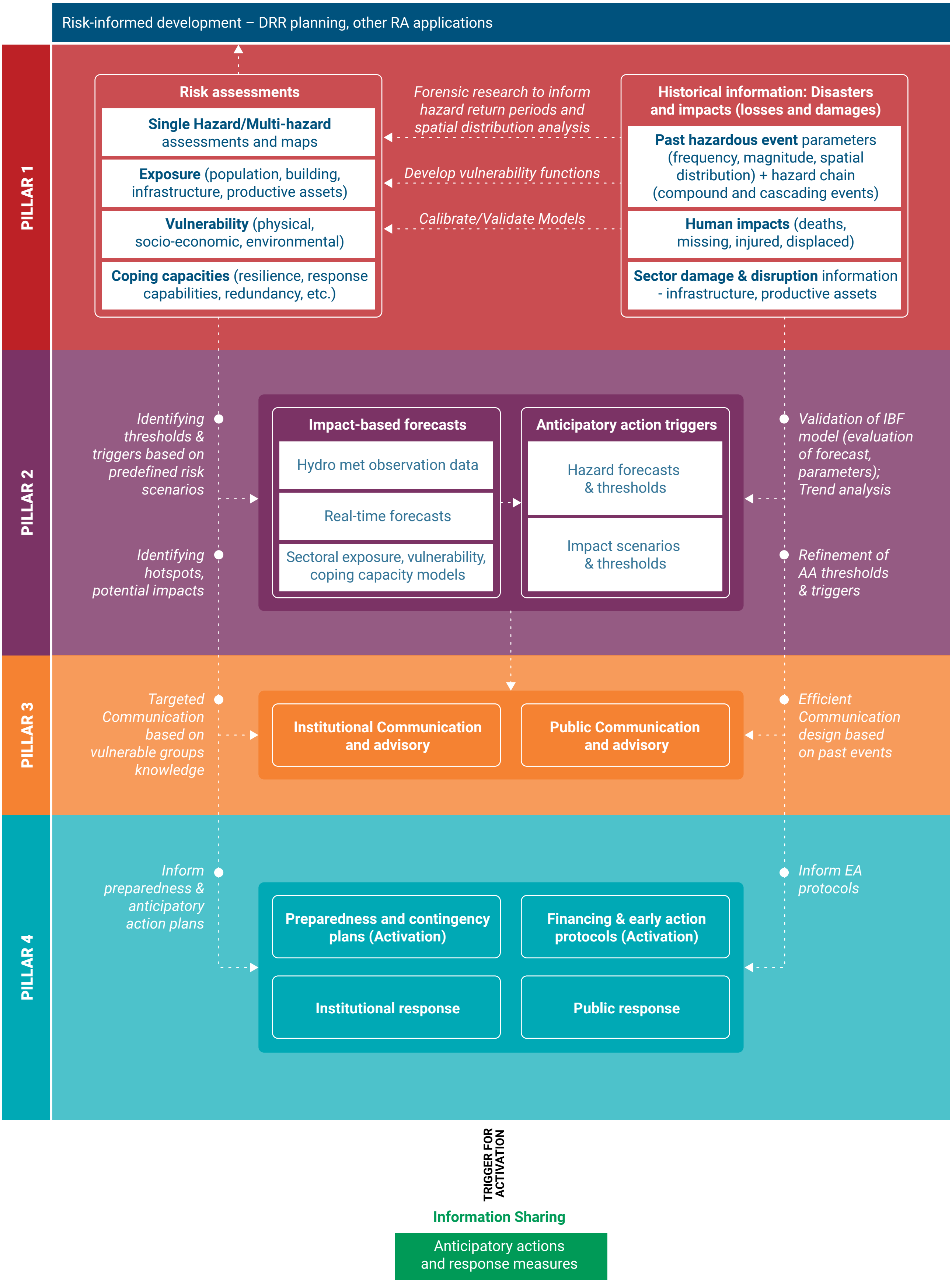
This wealth of information is essential for developing reference risk scenarios where potential impacts are identified along with their causal links to possible predictors.

These scenarios inform EWS processes in several ways, by:

- identifying the appropriate variables to monitor and forecast within the EWS and establish trigger thresholds for warning development
- determining the nature of possible impacts and potential impact hotspots, both in terms of location and sectors
- defining the impact information to be communicated, ensuring it resonates with the perceptions of those receiving the warnings
- allowing targeted messaging for different functions (e.g. institutional vs. public advisories) and different vulnerable groups exposed to potential impacts

Reference scenarios also form the basis for actionable emergency and preparedness plans that outline specific actions to be taken in response to EW, enhancing the readiness of communities and institutions. Anticipatory Actions (AA), such as evacuations and resource mobilisation, are triggered by EW and defined based on risk scenarios and their expected frequency. This includes financing protocols that are based on a proper risk assessment of potential impacts and losses.

Figure 2
The importance of risk knowledge (assembled from historical disaster loss and damage information) for the EW4All pillars and development of impact-based forecasts and anticipatory actions (modified by UNDRR)



1.4. Scope and structure of the handbook

Box 1: Target users
Target users include national institutions, meteorological and hydrological services, Disaster Risk Management (DRM) authorities and international organisations; with the public and media as indirect beneficiaries. The handbook addresses national and subnational levels, with an appeal to national actors to build capacity at community level. While the primary target users are national agencies, the handbook focuses on different levels, scales, actors, and perceptions of risk information. EWS can be national, regional or community-based, and developed for single or multiple hazards. As such, risk information needs to be generated and communicated as both multi-scale and multi-temporal.

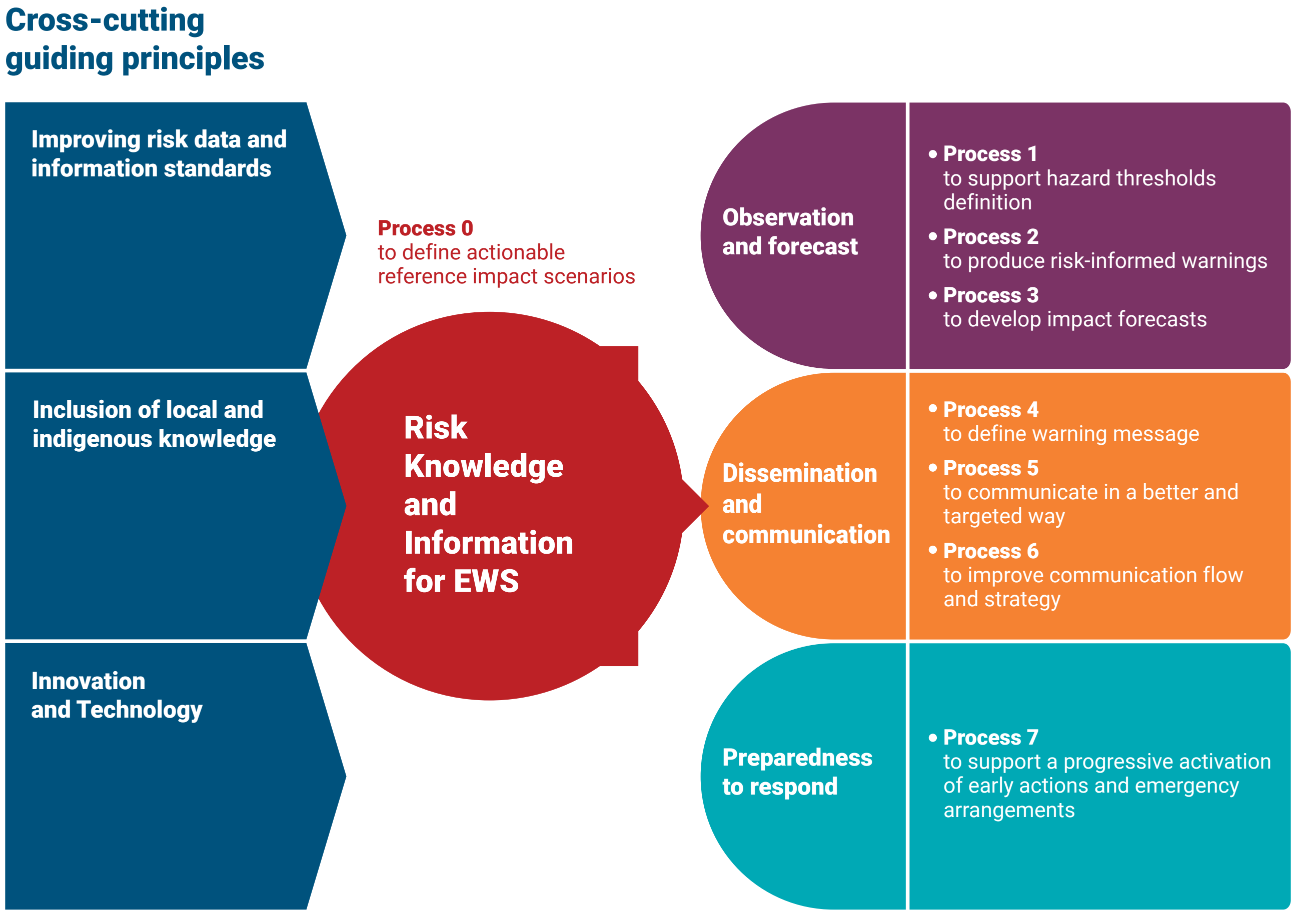
This handbook is a guide for DRR practitioners in the use, role and application of risk information to support the effective implementation of the EW4All pillars. Rather than focussing on the production of risk knowledge, the handbook documents how best risk information can feed into the different processes that comprise the EWS by emphasising the interconnected nature of EW4All across the four pillars. More specifically, it covers the processes represented by arrows in Figure 2. A practical approach is adopted, aiming at assisting actors and stakeholders engaged in EWS implementation. It serves as a tool, offering insights into how existing or forthcoming risk information can be effectively integrated into the design and operation of an EWS.

The handbook highlights the most important guiding principles to be endorsed, related to risk data and information standards, innovation and technology, the inclusion of Indigenous and Local Knowledge (ILK) in all the EWS development phases, as well as a summary of the key risk information needed for the implementation of each pillar. The practical slant helps countries understand where they are placed within the overall EWS and supports them in implementation.

It is structured around eight processes, identified as crucial steps for the implementation of an effective EWS that is properly informed by risk data and knowledge. The processes are associated with the EW4All pillars as described in Figure 3.

- **Process 0**: how risk information defines proper reference risk scenarios
- **Process 1**: how risk information supports the definition of hazard thresholds
- **Process 2**: how risk warnings are produced that include relevant and actionable risk information
- **Process 3**: how risk information can build technically sound impact forecasts
- **Process 4**: how risk information warnings are designed to be clear and readily understandable
- **Process 5**: how risk information identifies better and targeted communication methods for at-risk populations
- **Process 6**: how risk information improves the communication flow and strategy
- **Process 7**: how risk knowledge supports a progressive activation of early actions and emergency coordination arrangements

Figure 3
Handbook structure and workflow



While the general format of the handbook is relatively concise, it includes references to relevant literature and examples of existing good practices related to the key processes, to clarify details on strategies of system implementation and relevant data utilised. The handbook adopts the Sendai Framework Terminology on Disaster Risk Reduction[1] as its standard for definitions. Whenever terms are used differently in this text or their original meaning is key to understanding the principles presented, they are defined in the handbook.

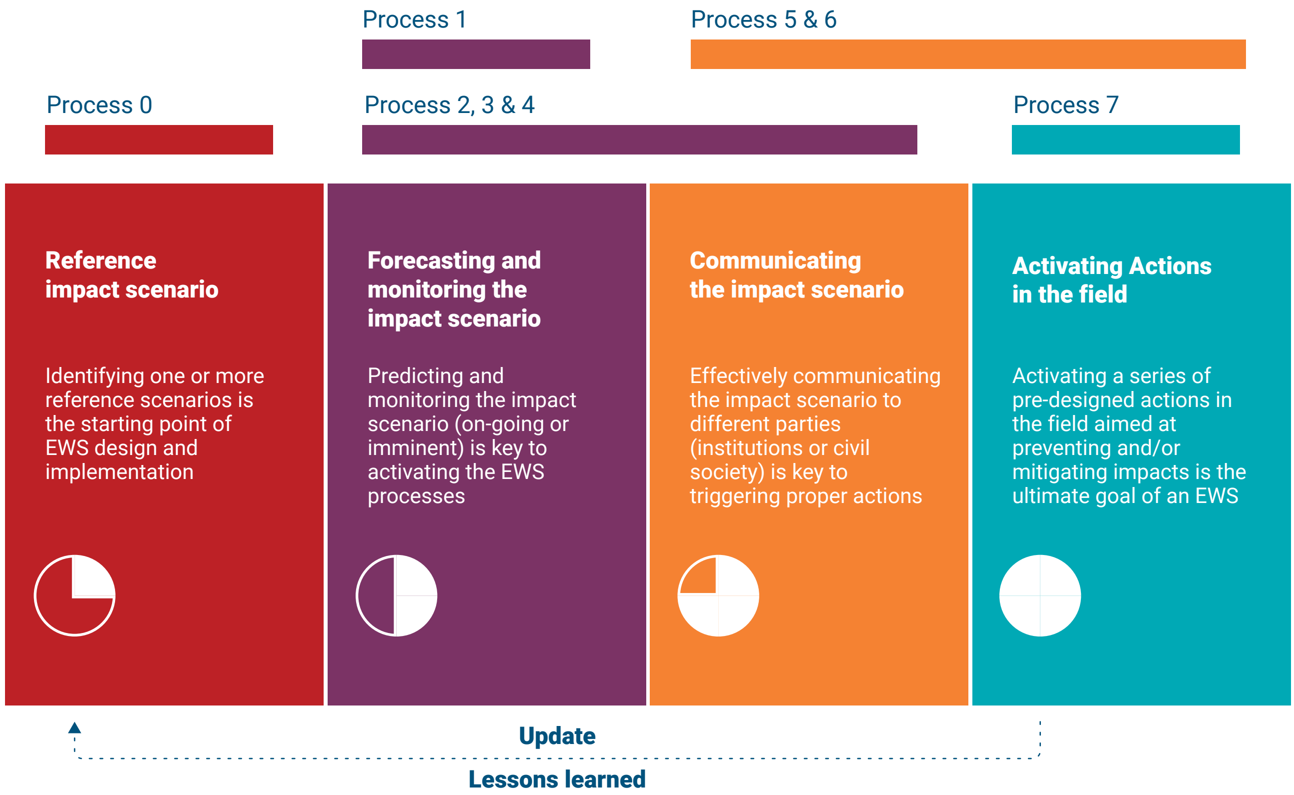
1.5. The Early Warning processes

EWS refers to a system of processes, activities and actors that supports the generation and use of EW for Early Actions (EA) (Figure 4). The handbook is built around the concept that impacts are embedded within the definition of EWS and that EW must be connected to impact information, through a process that enables:

- forecasting/ monitoring a threat potentially impacting a population, their assets or the environment (impact scenario)
- timely and efficient communication of such impact scenarios to and by the relevant actors (e.g. institutions, population) to allow AA to avoid, reduce or mitigate disaster impacts

How the impact scenario is identified, forecasted and communicated may vary in detail, reliability and complexity (e.g. connection between certain forecasted/ monitored variables and their possible consequences may be done according to knowledge of past events, or experts' perceptions in the field). However, no matter how simple the EWS is, it should always refer to potential impacts.

Figure 4
The early warning concept and processes



An EWS is a set of structured processes designed to detect and communicate potential threats or hazards before they escalate, thereby allowing for timely and effective response measures. The key components of an EWS include: prefiguring impact scenarios, forecasting and monitoring such scenarios on the basis of adequate triggers, and communicating such scenarios to the different actors to activate appropriate EA.

Prefiguring impact scenarios based on scientifically sound risk information is the starting point of an EWS (Process 0). Described as a people-centred and action-based EWS, this step involves identifying and understanding potential hazards that could have significant impacts on a system, community, or organisation. Scenarios can be developed based on historical data, scientific analysis, and expert input to envision the range of possible events or situations that could unfold. Starting the process by prefiguring a potential EA that should and could be implemented helps in identifying the needs of decision-makers in terms of EWS, and consequently selecting the most appropriate risk information (e.g. nature, level of disaggregation, temporal and spatial resolution, format) to steer the overall EWS process.

When reference impact scenarios are identified in partnership with scientific actors, such as National Hydro-Meteorological Services (NHMS), forecasting and monitoring is essential. Tools and methods, such as observations, meteorological models, and statistical analysis, are used to forecast the likelihood and severity of specific impact scenarios (Processes 1, 2 and 3). Forecasting involves continuous monitoring of relevant indicators and variables to update predictions as new inputs become available. The goal is to provide decision-makers with reliable and timely information about the potential threats, enabling them to make risk-informed decisions.

Once these potential threats are identified and warnings are generated, effective communication channels are needed to disseminate the information to relevant stakeholders (Processes 4, 5 and 6). Communication can comprise different formats - alerts, notifications, reports, briefings - depending on the nature of the threat and the target audience. Clarity, timeliness, and accessibility are essential. The content of the warning should include risk information and stem from the reference scenario identified (Processes 3 and 4).

An EWS designed according to these principles can prompt timely and appropriate actions to mitigate the impact of identified threats (Process 7). Mitigation includes evacuation plans, infrastructure reinforcements, resource allocation, among other measures aimed at reducing vulnerability and exposure, and enhancing resilience.

An effective EWS includes feedback to assess the accuracy of predictions, appropriateness of early response actions, and overall performance of the system. Continuous improvement is essential to adapt to changing conditions, improve forecasting accuracy, and enhance the effectiveness of mitigation strategies.

In essence, an EWS is a dynamic and integrated process that involves anticipating potential impacts, forecasting events, communicating information effectively, and triggering appropriate actions to minimise the negative consequences of threats or hazards. It is a proactive approach to risk management, emphasising preparedness and resilience.

The advantage of starting from a realistic representation of a possible impact scenario is to ensure consistency among the EWS processes. Adopting the same reference scenario to identify actions on the field and to define the warning characteristics to trigger them for different stakeholder groups should be at the heart of an efficient EWS.

However, due to the inter-institutional nature of EWS and the subsequent fragmentation in responsibility for different components, investments in EWS are not always coordinated. In some cases, an EWS is the result of an urgent need to respond to an event, while in others, it might be a technological and infrastructural investment. As a result, initiatives are often put in place but the coordination among them comes at a later stage. This inevitably creates problems in connecting components that were not harmoniously designed. This handbook aims to address this approach, by providing a pragmatic reference for institutions responsible for the implementation of EWS, so that different processes can be consistently connected even at later stages of development.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Standards and cross-cutting guiding principles for the production and use of risk knowledge and information specific to EWS (Pillar 1)

02

Standards and cross-cutting guiding principles for the production and use of risk knowledge and information specific to EWS (Pillar 1)

Several standards and cross-cutting guiding principles should be considered in the production and use of risk knowledge for EWS, referenced in the EW4All executive action plan (CDEMA, 2020 - p15). This section outlines information on the most relevant standards and principles, so as to ensure the quality, availability, accessibility, and use of risk information at continental, regional, national and local scales specific to impact-based EWS (AUC DRR, 2020).

Abundant materials and checklists generate risk information specific to EWS and baseline data for risk knowledge (EWC III, 2006; WMO, 2018). This handbook complements these resources by providing a practical list of the minimum information requirements to build risk knowledge specific to each EWS pillar, organised according to the risk assessment process (section 2.1).

General guidance is provided on the standards for risk knowledge production, by listing (section 2.2) the criteria necessary to generate standardised and sustainable risk information for EWS. The section also emphasises the importance of communicating uncertainties related to risk information.

As stated in the EW4All executive action plan (2023-2027),[2] ILK must be part and parcel of risk knowledge production. Section 2.3 describes how ILK is used, within the Community Engagement Objective Framework (FAO, 2023), for each step. In addition, specific attention is required to ensure that the EWS is equitable, thereby reducing discrepancies in impact. For example, during the 2004 Indian Ocean Tsunami four times more women died compared to men (MacDonald, 2005).

This underlines how an EWS must make sure that the most vulnerable populations (children, youth, the elderly, people with disabilities, etc.) are reached and that messages are tailored to them. In particular, consideration of gender issues in the production and use of local knowledge is necessary in the design and implementation of EWS.

Innovation and technology is indispensable in augmenting the production and effective utilisation of risk information within EWS. Section 2.4 highlights the relevance of satellite information, big data and artificial intelligence (AI). Satellite data offers a comprehensive view of the Earth's surface, allowing for real-time monitoring of environmental changes improving hazard assessment, exposure assessment as well as the characterization of vulnerability. This permits the mapping of hazards with a short revisit time so that the dynamic nature of all components can be captured. By harnessing this wealth of information, EWS can promptly detect potential risks, enabling proactive measures to mitigate their impacts. Big data analytics empowers EWS to process large volumes of diverse information rapidly, enhancing decision-making capabilities. Likewise, AI algorithms can analyse vast datasets generated by satellites and other sources to identify patterns and trends, facilitating more accurate risk assessment and prediction. AI is in its infancy on disaster related applications and will gain importance in future EWS. Embracing innovation and technology is essential for advancing EWS to effectively address the complexities of today's dynamic risk landscape. Innovation and technology contribution to EWS will be widely addressed in a forthcoming handbook on I&T, while this handbook offers considerations as presented in section 2.4.

Finally section 2.5 summarises the eight processes identified for the use of risk knowledge in the development of EWS, and their inter-linkages.

2.1. Minimum information requirements to build risk knowledge for each EWS pillar

Building knowledge on disaster risk and impacts is an essential step in EWS development, as it prioritises hazards and identifies hotspots where populations are most at risk. Furthermore, understanding how hazards affect people in different places helps tailor the development of effective EWS, as it comprises comprehensive and actionable information, thereby reducing the time between an early sign of a shock and its potential to manifest into a disaster.

Risk information is analysed here using the classical components of the risk equation: hazard, vulnerability, exposure, and capacity (UN, 2015). (Information on governance, inclusion, structures and regulations are also part of risk information, but are not included in this handbook). The historical information on impacts is the first step in the process. Components are analysed in respect of their relevance for the development of an EWS, with indications being given on the importance of the risk information elements for each pillar.

Box 2: Risk data for fragile and conflict-affected areas

The forthcoming handbook - "Early Warning Systems and Early Action in Fragile, Conflict, and Violent (FCV) Contexts: addressing growing climate and disaster risks" by the WMO-UNDRR Centre of Excellence for Disaster and Climate Resilience – will ensure that fragile- and conflict-affected countries are supported within the wider ecosystem of EWS stakeholders. This is essential as 19 of the top 25 most climate vulnerable countries are considered fragile and/or conflict-affected.

However, realising these connections with conflict-affected populations is challenging, as they are often displaced or on the move, have lost assets (including mobile phones), and may be highly suspicious of information sources stemming from government or authority figures. Nevertheless, better and more dynamic data on the number, location, and needs of displaced people in FCV contexts is required, to better understand current and projected hazard exposure. The volatility and significant daily challenges inherent to many FCV contexts may also affect the uptake of warning messages (if received), as the risk perceptions or competing priorities of affected populations may necessitate tailored and trauma-informed messaging.

Establishing EWS in refugee and Internally Displaced People (IDPs) camps is complex due to the challenges faced by these populations. For refugees, these include restrictions on freedom of movement hampering the evacuation of camps during extreme weather events, as well as the types of building materials and infrastructure permissible in camps, which host governments often restrict to temporary rather than durable materials. These factors can increase refugee vulnerability to natural hazards. At the same time, the frequently large humanitarian presence in camps provides an opportunity to establish or strengthen EWS by making use of existing humanitarian responses and coordination systems.

More information on the handbook and wider initiatives are available: https://www.preventionweb.net/publication/early-warning-systems-and-early-action-fragile-conflict-and-violent-contexts-addressing

2.1.1. Historical Impacts

Gathering historical data on past and current incidents or events related to specific hazards recurring in an area is of paramount importance. For EWS, historical-disaster records help validate the risk knowledge produced, as well as furnish information to build simplified reference impact scenarios. The retrospective analysis of disaster data is particularly pertinent to risk assessment and IBF calibration, to inform detailed preparedness planning, and identify the emergence of new risk patterns and trends. The analysis of historical impacts also helps build an accurate perception of pending risk on the geographical scope of the EWS.

In this regard, disaster losses and damage data and statistics - disaggregated by hazard typology, location and impact categories – need to be collected and shared across and within institutions. Efforts to develop a disaster loss database that is compliant with the Sendai Framework for Disaster Risk Reduction 2015-2030, monitoring minimum requirements, have been made. They are defined as a set of systematically collected records on disaster occurrence, damages, losses, and impacts. Examples of global sources of information for disaster related impacts include: Desinventar,[3] EM-DAT,[4] NatCatSERVICE[5] (Munich Re) databases, and Swiss Research Institute Sigma Explorer.[6] DesInventar is particularly relevant in the development of EWS as it has been collecting, since the early 1990s, a broad range of impact data (including physical damage to housing, agriculture, infrastructure, schools, and health facilities at local level) on all disaster magnitudes, and is available (at different degrees of completeness) for 110 countries. These datasets can be further complimented by online media (e.g. floodlist[7]), humanitarian reports (e.g. webrelief[8]), and information derived from emergency appeals (e.g. IFRC-Go[9]) or post disaster needs assessments (e.g. Preventionweb[10]).

At present, UNDRR, UNDP and WMO are encouraging the NHMS to enrich their disaster catalogues with a new disaster data information system under development. Known as the Disaster Losses and Damages Tracking system (DLDT[11]) it employs a new methodology for gathering information on hazardous, weather, climate, water, and space weather events, known as Cataloguing Hazardous Events (CHE).[12] The CHE model will provide records of hazardous events that can be linked to related observed disaster impacts. Recognizing the need for an upgraded, comprehensive, and inter-operable system, UNDRR, UNDP and WMO are collaborating to develop this new generation tracking system. It aims to enhance a country's capacity to better understand disaster data value chains, support data governance, enable actionable information, and facilitate knowledge brokerage for positive change. It comes as an upgrade to Desinventar to address growing data needs and inter-operability, as well as data standards, institutionalisation and sustainability. It will enhance the possibility of recording the causal nexus between hazard observations and impacts, a vital feature to support EWS design and implementation. Furthermore, the DLDT will leave sufficient room to incorporate the results of the on-going development on methodological and technical aspects, such as the advancement of accounting methodologies for environmental loss assessment, the development of a new disaster-related statistics framework, or the adaptation of post-disaster needs assessments to slow-onset events.

Table 1, below, illustrates the historical impact elements needed for EWS.

Table 1
Historical impact information needed for EWS

Variables	Description	Use in each pillar	Disaggregation	Resolution	Sources
Historical hazard event dates and location	List of past and current shocks or events related to specific hazards occurring in an area (aligned to the HIPs and new CHE)	Pillar 2: Understand frequency, identify hotspots, model validation Pillar 3: Refer to past events in warning messages and recommend mitigative actions based on analysis of past avoided and/or minimized loss and damage Pillar 4: Define reference scenarios. Tailored plans that consider seasonality and geographical distribution of past shocks and disasters, including summary of exposure dynamics (people, assets, infrastructure, services), vulnerabilities, and the mitigative actions undertaken to reduce impacts based on people's risk perception	Important to include different typologies of disaster (e.g. flash flood, dam break) and the causality chain (e.g. rainfall induced, snow-melt induces, cyclonic surge, post-cyclonic heatwaves). Important to include the timeline of the triggering hazard event, followed by the sequence of possible direct/ primary and indirect/ secondary effects	Depending on the scope of the EWS: at the highest administrative divisions possible. Added value to have a precise coordinate for localised disasters. Precise time and date (at least the day)	e.g. Desinventar, EM-DAT, NatCatSERVICE (Munich Re) databases, SIGMA Could be completed manually by online media (e.g. floodlist) humanitarian reports (e.g. webrelief) and information from emergency appeal (IFRC-Go) or post disaster need assessments (PDNAs) (Preventionweb), new technologies like web crawling could be also used
Historical impacts of shocks and disasters on different assets. This includes losses and damage assessment reports from historical and recent events	Quantitative records of the direct and indirect impacts of each historical event occurring in the area, on different assets, services and sectors	Pillar 2: Reference impact scenarios to define warning thresholds Pillar 3: Prepare impact-based forecast warnings Refer to impactful historical events in warning messages, reference to specific impact categories Pillar 4: Level of preparedness and response sized according to historical impacts, while noting that climate change is introducing impacts previously not recorded Lessons learned from past emergency relief and post disaster needs assessments and recovery programmes	Information should be available per assets and sector (population, agriculture, housing, critical infrastructure (e.g. bridges, roads, electricity), environment). Forensic approach to the impact, linking impacts with their causes[13]	Depending on the scope of the EWS: at sub-national levels (at least district level, admin 2)	

Reference hydro-meteorological values observed during past major events	Maximum extreme hydro-meteorological conditions (e.g. precipitation rate, temperature) during or preceding each event	Pillar 2: Understand hazard severity and identify hazard variables, define thresholds "e.g. Desinventar, EM-DAT, NatCatSERVICE (Munich Re) databases, SIGMA. Could be completed manually by online media (e.g. floodlist) humanitarian reports (e.g. webrelief) and information from emergency appeal (IFRC-Go) or post disaster need assessments (PDNAs), the upcoming Disaster Losses and Damages Tracking System (DLDT), and new technologies like web crawling Pillar 3: Refer to past impactful events in warning messages	Information should be as quantitative as possible, and should include units, temporal and spatial references. In absence of such quantitative information categorical information can be used	Depending on the scope of the EWS: at the highest administrative divisions possible	NHMS historical records, Event reports from mandated institutions or the Humanitarian sector, online media (e.g., floodlist)
Assessment of exposed people, services, infrastructure, assets, etc. as well as coping capacity at the time of the recorded event	Specific data on population, urbanisation, IDP camps and other highly variable exposed assets; specific vulnerability conditions due to previous / recent events; specific conditions of the population: displaced, food security level, epidemics	Pillar 2: Update and modify of the reference scenario according to the current level of coping capacity, exposure, and vulnerability levels Pillar 3: Prepare impact-based forecast warnings in collaboration with Pillar 2, including updating the coping capacity, exposure, and vulnerability levels Pillar 4: Update and modify of the level of preparedness and response needed as well as the reference scenario according to the current level of coping capacity, exposure, and vulnerability levels. This can be sized based on historical impacts	Per sector, per category of population	Depending on the scope of the EWS: at the highest administrative divisions possible	Damage and loss assessments summarised in Post-Disaster Needs Assessments (PDNA) https://www.gfdrr.org/en/damage-loss-and-needs-assessment-tools-and-methodology https://www.gfdrr.org/en/post-disaster-needs-assessments
Community perception of risk and warnings, as well as trust of messages and communication channels used from past experiences	Info. on past access and use of warnings (e.g. format, channel used, effectiveness, timeliness, perception)	Pillar 3: Identify communication channels that have been used in the past and their effectiveness Pillar 4: Adapt actions to risk perception and past response	Important to disaggregate information per demographic group (including gender and vulnerable groups) as well as spatially	Depending on the scope of the EWS: at the highest administrative divisions possible (community levels)	Should be gathered through community engagements and participatory approaches
Root causes of past disasters (socio-economic, environmental)	Information on context leading to past disasters (e.g. deforestation, agricultural practices, defence failure)	Pillar 2: Define predictors Pillar 4: Tailor preparedness plan	Information should be at local/community level	Depending on the scope of the EWS: at the highest administrative divisions possible (community levels)	Should be gathered by local communities or through FGD or KII

2.1.2. Hazard elements

Understanding how a specific hazard may occur, spatially in terms of location and extent, and temporarily in terms of frequency, duration, and season, is a key step in hazard prioritisation and a key component of the risk scenario. It forms the foundation for understanding the nature, magnitude, and potential impact of specific hazards and is the basis to trigger warnings, shape messages, and inform response strategies. The hazard-related information detailed in Table 2 is particularly relevant for developing EWS. In multi-hazard scenarios, in addition to retrieving data for each hazard, the compound effects need to be analysed. Access to hazard information will soon be facilitated by the implementation of the CHE standards by WMO (WMO-CHE) that will help identify relations between hazard and impact magnitude in the analysed environments. The possibility of linking impacts to a single event will be crucial in allowing analysis at event level, which will in turn inform the design of reference risk scenarios in all its complexity. Useful information on hazard classification can be found in the UNDRR's hazard definition and classification review: Technical report[14] and the related Hazard Information Profiles (HIPs).[15]

Table 2, below, illustrates the hazard elements needed for EWS.

Table 2
Hazard elements needed for EWS

Variables		Description	Use in each pillar	Disaggregation	Resolution	Sources
Temporal characterization Speed of onset	Speed of onset	Information on time lag between first precursor sign and impact (e.g. hours, days, months)	Pillar 2: Inform on the detection and forecast methods to use Pillar 3: Informs the content of warning messages (type of hazards) and type of message (advisory, warning, emergency alert) Pillar 4: Define duration of the potential window of opportunity (between warning and impact), to take early actions	Information needed for each potential hazard in the area of interest and for a sufficient number of hazard scenarios	Variable, depending on the hazard (see hazard maps)	National-local hazard assessment - regional and global-scale systems as back-up (WMO Words into Action MHEWS: [https://www.undrr.org/words-into-action/guide-multi-hazard-early-warning)](https://www.undrr.org/words-into-action/guide-multi-hazard-early-warning)
	Hazard duration	Duration of hazardous conditions	Pillar 2: Define disaster time-space scale Pillar 3: Informs the content of warning messages (duration) Pillar 4: Informs the level of preparedness required, and prioritises mitigation and response efforts	Information needed for each potential hazard in the area of interest and for a sufficient number of hazard scenarios	Variable admin. level, depending on the hazard (river reach or river basin scale for river/ flash floods, admin. level for drought/ wildfires/ meteorological hazards)	National-local hazard assessment - regional and global-scale systems as backup (WMO Words into Action MHEWS
Spatial characterization	Hazard maps	Spatial extent of areas affected by the hazard. Best if it includes hazard intensity (e.g. max water depth, max wind speed…)	Pillar 2: Define disaster time-space scale Pillar 3: Informs the content of warning messages (location, intensity, risk to exposed assets, e.g., wind speeds sufficient to cause roof damage) Pillar 4: Guiding resource allocation for response and preparedness efforts	Information needed for each potential hazard in the area of interest and for a sufficient number of hazard scenarios	Variable, depending on the hazard (e.g. 10m to 1m for flood hazard maps, admin. levels for drought hazard maps etc.)	National-local hazard assessment - regional and global-scale systems as backup (WMO Words into Action MHEWS

Frequency characterization	Probability of occurrence	Information on the frequency of relevant hazard events	Pillar 2: Use in combination with hazard thresholds Pillar 3: Informs the content of warning messages (probability) Pillar 4: Understanding of the level of preparedness required	Information needed for each potential hazard in the area of interest and for a sufficient number of hazard scenarios	Variable, depending on the hazard (river reach or river basin scale for floods, admin. level for drought/ wildfires/ meteorological hazards)	National-local hazard assessment - regional and global-scale systems as backup (WMO Words into Action MHEWS
Forecasting and monitoring parameters	Knowledge of predictors and early signs	Information on the conditions and early signs preceding the onset of hazard event(s), based on scientific literature, historic data, indigenous and local knowledge (ILK)	Pillar 2: Choice of hazard detection variables Pillar 3: Warnings can refer to ILK on early environmental sign = trust Pillar 4: Potentially increasing window of opportunity	Information needed for each potential hazard in the area of interest and for a sufficient number of hazard scenarios	Variable, depending on the hazard (river reach or river basin scale for floods, admin. level for drought/ wildfires/ meteorological hazards)	National-local monitoring-forecasting systems - regional and global-scale systems as back-up (UNDRR Global Status of EWS, https://www.undrr.org/reports/global-status-MHEWS-2023)
	Real-time monitoring variables	Real-time monitoring of hazard-specific variables	Pillar 2: Detect values and trends that may indicate an impending hazard event Pillar 3: Detect values that might trigger the issue of warnings and communication actions Pillar 4: Detect values that might trigger preparedness-response actions	Information needed for each potential hazard in the area of interest	Variable, depending on the hazard. See WMO guidelines for density of monitoring networks (https://library.wmo.int/records/item/35631-technical-regulations-volume-iii-hydrology?offset=2)	National-local monitoring-forecasting systems - regional and global-scale systems as backup (UNDRR Global Status of EWS)

Secondary and cascading hazards	Schematic of compound and cascading effects	Information on mechanisms causing the onset of cascading hazards (hazard triggered by another hazard event, e.g. heavy rainfall causing landslides) and compound hazards (concurrent occurrence of related hazard, e.g. river and coastal flooding)	Pillar 2: Identify a combination of triggers Pillar 3: Informs the content of warning messages (potential occurrence of multiple hazards) Pillar 4: Tailor plan to compound effects	Information needed for each potential hazard in the area of interest and for a sufficient number of hazard scenarios	Variable, depending on the hazard	National-local hazard assessment - regional and global-scale systems as backup (WMO Words into Action MHEWS

2.1.3. Exposure elements

Exposure-related risk information is key to inform risk assessments and EWS chains. Exposure, as defined by UNDRR, refers to the presence and distribution of people, infrastructure, assets, and other elements of value in areas that are susceptible to the impacts of hazards. Indeed, exposure-related risk information is critical to assess the potential impact of an upcoming hazard on vulnerable populations, infrastructure, and assets, and to develop effective warning and response strategies. It captures the level of disaggregation of exposure elements as well as their dynamics, whether fast (e.g. day/ night or seasonal population distribution, IDPs) or slow (e.g. urbanization, changes in urban development, land use).

Knowledge about where people live and their movements over time is fundamental for risk exposure analysis, while other risk factors are secondary in understanding and gauging the exposure to an upcoming hazard.

Table 3, below, illustrates the exposure elements needed for EWS.

Table 3
Exposure elements needed for EWS

Variables	Description	Use in each pillar	Disaggregation	Resolution	Sources
Population data					
Residential population (where people live)	Population density connected to settlements	Pillar 2: Number of people about to be affected-> define warning categories	No need of specific disaggregation	Admin. level consistent with the application	National census data (most accurate and of high resolution) Demographics and health surveys (country specific) Global population distributions (e.g. WorldPop. GHSL. WSF) (https://www.portal.worldpop.org/demographics/) or other upcoming efforts (e.g. Microsoft, Planet Labs, and the University of Washington's IHME working together on a global population map[16])
		Pillar 3: Understand how the population potentially affected is distributed spatially in order to adapt warning dissemination channels. Essential for developing accurate and context specific warnings	Vulnerable groups: gender, religion, language, age, disabilities, etc.	Census Tracts	
		Pillar 4: Guide resource allocation for shelters, medical facilities, and food distribution centres. Essential for planning evacuation orders in high-risk areas		Census Tracts, Communities level	

Working/ living/studying population (where people work/live/ study)	Population distributed with reference to working/ living/ studying places and related livelihoods	Pillar 2: Understand the patterns of human movement from daytime to night-time; tracking the progress/ status of post disaster recovery period	No need of specific disaggregation	At the highest possible admin. level	
		Pillar 3: Warnings to be disseminated effectively to areas with high concentration of labour force during the day etc.			
		Pillar 4: Leverage private sector networks and communities to deliver necessary support; also prepare for cascading disasters, e.g. residential fires to be triggered during popular cooking time			
Migration patterns: understanding population movement and displacement patterns (temporary population)	Description of population movement and displacement patterns (temporary population)	Pillar 2: Could be included in defining warning thresholds	Vulnerable groups: gender, religion, language, age, disabilities, etc.		Developing Indicators on Displacement for Disaster Risk Reduction | Environmental Migration Portal
		Pillar 3: Warnings design and dissemination integrating seasonal migrations or displacement due to conflicts			
		Pillar 4: Adapt plans to migration patterns (e.g., monitor changes in displacement duration, exposure to new hazards in hosting locations)			

Infrastructure data					
Exposed settlements and buildings	Information on any infrastructure that is at risk and their characteristics including location, materials used, purpose, and economic recovery value	Pillar 2: Estimate the number of building, households, temporary shelters, etc, about to be affected (for IBF)	Disaggregation per sector such as industry, housing, commercial facilities	At the highest possible resolution (building footprints or point location)	Official building databases, cadastral databases, census data and field surveys Building footprint from OpenStreet Map (https://www.open streetmap.org/) https://global.infrastructure resilience.org/view /exposure?y=20&x=-40&z=3&sections=%7B%22exposure %22%3A% 7B%7D%7D Copernicus Global Human Settle-ment Layers[17]
		Pillar 3: Tailor sector-specific warnings at different admin. levels			
		Pillar 4: Plan preparedness and response plan in space			
Places of cultural value		Pillar 2: Estimate the place of cultural values about to be affected (for IBF)	Disaggregation per type of cultural place (cultural heritage, museum centres, places of cult, archives and libraries, historical centres)		Field survey, OpenStreetMap, National datasets in Humanitarian Data Exchange
		Pillar 3: Tailor warnings to cultural tradition and habits			
		Pillar 4: Adapt preparedness and emergency plans (e.g. evacuation)			
Exposed services and critical infrastructure: e.g. hospitals, schools, shelters, roads, protection walls, evacuation routes, bridges, transportation hubs,water, sewerage, energy/ electricity systems and other utilities		Pillar 2: Calculate potential upcoming damages in each sector while considering resilient infrastructure (for IBF and IF)	Disaggregation of exposure data per sector and economic characteristics		Nationally-operated Risk Information Management Systems & Platforms, if available OpenStreetMap (https://www.openstreetmap.org/) National geonodes and risk data repository Humanitarian Data Exchange (https://data.humdata.org/) Global Exposure Socio-Economic and Building Layer (GESEBL) https://data.humdata.org/dataset/exposed-economic-stock
		Pillar 3: Important for communicating potential disruptions to critical infrastructure and services (e.g. to hospitals and emergency services)			
		Pillar 4: Helps prioritise short-and-long-term response efforts, resource allocation, and coordinate rescue and relief operations			

Land-use and land-cover data					
Land-use map	Maps representing the different types of land use (e.g. crops, livestock), in vector or raster format	Pillar 2: Estimates upcoming impacts on livelihoods, food security, and economic activities	Disaggregation per type of land-use: residential, agricultural, industrial	To the highest resolution available	Census data, cadastral databases OSM Land Use Data, GEOGLAM Crop Monitor and ESA's World Cereal[MOU2] https://gaez.fao.org/pages/data-viewer-theme-2 https://glad.earthengine.app/view/global-forest-change#dl=0;bl=off;old=off;lon=20;lat=10;zoom=3;
		Pillar 3: Tailor sector specific warning at different admin. levels			
		Pillar 4: Tailor sector-specific strategies and plans depending on contexts of land-use impacts			
Land-cover and land degradation	Information and location of the specific natural environment (e.g. forest, wetlands, coastal areas) that are vulnerable to the specific hazard	Pillar 2: Assess environmental impacts and predict potential secondary effects like landslides or flooding Assess the effectiveness of nature-based solutions	Disaggregation per type of land-cover: forest, wetlands, coastal areas		UNEP GRID, https://unepgrid.ch/en/platforms FAO, https://landportal.org/es/book/dataset/fao-lu Global Land Cover dataset: e.g. Copernicus global land cover data: https://land.copernicus.eu/global/products/lc ESA-CCI 2018 land cover at 300m resolution https://www.esa-landcover-cci.org/ https://explorer.naturemap.earth/map
		Pillar 3: Messages relating to environmental impact are important in some contexts (e.g. ecosystem services, including natural resources for tourism)			
		Pillar 4: Reflect on policy and implementation for nature conservations, management and nature-based solutions solutions to reduce the impacts of shocks and disasters			

2.1.4. Vulnerability (and coping capacity) elements

There are many different definitions of vulnerability. Vulnerability refers to the predisposition of an exposed element to be adversely affected (IPCC, Annex B., 2012) and addresses the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, community, assets or systems to the impacts of hazards (UNDRR). Vulnerability-related risk information improves the assessment of the potential impact of hazards on populations, infrastructure, and ecosystems, making it essential to the effectiveness of each EWS pillar. In a threatening hazard situation, it assists in identifying and prioritising at-risk populations, improving the accuracy of warnings, ensuring accessibility for all, and guiding response efforts to protect the most vulnerable members of the community.

The vulnerability of a place and its population is related to the social, political, cultural, economic, and institutional characteristics that influence how people can prepare, experience and recover from hazard events. The vulnerability of a population cannot be directly observed or measured, however data can be combined to quantitatively estimate relative vulnerability from available proxy variable characteristics (Bucherie et al., 2022a). For example, population vulnerability information related to the identification of vulnerable groups (e.g. disability), demographics (e.g. age and gender), health status, education, poverty (e.g. income, inequality), and coping capacity (e.g. access to critical services) helps identify groups that may be more susceptible to the effects of hazards.

The vulnerability of infrastructure is often expressed in terms of structural vulnerability, and considers factors such as construction quality, building code compliance, and maintenance practices that help determine the resilience of infrastructure to various hazards

Table 4, below, illustrates the vulnerability and coping capacity elements needed for EWS.

Table 4
Vulnerability and coping capacity elements needed for EWS

Variables	Description	Use in each pillar	Disaggregation	Resolution	Sources
Population vulnerability					
Vulnerability indicators from demographic and socio-economic data	Inherent socio-economic characteristics of the population informing on individual, household and community vulnerability, as well as variables describing how the vulnerable groups can cope with disasters	Pillar 2: Vulnerability data assists in refining hazard monitoring and warning systems Pillar 3: Identify the specific characteristics of the user/ users and tailor warning messages to specific population groups Pillar 4: Define early warning actions tailored to different vulnerability groups and the spatial differences in social vulnerability	Disaggregation into various variables and dimensions: vulnerable groups (e.g. disability, literacy), socio-economic (e.g. poverty index), health, education level, demographic (age, gender)	At the lowest possible admin. level	Census data Social registries National bureau of statistics databases INFORM index Subnational Human Development Index (SHDI) Subnational Gender Development Index (SGDI) Education Component of SHDI Standard of Living Component of SHDI Humanitarian Data Exchange (HDX) Socio-economic Data and Application Center (https://sedac.ciesin.columbia.edu/data/sets/browse?facets=theme:population)
Coping capacity: population access to critical functions	Information about how population/ communities have access to critical Infrastructure and communication network	Pillar 2: Relative degree of coping capacity of different populations can help refine impact forecasts Pillar 3: Tailor warning messages based on the relative accessibility of people to services allowing them to cope with shocks and disasters (e.g. remoteness) Pillar 4: Adapt plans and early actions based on the accessibility of population to critical services	Disaggregation into various variables and dimensions: access to infrastructure (e.g. water, sanitation, roads, power), access to communication networks (e.g. mobile, internet, radio)	At the lowest possible admin. level	

Infrastructure vulnerability					
Physical vulnerability indicators of built-up and critical infrastructures	Information related to construction quality, building codes compliance, and maintenance practices which help determine the resilience of critical infrastructure and build-up to various hazards	Pillar 2: Use building type and standard to estimate potential damages and warning thresholds (data sourced from sector ministries and departments) Pillar 3: Tailor messages including potential damage to build-up and infrastructure Pillar 4: Tailor plans specific to physical vulnerability contexts	No specific disaggregation needed	At the highest possible resolution (building footprints or point location)	National bureau of statistics E.g. vulnerability curves for flood https://ecapra.org/topics/vulne-rability JRC Flood-depth damage curve ht-tps://publications.jrc.ec.europa.eu/repository/handle/JRC105688
Functionalities of services	Information relative to the level of functionality and resilience of services	Pillar 3: Tailor warning for the (potentially) impacted service; Importance to know if communication channel might be affected Pillar 4: Plan for services interruption and back-up for emergency planning	Disaggregation in terms of infrastructure type (water, sanitation, roads, power, communication networks)	Resolution at which the information is available	National institu-tions in charge of critical infra-structures

2.2. Improving risk data and information standards

Improving risk data and information standards for EWS is crucial to enhance the accuracy, effectiveness, and inter-operability of these systems (UNDRR, 2016). It is an on-going process that requires collaboration, adherence, and commitment to best practices, such as standardising data formats and metadata, adopting common data collection and sharing protocols, collaborating with data providers, conducting data standard and literacy training. Standardised data helps EWS operate more effectively, share information with other agencies, and deliver timely, accurate warnings to protect communities from disasters and hazards. UNDRR promotes open-data as a digital public good (World Bank, 2022). Standardised data helps EWS operate more effectively, share information across agencies, and deliver timely, accurate warnings to protect communities from shocks and disasters. In general, the use of Spatial Data Infrastructure (SDI) can help governments enhance their capacity to evaluate and ensure the sufficiency and quality of spatial and temporal disaster risk data. References and good practices to improve risk knowledge production for EWS entail the following:

- promoting the development of quality standards (e.g. in data collection, analysis, assessment and certifications) particularly at national and regional levels
- ensuring that EWS sensors, databases, tools for analysis and communication platforms can inter-operate and exchange data effectively, adopting data format standards, so as to ensure real-time and near real-time access to reliable data
- improving the understanding and communication of uncertainties in risk information

2.2.1. Data quality and sufficiency criteria

Effective EWS rely on data of sufficient availability and quality to produce accurate risk information and provide timely warnings. Cai and Zhu (2015) outline five dimensions of data quality that can be adapted and applied in the context of disaster risk and EWS. They encapsulate key data criteria and standards that help prioritise and organise efforts to ensure effective data quality.

In the context of EWS, the main criteria for data quality and sufficiency include:

1. Availability: data accessibility and timeliness

- is the data public, for purchase or needs authorization, and is it regularly updated?
- is the collection, processing, and dissemination of risk data timely, so as to support EW and decision-making? Given that real time population flows can change significantly and rapidly, obstructed data can result in delayed warnings, thereby reducing effectiveness. Real-time or near-real-time risk data (including hazard data) is therefore of paramount importance

Examples of good practice
The Disaster-Related Statistics Framework (DRSF)[18] is a guideline developed by the Economic and Social Commission for Asia and the Pacific (ESCAP) to improve countries' capacities to customise and adopt their own national standards in order to produce high quality, integrated statistics on disaster. (Free training: https://www.unsdglearn.org/courses/disaster-related-statistics-framework/)

The COnsolidated criteria for REporting Qualitative research (COREQ) Checklist has been developed to ensure quality control of qualitative data collected through surveys, interviews and FGDs. https://cdn.elsevier.com/promis_misc/ISSM_COREQ_Checklist.pdf

2. Reliability: data accuracy, precision, completeness and consistency

- disaster risk data have an inherent degree of error (CRED and UNDRR, 2020), therefore the accuracy and limitations of available information must be known (section 3.2.3)
- data quality assurance must be ascertained through regular data validation and quality checks, such as internal quality control of real time data, or external data validation from subject-matter experts who can audit the data for correctness
- data needs to be precise, and presented in known values, using consistent standards, units of measurement, and appropriate methodologies
- data must cover all relevant aspects of disaster risk (relative to hazards, impact, exposure, as well as physical and socio-economic vulnerabilities), and all relevant groups (especially vulnerable groups, persons with disabilities, children/youth)
- consistency ensures that measurements and observations are collected using the same standards and methods over time, in a sustainable way. Inconsistent data can lead to confusion and misinterpretation

3. Fitness: data relevance and redundancy
Data fitness means that the datasets adopted match the users' needs: for EWS, only data sources and parameters relevant to the types of disasters or hazards being monitored should be selected.

- spatial and temporal coverage, as well as resolution of data is key to address data sufficiency: spatial and temporal resolution of the data must be commensurate with the hazard under investigation
- EWS data should have redundancy, meaning that if one data source fails, there are backups or alternative sources available

4. Security, Privacy, and Ethical Considerations
Data collection and usage must comply with legal and ethical standards, including security, privacy, consent, data ownership, and transparency, particularly when dealing with sensitive information. The "do no harm" principle needs to be applied when generating risk information, especially in contexts where risk data and information (particularly related to social vulnerability) needs to be collected and shared.

2.2.2 Standards for risk data inter-operability and exchange

Achieving inter-operability of risk data is fundamental for EWS. It involves compatibility among EWS organisations and their components (governments, meteorological institutes, local communities) and effective data exchange among sensors, databases, tools for analysis, and communication systems. One way to promote data inter-operability is through the establishment of Application Programming Interfaces (APIs) for real-time data sharing. For example MISTRAL[19] (Meteo Italian SupercompuTing PoRtAL) is a national initiative that avails meteorological data from various observation networks and forecasts (Bottazzi et al., 2021). Similarly, the Open Geospatial Consortium (OGC) spearheads efforts in standardising geospatial content, location-based services, sensor web, and Internet of Things (IoT). This runs alongside GIS data processing and sharing, with working groups harmonising inter-operability standards within the disaster management community.[20]

The need for data openness cannot be overstated, as it ensures access to crucial information among the public, stakeholders, and other interested parties. Embracing open-source data integration, particularly in scenarios where national data accessibility is limited, becomes a pivotal strategy for risk assessment and EWS development (Lindersson et al., 2020). Open data not only fosters transparency and accountability in risk information but also empowers communities by providing them with access to pertinent data. Moreover, it catalyses cross-sectoral and international collaborations while fostering scientific research and innovation.[21] In Indonesia, the National Disaster Management Agency (BNPB) and the National Statistics office (BPS Statistics Indonesia) jointly developed the Satu Data Bencana (Indonesia One Disaster Data), a reference initiative for gathering national open data policies and guidelines relative to disaster risk data (BNPB and BPS, 2020). A comprehensive list of commonly used open-source risk datasets is referenced in the annex of this handbook.

Numerous platforms exist for sharing standardised national risk data and information in geo-referenced formats. These include initiatives such as the Risk Data Collection Library, a joint effort by GFDRR and the World Bank Development Data Hub, aimed at consolidating risk data (https://riskdatalibrary.org/). Additionally, the OSGeo community offers opportunities to create national geonodes through its open-source platform (https://geonode.org). The UNOCHA's Humanitarian Data Exchange Platform (https://data.humdata.org/) and UNDRR's Risk Information Exchange platform RiX[22] are also instrumental in facilitating data sharing among humanitarian organisations and governments.

Standardisation in communicating and disseminating risk information is equally pivotal for the effectiveness of EWS. The Common Alerting Protocol (CAP),[23] initially developed by the Organization for the Advancement of Structured Information Standards (OASIS), provides a standardised, adaptable, and scalable format for exchanging disaster emergency alerts and public warnings across various networks. With collaborative endeavours, CAP could reach global adoption, enhancing inter-operability and exchange among EWS worldwide.

2.2.3 Understanding and communicating uncertainty related to risk information

Uncertainty is a pivotal consideration across the whole EWS. Hazard forecasts inherently harbour elements of uncertainty, which invariably permeate through IBF, warning generation and dissemination, and into preparedness and response (P&R) phases. Tate (2012) underscores the inherent uncertainty in disaster risk analysis, highlighting the challenges of quantifying risk across various dimensions.

High-magnitude events are particularly demanding, as they are seldom observed and, when they do occur, are challenging to reconstruct in detail. Consequently, interpreting risk information derived from such events must be done with caution. ILK can play a pivotal role in mitigating uncertainty, as it offers valuable insights by providing information on past events and enhancing the reliability of hazard models. Moreover, ILK often conveys qualitative information through narratives and stories, which complements formal scientific data. Kniveton et al. (2015) elaborate on how the integration of local and scientific risk knowledge can enhance the understanding of uncertainty in risk knowledge production. By synthesising and comparing these diverse forms of knowledge, a more comprehensive understanding of uncertainty can be achieved, fostering stronger collaboration between information providers and users.

In scientific literature, studies have shown how uncertainty manifests across different phases of EWS implementation. Research by Smith et al. (2018) delves into the challenges of incorporating uncertainty into hazard forecasts and its implications for decision-making in EW dissemination. The UK Met Office uses the Met Office Global and Regional Ensemble Prediction System (MOGREPS) to account for uncertainty due to starting conditions and forecast models. Furthermore, exposure and vulnerability components should be factored within the overall uncertainty of IBF (Cloke and Pappenberger, 2009; Merz et al., 2020).

The communication of uncertainty can be addressed through the use of risk matrices, employing the likelihood of the forecasted event to incorporate information on uncertainty. P&R measures need to be robust and designed to deal with the possibility of missed events and false alarms, to ensure that all possible EA are taken. More details and examples are provided in the following sections.

2.3. Inclusion of Indigenous and Local knowledge

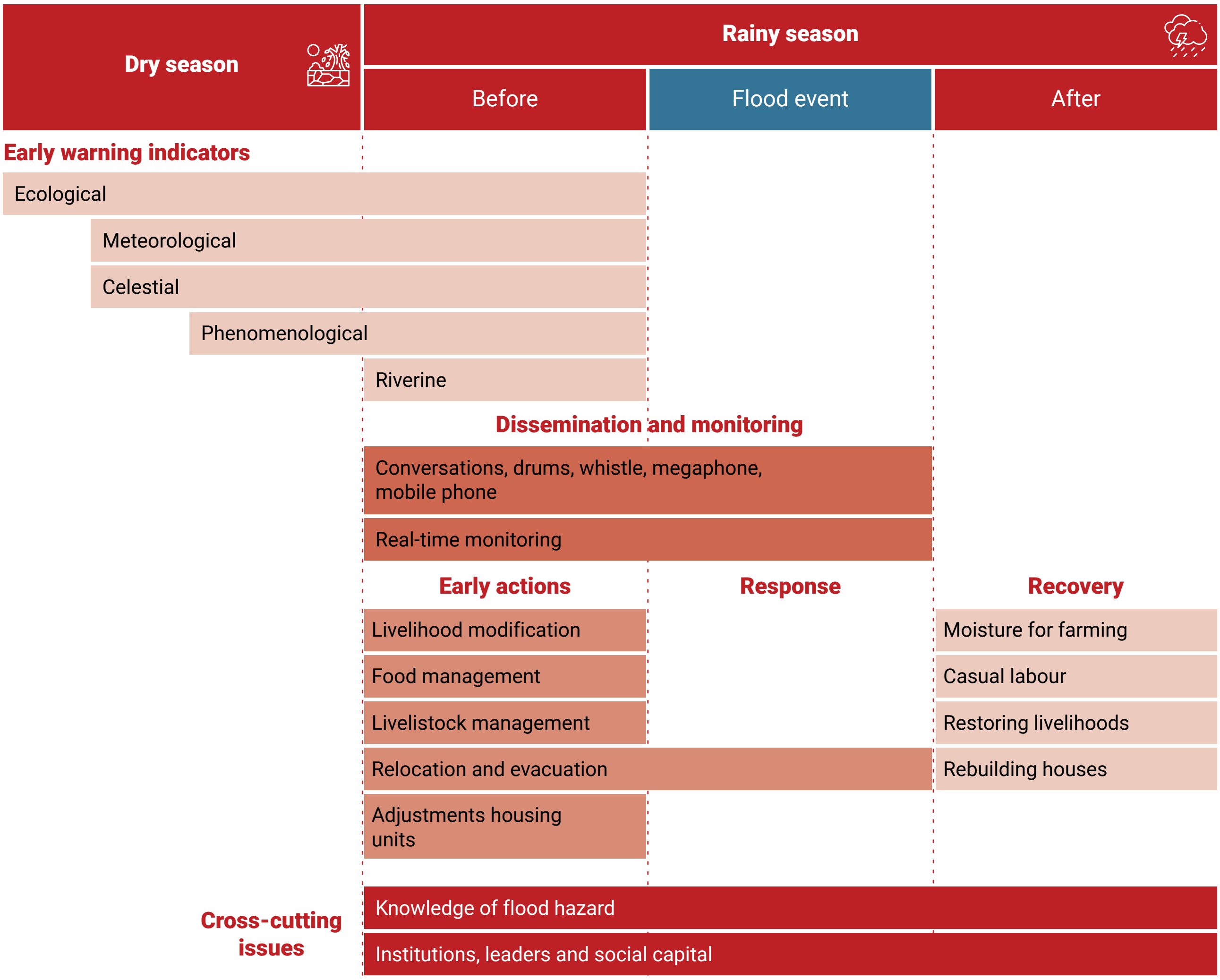
Local, indigenous or traditional knowledge refers to the understanding, skills, and philosophies developed by societies with long histories of interaction with their natural surroundings.[24] While there is no consensus on the definition and use of the terms (Onyancha, 2022; Petzold et al., 2020), Indigenous and Local Knowledge (ILK) in this report refers to all disaster-related risk knowledge accumulated by people who live in close contact with the natural environment and are associated with local culture (Hermans et al., 2022; Codjoe et al., 2014; Roncoli et al., 2002; Muita et al., 2016). Based on personal and collective experience of the local context and surroundings, ILK includes the identification and monitoring of indicators leading to hazards, knowledge of local vulnerability, coping and adaptation strategies to disasters, as well as the modalities of risk communication (Dekens, 2007).

Indigenous peoples and local communities have developed methods to anticipate, prepare for, and respond to disasters, based on traditional knowledge and experience of their surroundings, that have been successfully used for generations. While ILK is often described as a distinct type of knowledge, this handbook endorses the adoption of all types of knowledge in risk information, from local/ traditional to science-centric risk knowledge. It encourages the cross-fertilisation of learning from knowledge-types including perspectives of vulnerable groups and marginalised communities (women, children and youth, economically disadvantaged communities, persons with disabilities, different ethnic groups, etc.). ILK can also be characterised by the way in which they generate their local knowledge (Raymond et al., 2010), such as professionals working at local level, who acquire their knowledge through a structured or formalised, though not scientific, process. In the context of an EWS, this could be the local meteorologist or hydrologist, agricultural extension worker or member of a disaster management committee. Multiple ILK holders are involved in the generation, communication and dissemination of EW information along the EWS value chain from the weather modellers at national or regional level to the community at local level (I-CISK, 2023). The more involved these local intermediaries are, the better the adaptation and translation of risk information is to the local context.

Over the past decade, people-centred EWS have been an important part of global DRR policies and practices (IFRC, 2021; Gaillard-Waipapa et al., 2022). There are convincing reasons to include ILK throughout the EWS design and operation to make it more effective from national to local levels, and to develop two-way communication between data providers/ modellers and intermediaries and end-users (I-CISK, 2023). Community-based EWS are key to providing understandable, timely and actionable information to people at risk. Primarily, the integration of ILK and scientific knowledge enhances the appropriateness of EWS to local settings and enables warnings to reach the most remote areas (Hermans et al., 2022). Indeed, ILK is necessary for scientific knowledge to be grounded and relevant to the local context.

Building inclusive EWS requires extensive and long-term community engagement, with the commitment of all institutions to adopt a co-production approach (ICPAC, 2021) in the development of EWS.[25] Moving away from top-down methods (training / gathering risk information from local people), community engagement and co-production approaches empower the population, bringing value to the entire EWS chain (Facilitating Power, 2020). Community engagement tools should be used to inform, consult, involve, collaborate with and empower the population in the development of EW and AA systems (Figure 5). This inclusive space for exchange, participation and co-production of knowledge empowers people, rather than relegating them as vulnerable communities in need of help (Dekens 2007). People at risk are best placed to voice their needs and provide guidance for locally relevant and sustainable solutions based on local capacities. Moreover, EWS methods are more likely to be accepted when they encompass indigenous and endogenous knowledge and technologies (Šakić Trogrlić et al., 2021).

Figure 5
ILK perspective on flood risk in Malawi (Trogrlić et al., 2019)



Community engagement practices in EWS are generally used to involve communities to collect, assess, monitor, and disseminate hazard risk information to those at risk as well as facilitate disaster responses (IFRC, 2012a). However, additional efforts, as shown in Figure 6 are necessary to maintain community engagement in all phases of EWS development and to tackle the following challenges (Sufri et al., 2020):

- sustaining community engagement in EWS, and maintaining the participation of local institutions and individuals to keep ILK alive in the long-term
- combining local and scientific knowledge into EWS design and operation including all vulnerable groups in the system

Figure 6
Example of community engagement objectives and outcomes across the Anticipatory Action system (FAO, 2023)

1 – Inform
- Inform by providing one-way information about upcoming Anticipatory Action system (e.g. through means of radio, flyers, etc.)
- Inform to ensure that communities know and understand risks

2 – Consult
- Consult by facilitating focus group discussioins, interviews, etc. as part of context and gender analysis and stakeholder mapping
- Consult learn about prevalent risks and get community feedback on risk analysis

3 – Involve
- Involve by holding community meetings, workshops, and set up community feedback mechanisms to inform the crisis timeline
- Involve to work directly with communities to identify and prioritize risks and actions

4 – Collaborate
- Collaborate by conducting participatory analysis and planning as part of establishing the crisis timeline
- Collaborate to incorporate community priorities and solutions

5 – Empower
- Empower by placing final decision-making in the hands of communities
- Empower to ensure community ownership and long-term resilience

Box 3: How to incorporate ILK in risk knowledge production for EWS?

The incorporation of ILK in risk knowledge and risk assessment production (pillar 1) is critical to build an inclusive risk knowledge base that is functional for the implementation of other EWS pillars. However, documenting ILK is not enough, as it should never be dissociated from its geographical, social, political, and cultural contexts. The following steps are identified for the successful incorporation of indigenous and local risk knowledge into risk information production, integrating local and multi-hazard contexts (Gaillard -Waipapa et al., 2022). These steps are related to the three following community engagement principles: inform, consult and involve.

INFORM

- ensuring **communities and disaster practitioners know and understand risk** through exchanges of local and scientific risk knowledge is key to building a shared and inclusive knowledge base relative to hazard, impact, vulnerability, and coping capacity characteristics. Risk knowledge co-creation workshops and endorsement through participatory approaches can be conducted, based on the sharing of local and scientific risk information
- using opportunities to embed disaster risk knowledge training into education curricula to ensure sustainability and mainstreaming of knowledge in the wider population

CONSULT

Community engagement approaches are useful to **gather information on historical disasters** and their impacts, as local communities often possess valuable knowledge and experiences that may not be documented in official records. Communities can be consulted through FGD[26] and KII[27] with community leaders to gather information about historical events, magnitude and impacts on communities. For example, indigenous knowledge can be used to improve EWS by anticipating landslide damage in tribal communities (Lin and Chang, 2020). The Malawi Red Cross Society carried out community consultations in the northern district of Karonga, to gather historical accounts of flash flooding events and impacts, along with the local perception of frequency, and magnitude. Combined with disaster database records, this consultation helped build the understanding of the risks of flash flooding and consequently the importance of EW (Bucherie et al., 2022b).

INVOLVE

Long-term community involvement is of paramount importance. Four common participatory practices are suggested to address the prioritisation of hazards, areas and targeted populations for the implementation of EWS:

- conducting **participatory risk mapping** at local levels as a way to identify hazards, exposed assets and past impacts, as well as risk perception (Cadag and Gaillard, 2012). Crowdsourcing approaches can be implemented to map exposed assets (such as roads, water points) using OpenStreetMap platforms (Gebremedhin et al., 2020), good practices in participatory mapping (IFAD 2022[28]) as well as participatory mapping toolkits (HOT[29])
- assessing **population vulnerability** is recommended through livelihood surveys. Often conducted at household level, local testimonies are used to identify community needs (e.g. Enhanced Vulnerability and Capacity Assessment - IFRC[30])
- engaging communities in exploring the **local adaptation and disaster risk reduction strategies** in place to cope with disasters and environmental change
- ensuring the **inclusion** of all groups in the development and validation of the above risk assessment process (UNICEF, 2016). For instance, children and youth have different needs and vulnerabilities to map (e.g. school infrastructure) than persons with disabilities

Box 4: Case study from Kenya: co-creation of inclusive disaster risk plans through meaningful youth engagement

In Kenya, UNICEF engages with young people in the co-development of the subnational climate and disaster risk assessment model, using UNICEF's children's climate risk index - disaster risk model (CCRI-DRM). The involvement and capacity building of national young climate and DRR champions is key for the entire process, including:

- assessment of children's local exposure to multiple hazards, shocks, stresses and vulnerabilities. Through the mapping of urban, informal and formal hotspots, and fragile cases an improved understanding and management of risks that children, young people, families and their communities face from multiple hazards and localised vulnerabilities was created
- development of the National Climate Change Action Plan (NCCAP) 2023 - 2028 in partnership with the Ministry of Environment, Climate Change & Forestry (MoECCF). The continuous use of the model (including the validation of outputs and activity recommendations) lead to increased awareness of youth of disaster risks and opportunities to be resilient

Rania Dagesh, Deputy Regional Director, ESARO and Edwin Odhiambo, CCRI-DRM youth champion, discussing the value of defining risk for children in Kenya, and intergenerational solidarity at the African Youth Climate Assembly 2023. ©2023 UNICEF Kenya

Critical lessons: formal and coordinated engagements with young people bring authenticity and make outcomes more reliable in national frameworks and plans. It ensures inter-generational solidarity, responsibility, and action at national scale. The youth champions engaged were also instrumental in their ability to educate additional youth on the potential and use of the CCRI-DRM tool and resulting risk knowledge for youth-led advocacy, training and DRM.

Summary of good practices:

- engage young people (present or future DRM champions) and youth-led organisations and networks throughout the DRM cycle through a formal and coordinated process
- ensure inclusion of specific children and youth related disaster risk knowledge and related responses into national frameworks and plans to garner an overall more resilient population

https://www.environment.go.ke/ccri-drm-portal/
https://www.unicef.org/documents/CCRI-DRM

2.4. Innovation and technology

Innovation and technology is a key outcome of Pillar 1 and is expected to drive rapid change towards building disaster risk knowledge, particularly for the use and application of risk data and information. In this regard, the UN Climate Change Technology Executive Committee[31] (TEC) partnered with the Group on Earth Observations[32] (GEO) through the EW4All initiative[33] to help vulnerable countries utilise Earth observation technology in the development of climate policies and adaptation projects. Within this framework, a knowledge product will be developed, showcasing technologies, innovations, and tools designed to enhance disaster risk information sharing. Innovation and technology play critical roles in enhancing the generation and effective utilisation of risk information within EWS, particularly through:

- **satellite imagery and remote sensing** enables the collection and generation of vast amounts of data and information on the environment and potential hazards, with global coverage. Indeed, satellites equipped with remote sensing instruments (e.g. radar, optical sensors) allow for the real-time monitoring of various environmental changes such as weather patterns, land cover, geological phenomena, soil moisture, river water levels and extent, as well as population movements (Box 6). This data provides valuable insights into the environmental and socio-economic conditions that may lead to natural disasters. In addition, satellites can capture high-resolution imagery of affected areas, so as to build knowledge on disaster damage and costs, critical for IBF. For example, the Copernicus Emergency Management Service[34] provides global flood monitoring based on remote sensing and useful risk information for emergency response and DRM.
- **big data** technologies offer scalability and flexibility, allowing EWS to process and analyse large volumes of data in real-time, enhancing decision-making capabilities. This capability is particularly crucial in rapidly evolving disaster scenarios and in regions prone to multiple hazards, where timely decision-making is essential for effective risk management. Big data analytics can improve forecasting accuracy, enhancing risk assessment, enabling real-time monitoring, and supporting adaptive response strategies, and therefore the robustness, proactivity, and effectiveness of EWS (Box 7).
- **artificial intelligence (AI)** and machine learning algorithms can identify patterns and trends in the past or in real-time, and enrich risk assessment. Moreover, AI allows for the development of sophisticated predictive models able to forecast future potential risks with higher accuracy. These models could support the incorporation of numerous factors such as weather patterns, geological data, and socio-economic indicators to provide EW and inform disaster preparedness efforts in future EWS. In addition, AI can be used to extract existent risk information using text mining from numerous sources of information to support risk scenario building (Box 8).

Other technologies have previously proven their worth for risk data and information generation in developing EWS and will increase their weight while the supporting technologies advance. Two examples are detailed below: crowdsourcing and citizen science, and innovative communication technologies.

- **crowd-sourcing and citizen science** are powerful means of leveraging the collective intelligence of communities to address complex challenges like DRM. Crowdsourcing platforms enable citizens to report real-time information on hazards, such as flooding, earthquakes, or wildfires, directly from the affected areas. This immediate and localised data can supplement traditional sources of information, providing emergency responders and policymakers with a more comprehensive understanding of the situation on the ground. Citizen science involves the active participation of volunteers in scientific research or data collection. In the realm of EWS, citizen science initiatives engage local communities in gathering data related to various aspects of risk, including environmental conditions, infrastructure vulnerabilities, and community resilience. By involving citizens in scientific endeavours, these initiatives not only generate valuable datasets but also foster a sense of empowerment and ownership among participants, leading to more effective communication of risk even during events.

  Through crowdsourcing and citizen science, individuals contribute first-hand observations, experiences, and insights that may not be captured through traditional scientific methods. For example, residents living in flood-prone areas can recount historical flooding events, local topography, and informal coping mechanisms employed by communities during emergencies. By amalgamating these diverse sources of information, including local perspectives, researchers and decision-makers can gain a more nuanced understanding of disaster risks, leading to more informed planning, preparedness, and response efforts. By actively involving citizens in the data collection process, these approaches ensure that risk assessments and mitigation strategies are grounded in the lived experiences and priorities of the people most affected by disasters. This bottom-up approach fosters trust, collaboration, and resilience-building within communities, ultimately enhancing the effectiveness and sustainability of disaster risk reduction efforts.

- **innovative communication technologies**, including social media, mobile apps, and online platforms, play a crucial role in disseminating timely and accurate information before, during, and after disasters. These technologies facilitate real-time communication, emergency alerts, and coordination among various stakeholders, enhancing overall disaster P&R. In particular, social media platforms such as Twitter, Facebook, and Instagram have become indispensable tools for communication as they enable individuals to share real-time updates, photos, and videos from affected areas, providing valuable situational awareness to emergency responders, media outlets, and the general public. Moreover, social media can serve as a two-way communication channel, allowing authorities to disseminate emergency alerts and instructions while also receiving feedback and reports from citizens on the ground. By harnessing the power of social networks, emergency managers can reach a broader audience and quickly disseminate critical information to facilitate effective response and evacuation efforts.

  The widespread adoption of smartphones has led to the proliferation of mobile apps designed to support disaster P&R efforts. These apps offer a range of functionalities, including real-time weather alerts, emergency contact information, evacuation routes, and shelter locations. Some apps also enable users to report emergencies, request assistance, or volunteer their services during disasters. By providing access to vital information and resources at users' fingertips, mobile apps enhance individual and community resilience, enabling people to make informed decisions and take proactive measures to mitigate risks and protect themselves and their circles.

  Various online platforms and websites serve as centralised hubs for disaster-related information and resources. These platforms may include official government websites, community forums, and crisis mapping platforms that aggregate data from multiple sources to provide comprehensive situational awareness. Through these platforms, users can access up-to-date information on disaster alerts, evacuation orders, road closures, and relief efforts, facilitating informed decision-making and coordination among stakeholders. Additionally, online platforms often host interactive tools and resources, such as risk assessment tools, preparedness guides, and virtual training modules, to empower individuals and communities to better prepare for and respond to disasters.

Innovative communication technologies not only enable information dissemination but also facilitate coordination and collaboration among various stakeholders involved in disaster management. For example, emergency management agencies, first responders, non-profit organisations, and private sector partners can utilise communication platforms to share resources, coordinate response efforts, and exchange best practices in real time. By fostering collaboration and inter-operability among diverse actors, these technologies enhance the overall effectiveness and efficiency of disaster preparedness, response, and recovery operations, ultimately saving lives and minimising the impact of disasters on communities.

Box 5: Innovation and Technology - Microsoft, IHME, and Planet collaborate to map climate-vulnerable populations In unprecedented detail

Satellite data is revolutionizing approaches to managing climate-related risks by enabling the development of advanced AI models. Collaboratively, Microsoft's AI for Good Lab, the University of Washington's Institute for Health Metrics and Evaluation (IHME), and Planet are leveraging this technology to help countries understand where vulnerable populations reside in areas prone to environmental stress.

In regions like Zinder, Niger, rapid urbanization outpaces official census data, leaving many people unaccounted for and invisible on traditional maps. This oversight is particularly critical during climate disasters, such as the devastating 2022 floods in Pakistan, which highlighted the urgent need for precise population mapping to support effective crisis response and mitigation efforts.

Recognizing these challenges, Planet, Microsoft, and IHME are working together to combine high quality data, AI models, and validation to more clearly map populations and risk. Planet's high-resolution satellite imagery gathers data daily for the entire Earth thereby providing a unique, foundational dataset. Microsoft's AI for Good Lab applies machine learning algorithms to analyse this data, generating detailed building maps that reflect up-to-date urban growth patterns. IHME then integrates these outputs into comprehensive demographic and population distribution maps and validates them, linking population density and movement with factors like disease transmission dynamics and climate vulnerabilities.

Currently, the team is working with Ethiopia and UNDRR to understand where populations and crops are threatened by historical flood risks. Partnering with ITU, they are working to determine where people live without any connectivity or ability to receive EW. These are just two of the many risks in which AI will help countries understand situations quickly and at scale.

Working with the United Nations, this collaborative effort aims to fill gaps in conventional mapping efforts, especially in low-resource settings where accurate population data is scarce but crucial for planning and resource allocation. By understanding where people live and how their communities evolve over time, governments and NGOs can anticipate and address emerging risks more effectively. These initiatives represent a pioneering approach to harnessing technology for humanitarian purposes, enabling proactive measures to protect and support vulnerable populations amidst escalating climate challenges.

For more information on this project, visit: https://www.ihmeclientservices.org/populationinsights.html

Box 6: Innovation and Technology - Microsoft, IHME, and Planet collaborate to map climate-vulnerable populations In unprecedented detail

myDEWETRA.world (https://www.infomydewetra.world/) is an open-source web-based system for real-time monitoring and forecasting of natural hazards like floods, landslides, and wildfires. The application is designed to be a single point of access to a wealth of information and data available at global, regional and local scale, provided by multiple authoritative institutions and agencies. Its IT architecture systematically organises data and information, allowing for a wide range of users to access, share and integrate both time-varying data and static layers. myDEWETRA.world is subject to an agreement with the Italian NDCP and WMO and is available to every country on request.

However, myDewetra goes beyond being just a technological platform; it embodies a collaborative process among the various actors involved in the intricate workings of an EWS. Developed hand-in-hand with the NDCP and Cima Foundation, myDewetra acts as a digital nexus, bringing together hydro-meteorologists and decision-makers to exchange vital information. This collaborative approach ensures all stakeholders are equipped with the insights they need to make informed decisions in times of crisis.

Through myDewetra, National Disaster Management Authority (NDMA) and Hydromet services worldwide engage in continuous dialogue, sharing expertise and resources to enhance the effectiveness of EWS. By fostering such collaboration, myDewetra aims to transform the traditional notion of a technological platform into a dynamic process of collective action.

This collaborative ethos permeates every aspect of myDewetra's functionality. From its role as a centralized repository based on a federated concept for data integration to its facilitation of real-time risk assessments, myDewetra embodies the shared commitment of stakeholders to build resilience and mitigate disaster risks. In essence, myDewetra.world is not just a tool, but a process based on the collaborative spirit that underpins effective disaster risk management.

Box 7: Innovation and Technology: Enhancing Risk Knowledge Production with Large Language Models
Recent advancements in AI, particularly in the domain of Large Language Models (LLM), mark a significant leap forward from earlier AI applications in disaster management. Traditional AI methods, such as deep learning for image classification in damage assessments and Natural Language Processing (NLP) for analysing social media during emergencies, have primarily focused on specific, narrowly defined tasks. LLMs, however, bring a broader, more versatile approach to the processing and analysis of risk knowledge essential for developing multi-hazard early warning systems (MHEWS).

Definition and impact of LLM: LLMs are AI systems trained on vast datasets with the aim to generate coherent, contextually relevant text, codes, images, and video outputs based on inputs from the end-user. Unlike their predecessors, which essentially interpreted visual data or classified short texts, LLMs can understand and produce human-like text, making them particularly useful for synthesising and interpreting extensive risk-related information. This capability allows LLM to assist significantly in the interpretation of risk knowledge and information, potentially enabling a wider range of stakeholders to participate in the development and refinement of MHEWS. As the presence of LLM becomes increasingly prominent across various sectors, one of the challenges for the coming years will be for industries to effectively harness their potential. The focus will likely shift towards developing tailor-made applications, or AI co-pilots, that build on the core capabilities of LLM to address specific needs within distinct domains, such as the integration of risk knowledge in MHEWS. Critical in this transition is providing governance mechanisms and ethical guidelines for using AI-pilots in the context of risk knowledge and EWS to ensure they are people-centred and inclusive. This entails not just applying generic models but customising them to enhance performance on tasks that require domain expertise and localised information. For instance, in DRM, this might mean training models on specialised datasets that include geographical, meteorological, and historical disaster data to provide more accurate and context-sensitive predictions and analyses.

Specialising LLM in MHEWS: Two techniques stand out for their potential to tailor LLM for MHEWS: Retrieval-Augmented Generation (RAG) and fine-tuning. RAG enhances the responses of a language model by integrating a retrieval component. This element searches a large corpus of documents to find relevant information that is used to inform the model's output. In the context of MHEWS, RAG can enable LLM to access and incorporate up-to-date, specific risk data from diverse sources such as scientific articles, emergency reports, and historical hazard data. This process not only improves the accuracy of the generated content but also ensures that the recommendations and guidelines provided are grounded in the most current knowledge available. Fine-tuning involves adjusting the pre-trained parameters of an LLM on a smaller, specific dataset to specialise its responses according to requirements. For MHEWS, fine-tuning LLM on datasets specific to types of hazards, regional risk factors, and past disaster management outcomes can tailor the model to generate more precise and contextually relevant advice for system developers and policymakers.

UNU-EHS edits specialising for MHEWS:
- AI applications can help collect and process high-resolution and **dynamic vulnerability and exposure** data, advancing risk knowledge in data-scarce regions. These regions are often not covered by EWS due to the limited availability of data. AI can help protect people in remote areas and in the Global South, where data gaps are even more prominent
- while advancing risk knowledge in terms of data, AI can also provide a rapid overview of existing knowledge and information from scientific literature or disaster response reports, describing the risk context or rapidly processing end-user inputs on emergency scenarios
- AI can support risk assessments by processing **large amounts of high-resolution data in real-time**, such as satellite imagery or weather stations. In changing disaster contexts, AI can critically help make risk-informed decisions

Challenges

- risk knowledge is context-specific, with nuances of vulnerability and exposure differing across social groups. It is critical to ensure that there are community mechanisms to co-produce and own data to avoid automated tools overlooking those nuances
- including communities in **co-producing risk knowledge and owning the information** that is fed into the automated tools is essential. AI has enormous extractive potential making it critical for communities to know how the data will be used. For example, what happens to information when automated and fed into data models by automated tools, and who has access to or decision-making rights on the purpose of its use are important ethical considerations. This reflection is pressing, especially in the context of understanding/ assessing risks and subsequently sharing these concerns

Potential uses of AI co-pilots in risk knowledge and MHEWS: Using datasets from the agricultural industry, a 2024 study by Microsoft researchers demonstrated that systems built using LLM can be adapted to respond and incorporate knowledge across a dimension that is critical for a specific industry. This precedent underscores the potential for similarly impactful applications within MHEWS. The parallels between agriculture and DRM — both requiring precise, localized knowledge and specialized technical expertise — suggest that AI co-pilots could similarly impact the integration of risk knowledge into MHEWS.

An operational example of AI pilots advancing MHEWS is the WMO Severe Weather Information Center 3.0 (SWIC 3.0), in which large amounts of data on extreme weather is consolidated and processed, thereby informing an operational multi-hazard alert system.

Benefits of machine learning and AI are being piloted in South Asia by the United Nations ESCAP, with an automated seasonal impact forecasting tool being used to advance warning communication. This provides automated impact-generated information on key sectors when users input information on forecasts for precipitation. Humanitarian agencies are exploring the use of AI in MHEWS to accelerate response and preparedness. Pilot applications are using AI to simulate disaster scenarios and engage user inputs that can be integrated into situational awareness reporting to decision-makers and the public.

Some of the uses could be:

- **suggesting specifications for MHEWS**: AI co-pilots could be instrumental in recommending specifications of MHEWS by utilizing localized risk data to suggest appropriate triggers and thresholds for warnings or even EA based on the warnings. For a set of warnings, AI co-pilots could suggest potential EA tailored to the local context or capacities in terms of local response. These might include evacuation routes, temporary shelter and health-care facility locations, or pre-disaster resource allocations. Based on historical data, technical guidelines, research literature and other data, AI co-pilots could also recommend specific environmental or situational thresholds that should trigger EW
- **enhancing communication and reporting**: AI co-pilots could automate and enhance the communication processes within MHEWS, ensuring that all stakeholders — from local authorities to the public— receive timely, accurate, and understandable information. This could be tailored to the specific needs of different audiences, such as technical reports for operators and concise, actionable advice for the public
- **generating risk-based scenarios**: AI co-pilots could be used to generate detailed, realistic risk scenarios based on local data
- **tailoring warning information to user demands** (including automatized translations into different languages): AI could accelerate its actionability for different target groups, as well as tailor early action plans to those most-at-risk
- **designing, supporting and evaluating** the outcome of drills and simulations for response agencies
- **enabling the timely processing of estimating impact** on people, livelihoods, and sectors, thereby providing useful, detailed information for EW, even within a short lead time
- **simulating emergency scenarios** with concrete linkages to potential resources needed for vulnerable groups.
- **building dynamic needs assessments to aid response agencies in contingency planning** and initiate appropriate actions

Challenges

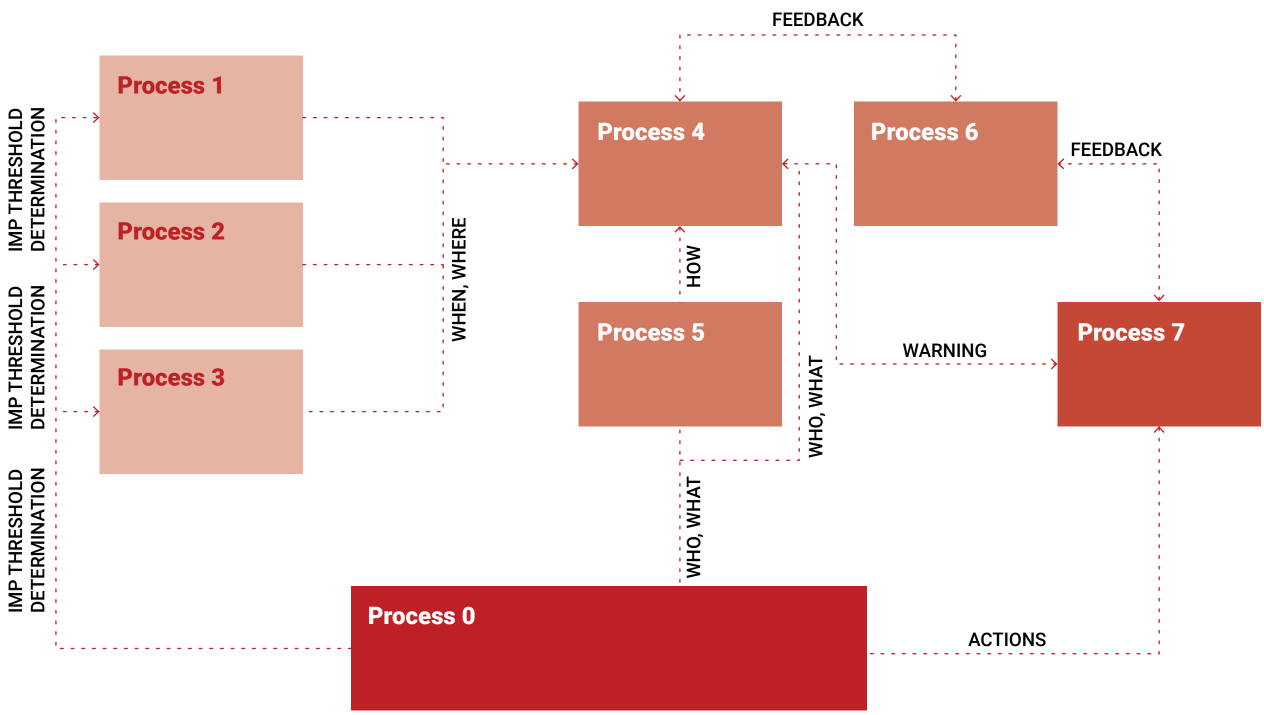
- while AI co-pilots can automate communication processes, the application might replicate existing data biases or overlook critical information concerning marginalised groups when analysing and processing large amounts of data
- AI models might misinterpret vulnerability and exposure data that is context and case-specific
- the disproportionate lack of access and decision-making power of vulnerable groups to shape innovation and technological applications create challenges for accurately informing risk-based scenarios. This can widen a digital divide that can be devastating for MHEWS' inclusivity. Especially when designed and run without end-users, inequalities such as lack of access to warnings could be amplified for local groups

DRR Voices blog: Strengthening equitable, impact-based early warning through artificial intelligence: four key perspectives | PreventionWeb

2.5. How to use risk information for EWS (process linkages)

Guidance on how best to use risk information for EWS is articulated around the eight processes that structure this handbook. All processes are interconnected and mutually reinforced, as illustrated in Figure 7.

Figure 7
Risk information for EWS: workflow, processes and linkages



Process 0 commands a pivotal position as it establishes one or more reference scenarios for the EWS, grounded in risk knowledge. Process 0 can be considered as a foundational process, that furnishes critical information to Processes 1, 2, and 3, enabling the definition of key data for identifying hazard or impact thresholds depending on the selected EWS paradigm: hazard-based, impact-based, or impact forecast-based. Processes 1, 2, and 3 delineate when and where a specific event is predicted to produce a certain level of impact. This information is used in Process 4 to construct warning messages. Process 4 leverages insights from Process 0 to assess who will be impacted and which actions can be initiated to mitigate the anticipated impact. Process 4 is supplemented by Process 5, which, based on disaggregated information provided in Process 0, instructs on how the message should be crafted to address different target user groups. Process 6 gathers feedback from past events to enhance the dissemination of information produced by Process 4, thereby improving the effectiveness of actions activated through Process 7. Process 7, upon receiving warning information from Process 4 and based on risk insights derived from Process 0, identifies the most appropriate actions to be deployed in the field.

In summary, these interconnected processes, rooted in risk information, form the foundation of an effective EWS, facilitating timely and targeted responses to potential hazards.

2.6. Process 0: How to use risk information to define proper reference risk scenarios

Understanding risks and developing impact scenarios are pivotal for designing proactive measures and readiness protocols. As a result, effective action-oriented and people-centric EWS can be designed and implemented.

Impact scenarios combine data on hazards, historical impacts, exposure, vulnerability, and capacity into cohesive descriptions that outline the potential effects of hazardous events. These narratives help DRM stakeholders to formulate P&R strategies, including EA. Moreover, they predict the time required to execute the actions. The reference impact scenario must be able to forecast and monitor such events with sufficient lead-time for a coherent and effective operational activation of the EWS (Processes 1, 2, and 3).

One primary objective of this process is to ensure that the reference scenarios set for EA and P&R are harmonious with the risk information used in defining other EWS processes. Despite its importance, emergency planning often takes place independently from the design of EWS processes that are closely tied to EW production and communication. This fragmentation arises because they may be funded separately, or overseen by different entities, leading to limited communication until later stages of design or implementation. It is imperative to ensure that EW scenarios align with risk scenarios to plan EA effectively. This guarantees clarity in the interconnection among processes for all participating institutions involved in EWS design and implementation, with reference scenarios serving as a unifying element across processes.

Some key steps can be identified for defining reference scenarios:

- choose the most appropriate approach for describing and characterizing the scenario
- assess the risk information and its availability
- develop impact scenarios through the analysis of hazard, historical impacts, exposure, vulnerability and capacity for EA

2.6.1. Choice of approach for reference impact scenario

When choosing and developing scenarios, some characteristics common to P&R and EA need to be considered. These include their protective intent; high time-sensitivity; pre-agreed and risk-informed triggers; and actual capacities and provisions of funding (adapted from ASEAN, 2022).

The approach to be followed to define a scenario can differ considering specific hazards and their characteristics.

Guiding questions are:

- what is the forecasted time and hazard onset to be addressed?
- what are the geographic scopes and territorial scales to be adopted?
- what are the potential user/ decision maker and thus type of mitigation measures to be activated?

There are several methods and approaches for developing impact scenarios around specific planning objectives as reported in Table 5. While these approaches can be applied in different ways, it is important to keep in mind the planning objective from the onset so as to choose the most suitable one.

Table 5
Different approaches to risk scenario development (adapted from IFRC, 2012b)

Approach	Advantages	Best use
Specific scenario (best, most likely and worst case)	• provides a basis for planning for different scales of shock or hazard event • easy to understand and discuss	• when planning for a single situation • when scenario development involves many actors
Timeline	• allows planners to adapt operations over time as a crisis evolves	• when rapid-onset crises occur, response needs can change very rapidly in the initial days and weeks • when planning for slow onset hazards facilitating a phased approach and the adaptation of anticipatory action options to the evolving hazard context
Augmentation	• allows planners to adapt to situations that increase in magnitude over time • easy to build plans that allow expansion of operations	• when planning for displacement situations (internally displaced persons and refugees)
Impact chain	• helps identifying primary and secondary impacts • allows for the identification of vulnerable groups and the specific mitigation measures to be applied • implies participation and therefore augments the awareness and ownership of the stakeholders involved in the process	• when describing the causal effects in complex environments where secondary effects are important • in situations of slow onset hazards where the interactions between hazard, exposure and vulnerability factors is articulated

Among the methodologies available, the **specific scenario approach** emerges as the most prevalent and adaptable, particularly in multi-stakeholder environments (IFRC, 2012b; UNDRR, 2017). It typically involves formulating scenarios tailored to specific circumstances, such as "most probable" or "most severe" ("worst-case"). Embracing this approach entails analysing multiple situations with varying likelihoods of occurrence, as recommended by UNDRR (2017), enabling planners to assess different levels of severity and scales of potential crises (Choularton, 2007). By doing so, stakeholders gain a comprehensive understanding of potential crises, encompassing even the most severe scenarios; while hazard maps, with different probability levels, aid planners in prioritising protective measures. Moreover, considering multiple scenarios addresses the need for flexibility in the approach.

The "worst-case" scenario serves to stress-test the system's capacity by examining situations that could push its limits. Conversely, the "best case" scenario evaluates routine operations that the emergency system should handle upon activation. The "most frequent" scenario serves as a benchmark, highlighting the endurance of the emergency system over time and guiding resource allocation for optimal system operation. While determining the frequency of these reference scenarios can be approximated through historical analysis or expert elicitation, employing Probabilistic Risk Assessment (PRA) methodologies is advisable for scientifically sound estimations. However, PRA requires significant time, resources, and expertise, necessitating careful evaluation within the EWS context. Given PRA's versatility (as outlined in UNDRR-Regional Office for Africa et al., 2020), leveraging its functionality across sectors could render its integration into EWS implementation cost-effective.

Due to its focus on a limited number of situations, the specific scenario approach allows for the evaluation of potentially cascading or compound events, thereby providing planners with a comprehensive understanding of events, including quantified effects. This quantitative information is invaluable for designing EA based on available capacities.
The specific scenario approach facilitates the

strategic placement of safe areas, such as shelters, and evacuation zones, as well as the identification of optimal locations for operational coordination centres. This becomes especially relevant in multi-hazard "worst-case" scenarios, assuming the availability of hazard-specific maps and considering the diverse nature of potential risks.

By integrating information from various hazard maps, planners are able to identify areas that may not be susceptible to risks and therefore can strategically organise access routes.

Careful consideration must be given to guarantee the functionality of operational coordination centres, while simultaneously addressing the needs of individuals in the context of safe areas and evacuation routes.

An alternative way of interpreting best, most-likely, and worst-case scenarios involves aligning them with different organisational tiers responsible for their management. At local level, where initial responses to EW or on-going hazardous events occur, the best-case scenario serves as the reference point, reflecting immediate and localised responses. The most-likely scenario aligns with the subnational or national level, acknowledging broader involvement and coordination. Conversely, the worst-case scenario is primarily addressed at the national or international level, recognizing the need for comprehensive and coordinated responses on a larger scale (IFRC, 2012b). This tiered interpretation enhances scenario applicability across diverse operational levels within organisations, fostering a more nuanced and effective approach to emergency management.

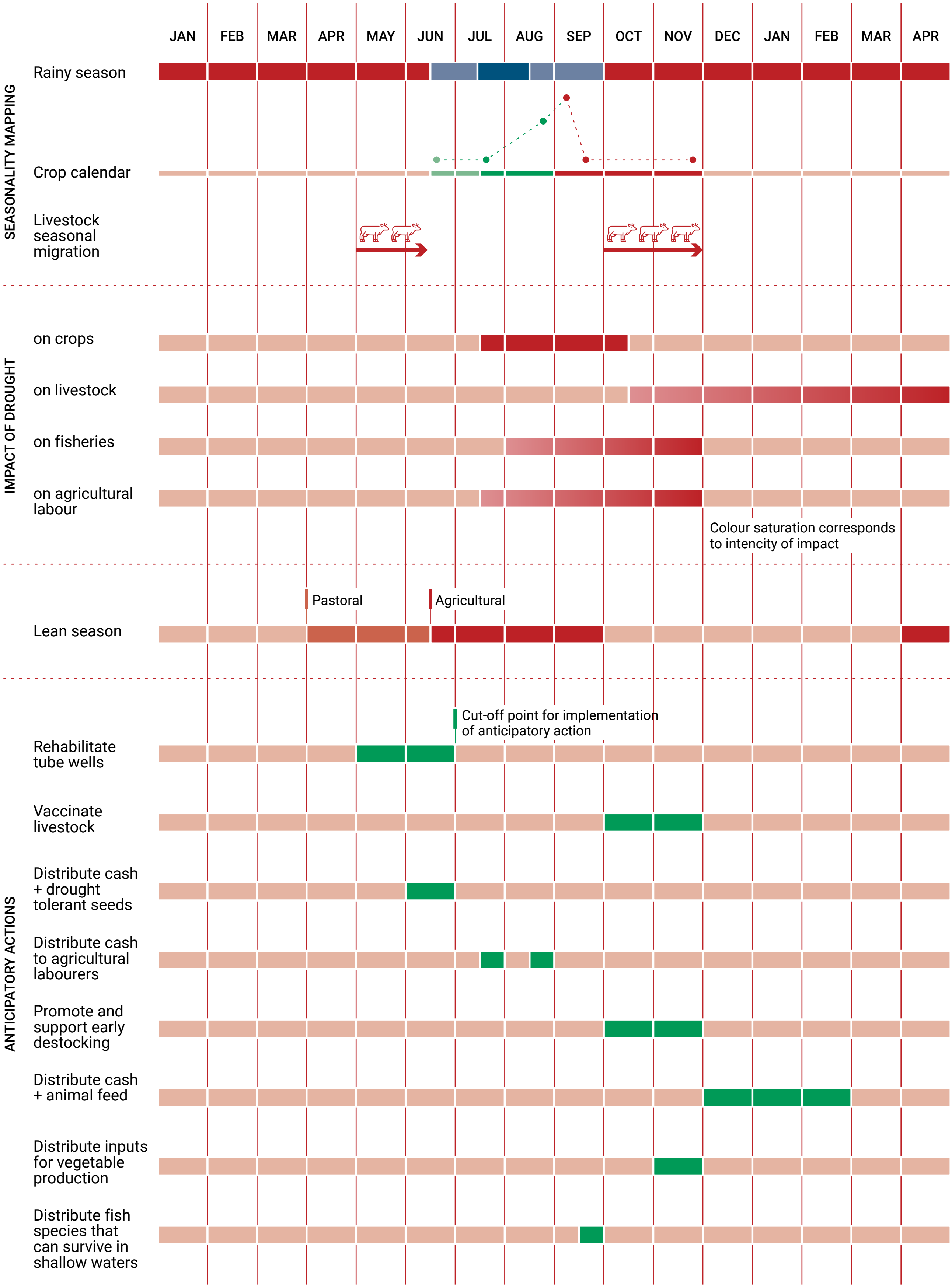
A second approach to risk scenario development is the **"timeline approach"** or *"timeline crisis"*. It defines conditions at set points in time, starting with the EW (adapted from Choularton, 2007). This approach can address time-sensitive characteristics of EA and its connection to forecasts and EW that need to be linked to specific thresholds. It is one of the most recommended approaches (e.g. by OCHA[35], FAO[36]), especially for slow onset hazards.

For example, impacts of slow onset hazards on agricultural livelihoods and food security may be interdependent, and distributed over time. Understanding the time lapse of such impacts foresees a certain amount of programming complexity; at the same time, it provides multiple windows of opportunity in which action can be taken before the full brunt of the impact materialises (FAO, Building a crisis timeline Version 1.0.).

The timeline allows planners to visualise and define the actions their organisations need to take – according to the hazard and context - and when to take them. This facilitates a phased approach that embraces uncertainties associated with EW information and thereby assists in the selection of AA options to fit the evolving hazard context (FAO, 2022). Process 7 of this handbook will further analyse this aspect.

Figure 8 provides an example of a crisis timeline for drought in an area with a uni-modal rainfall regime with associated AA. Choularton (2007) reported an example of a flood scenario timeline developed by CARE India in 2003.

Figure 8
Example of a crisis timeline for drought in an area with a uni-modal rainfall regime with selected anticipatory actions for drought. Source: (FAO, 2022)



Another method is the "augmentation or step scenario" approach, which explores the conceivable escalation of a crisis within the scenario, outlining the corresponding response requirements at each stage. As articulated by Choularton (2007), this scenario-building technique is useful in contingency planning, especially in dynamic contexts like displacement crises. In these situations, the number of individuals affected tends to increase progressively as the crisis unfolds. Correspondingly, the response capacity required from relevant actors must be scalable and adaptable to effectively address the expanding scope of the crisis.

This approach not only enhances preparedness but also ensures that response strategies are aligned with the evolving nature of the crisis, enabling timely and effective interventions. Its application extends beyond displacement crises, offering a versatile framework for anticipating and managing various scenarios that may undergo progressive escalation.

A relatively new approach to scenarios composition is the "**Impact Chain**" methodology, (see e.g., Fritzsche et al. (2014), Hagenlocher et al. (2018), and Zebisch et al. (2023)). This approach provides a structured way to assessing and mapping the potential impacts of different risks and it is increasingly showing relevance in the context of EWS thanks to its ability in visualising relationships and dependencies between the hazard, exposure, and vulnerability components. This allows stakeholders to see the potential pathways through which a hazard could impact the system, enabling a clearer understanding of the underlying dynamics (see Box 8 for more details on the approach).

Box 8: Conceptual risk models to support impact-based early warning

Risk knowledge forms the cornerstone of the transition from hazard-based to IBF and impact-based early warning (IbEW). A crucial component of risk knowledge is identifying who and what is exposed to a certain hazard (or multiple interacting hazards), vulnerable to it - and why. This allows tailoring warnings to vulnerable groups, enhancing their understandability and identifying EA to protect lives, livelihoods and assets.

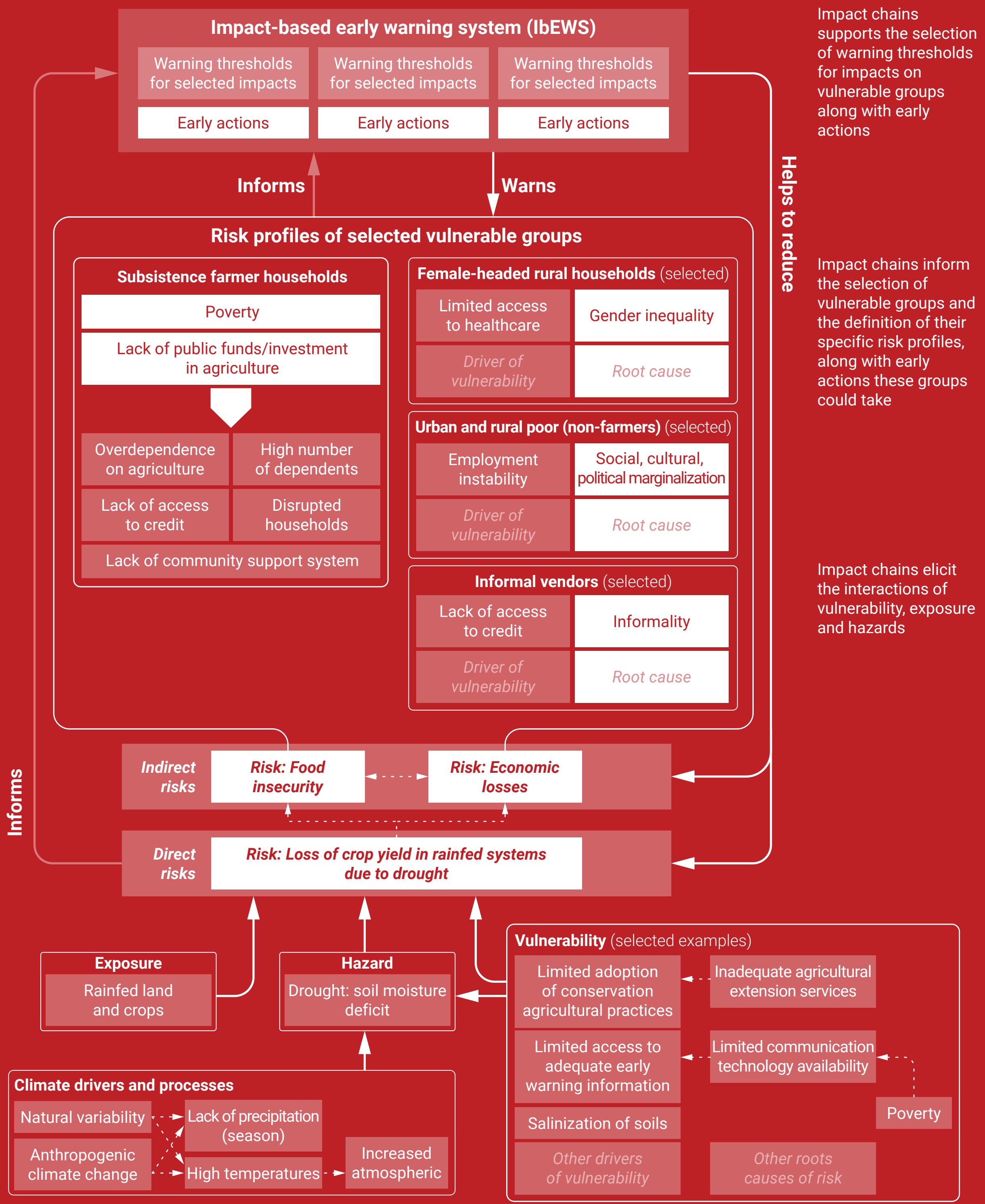
In the context of climate and disaster risk assessments conceptual risk models have long been used to decipher the complexity of risks and provide entry points for Comprehensive Risk Management (CRM) and adaptation (Menk et al. 2022). Their use in the context of EW is however less established.

One approach that has seen a growing number of applications in recent years is 'impact chains' (Fritzsche et al. 2014; Hagenlocher et al. 2018; Zebisch et al. 2023). Co-created with relevant stakeholders, impact chains illustrate the progression from root causes to possible impacts, including relationships between risk drivers of hazard, exposure and vulnerability (de Brito et al. 2024). By elucidating how specific impacts occur, impact chains provide multiple opportunities to advance risk knowledge for IbEW. First, they provide a framework to co-identify and prioritize (i) the potential risks that could have significant impacts on a system, sector, community, or organization (Process 0), (ii) associated hazards (Process 1), and (iii) drivers of exposure and vulnerability, including relevant data for IbEW. Secondly, they provide the knowledge base needed to produce risk-informed warning and actionable risk information (Process 2): in particular, impact chains can help identify vulnerable groups, characterized by specific drivers of risk, and each with different capacities and barriers to receive EW information and enact EA. Impact chains offer a comprehensive view on risks, thus allowing the integration of EW with other risk reduction options. While the construction of impact chains can be time-consuming, the co-creation process also constitutes an opportunity to enhance the stakeholders' buy-in and investment in the project.

In the UNDRR-funded EarlyWarning4IGAD project, United Nations University (UNU-EHS) and partners co-created impact chains as an integral part of a novel approach for IBF and IbEW, using Kenya, Ethiopia and the wider Intergovernmental Authority on Development (IGAD) region in Eastern Africa as pilot studies (Figure 9). Figure 9 showcases how IbEW (green box) is informed by the components of hazard, exposure and vulnerability (bottom half of the figure), and should be adapted (in terms of content, language and delivery) to the characteristics of each vulnerable group (upper half of the figure), e.g. subsistence farmer households. Moreover, considering the capacities and barriers specific to each group is essential to connect impact warnings with EA.

In line with ongoing calls to develop and promote EW for complex risks, recent developments, such as the novel 'impact webs' approach (i.e. conceptual risk models to decipher complex, systemic risks; Sparkes et al. 2024) offer a promising tool for such endeavors. By providing relevant risk knowledge, the co-creation of conceptual risk models can be a win-win for EA and sustainable risk reduction which is increasingly needed as hazards become more intense and frequent and their impacts more widespread in many parts of the world.

Figure 9
Impact chain to support IBF and IbEW. Through selected examples, the figure shows a simplified version of the interconnections of drivers of risks and risk profiles for direct ("Loss of crop yield in rainfed systems due to drought") and indirect risks ("Food insecurity", "Economic losses") in Kenya. The model also illustrates how impact-based warning and early actions can be informed by and subsequently help reduce these risks.



2.6.2. Assess risk information and develop impact scenario

Risk scenario development is strongly connected with the identification of useful and pre-existing risk information. The choice of information regarding the risk components under consideration and their optimal combination, depends on certain preliminary matters:

- if a priori optimal risk information does not exist, then the risk information gathered must fit the specific purpose of the study. The first source of risk information ideally is pre-existing data that may need to be adapted to fit the scope of EWS
- in terms of application, potential EA need to be determined: the possibility of implementing a specific action refers to the ownership and accountability of the user/ decision maker involved, while the opportunity of implementing EA depends on reducing impacts, and thus on risk conditions

The development of impact scenarios depends on a detailed and accurate evaluation of the hazards, historical impacts, and analysis of the vulnerability, exposure and capacities of the elements within the specific geographic area and time frame.
Guiding questions are:

- what values should be protected according to the roles and mandates of the decision-makers?
- who is the potential user/ decision-maker, and thus what type of mitigation measures are to be activated?
- how can information on risk components help shape measures?

Below, the potential contributions of each risk component are examined in accordance with standard risk assessment.

Historical impact - examining historical events is the first step in any risk analysis, as it provides the foundation for risk identification, comprehension, and refinement of models and risk assessments. Historical information provides valuable insights into the severity and repercussions of past hazards and incidents, thereby informing the level of preparedness necessary to mitigate such events. A retrospective analysis helps discern the evolution of scenarios, identifying successful strategies, and pinpointing areas for improvement in terms of preparedness and proactive measures. However, caution is required as the characteristics of historical events might differ from those needed for loss accounting or generic risk assessment modelling.

Key information on past events includes:

- dates and duration determined according to identifiable parameters
- location, including where the event began and where it impacted
- timing and evolution
- severity and frequency, estimated in absolute terms according to objective and measurable parameters or other historical events in the area
- impacts on relevant sectors such as health, infrastructure, agriculture, food security, and water
- details on the coping capacity and performances of the EWS, if in place

The analysis of past events helps determine the types of impacts to address during the P&R phases, to enhance the effectiveness of EA (IFRC, 2023). This valuable information has been systematically amassed over the years, employing methodologies such as DesInventar and adhering to standards like global indicators for monitoring the Sendai Framework. The evolution of disaster loss databases has paved the way for consolidating this requirement and standardising the quality of measured parameters.

While these databases did not initially integrate hazard parameters with impact data, forthcoming advances in the tracking system for hazardous events, losses, and damages will enhance these linkages. The refinement of such systems will contribute to a more comprehensive understanding of the interplay between hazards and their resulting impacts, thereby fortifying P&R strategies.

Two critical aspects of historical disaster data collection for EWS are the inclusion of temporal and forensic dimensions. The first encompasses the evolution of events over time, which while not a priority in applications like loss accounting or risk assessment, it is essential to understand the progression and dynamics of disasters. The forensic dimension emphasises the cause-and-effect relationships of impacts, encompassing secondary and cascading effects. It explores the interplay of factors that contribute to disaster outcomes, offering insights into root causes and mechanisms behind the impacts experienced. By examining factors such as meteorological conditions, geophysical processes, land use patterns, and human activities leading up to the event, researchers can uncover underlying vulnerabilities that contributed to the severity of the disaster. For example, forensic research on a hurricane might reveal vulnerabilities in coastal defences, urban planning decisions, or evacuation procedures.

Another critical characteristic of historical data regards their spatial resolution. If the precise location of the impact is available, it can facilitate the identification of critical hot spots that need to be monitored and managed through specific EA. For example, critical areas for flood risk can be subways, topographically depressed areas and/or areas with particular drainage issues (Fabi et al., 2021).

Past information can be invaluable for assessing physical and socio-economic vulnerability to specific hazards. After an event, conducting thorough assessments of the damage and impacts can provide insights into the vulnerabilities of that particular hazard. These assessments document the physical damage to infrastructure, buildings, and natural systems, as well as the socio-economic impacts on communities. Analysing these assessments identifies vulnerabilities such as weak building structures, inadequate infrastructure, or ineffective emergency response systems.

In summary, debriefing after an event with key actors of the EW - EA system is crucial to garner lessons for planning for future events. This process allows planners to tailor P&R plans as well as to adapt EA, taking into account the community risk perception and reaction of the entire system of actors to EW.

Hazard - EA should be built upon a thorough understanding of the impending hazards. It is crucial to know where a hazard may occur (location and extent), its temporal characteristics (frequency, duration and season), reference scale, intensity and the probability of occurrence (IFRC, 2012). These characteristics need to be explicitly described in the reference scenario. For example, to create both worst-case and most-likely scenarios for preparedness and EA, compiling information on the probability of occurrence and access to hazard maps detailing intensity is necessary. If a timeline is followed, understanding factors such as hazard duration, frequency, and seasonality, often gleaned from historical event analysis, is essential for developing a timely response, particularly for slow-onset hazards. This approach essentially relies on a seasonal hazards calendar, where hazard data are superimposed on impact data to inform the design of early interventions. Table 6 details hazard information needed to develop a reference scenario, with an indication of why that information is essential.

Table 6
Required hazard elements

Hazard Information	Purpose
Hazard maps including intensity and specific hotspots	• guides resource allocation for response and preparedness efforts and the scale of counteractions
Hazard duration, frequency and seasonality	• supports the understanding of the level of preparedness required • **critical for building up the timeline for designing early actions**
Hazard onset	• defines the duration of the potential window(s) of opportunity to take early actions (see also Process 7)
Probability of occurrence	• guides resource allocation for response and preparedness efforts and supports the understanding of the level of preparedness required • supports the prioritisation of early actions • **critical for building up "worst-case" and "most-likely" scenarios and/or a combination of both**
Outline of compound and cascading effects	• tailors plan to compound effects/ actions identification

Exposure - characterising and analysing exposure is vital for identifying and quantifying the individuals, property, systems, or other elements located within hazard zones, and thus susceptible to potential losses. When analysing exposed elements for EA and preparedness, the following key questions should be addressed:

- what are the primary beneficiaries of EA, and consequently, what assets need protection, including any possible secondary impacts?
- where are these assets located, and how many are there?

AA aims to protect people and assets likely to be affected, thus highlighting the importance of assessing exposure, vulnerability, and capacity (ASEAN, 2022). Risk information pertaining to various types of assets, critical infrastructure, services, businesses, and populations needs to be reviewed to establish protocols for minimising damage or loss upon issuance of a warning (adapted from Scaling up EWS: Checklist for Gap Analysis).

During an analysis of exposure, assets may be considered exposed, while at the same time being part of the response scenario. For example, critical facilities such as hospitals, healthcare facilities, and headquarters should be considered for:

- planning tailored EA to protect them
- evaluating them as active assets (e.g. shelters) for P&R, ensuring effective emergency management (Process 7). Assessing their value contributes to defining the overall capacity of the system

Furthermore, the impact on some exposed elements could have cascading effects – such as production plants, that could pose additional hazards to the surrounding area if severely damaged – or indirect effects on the population – such as the loss of agricultural production, leading to potential food security issues.

Understanding the dynamic aspects of exposure is crucial for effective EWS. It involves recognizing population fluctuations through time and across seasons, as well as those caused by situations such as displacement and migration due to conflicts or other natural hazards. Real-time population data can be characterised with the use of census data and population surveys to understand daily and seasonal fluctuations in population density. This can be supplemented with real-time data from mobile phones, social media, or remote sensing technologies to track population movements. These data and technologies are becoming increasingly available. Satellite imagery and aerial photography can also provide valuable insights into changes in land use, infrastructure, and population distribution over time (e.g. newly developed population distributions that are characterised in space, and in time with retrospective and prospective evaluations (GHSL, CIESIN)). Advanced image processing techniques can help detect population movements and settlements in remote or inaccessible areas.

The selection of exposure categories to consider is closely tied to the role and responsibilities of the end user, and should focus on categories directly or indirectly impacted by the user's early interventions. Similarly, spatial resolution and data disaggregation should align with user needs. For example, a national entity tasked with pre-positioning civil protection modules for rapid response to large-scale events would find it beneficial to prioritise districts with the highest expected population affected. In this case, knowledge of population distribution at the municipal level might suffice. Conversely, a user responsible for managing the district level health system might require insights into the system's potential damage during disasters, status of transportation networks (for accessing health facilities), and number of people likely to need medical assistance. This information would help enhance services at nearby health centres unaffected by the disaster. To achieve this, precise localization data for hospitals and transportation infrastructure, along with high-resolution population distribution, are necessary.

Table 7 presents a possible classification of exposure categories and some guiding indications for users to link exposure elements with possible early protection actions, and helps evaluate them in terms of assets for P&R, and those potentially leading to cascading effects or secondary impacts on population. As exposure can be strictly connected to vulnerability, some cross-references among the different risk components can be found in the table.

Table 7
Exposure elements, early actions and spatial dimensions

Exposure category	Description	Possible early protection actions (non-exhaustive list)	Assets for preparedness and response	Assets potentially leading to cascading effects	Assets potentially leading to secondary impacts on population	Indicators for exposure quantification	Representation of spatial distribution
Population	Census of resident populations and estimates of disbursed populations due to migration; census of people with fragility and disabilities	Evacuation, temporary relocation, relocation in shelters, auto-protection measures	NA	NA	NA	Residential population, number of households, tourism (or other) flows, presence of vulnerable groups (see vulnerability section)	Representation at building level (number of people per building), or at census/ district level
Settlements	List of residential settlements	Adjustments to NA housing units (e.g. building temporary dikes for floods, closing of waterproof gates), reinforcement of housing elements such as roofs, windows, etc.	NA	NA	NA	Number of buildings, building use, physical vulnerability characteristics (e.g. building typology – see vulnerability section)	Single building representation, or at census/ district level (e.g. number of 1-floor building in the district)
Critical facilities (e.g. hospitals) and basic services (e.g. schools)	Census of strategic healthcare facilities (hospitals, nursing homes, clinics, health agencies), headquarters of central and regional administrations, prefectures, provinces, town halls and barracks	Check redundancy systems (e.g. power generators for hospitals), activation of communication protocols, activation of procedures for controlled access to the facilities	x	x		Facility typology, service area and potential number of users	Single element (building) identification
Areas of aggregation	Census of public buildings, public and private nurseries and schools of all levels, houses of worship, sports facilities and prisons	Activation of communication protocols, activation of procedures for controlled access to the areas	x		x	Typology of area, extension, capacity, potential users, period of day/ year of use	Single element (building or area) identification
Areas of cultural value (e.g. heritage sites)	Census of cultural heritage, places of culture such as museums, archives and libraries; delimitation of historical centres and aggregates	Temporary relocation of movable elements; installation of temporary protection elements for sites; evacuation of non-essential personnel			x	Typology and number of sites, valuable elements (e.g. artworks), and non-movable elements	Single area identification

Critical infrastructure	Identification of mobility infrastructures and essential services (e.g. energy, water, communication, ports, airports, road & railway network)	Check redundancy systems, activation of communication protocols, evacuation of non-essential personnel, disconnection from the general grid/ network, activation of procedures for controlled access to the infrastructure, pre-emptive maintenance or cleaning (e.g. ahead of rainy season)		x	Infrastructure typology and level of functioning, number of potential users	Depending on the infrastructure typology; network or single element representation
Production/ industrial sites	Location of production and commercial facilities (e.g. shopping centres, medium - large production activities); location of facilities at risk of major accidents (e.g. Chemical plants)	Evacuation of non-essential personnel, monitoring, installation of temporary protection elements, restriction of access	x	x	Site typology, possible presence of hazardous components, dimension of the site	Single site identification
Agriculture production areas	Census and mapping of farms, livestock farms, and agricultural lands	Anticipation of seeding or harvesting periods, storage of extra seeds for replanting, livestock evacuation, livestock vaccination		x	Crop/livestock typologies, yearly crop production, crop calendar, livestock consistency	Land use classification of areas dedicated to crop and livestock, single sites identification in case of buildings dedicated to agriculture activities
Environmental assets	Delimitation of green, wooded and protected areas	Preventive stockage of firefighting material, prescribed cool burns; controlled reservoirs drawdowns/ refilling	x	x	Biospecimen typologies and consistency	Single area identification
Permanent protection assets (e.g. levee for floods or rock fall nets)	Inventory of permanent structural measures designed to reduce hazard impacts (e.g. levees, floodwalls, dikes, breakwaters, retaining walls, rockfall nets, and erosion control structures)	Monitoring, strengthening of the assets (e.g. placing sandbags close to levees)	x		Typology of asset, assessment of their condition, design capacity, and coverage area	Single element identification (point or linear)

Table 8
Factors contributing to the vulnerability of exposed elements

Category	Related factors
People	age, gender, disability, legal status (e.g. migrant worker vs national /permanent residents), socio-economic status, access to services
Infrastructure	design considerations, construction period, maintenance, age, number of floors, inspection history, regular load (e.g., cars per week, kW per day)
Economic activities	level of dependence on vulnerable infrastructure or location, diversification of economic sectors
Environment	fragility of ecosystems and species

Vulnerability - a further step in the definition and planning of EA is the characterization of assets in terms of vulnerability, that can describe and measure the susceptibility of an individual, community, asset, or system to the impacts of hazards (adapted from UNDRR terminology, 2017). Vulnerability is a complex concept, with no common agreement among sectors on its operational definition, but in the context of DRR it is usually described from two main standpoints: physical and social. Both are key for the prioritisation of EA: in fact, vulnerability can help in differentiating - among single asset categories - the specific assets on which the intervention is most urgent. For example, when defining where to place temporary flood protection measures for settlements, the choice can be determined by both physical vulnerability - e.g. giving priority to settlements with low resistance construction - and social vulnerability - e.g. giving priority to settlements with a high presence of elderly people, who could require rapid evacuation.

The characterization of vulnerability can also help in the design of specific interventions. Differentiating populations as marginalised or vulnerable groups can help define specific needs, and thus identify the actions to be taken (e.g. communications for a generic population, but the need for multilingual messages when a linguistic minority is present).

In general, to plan EA it is necessary to evaluate the factors that contribute to the vulnerability of each exposed element. Table 8 categorises the factors contributing to vulnerability under four main categories: people, infrastructure, economic activities, and environment. Under each category, a non-exhaustive list of specific factors related to vulnerability is presented.

Vulnerability analysis can be as detailed and comprehensive as required. The level of detail and assessment methodology used depends on the time and resources available to gather and update data (adapted from IFRC, 2012b), and the scale of the EA to be taken. Information needs to be regularly updated to maintain its quality. Vulnerability can be expressed through qualitative and/ or quantitative indicators in the case of EA at regional or national scale.

For example, the use of INFORM risk indicators for vulnerability could be an appropriate choice when working at regional level, so as to compare potential effects of large-scale events across different countries. Similar indicators defined on sub-national information should be adopted for users at national scale, while a deeper and geo-referenced analysis would be required for EA at local level. At national level, poverty analysis can be used to define hotspot areas even if the hazard is relatively uniform, while at local level the composition of households, and their characteristics can help planners in designing evacuation strategies or shelters.

Index-based approaches are normally employed to characterise socio-economic aspects of vulnerability and condense complex information into readily understandable indices, facilitating communication and decision-making. They are often able to provide quantitative measures of vulnerability in relative terms, allowing for comparisons across different regions or time periods and usually employ standardised methodologies, enabling consistent assessments and benchmarking. On the other hand, they may oversimplify vulnerability by reducing it to a single score, potentially overlooking nuanced vulnerabilities and interdependencies. They rely on data availability and quality, which may vary across regions and sectors, leading to uncertainties and biases, and might create subjectivity in the selection of indicators and weighting schemes in index construction, which in turn could introduce biases and influence results. It is therefore important to use index-based approaches judiciously and complement them with qualitative analyses and context-specific information to ensure a comprehensive understanding of vulnerability.

Past information, including post-disaster assessments, disaster forensic research, in addition to loss databases, can be used for assessing the vulnerability to specific hazards.

Capacity - effective P&R planning requires a thorough assessment of both community and institutional capacities to manage hazardous events. This assessment helps identify opportunities and strategies for strengthening and leveraging these capacities for EA.

When it comes to community capacities, the preparedness and awareness among community members plays a critical role in their ability to respond efficiently to impending hazards. This is particularly true for fast-onset hazards, where a high level of preparedness is essential. EA must be tailored to and built upon local capacities to be effective.

For example, a community that has actively participated in preparedness exercises and planning initiatives, and therefore knows how to respond to EW, will be better equipped to handle a hazard than one that lacks awareness of local risks. This understanding also shapes the approach to designing EA. For example, in areas with low community capacity, early evacuation measures might need to be initiated at the onset of flood precursors.

When considering institutional and organisational capacities, planners must ensure that EA align with the resources and capabilities available, as highlighted by Tozier de la Poterie et al. (2023). If the necessary capacities for EA cannot be sustained, it may be necessary to develop more flexible, less technical AA systems that reduce barriers to implementation. Additionally, if local actors cannot manage the risk and its associated EA on their own, agreements and coordination mechanisms with other stakeholders should be established in advance, while also considering the subsidiarity principle inherent in civil protection and emergency systems.

Accurate and reliable information on institutional and governance capacities and resources is crucial for identifying weaknesses, gaps, and opportunities for optimization. This analysis can also be strategically used to identify areas for capacity enhancement to meet anticipated needs during potential disasters (adapted from IFRC, 2012b).

Several methodologies and tools can be used to collect vulnerability and capacity information, including questionnaires, interviews, meetings or surveys. Particularly at local level, the Enhanced Vulnerability and Capacity Assessment (VCA)[37] method used by IFRC, provides extensive resources for undertaking this exercise. In addition, to review gaps and strengths of institutional preparedness capacities, IFRC developed the preparedness for effective response framework that could be adopted by other organisations and governments to explore their response preparedness system holistically.
In synthesis, the development of the reference scenario is a complex process that cannot be separated either from the specific user or the EA to be put in place. Moreover, the scenario's utility hinges on its integration with a forecast. Table 9 offers a series of practical questions, tailored to specific user needs for the scenario. These questions focus on leveraging existing risk information pertinent to the area of interest; their integration with the forecast will be addressed in Processes 1, 2, and 3.

Table 9
Guiding questions for scenario development

Step	Question	Risk component
Choose the scenario type	What is the most frequent hazard in the chosen area?	Hazard
	Is hazard frequency characterization suitable for discriminating among different typologies of scenarios?	Hazard
	Is there a scenario (historical or modelled) that can be used as a starting point for the reference scenario development?	
	Is the spatial representation of hazard complete and coherent with the extent of the analysis?	Hazard
Define the values to protect (considering the user goals, and the possible related EA)	Which categories of potentially exposed elements (assets) are mostly impacted by the selected hazard?	Impacts
	How is the hazard spatially distributed within the reference area? (e.g. Is the hazard spatial footprint available? If not, all the assets suffering impacts should be considered as potentially exposed)	Hazard

Use the information on risk components for shaping EA	For each considered asset category, does the asset have an active role in preparedness and response?	Exposure
	For each considered asset category, could impacts on the asset lead to cascading effects?	Exposure/ Impacts
	For each considered asset category, could impacts on the asset lead to secondary impacts on population?	Exposure/ Impacts
	Are there specific sub-categories within each asset category that require targeted EA? (e.g. should we address crop areas collectively, or should we delineate specific actions for areas where non-drought resistant crops are cultivated?)	Exposure
	For each category/sub-category, which elements are the most vulnerable and therefore require specific targeted actions or prioritisation? (e.g. should priority be given to evacuating populations residing in single-story buildings when issuing flood warnings for a particular area?)	Vulnerability (physical)
	For each category/sub-category, do specific elements require priority interventions due to their social characteristics?	Vulnerability (social)
	For each category/sub-category, do specific elements require priority interventions due to the severity of potential impacts?	Impacts

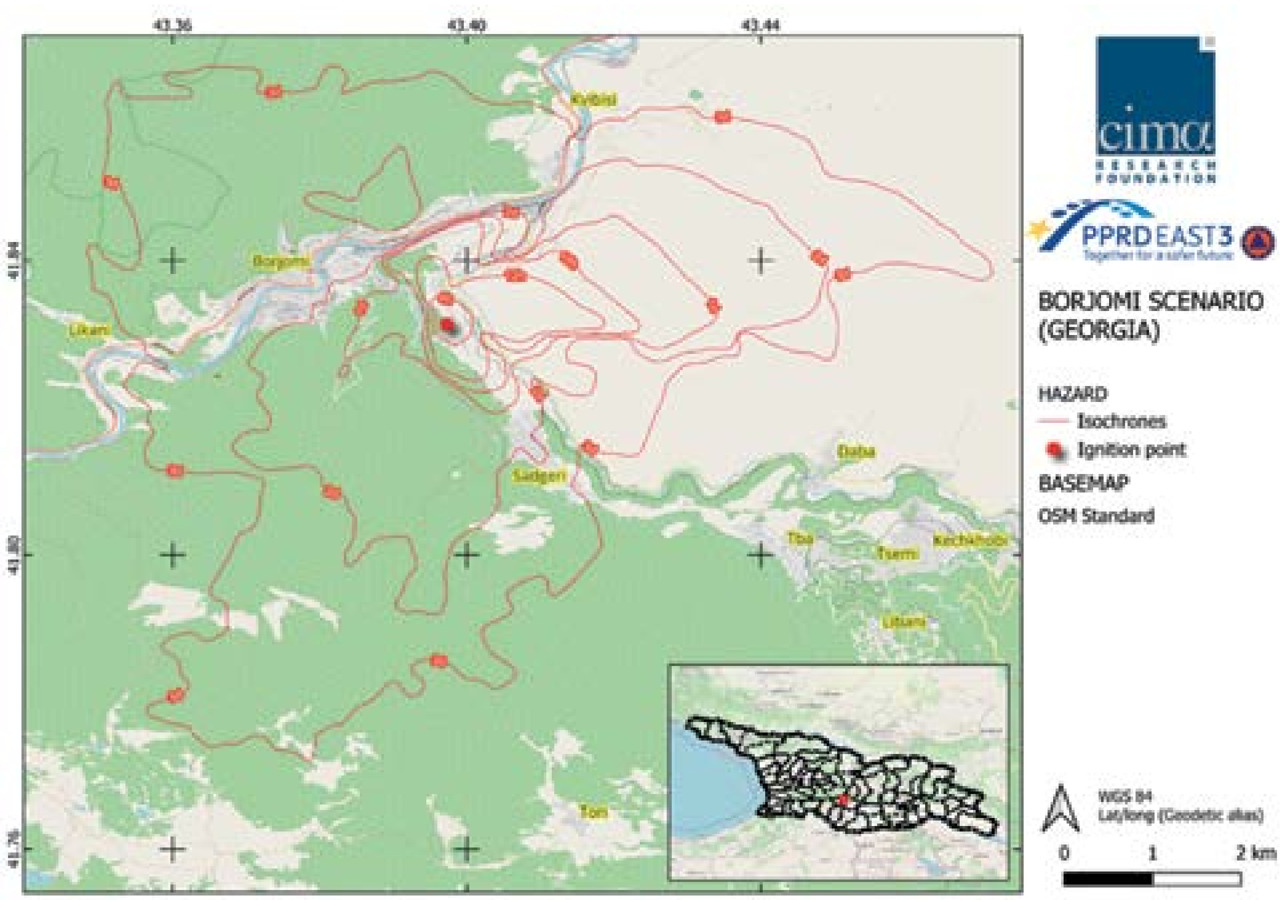
The questions above provide the basis for defining practical outputs to support EA planning, shaped according to the specific user and chosen scenario:

- maps showing the expected spatial distribution of major hazards and their intensities
- spatial distribution of all exposed elements in need of protection - such as population, infrastructures, naturally protected areas etc.; separate maps for different elements can be prepared and combined using GIS
- spatial distribution of vulnerability in terms of physical and social components, and of susceptibility to impacts for all relevant subjects of protection (in separate maps for different subjects of protection)
- prioritisation maps combining likelihood and impact of a single or aggregated hazard
- timeline, if relevant, of the potential events and effects, linking the components identified with the different spatial distributions described by the previous maps

If the risk analysis refers to community-based EWS, outputs should also encompass the perception of risk and community EW and EA systems, and identification of key local/ community leaders as key stakeholders in times of EW.

Figure 10 offers an example of an output of this process. Using the PPRD East 3 programme[38] for a pilot case in Georgia, it represents some of the outputs from the development of a worst-case scenario related to wildfire.

Figure 10
Example of a risk scenario development



Days	Hours	ISO Isochrones	Environment	Residential	People	Roads	Points of interest
1st day Friday	20:00	0 h	Fire starts after multiple explosions in a camp site in the mountains around Borjomi				
	02:00	6 h	+5 ha forested area	+1 ha low residential area around Borjomi	+9 persons	+680 m tertiary road + 350 m railroad	+1 cafè +1 campsite
	08:00	12 h	+25 ha forested area		+134 persons	+1200 m secondary road + 1200 m railroad	+1 attraction +1 restaurant +2 toilet +1 viewpoint +1 religion: christian/ orthodox church
	14:00	18 h	+31 ha forested area +1 ha park area	+1 ha low residential area around Borjomi	+255 persons	+450 m secondary road + 1500 m tertiary road + 200 m tertiary road +1000 m railroad	

More specifically, it includes:

- map showing the isochrones generated through the model PROPAGATOR, developed by CIMA Foundation, that simulates the propagation of a wildfire from a trigger point and under meteorological conditions at each simulated hour (such as wind speed and direction, soil humidity), based on probabilistic and physical equations
- associated timeline with increasing impacts per isochronous

(For further details on risk scenario choice and development, and for examples, see Bibliography: references for Section 2.6.2)

Risk information for monitoring and forecasting (Pillar 2)

03

Risk information for monitoring and forecasting (Pillar 2)

In essence, an EWS constitutes a well-defined workflow facilitating the anticipation of potential impacts on target values, within a scenario. The objective is to communicate this scenario promptly and effectively to institutions and individuals, empowering them to take organised preventive and mitigated actions against the foreseen impacts.

The ability to forecast and monitor such scenarios is critical for EWS, emphasising the importance of establishing a clear link between warnings and associated impact scenarios (Harrison et al., 2022), (IFRC, 2020). The WMO outlines three paradigms commonly employed in EWS implementation and related to the specific content of the warnings that are issued:

- weather forecasts and warnings (hazard only): Paradigm 1 focuses on providing information related solely to hazard variables and their anticipated changes. Weather warnings under this paradigm specifically target forecasting weather-related hazards. (e.g. "on <date> in the lower part of the <river name>, high water levels and possible flooding are expected")
- impact-based forecasts and warnings (IBF, hazards and vulnerability): Paradigm 2 aims to articulate the expected impacts resulting from anticipated weather conditions. Usually, IBW provide qualitative descriptions of expected impacts from forecasted hazardous conditions, based on vulnerability considerations (e.g. "on <date> in the lower part of the <river name>, high water levels and consequent flooding are expected to cause traffic disruptions on the road network and affect population and cropland")
- impact forecasts and warnings (hazard, vulnerability, and exposure): Paradigm 3 explores the provision of detailed and specific impact information at individual, activity, or community levels.[39] Warnings based on impact forecasts can provide detailed quantitative information of impacts, including information on the forecast uncertainty (e.g. "on <date> in the lower part of the <river name>, high water levels and consequent flooding are expected to affect 40,000 people in <region_name>, 13 km of roads and 15,000 hectares of cropland")

While Paradigm 3 is preferable, operational challenges, particularly in terms of capacity and resources, may necessitate the use of the other paradigms in EWS implementation. Despite Paradigms 2 and 3 explicitly addressing impact, risk-related information is also pivotal for the scientifically sound implementation of Paradigm 1.

This section offers guidance on critical risk information for three distinct processes aligning with the above paradigms. It highlights the type of risk information, preferred levels of disaggregation and granularity, and potential sources for obtaining this information. The section is structured around the following processes:

- Process 1 - How risk information supports hazard-based monitoring and warning (Paradigm 1)
- Process 2 - How risk-informed warnings, including relevant and actionable risk information, are produced (Paradigm 2)
- Process 3 - How risk information is used to build technically sound impact forecasts (Paradigm 3)

3.1. Process 1: How risk information supports hazard-based monitoring and warning?

Monitoring and forecasting variables that correlate with ground-level impacts are pivotal components of an effective EWS. These variables serve as triggers for warnings based on predetermined threshold values, intimately connected with anticipated impacts. Risk information derived from models or past events plays an essential role in determining these thresholds in a scientifically sound manner, based on their correlation with expected impacts. Leveraging past information helps understanding which variables are most suitable for consideration based on their timely availability, relevance to the impact scenario under description, and the associated uncertainties in observation or forecasting. This process entails three steps with a specific focus on the role of risk information:

- identify a variable suitable as a predictor for the considered hazard
- identify the source of information for the considered variable
- identify hazard thresholds for the monitored variable and potential impacts

The integration of risk information within these steps enhances the scientific robustness of EWS, ensuring a comprehensive understanding of variables, their thresholds, and their correlation with potential impacts on the ground.

3.1.1. Identify a variable suitable as a predictor for the considered hazard

The identification of upcoming hazards for EW purposes is typically performed by monitoring representative variables that can be observed or forecast at the locations of interest. Hazardous conditions are detected when such variables are expected to exceed predefined threshold levels within the temporal range of interest. The choice of the representative variable (or set of variables) is made according to the hazard and risk conditions in specific climatic, morphologic, socio-economic contexts, as well as by data availability. Table 10 provides a non-exhaustive list of dynamic variables commonly used as predictors of different natural hazards, while indicating their space and time scales.

Table 10
Spatial scale, lead-time and examples of variables used as predictors for different natural hazards (adapted from Merz et al., 2020)

Hazard	Variable	Spatial scale	Lead time
River flooding	Precipitation, snow melt, river discharge, water level, inundation extent, water level/ discharge occurrence probability	few to thousands km2	Few hours to weeks
Flash flooding	Precipitation, soil moisture, river discharge, probability of precipitation / discharge, runoff index	few to hundreds km2	Minutes to few hours
Coastal flooding	Total water level, wave height, recurrence interval of storm surge/wave height	few to thousands km2	Few hours to weeks
Pluvial flooding	Precipitation, soil moisture	few to tenths km2	up to 12 hours
Meteorological drought	Standardised Precipitation Evapotranspiration Index (SPEI), Standardised Precipitation Index (SPI) (Merz et al., 2020)	hundreds to several thousands km2	1 month to 1 year
Hydrological drought	River discharge or corresponding percentile/ recurrence interval, Low Flow Index (LFI), Standardised Runoff Index, (SRI) Standardised Reservoir Storage Index (SRSI), Standardised Groundwater level Index (SGI), Standardised Snow Water Equivalent (SSWE)	hundreds to several thousands km2	days to 1 year
Agricultural/ vegetation drought	FAPAR, Combined Drought Index (CDI),[40] Evapotranspiration (ET), Normalized Difference Vegetation Index (NDVI), Vegetation Health Index (VHI)	hundreds to several thousands km2	1 month to 1 year
Tropical cyclones / Extratropical windstorms	Wind speed,wind gust, precipitation, storm surge	tenths to thousands km2	few hours to 1 week
Avalanches	Composite indicators (e.g. avalanche danger scale[41])	few km2	few seconds (hazard signs up to days)
Heat/cold waves	Air temperature, relative humidity	hundreds to several thousands km2	few days up to 2 weeks
Forest fires	Composite indicators[42]	few to hundreds km2	up to few hours
Landslides	Precipitation, snow melt. soil moisture anomaly	few km2	few seconds to minutes (hazard sign up to days)

During this process, the analysis of historical disaster events and risk models are crucial in discerning the critical variables that correlate with the severity and impact of a specific hazard. For example, in several river basins in Europe, snow melts and antecedent moisture conditions are more important than rainfall in determining flood conditions (Berghuijs et al., 2019).

The analysis of historical events is also key for deciphering the lead-time between the identification of early hazard signs (given by precursor variables) and the actual occurrence of impacts. In doing so, EWS can extend their predictive capabilities and provide a longer window of opportunity to act. Communities can benefit from a more proactive response, allowing for orderly evacuations and strategic allocations of resources before the hazard's impact (Process 7). Also, information on past events permits assessing the uncertainty in hazard-impact links, which is crucial to find an appropriate trade-off between accuracy and early information.

In addition to the causal relationship between hazard predictors and impacts derived from the historical analysis, the choice of the dynamic variable used for hazard detection is influenced by several factors. Priority should be given to variables with the following characteristics:

- constant availability within the area of interest (national or regional level) with sufficient resolution to characterise its spatial extremes (see WMO recommendations on the density of monitoring networks)
- uninterrupted temporal availability, with sufficient resolution to characterise its temporal extremes and derive hazard thresholds (e.g. adequate historical record to analyse the variable climatology and its related impacts). Importantly, information on historical extreme events should be leveraged to extend measured records and increase the knowledge of conditions leading to impacts. For example, the catastrophic flood that occurred in July 2021 in the Ahr River valley in Germany was unprecedented in the available river flow measurements (starting in the 50s); yet, the analysis of historical flood events had revealed other comparable events occurred in the 19th century (Roggenkamp and Herget, 2014)
- short data latency (i.e. delay between measurement or forecast and product availability)
- availability of observation or forecast data giving sufficient lead-time to support decision making for EA in the endangered regions. This implies, for instance, an accurate selection of locations for river flow monitoring, use of regional-scale meteorological forecasts to provide early signals of potentially hazardous weather conditions

3.1.2. Identify the source of dynamic information for the variable

The parameters outlined above determine the source of information to be used to infer predictor variables for the hazards of interest. The distinction lies between observed variables (measured from in situ and remote sensors) and simulated variables (calculated by numerical models). Thanks to the widespread availability of regional and global Numerical Weather Predictions (NWP)[43] model output, NWP-derived variables are key candidates for use in monitoring and forecasting several hazard processes (WMO, 2023). Some output variables (e.g. temperature, precipitation, wind speed and direction) can be directly compared with hazard thresholds to estimate the level of hazard (e.g. pluvial flooding, windstorms, cold waves), while for others the information is fed into computer models so that processing tools can generate the desired variable (e.g. river discharge, inundated areas, combined drought index, soil moisture).

By adopting NWP, most weather-related hazards have procedures to detect upcoming events with sufficient lead-time to inform decision makers so EA and EW can be duly conveyed. On the other hand, hazards that impact ground and land use conditions (e.g. landslides, avalanches, wildfires) are more difficult to forecast, particularly in terms of timing and magnitude.

Some hazards are detected through observed rather than forecast variables, such as:

- impacts that occur well after the observation, guaranteeing enough time to issue EW
- forecast variables for a hazard that are non-existent or highly uncertain

Examples of the first category include downstream riverine flooding where the risk of inundation can be predicted from the propagation of flood waves originating upstream; or slow onset hazards, such as droughts, that develop over extensive time periods enabling effective action based on observations. The second category comprises coastal flooding triggered by tsunamis, earthquakes and volcanic activity.

The pilot flood decision support system established for the Vaisigano River in Samoa uses both observed and forecasted thresholds of rainfall and river discharge to inform local emergency responders (Williams et al., 2021).

The choice of the most appropriate source of information depends on the physical processes characterising the hazard, and the window of opportunity defined by the actions to be put in place. The latter are, in turn, determined by the impact and risk conditions analysed in the reference risk scenario (Process 0).

3.1.3. Identify hazard thresholds

Establishing threshold values of the monitored variable is key. It involves defining levels at which the variable's values are linked to an impending hazard, and hence the importance of risk information.

Once the variable identified as a predictor is established, the hazard thresholds that serve as the foundation for issuing timely warnings need to be defined. Hazard thresholds are a set of values associated with observed/ forecasted variables, distinguishing between normal conditions and escalating levels of hazard conditions leading to impacts on the territory.

These thresholds are inherently linked to a geographical location and should be periodically reassessed, especially considering climate variations or human interventions that might alter risk conditions (e.g. construction of a upstream dam or a road over a precarious slope).

Deriving hazard thresholds is a nuanced process, defined by various methods:

- **literature values**, particularly those linked to observable hazard-induced disturbances (e.g. wind speed leading to tree breakage or uprooting, temperature leading to human health risk or impact to critical infrastructures). For example, the flood decision support system of the Vaisigano River in Samoa (Williams et al., 2021) uses rainfall thresholds developed for nearby islands of Western Samoa, due to the absence of local data
- **reference values** from observations of past events, offers practical insights into the historic performance of the variable under extreme conditions. However, measurements during extreme events can be highly uncertain (e.g. failure or malfunctioning of wind/ discharge gauges) and vulnerability and/ or exposure conditions might have changed, thus altering the level of hazard causing impacts. As such, these factors needs to be analysed, as for example, the EWS developed by the National Meteorological Service of Argentina which is informed by a detailed study of the health impacts experienced following the 2013-14 heat wave that hit Argentina (https://www.smn.gob.ar/smn_alertas/olas_de_calor)
- **long-term statistics**, derived from hazard variables, sourced from observations, modelling or reanalysis products. Techniques such as extreme value statistics or selecting percentiles contribute to a comprehensive understanding of the variable's behaviour over time. This method may involve a systematic examination of the variable's historical patterns and associated risks, providing a robust foundation for threshold determination. Cautions apply such as varying exposure and vulnerability conditions

The choice of methodology depends on the specific context, data availability, and nature of the hazard. While all methodologies offer valuable insights, the use of only literature values applies if information on local conditions is not available. The relations between hazard and impacts can be complex and connected to local conditions, therefore the use of generic threshold values might produce systematic biases emanating from the regions where such values were derived. The use of reference values from past events has the advantage of being grounded on concrete experience, but needs to consider that: i) worst scenarios might not yet have occurred; ii) past conditions that led to recorded events might have changed in terms of hazard (e.g. increased intensity/ frequency due to climate change), exposure (e.g. urbanisation, population growth) and/ or vulnerability (e.g. adoption of building codes, precautionary measures). Long term statistical methods can be widely applied to global contexts as it relies on the analysis of hazard statistics as observed or produced by the model used for the forecast (e.g. GloFAS system[44] for riverine floods and Guzzetti et al.'s (2020) review for landslides). However, long term statistical methods often rely on an analysis of past events only and imply a relation between hazard severity and expected impacts that could differ from place to place as a function of vulnerability and exposure concentration; furthermore, if regional/ global datasets are applied, they may not be representative of the area of interest. Statistical analyses based on risk modelling may provide preferable solutions, especially if reliable observations are available for calibration and validation. These enable the evaluation of multiple impact scenarios and identify relevant thresholds (e.g. Rossi et al., 2023). The risk modelling approach also offers a more dynamic and adaptive approach, accommodating changes over time. However, setting up a risk model requires considerable time, resources and capacity compared to other methods.

Defining the hazard level as the maximum threshold exceeded in the period of interest is common practice. Usually 3 or 4 hazard classes are considered (Neußner, 2021). The period of interest depends on several factors: type of hazard, preparedness of the population, capacity of the emergency system, as well as the actions that can be put in place (Processes 0 and 7). For instance, the period of interest typically is 1-2 days after the event for national civil protection agencies, but may be longer, particularly for hazards with large impacts expected in the future (e.g. tropical cyclones, river flooding).

Quantifying hazard uncertainty is key to accurately identifying a hazard class. Several sources of uncertainty can affect the prediction, including uncertainty in the initial conditions, modelling processes, input data, and uncertainty due to spatial

and temporal sampling. Here, the availability of risk-based information is crucial to quantify the components of uncertainty. For instance, forecast uncertainty due to NWP is usually accounted for by considering a range of possible predicted scenarios, through probabilistic or ensemble forecasts (Cloke and Pappenberger, 2009). Furthermore, information about past damaging events might help determine the best compromise between minimising uncertainty while maximising lead-time.

Setting thresholds should be done in view of the operational assessment of threshold excesses within the desired range of interest to identify potential hazards. This additional step involves the continuous assessment of data and relies on risk information to identify hazards potentially leading to impacts and triggering timely warnings.

3.1.4. Clarifying examples / references to existing literature

The IFRC Anticipation Hub provides a repository of country-level examples of trigger systems for EA, describing how hazard thresholds were defined using risk information (https://www.anticipation-hub.org/experience/triggers/trigger-database). For example, the Ecuadorian Red Cross has created, with technical inputs from national and regional institutions, an EA protocol for extreme rainfall related to the El Niño phenomenon along its coastline.[45] It guides the timely and effective implementation of EA triggered by a range of weather forecasts. The selection of rainfall thresholds (and related EA) is based on national experience and past responses, by the Red Cross, to extreme rainfall and floods causing medium and severe impact in Ecuadorian coastal areas.

The Uganda Crop Monitor System leverages satellite-based data from the Global Agriculture Monitoring System (GLAM)[46] and ground data to evaluate drought-induced crop failures, and inform the Inter-Ministerial integrated multi-hazard early warning monthly bulletin (https://www.necoc.opm.go.ug/bulletins.php), to activate disaster risk finance. In this way, the Ugandan government can estimate how much to invest in public works to provide additional employment opportunities for vulnerable communities and can calculate the number of households affected by drought, the estimated coverage of the social safety net programme, and the estimated costs for each district.[47]

3.2. Process 2: How risk-informed warnings, including relevant and actionable risk information, are produced

Producing risk-informed warnings is a critical component of disaster risk reduction and response efforts. Traditional hazard-based warning systems focus primarily on the characteristics of the hazard itself, and rely on the expertise of local forecasters and disaster managers to assess the impacts of impending disasters. While these systems are valuable, there is a growing acceptance of the need to transition towards impact-based warnings (IBW). This shift allows for more informed and evidence-based decision-making, ensuring that actions are guided by the best available information (IFRC, 2023, p. 81). Therefore, EWS for weather-related hazards are increasingly expanding to impact-based EWS, moving from the traditional concept of "what the weather will be" to the more people-centred approach of "what the weather will do" (WMO, 2015, 2021).

Three steps are undertaken:

- identify impact indicators coherent with the considered hazard (Process 1)
- identify data and methods for the considered indicator(s)
- identify relevant impact thresholds to classify the warning severity

According to WMO (2015), IBW are designed to express the expected impacts of hazardous weather conditions. This is done by combining hazard forecast and monitoring (Process 1) with information on the vulnerability of population, vehicles, buildings, critical infrastructures, crops, and any element that may suffer significant impacts. The process of determining potential impacts from hazard forecasts may incorporate the use of quantitative impact models. However, such models are complex to set up as they require the modelling of all processes related to potential impacts (Process 3). If detailed impact forecasts are not available, impact-based information can be derived by linking forecasted hazard conditions with reference risk scenarios (Process 0). As such, IBW generally provide a qualitative description of expected impacts from forecasted hazardous conditions, based on generic vulnerability models. The goal, as in all EWS, is to minimise impacts by enabling the triggering of EA.

3.2.1. Identify impact indicators coherent with the considered hazard

The process of identifying relevant impact indicators starts from the examination of the available risk information from reference scenario(s) and historical events. IFRC (2020) provides a good guide for IBF including an exhaustive list of possible impacts for each hazard. The examination should include past experiences of emergency management stakeholders on the ground, impact information from national repositories (e.g. DesInventar (https://www.desinventar.net/) as well as other sources to understand the impacts on local communities and their livelihoods.

Common indicators used to trigger impact warnings are related to populations, given that the goal of warnings is to safeguard human lives in times of crisis. Therefore, the severity of a hazardous event is usually assessed by the possible impacts to people potentially hit by an impending hazard. Other important indicators regard the potential impacts on transport networks (e.g. flooding of underway crossings, debris/ trees falling over roads) that put people at risk or have serious secondary consequences for society. The choice of impact indicators should be guided not only by data availability, but also by the information to be included in warning production and dissemination (i.e. different end-users might want to receive different information, Process 5), because the aim is to define flexible indicators that can trigger actions benefiting at-risk communities (Mitheu et al., 2023a).

3.2.2. Identify data and methods for the considered indicator(s)

Hazardous conditions can generate a range of impacts on population, buildings and infrastructures, which can be assessed using vulnerability functions and methods. The methods applied for characterising vulnerability in risk scenarios are usually applicable in IBW to assess potential impacts of forecasted hazard conditions. It is recommended that vulnerability models used for risk profiling and determining the reference risk scenario are also used in the construction of the warning to be delivered.

For example, vulnerability methods can be applied to evaluate the following impacts:

- for populations:
  - risk of instability/ drowning related to flood water depth and velocity
  - risk of heat strokes or hypothermia related to air temperature and humidity
- for vehicles, vulnerability may include, but are not limited to:
  - risk of floating related to flood water depth and velocity (terrestrial vehicles)
  - risk of damage from falling objects due to wind
  - risk of damage/ sinking due to waves and wind (ships)

For buildings and infrastructures, the assessment of potential impacts is usually based on fragility curves that allow us to determine damaging/ failure mechanisms due to floodwaters, landslides, extreme temperatures and other hazards.

For example, the South Africa Weather Service has implemented an IBW and advisory service that provides information on potential impacts due to severe weather conditions.[48] The system was developed using selected hazard and impact information from pilot events and gradually extended to the entire country, with national hydrological and meteorological services working together with users to determine the hazards to prioritise.

Other examples of country-specific vulnerability assessment are used in the drought warning system in Papua New Guinea[49] and on tropical cyclone warnings in Malawi.[50]

3.2.3. Identify relevant thresholds to classify the warning severity

IBW classes are established using specific thresholds that delineate various levels of anticipated impacts. These thresholds are tied to forecasted or monitored hazard variables and should align with those identified through Process 1. In Process 1, vulnerability and exposure elements are indirectly factored in by establishing hazard thresholds connected to potential impacts through analogy. Conversely, in Process 2, these elements are explicitly considered and contribute to determining the thresholds.

In instances where hazard thresholds are not properly linked to contextual impacts, disparities may arise between the thresholds identified in the two processes. This discrepancy emerges because IBW integrate information on exposure and vulnerability with the hazard. For example, a high severity hazard might not lead to significant impacts and, consequently, no warnings are issued in uninhabited areas such as deserts, glacial regions, or dense forests.

Risk information is crucial in this step to evaluate how impacts can evolve according to hazard conditions, and therefore associate different impact levels to available hazard forecast and monitoring. As an example, impact thresholds can identify the following conditions:

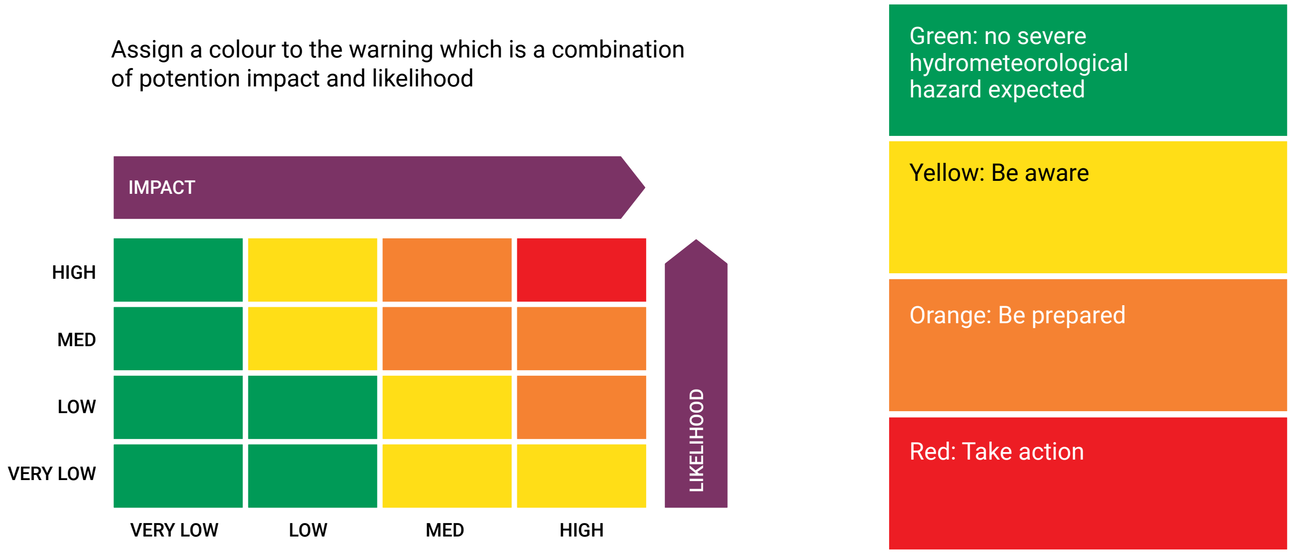
- onset of impacts: when localised impacts occur in the area of interest (e.g. flooding of roads or buildings)
- significant/ severe impacts: when impacts extend over a large part of the area of interest, and/ or when local impacts become severe
- extreme impacts: when the severity and extent of impacts becomes widespread over the area of interest (e.g. risk of fatalities and/ or collapsing of several buildings and infrastructures)

Determining a warning level involves not only assessing forecasted disaster impacts but also incorporating prediction uncertainty or the likelihood of occurrence (Figure 10). Ideally, this uncertainty should be evaluated through a thorough performance analysis based on previous events of varying severity, possibly including recent occurrences. The use of probabilistic risk models greatly streamlines the tasks associated with setting thresholds and evaluating uncertainty.

Enhancing confidence in predictions often involves monitoring observational data from in situ sources and remote sensing products available before the event. Forecasters and disaster managers' local knowledge, detailed evaluation of hydro-meteorological conditions, and experience from past emergencies, along with their recollection of previous disaster losses and damages, are invaluable during this phase. In flood forecasting, for instance, information about soil moisture anomalies or river discharge before the event may be accessible through station data or remote sensing. This data, if different from the model simulation, must be integrated into the assessment to inform decisions regarding the warning level.

Warning and alert thresholds should be linked to specific response actions, taking into account the coping capacity in the areas potentially affected (Processes 0 and 7). For instance, the UK Environment Agency uses two sets of thresholds: operational which are linked to an action (e.g. issuing a warning) and impact which are linked to an event (e.g. flooding in a neighbourhood). Importantly, impact evaluation should be routinely updated to include dynamic changes in vulnerability or exposure, such as the presence of temporary refugee camps (increase of exposure) or regions that are recovering from recent disasters (increase of vulnerability), ensuring that no community is left unprepared. Also, impact thresholds need to be periodically reviewed to account for changes in coping capacity and the effect of risk reduction measures that are normally included in periodic risk assessments (e.g. improved water management practices against severe droughts, flood barriers and flood storage areas).

Figure 11
Example of colour-coded risk matrix to derive the severity of warnings. Source: UK Met Office



Examples of good practice
In Indonesia, the BMKG (Meteorology, Climatology, and Geophysical Agency) and BNPB (Indonesian National Board for Disaster Management) jointly developed the System for Multi Generation Weather Model Analysis and Impact Forecast (Signature[51]), using a national-scale database DIBI (https://dibi.bnpb.go.id/) to produce and calibrate IBF for different hydro-meteorological hazards (floods, landslides, land and forest fires, severe weather such as heavy rain).

Within the Africa Multi-hazard Early Warning and Action System (AMHEWAS), twice a week the African Union Commission produces and issues to its member states the Continental Watch, a multi-hazard 5-day outlook on extreme precipitation, riverine flooding and wind-storm impacts at sub-national aggregation level. The warning severity is estimated by considering all the components of risk: hazard, exposure, vulnerability and coping capacity. Warning levels 3 and 4, particularly in transboundary contexts, trigger the meeting of the Continental Situation Room and AA to coordinate efforts among key institutes involved in disaster response at the continental, regional and national levels.

3.3. Process 3: How risk information is used to build technically sound impact forecasts

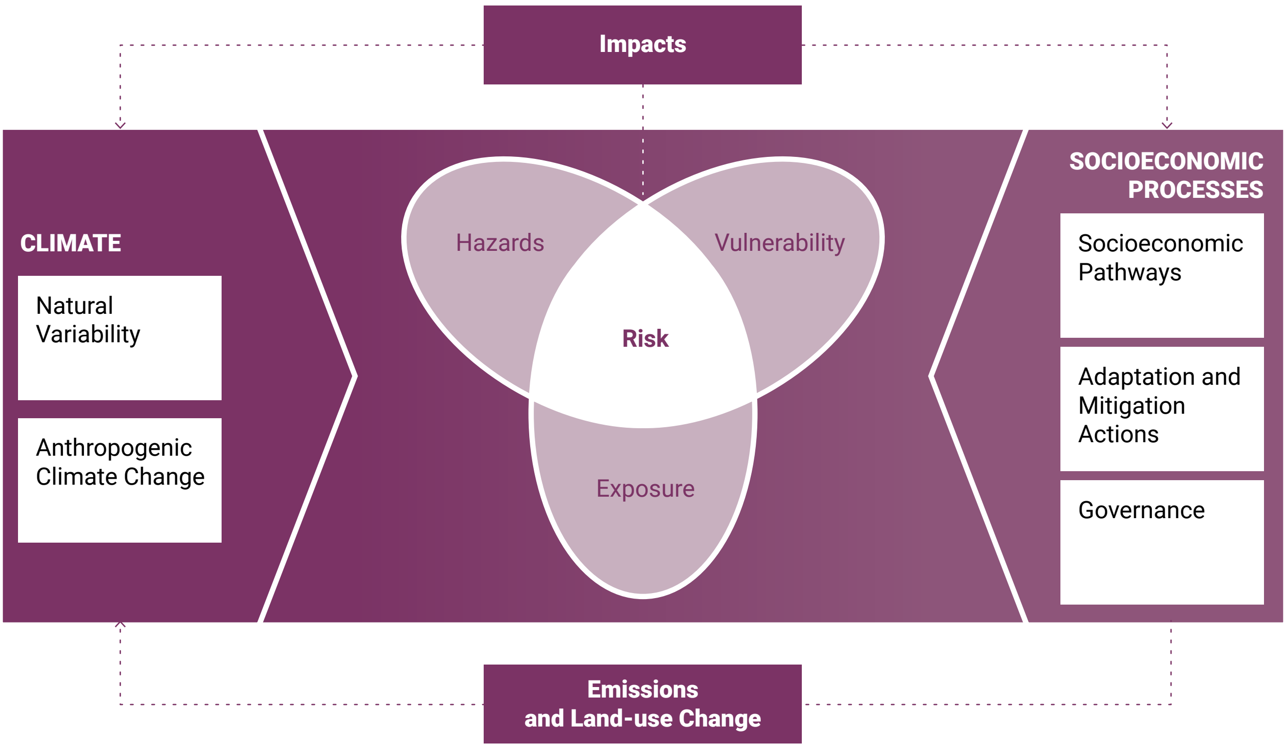
Transitioning to impact forecasting is important as it represents a shift from focusing solely on predicting the occurrence and intensity of hazards to forecasting the actual impacts those hazards will have on communities, infrastructure, and the environment. This transition allows for more actionable and relevant information to be provided to decision-makers, emergency responders, and the public. The process can be complex because of the nature of the models to be put in place and the amount of information needed to characterise the different components of the risk equation. This final aspect leverages the risk information that is produced within Pillar 1 for different purposes and applications, and that needs to be adapted for impact/risk evaluations in real time.

To accomplish this, three key steps are performed:

- identify indicators of exposure and vulnerability, taking into account the relevant hazards in the area of interest (Processes 1 and 2)
- identify and implement adequate methods for impact calculation
- identify impact thresholds coherent with the monitored hazard variable(s) (Processes 1 and 2)

Impact forecasts and warning services extend standard forecasts of hazard characteristics (intensity, duration, spatial extent) by estimating the expected impacts on the elements potentially affected, including information on their exposure, vulnerability and coping capacity (Figure 12). Warnings based on impact forecasts are also an improvement over IBW in that they can provide quantitative information on impacts and identify specific elements at risk.

Figure 12
The IPCC AR5 conceptual risk assessment framework (IPCC, 2014)



Below, the steps to produce impact forecasts are described, including suggestions to derive IBF from impact forecasts, as part of the production and dissemination of risk-based warnings.

3.3.1. Identify indicators of exposure and vulnerability

Setting up an impact forecasting system requires accurate exposure and vulnerability datasets, which are also crucial to identify relevant indicators for triggering impact warnings.

The analysis of reference risk scenarios and quantitative information on past weather-related impacts enable the identification of indicators to determine the severity of an event. Quantifiable variables on populations, such as the number of people affected by an upcoming hazard, serve as an indicator for the severity of a disaster. In this way, warning thresholds can be defined as specific values of people affected corresponding to increasing emergency conditions and the response capacity needed to cope with the situation. The expected impact on people can also be assessed in terms of estimated numbers of displaced individuals or victims, although such indicators are more complex to forecast. Other important indicators regard impacts on transport networks, especially roads (e.g. Surface Water Flooding Model and Vehicle Overturning Model by the United Kingdom Meteorological Office). Absolute impact thresholds may be complemented with relative thresholds, i.e. ratios compared to the overall resident population in the affected region. Such information helps gauge the capacity of a country or administrative region to cope with the disaster autonomously or if external support is required. For instance, an impact forecasting system for riverine flooding used in the Greater Horn of Africa, determines relative impacts on population to understand regional priorities for humanitarian interventions (Alfieri et al., 2024).

The choice of impact indicators is guided by the information to be included in warning production and dissemination. Furthermore, indicators need to be continuously updated so as to monitor the development of hazard and risk conditions. For example, the European Flood Awareness System (EFAS) uses the number of potentially affected people as an impact indicator to classify the severity of predicted floods, with the indicator being updated every 12 hours to account for changing conditions.

Detailed information on exposure is crucial for delivering reliable and targeted warnings and should include spatially distributed data on population, buildings, services and infrastructures (Process 7). Ideally, these datasets should coincide with those collected and applied in the risk analysis processes. Equally important is the availability of data and methods for characterising vulnerability and quantifying potential impacts (Process 2). Exposure data should account for specific cases such as informal settlements (e.g. refugee camps) which are usually not included in standard statistics and may need dedicated mapping, particularly due to their increased vulnerability (e.g. Zaman et al., 2020).

3.3.2. Identify and implement adequate methods for impact calculation

To produce impact forecasts, hazard forecasts need to be combined with exposure and vulnerability data using methodologies that associate each prediction with the extent and magnitude of expected impacts.

Impact forecasts can include direct and indirect effects, described by quantitative physical and socioeconomic indicators (Merz et al., 2020). Physical and/ or economic damage to buildings and infrastructures can be evaluated using vulnerability functions that relate hazard characteristics with the expected level of impacts (e.g. damaging or failure of a structure, partial/ complete loss of crop yield). Impacts on population are quantified considering the number of people potentially affected by an upcoming hazard, which is usually done by considering people residing or working in hazard-affected areas. A further breakdown can be made considering the exposure of vulnerable groups (elderly people, children, disabled people), which are more at risk of suffering consequences from impending hazards (e.g. risk of drowning from floods, heat strokes from heat waves). As outlined under Pillar 2, the methods for characterising vulnerability in risk scenarios can also assess potential impacts of forecasted hazard conditions. Importantly, the methodologies applied should be able to provide quantitative information on expected impacts (e.g. number and location of roads potentially flooded or damaged by landslides).

Although rarely considered in EWS, indirect impacts can account for a large proportion of total impacts, with longer lasting effects, and affecting a significantly larger area compared to that directly hit by disaster (Botzen et al., 2019). For instance, damage to critical infrastructures such as electricity and water supply networks can lead to service disruptions. Although this is cumbersome to include in the impact computations in real time, the impact forecast can be sustained by reference scenarios that can be built offline and include secondary and cascading effects. In particular, impacts on infrastructures serving specific vulnerable groups, like schools, are of utmost importance and therefore should be included in mapping exercises. This also enables the inclusion of children and youth in various processes of EWS, increasing their understanding and engagement with risk knowledge. As another example, severe drought events can impact a range of economic sectors, from agriculture to energy production and inland navigation networks (Merz et al., 2020). As such, impact chains can be referred to in warning messages (Rossi et al., 2023,[52] Merz et al., 2020).

3.3.3. Identify impact thresholds coherent with the monitored hazard variable(s)

During operational use, impact forecasts are compared with thresholds (based on exposure and vulnerability indicators) to produce risk-informed alerts (Process 2) and select preparedness actions (Processes 0 and 7). For IBF, the quantitative information calculated from impact models may be synthesised to create concise risk-based warnings, aimed at specific end-users. Here, the use of dynamic risk information (e.g. historical and recent events, up-to-date risk scenarios) is crucial for the correct calibration of impact thresholds based on observed events.

Warning and alert thresholds should be linked to specific response actions, taking into account the coping capacity of the areas affected. Also, impact thresholds need to be periodically reviewed to account for changes in coping capacity and risk reduction measures (e.g. improved water management practices against severe droughts, flood barriers, flood storage areas, Processes 0 and 7). EWS themselves, when enabling EA, are an effective adaptation measure and contribute to reducing exposure and vulnerability to disasters (Pappenberger et al., 2015).

Examples of good practice

Nepal's BIPAD is a pilot impact forecasting system that leverages local risk information using large-scale models. The BIPAD portal is currently focused on riverine floods and is undergoing pilot testing at two river stations in West Nepal. It incorporates hydrological forecast data from the Global Flood Awareness System (GLoFAS) for these locations with METEOR flood inundation maps, at different periods to assess and visualize flood impacts effectively.

Integrating flood hazard data with risk assessments from various spatial scales (e.g. vulnerability, coping capacity, exposure), the portal offers real-time visualization of potential impacts from forecasted flood events. The data and information are presented interactively with imaging to facilitate understanding among end-users, empowering them to prepare for the expected impacts.

Although the portal currently integrates global flood forecasts with lead times of up to 10 days, it is adaptable to incorporate local flood forecasts from the Department of Hydrology and Meteorology. This adaptability allows BIPAD to quantify the potential impact levels associated with flood warnings with shorter lead times.

https://www.anticipation-hub.org/news/developing-an-impact-based-forecasting-model-within-nepals-national-disaster-information-management-system-the-bipad-portal

Box 9: How to incorporate ILK into monitoring and forecasting?

Local populations know the early signs in their environment that lead to natural hazards. Local communities and institutions therefore generate hydrological and meteorological monitoring and forecasting information, based on ecological, hydro-meteorological, or celestial indicators. For instance, in the Gandak River basin in India, communities can forecast flood and heavy rainfalls, producing local information that can be triangulated with official and scientific EWS (Acharya and Prakash, 2019). In Southern Uganda, a system of indigenous climate knowledge is used by farmers to anticipate inter-annual variability and rainfall season characteristics, critical for rain-fed agriculture (Orlove et al., 2010). These types of local knowledge systems are of paramount importance for the local effectiveness and sustainability of EWS, and efforts should be made to integrate scientific forecast information to local knowledge systems (Vasileiou et al., 2022). Below some practical actions to successfully integrate local and scientific knowledge into monitoring and forecasting activities are listed:

INFORM

- introduce scientific monitoring and forecasting methods to the local population
- create awareness on different uses of local knowledge in EWS, such as how to generate input maps for validation, or strengthen forecasting models, or support the inclusion of appropriate scientific variables in models
- share knowledge on the benefits and needs of combining modern and local knowledge to predict hazards[53]

CONSULT

- understand the local knowledge system in place for hazard monitoring and forecasting through KII with local knowledge holders, community leaders, local disaster management council members
- consult community members regarding local knowledge on precursors to specific hazards through FGD. For example, in Malawi (Trogrlić et al., 2019) and in Zimbabwe (Dube and Munsaka, 2018) community awareness on EW indicators for floods is acute and could inform scientific knowledge; in Southern Africa, drought forecast data has been collected from local knowledge on trees and plants through structured questionnaires at household level (Chisadza et al., 2015)

- consult local practitioners/ experts, as in the Climate Outlook Fora, where scientific forecasts are discussed between experts of regional (SARCOF) and national/ local levels (https://www.clivar.org/panels-and-working-groups/africa/rcofs)

INVOLVE

- involve local communities in monitoring hazards and reporting environmental variables through crowdsourcing. For example WhatsApp or Telegrams are used by community disaster management committees or local volunteers in GFDRR project in Tanzania (https://www.gfdrr.org/sites/default/files/publication/Floodtags_TZ_final%20report.pdf and https://www.floodtags.com/realtime-flood-monitor-tanzanian-red-cross/), or in Malawi (the Weather Chasers, https://cdkn.org/story/feature-malawi-weather-chasers-celebrating-four-years-of-early-warning-and-civic-action)
- involve local communities in interactive modelling. For example, in Dar-es-Salaam, Tanzania, participatory modelling is applied to urban flood management (Gebremedhin et al., 2020)
- involve local knowledge holders in defining impact thresholds (UNISDR, 2015), or local decision-makers to ensure that ILK fits the local context. For instance, in Spain, community-based site-specific impact-based EWS for schools were developed using ILK for hazard and impact threshold definition (Meléndez-Landaverde and Sempere-Torres, 2022)

COOPERATE

- exposed communities should be integrated in the process of identifying hazard indicators based on their environment and scientific knowledge. Cooperation is necessary between communities relying on local knowledge forecasting systems and scientific communities. Proposing multiple evidence-based forecasting approaches is crucial to ensure EWS ownership and trust (Ebhuoma, 2020)

How to use risk information to improve the dissemination and communication of warnings (Pillar 3)

04

How to use risk information to improve the dissemination and communication of warnings (Pillar 3)

The dissemination and communication of warnings should consider key questions to safeguard that messages assist the intended users in getting prepared, and are addressed to the at-risk population in clear and understandable formats. In most cases, the effectiveness of the warning may entail behaviour changes from the warning being noticed, understood, considered, trusted, confirmed and subsequently acted-upon (Molinari and Handmer, 2011). The first chain of dissemination and communication comes from the hydro-meteorological authorities that issue warnings on weather variables and in some cases provide IBW.

Once these warnings are aired, government actors (e.g. disaster management authorities, civil protection) and sector specific authorities (agriculture, health, infrastructure) need to coordinate with the hydro-meteorological authorities to define context-specific warnings that clearly articulate the target audience and detail the timing and location of the hazard (WMO, 2021). Table 11 illustrates the types of risk information required, and where it might be sourced. In addition, appropriate communication channels should be identified (phones, print media, informal gatherings, sirens, among others).

Although this pillar requires coordinated and collaborative efforts, the legally-mandated authority to issue such warnings should take the lead to ensure credibility. Intermediary organisations should be involved as they enhance trust and uptake of the warning information.[54] Furthermore, in alignment with the existing legal frameworks, multiple warning stages might be adopted if enabled by the lead-time and demanded by the severity of the impending event.

Throughout the chain of communication and dissemination of warning messages, risk information needs to be considered to improve each step.

Table 11
Main type of risk information required for dissemination and communication

Risk information	Possible sources
Demographics disaggregated into various variables (age, gender, literacy, cultural and social backgrounds, disability status etc.), land use and infrastructure data	National Bureau of Statistics census information, household demographic and health surveys
Exposure, vulnerability, and coping indicators for the population, infrastructure and all other exposed elements	Country disaster risk assessment profiles, open-access database
Past information on communication channels, employed, community perception of risks and warnings, impacts	Community engagement and participatory approaches, impact databases

Three processes on how to use risk information in the design of dissemination and communication of warning messages are identified:

- Process 4: how to use risk information to define clear and readily understandable warnings
- Process 5: how to use risk information to identify better and targeted communication methods for at-risk populations
- Process 6: how to use risk information to improve communication flow and strategy

4.1. Process 4: How to use risk information to define warning messages

Warning messages should be defined in a context-specific manner. Prior risk information on target populations, including their demographics and social-cultural backgrounds, helps tailor warnings and determines the most appropriate dissemination channels. Once the warning is issued (e.g. by NHMS), it is the work of other actors, particularly the NDMA, to collaborate with competent institutions (e.g. NHMS, geological services) to transform the risk information, designing comprehensive warnings based on user characteristics. Standardised formats for defining warning messages should be explored. For example, the Common Alerting Protocol (CAP) should be used to design warning messages to ensure consistency, especially if using multiple dissemination channels and uptake. The CAP underlines six points (CAP, 2023) to consider when defining a warning message: what is the emergency, where is it, how soon should actions be taken, how serious is it, how accurate are the forecasts, and what should the recipient do?

Under this process, four key steps can be identified, to define:

- what type of hydro-meteorological hazard it is and when it is expected (Process 1)
- who will be the recipient/ user of the warning
- where the hazard impacts will occur
- what the content of the warning message should be based on the user groups and their roles (including any actions to be taken)

4.1.1. Identification of the hazard type

Typically, a hazard warning message should answer questions on what, when, who, and where. Furthermore, an IBW should include information on the likely impacts and any precautionary measures that the user can take. These elements are based on the CAP and ensure the consistency of the message across all hazards and over all dissemination channels. Risk information on past events and their impacts can be used to improve awareness of expected impacts.
In defining warning messages that are targeted to a specific hazard (hence 'what'), the following principles should be considered:

4.1.2. The user of the message

The question of who the audience is sets the stage. Once identified, risk data on demographics disaggregated to variables including literacy level, occupation, livelihood, language, and socio-cultural background should be used to inform how the warnings are presented. In most instances, risk information at this level should delineate the types of users and inform the likely impacts and precautions that these user groups should take to avoid risks.

4.1.3. Where the hazard will occur

Knowing the geographic location of where the hazard is likely to impact is important to ensure that the messages are directed accordingly. Location data enables the use of mobile EWS ensuring that warnings target risk areas without spreading panic. Geo-tagged messages safeguard that users (including emergency responders) have the required information for targeted actions. Data on exposure (including demographic characteristics), vulnerability and coping capacity can be used to delineate risk areas, if not previously supplied by the impact forecasting system. For example, considering that warning messages possess a location tag, risk information that is disaggregated to the lowest administrative level will help further identify the vulnerability levels and characteristics of the exposed population or assets. To that purpose, capturing disaggregated data on losses, damages and impact would enable the development of context-specific impact warning.

4.1.4. Content of the message

Conventionally, a warning message includes characteristics of the threat (what, when, where), expected impact and recommended actions (WMO, 2021). Therefore, although the content of the warning message might vary depending on the user, the characteristics of the threat using the required standard (such as the CAP) should be maintained. This means that what, when and where remains the same, but the likely impacts and preparedness actions should be defined according to the user characteristics. Again, when using colour schemes, the conventional way of representation should be maintained, where green indicates a 'normal' situation and 'red' represents a level of danger necessitating

alert and possible action (Neußner, 2021). However, as colours such as green and red are not colour-blind friendly, some adjustments need to be allowed to enhance comprehension. Other design features that encourage recipient response need to be included: simple plain language, physical appearance of the message (alert levels, visuals etc.), and length of message (short and precise) - notably adhering to the CAP guidelines.

Various categories of users of IBW have been identified (WMO, 2021) which help tailor the message content to enhance understanding and action, as shown in Figure 13, while Table 12 provides an example of a warning message for floods, according to recipient.

Figure 13
Key impact-based warning message user-groups (WMO, 2021)

Public

- Individual citizens
- Communities (including at risk groups)
- Community leaders ("influencers")

Government

- National government departments
- Local government

Disasters risk reduction and civil protection

- Emergency respoders
- Humanitarian and development agencies

Business

- Local, national and multinational

Infrastructure providers

- Transport
- Telecommunications
- Utilities

Table 12
Example of how to design warning messages for different user-groups

Characteristics of warning message	'Who is the user'		
	User 1 (road managers, motorists, pedestrians etc.)	User 2 (local community-farmers, pastoralists etc.)	User 3 (emergency responder, humanitarian actors, etc.)
What	Flooding caused by excessive rainfall is expected		
Where	A section of the southwest of ['names of districts/locality] and levels of neighbouring ['names of rivers'] expected to rise		
When	For consecutive 'hours/days', from 'time-date' to 'end time-date'		
Likely impacts	Flood water over major roads in the area, with water levels expected to rise along ['names of bridges']. Overflow in the drainage systems expected	Submerged croplands, flooding of low-lying flood-prone areas. cut-off roads [name of roads]	Flood water over major roads in the area, with water levels expected to rise along ['name of bridges']. Overflow in the drainage systems expected. Submerged croplands, flooding of low-lying flood-prone areas, cut-off [name of roads]
Precautionary/ preparedness actions	Avoid driving on flooded water, turn around. Do not cross flooded roads. Avoid ['names of roads']. Be cautious at night when recognising flooded roads is difficult	Move to higher grounds. Avoid flood waters. Dig trenches to drain water from farms and houses. Store produce in water-tight containers. Vaccinate livestock	Here the message should have precautionary measures to 'self'. [e.g. avoid flooded roads, move to higher grounds] [This user should use the likely impacts to define actions to help the at-risk groups]

Examples of good practice
The U.S. National Weather Service issues warning messages that are tailored to specific hazards with answers to issues of who, where, when and likely impacts. See https://www.weather.gov/. Official warnings and alerts are also available on national weather service websites for different countries around the world (https://www.smhi.se/en/weather/warnings-and-advisories/warnings-and-advisories/warnings, https://www.weathersa.co.za/home/warnings).

On the contrary, a study in Uganda showed that local flood affected communities were not able to act based on the warnings issued by the National Meteorological Authorities due to the format and language used, thereby affecting early actions (Mitheu et al., 2022)

4.2. Process 5: How to use risk information to communicate in an effective and targeted manner

Warning messages are effective if they reach the population at-risk at the right time and in a readily understandable format for people to act. To ensure dissemination to a wide audience, it is important to consider context-specific characteristics of the intended users to design user-oriented warnings (Kox et al., 2018). Risk information on demographics disaggregated according to variables should be used to inform the choice of communication and dissemination method. Depending on the location, information on previously used communication methods and their effectiveness should guide the choice. Furthermore, mapping the coverage and accessibility of available channels should inform what exists and their effectiveness. A multi-channel approach ensures that the needs of individual communities/ users are fulfilled, requiring the following considerations:

- identify the specific characteristics of the user/ users
- identify the communication channels that best suit the users based on their location
- identify communication channels that have been used in the past and their effectiveness
- decide on the time of dissemination to reach the intended/ identified users

4.2.1. Specific characteristics of the user

Specific user characteristics inform the most effective communication and dissemination methods to apply. Consideration of factors such as age, gender, disability status, literacy level, and social-cultural background help identify which method is most effective.

4.2.2. Communication channels

The appropriate communication channels to adopt will depend on their location, as well as factors such as coverage, reliability (in remote areas), format and timeliness (WMO 2021). Multiple communication channels, including media and informal communication (community gatherings etc), might be applicable to ensure that the warning message is better targeted. For example, media (radio, megaphones) are less suitable for those with impaired hearing and intellectual disability, while flyers with simple text and pictograms might be more effective. Information on the type of hazard (slow or rapid onset) is important to understand the lead-time required in communicating warnings and should be used to determine the choice of channel. For example, faster methods of dissemination (radio, sirens, phones) should be considered for rapid onset hazards to ensure that warnings reach the recipient in time for preparedness.

4.2.3. Information used in the past

Information on past and current communication channels and their reliability can inform the best method to adopt.

4.2.4. Time of dissemination

Messages need to be timed to ensure they reach their intended audience. Information gathered through community engagements and participatory approaches can help determine issues such as when household members are likely to be home or lead times for transmitting information to permit the necessary operations.

Box 10 highlights the risk information used to decide on effective communication methods.

Box 10: Location ['name of the area that the warning needs to be communicated]
Characteristics of the population: [Source National Bureau of Statistics]
Population: 5000people
Age bracket: 0-80 years, Male 54%, Female 46%
Disability status: 10% of population with disability [hearing, visual impaired, physical]
Literacy levels: 50% of the population can read and write using the main language.
[include all other variables that help define the audience]
Communication infrastructure coverage: No internet coverage / 100% power coverage / 80% mobile phone ownership

Which communication methods would be appropriate?
Mobile phones text messages
Inform gatherings (local language)
Local radios broadcast
Simple flyers
etc.

Communication systems also need to be tested during pre-defined times to ensure that they work properly when needed. Tests/ drills can be done through community participatory and simulation exercises thereby improving public reassurance.

Example of good practice
Bangladesh: a study on an EWS for cyclones was carried out in 2 districts, where the socio-economic profile (gender, household composition, occupation, roof type) of the communities was used to assess their perceptions and interpretation of warning messages. Results identified the preferred communication and dissemination channels, and specified reasons why residents refused to respond to warnings (Roy et al., 2015) https://www.sciencedirect.com/science/article/abs/pii/S2212420915000175?via%3Dihub

4.3. Process 6: How to use risk information to improve communication flow and strategy

Communication and dissemination of warning information should be a two-way process, Giving feedback builds confidence among users of the information being circulated and allows providers to further tailor their information. Furthermore, past information on the access and use of warnings can help develop better strategies for communication and delivery of warnings. Three steps are involved:

- gather risk information on access, community perception, methods used and historical performance
- develop a strategy on how to improve design and communication using past information
- identify back up measures in case communication channels fail

4.3.1. Gathering risk information

Historical/ past information on people's experiences in accessing and using warnings (e.g. format, channel used, timeliness) is critical in defining how warnings are designed and communicated. Community participation and engaging local NGOs who work with populations-at-risk can help shed light on how warnings are perceived and the effectiveness of the communication methods used. Promoting awareness campaigns at local level can help communities understand the risks they face.

4.3.2. Developing a strategy

Warning/ alerting institutions need to work collaboratively to design a communication and dissemination strategy. The strategy needs to be a living document that is regularly updated so that lessons learned are used to improve the design and diffusion of future messages.

4.3.3. Resilience of communication channels

Communication channels need to be resilient, and fit for purpose, with backup plans for any unforeseen failures. The international technical standards of communication methods must be adhered to so as to enable comparisons with other countries using the same standards (Rossi et al., 2018). Some of these internationally known standards provide a way to test the efficacy of the communication system based on certain requirements (Table 13). Such tests help ensure that the choice of communication methods is well informed.

Table 13 highlights how different notifications can be tested according to what is required and the technology each system adopts. In this example from Europe, these mobile device notification systems include paging, Instant Messaging (IM), Cell Broadcast (CB), SMS bulk messaging, Multimedia Broadcast/ Multicast Service (MBMS), Multimedia Messaging Service (MMS) and Unstructured Supplementary Service Data (USSD). Testing will show which systems are compliant and ensure the correct notification system is chosen.

Table 13

Example of how to verify communication methods against certain requirements. (Rossi et al., 2018)

Emergency notification system shall	Paging	CB	SMS	TV	MBMS	MMS	USSD	Email	IM Service	Legend
be able to reach citizens in their own dwelling	V	V	V	V	V	V	V	V	V	V = compliant
be able to reach citizens at their place of work	V	V	V	V	V	V	V	V	V	V = compliant
be able to reach citizens in public venues	V	V	V	V	V	V	V	V	V	V = compliant
be able to reach citizens on foot	V	V	V	V	V	V	V	V	V	V = compliant
be able to reach citizens in a vehicle	V	V	V	V	V	V	V	V	V	V = compliant X = watching video while driving a vehicle is not desired
be able to reach a citizen visiting another European country	V	V	V	V	V	V	V	V	V	V = compliant 0 = compliant when phone is configured correctly

Source: ETSI TS 102 182, 2010

Box 11: How to incorporate ILK into warning communication and dissemination?

Incorporating ILK into warning communication and dissemination necessitates the collaboration and engagement of government sectors, community leaders and vulnerable groups. Literature reveals that communication gaps (language, formats, content) in EWS are the main cause of decreased coping and response capacities among vulnerable groups affected by natural hazards (Mitheu et al., 2022). Everyone needs to have access to and understand warning messages (Hermans et al., 2022), which is enhanced by the use of local language and communication channels. Surveys conducted in Ethiopia, Kenya and Uganda reveal that over 80% of the population triangulate local knowledge and external information, and better trust external messages if they integrate local contexts, knowledge and experienced impacts (Trogrlić et al., 2023). As such, EWS need to be flexible in their design to accommodate local differences in access to information while still ensuring standard information delivery.

Practical actions enabling the inclusion of ILK into warning communication and dissemination should be considered according to the following three community engagement objectives:

CONSULT

- hold community engagements and participatory exercises to identify critical communication channels and understand past challenges in the use of warnings. Map the best combination of communication channels using local technologies,[55] ensuring that the needs of the most disadvantaged people are reached
- consult communities to understand how local knowledge based warnings are transferred among people in the community, including low-to-no technology (bamboo instruments, drums, horn)

INVOLVE

- involve community leaders in creating awareness and building trust on warnings. The co-production of video clips, with community input, improves the understanding of specific risk scenarios (Nakano et al., 2020) and therefore the contents of warning messages
- co-design warning messages: work with community members so that messages are clear, culturally appropriate, and accessible to all. This may include using local languages (verbal/ non-verbal) and symbols, being aware of literacy levels as well as traditional communication methods
- involve the community to choose which staged and colour-coded system is most appropriate given the local context

COLLABORATE

- work with community leaders to identify locations of vulnerable groups and how warning messages could reach them. In the Lower Mekong River, community members were trained to lead persons with disabilities and children to safety upon receiving flood warnings (IFRC, 2012a)
- collaborate with communities to create feedback mechanisms after disasters to improve communication and dissemination processes
- co-design community-centric EWS tools. The ITIKI[56] Mobile application monitoring, forecasting and issuing drought alerts in Kenya, Mozambique and South Africa was developed out of community centric design studies with local farmers, and integrates local and scientific knowledge (Masinde et al., 2013)

EMPOWER

- empower community leaders or mediators to take an active role in disseminating warnings using informal channels and in providing feedback on warnings. Local committees around the Zambezi Basin in Mozambique were empowered to notify the population with colour-coded flags, whistles and loudspeakers of imminent hazards (IFRC, 2012a)

How to use risk information to improve preparedness to respond (Pillar 4)

05

How to use risk information to improve preparedness to respond (Pillar 4)

When an EW is issued, it is a call for actors, including national and local authorities, businesses, communities, NGOs, the IFRC, UN and community groups to activate their respective P&R plans to reduce the impact of the hazard (WMO, 2022b). This entails the activation of responsible institutions from national to local level and their associated communication and coordination mechanisms, as well as the mobilization of anticipatory humanitarian aid and the implementation of self-protection measures by the community.

P&R should be designed based on risk knowledge: it informs planning and procedural elements, and guides P&R strategies - including EA and simulation exercises. Based on reference impact scenarios (Process 0), P&R planning allows key actors to envision, anticipate and solve problems that can arise during disasters (UNDRR Terminology, 2015).

For P&R, it is crucial that each relevant actor builds on risk knowledge, including:

- design of EA[57] and preparedness measures for protecting people, assets and the environment
- definition of mechanisms for the progressive activation of EA and emergency coordination arrangements

5.1. Process 7: How can risk knowledge support a progressive activation of early actions and emergency coordination arrangements?

Acting ahead of predicted hazardous events can safeguard lives and livelihoods and prevent or reduce impacts before they unfold. This results in more resilient communities and fewer people in need of emergency assistance (UNDRR, 2023).

As mentioned in Process 0, anticipation necessitates (i) reliable impact scenarios to guide action, (ii) related skilled forecasting and effective EW, (iii) operational capacities of actors to deliver EA, and (iv) pre-defined financing mechanisms to support the implementation of EA. Forecasts and EW provide probabilities about when and where a hazard of a particular intensity might hit, while impact scenarios illustrate the vulnerability, capacity, exposure of people or assets in the area, and the potential effects of the impinging hazard (adapted from ASEAN, 2022).

Based on those potential impacts, authorities and communities should plan tailored and grounded AA based on reference impact scenarios that rely on current priorities and resources (adapted from WMO, 2022a) and are clearly linked to pre-agreed triggering mechanisms for an efficient activation of EAs.

This process will examine how risk knowledge emanating from EW information and reference impact scenarios can:

- help decision-makers understand when to act
- support the development of a mechanism for a progressive and coordinated activation of EA and the emergency system through a phased approach

Key steps include:

- evaluate the window(s) of opportunity
- design and plan the EA
- define the activation mechanisms for EA, taking into account the windows of opportunity
- design, if appropriate, a progressive phased approach to EA and adapt the organisational arrangements

5.1.1. Evaluate the window(s) of opportunity

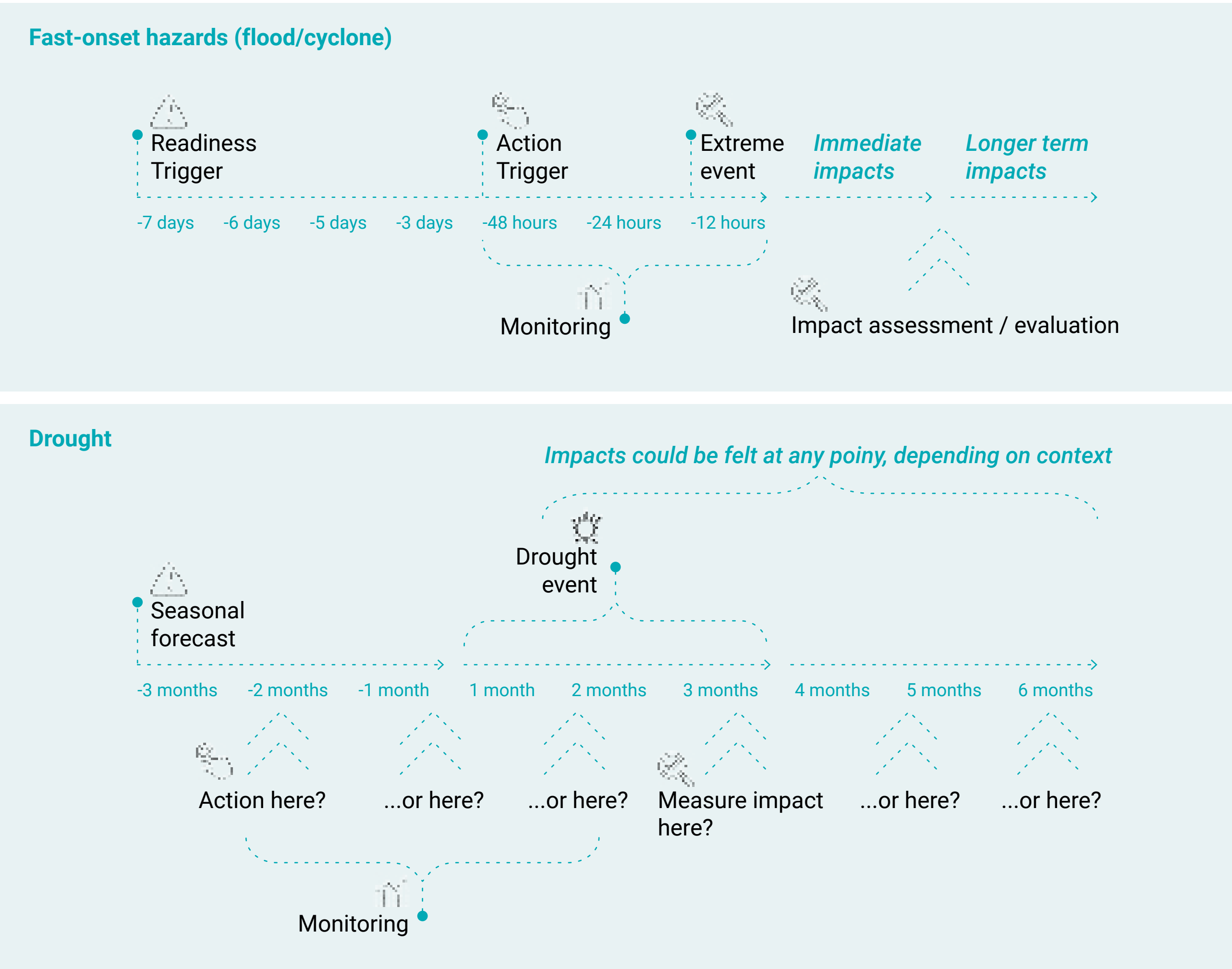
AA occur within the window of opportunity between receiving an EW and the onset of a hazard. As such, this concept refers to the timing of the hazard's onset, its lead-time, and the duration required by actors to implement EA after receiving an EW. In the case of rapid-onset events like floods, AA typically occur prior to the hazard event. Conversely, for slow-onset events such as droughts, AA may occur either before or after the initial hydro-meteorological or climatic hazard event, but always before the impacts of the disaster materialise on communities or societies (ASEAN, 2022).
Figure 14, below, illustrates the differences in timelines between droughts and fast-onset hazards such as floods and cyclones.

Forecasts for fast-onset hazards typically give a relatively narrow window of opportunity to act. For example, the amount of time for physical impacts to occur from a cyclone making landfall or a land area being flooded is usually short: hours to days, or sometimes weeks if severe and prolonged or repeated flooding occurs (WFP, 2021). In this context, the choice of EA is limited by time constraints and therefore the P&R planning has to be more efficient, and actors and communities more prepared. This can be addressed through exercises to test the EW-EA system, using a realistic scenario and involving at-risk communities.

On the other hand, slow onset disasters that build up gradually over time give longer and multiple windows of opportunities during which to undertake specific EA, before the peak of the negative impact is reached.

Furthermore, a window of opportunity should be evaluated in relation to available capacities and resources (see 'activation mechanism' below), as well as the time needed to implement AA (ASEAN, 2022) together with the reference impact scenarios.

Figure 14
Differences in timelines between fast-onset hazards (flood/ cyclone) and droughts (WFP, 2021)



As a concrete example, a possible flood might hit a:

- municipality located along a watercourse that drains a large catchment area (M1), or
- municipality located along a watercourse that drains a small catchment area (M2)

If both municipalities are characterised by the same contexts (capacity, exposure and vulnerability) and EWS of thresholds, the window of opportunity to act on an EW for M1 will be longer (12-24 hours), than that for M2 (less than 1 hour). This will influence the implementation of the EWS, as well as the actions the warning might trigger.

5.1.2. Design and planning of early actions

EA is defined by the EA database of the Anticipation Hub. Certain elements pertinent to the design and planning of EA are as follows:

- actions must align with the reference scenario outlined in Process 0: thus identify targets for action, including their vulnerabilities, from a spatial perspective
- users must assess whether the required actions align with available resources and capacities. For example – whether or not a community has received prior information and carried out simulation exercises, enabling them to act quickly on receiving a warning, or requiring more assistance
- users must ensure that the proposed action can be executed within the window of opportunity, and evaluate whether the necessary resources and capacities are available. For example, in M1 above, decision-makers may be able to evacuate at-risk individuals safely. However, in M2, evacuation may not be feasible, necessitating, sending a message to at-risk individuals to advise them to seek shelter on higher floors, based on the knowledge that high rise buildings (more than 2 floors) exist in the area

5.1.3. Activation mechanism

Decision-makers need to strategically plan the timing of EA by considering both the impact scenario developed in Process 0 and the most relevant forecasts and EW associated with that specific hazard (Processes 1, 2, and 3). The concept of "windows of opportunity" can be operationalized through activation mechanisms and phases, serving as a cornerstone of EA implementation.

As a fundamental requirement, EW should serve as the trigger for initiating EA in accordance with the

anticipated scenario. Moreover, upon activation, decision-makers must conduct a comprehensive assessment of the current risk situation and available capacities. This evaluation may involve factors such as recent events altering the risk context or significant public gatherings occurring in the area.

To establish the activation mechanism, it is essential to:

- define thresholds and evaluation mechanisms for activating EA based on the impact scenario, including hazards and potential impacts. This should also consider elements identified during the evaluation of the window(s) of opportunity
- evaluate the capacity to implement EA, which relies on the impact scenario in terms of exposure and vulnerability assessment. This evaluation should incorporate qualitative factors, such as identifying the targets of protection and their specific vulnerabilities and needs, as well as quantitative information, including the number and location of these targets

Activation mechanisms for EA do not always necessitate a specific threshold. For instance, upon receiving an EW, disaster risk management officials may convene various stakeholders to evaluate the situation and determine whether AA is warranted. Importantly, there should be a protocol in place outlining how decisions are made based on forecasts, EW, and risk information to ensure timely decision-making and action (adapted from ASEAN, 2022).

5.1.4. Activation mechanism through a progressive adaptive approach

More advanced systems can count on a set of thresholds developed on the basis of progressive and updated EW as the hazardous event unfolds, while new observations become available and forecasts become more accurate and precise. Particularly for fast-onset hazards, where the window of opportunity is short, it is crucial to have a highly efficient system. This system must be capable of continuously monitoring the situation and promptly alerting relevant stakeholders. Additionally, it should be agile enough to adapt to evolving conditions, including incorporating updated forecasts into real-time monitoring. This level of efficiency is essential for ensuring timely warnings and the implementation of EA, especially when the safety of at-risk individuals is at stake. The following simulations of EA protocols can be taken as concrete examples: Optimising protocols for early action in Ethiopia, Flood early action protocol (EAP) Simulation Exercise (SIMEX) scoping visit in Busia, Kenya.[58]

This approach enhances the opportunities for EA by facilitating a gradual activation process that can effectively address uncertainty and mitigate economic and social costs associated with specific actions. By employing a phased approach, referred to as "activation phases," the operational mobilisation of actors and the management of forecasted events across different territorial coordination levels can be systematically organised.

The term "activation" pertains to the mobilisation of the actor system and the management of forecasted events, while "phases" refer to the stages triggered by increasing scenarios related to EW and their associated AA and coordination arrangements (Giambelli et al., 2023).

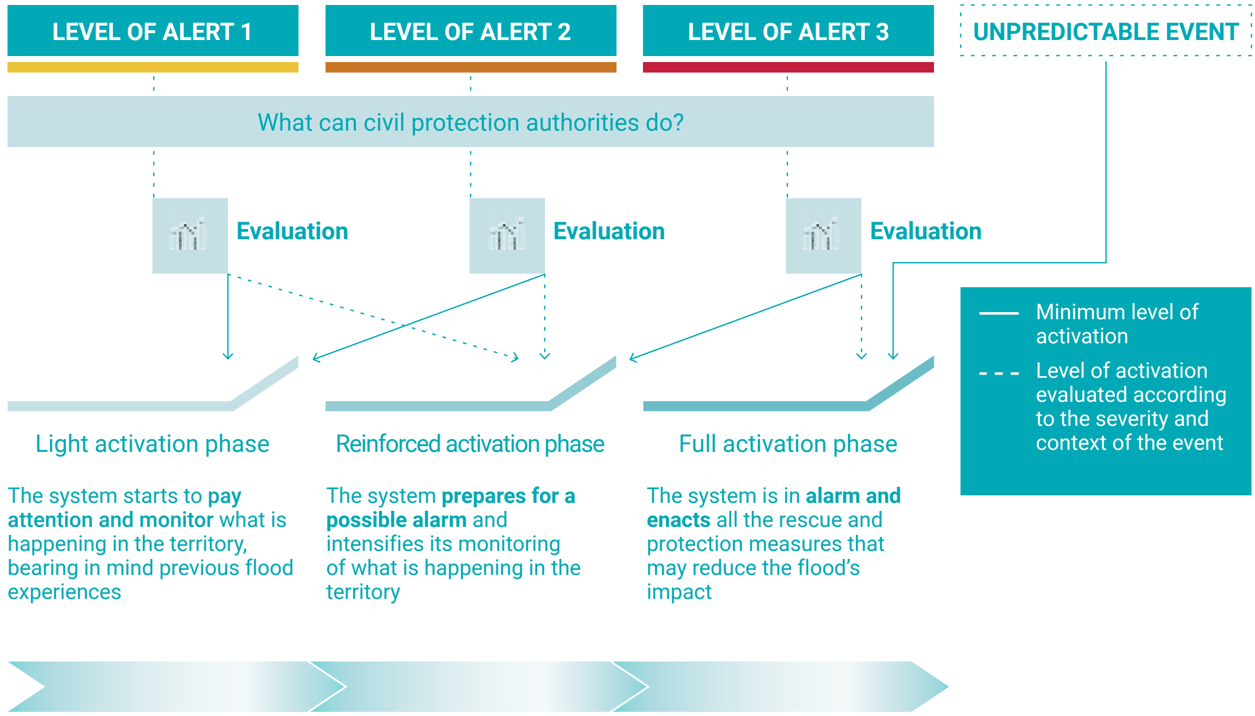
Understanding these activation phases is aided by examining the terminologies used in different contexts, such as 'Attention', 'Pre-alarm', and 'Alarm' in Italy, and 'Monitor', 'Prepare', and 'Act' at the Emergency Response and Coordination Centre (ERCC), or 'Stand by' and 'Alert' in Australia (Australian Disaster Resilience Knowledge Hub, 2020).
For example, Figure 15 illustrates increasing activation phases - Light, Reinforced and Full - linked to the severity of the warning (level of alert) associated with flood impact scenarios.

Each phase delineates the level of activation required by actors to execute planned measures and actions. With this framework in mind, a specific configuration for the activation of operational coordination centres and involvement of actors can be established in a modular and/ or progressive manner, depending on the evolution of EW and the hazardous event.
Such phased approaches are also applicable to slow hazard onsets, as outlined in Process 0 (timeline approach) and the evaluation of windows of opportunity.

Therefore, the establishment of a progressive activation mechanism is based on:

- identifying multiple thresholds within associated classes of risk-informed scenarios that consider elements related to windows of opportunity. This type of activation is bolstered by multiple impact scenarios or scenarios based on augmentation or timeline approaches (Process 0)
- prioritising and progressively activating EA based on risk analysis or the combination of hazard probability with exposure and vulnerability. The capacity of various stakeholders, ranging from forecasting and monitoring to dissemination and activation of EA, plays a pivotal role in the operational functioning of such an activation mechanism

Figure 15
Increasing activation phases of the civil protection system and related early actions for floods. Source: (Giambelli et al., 2023)



Some general notes for Process 7:

- while planning for P&R in disaster management, flexibility is essential. The operational approach should be adaptable to the evolving phenomena and its impacts, as well as the fluctuating operational capacity available over time
- plans must be regularly updated to account for climate change trends and compounding risk factors (WMO, 2022b)
- local actors should develop EA that aim to provide 'no-regret' interventions benefiting exposed groups, even if the hazard does not materialise
- assessing capacities within communities at risk not only supports P&R efforts but also facilitates the identification of opportunities and methods to strengthen and leverage these capacities for reducing disaster risk

For further details on activation mechanisms and for examples in the implementation of EW-EA System, see Bibliography, references for Section 5.1.4

Example of good practice

Forecast-based Financing (FbF) is a funding mechanism of the Red Cross and Red Crescent (RCRC) movement to release money to national societies prior to a disaster occurring. It is based on hydro-meteorological forecasts and risk analysis (IFRC, 2023). This enables them to take EA to prevent or mitigate the impact of the disaster, by providing basic needs such as food, water, and shelter to people in danger. FbF is a relatively new approach to humanitarian funding, but it has been shown to be effective in reducing the impact of disasters. For example, in 2021, the FbF was triggered to help communities in Madagascar prepare for a drought. As a result, the number of people affected was significantly reduced. FbF is a more efficient and effective way to use humanitarian resources, and can help save lives. The Anticipation Hub[59] provides an overview of AA initiatives from around the world.

Risk information is essential for setting up a FbF scheme, because it forms the foundation upon which effective and timely humanitarian response can be built. FbF is a proactive approach to disaster management that aims to allocate resources and trigger actions based on EW forecasts rather than waiting for a disaster to occur. In this context, risk information plays a crucial role for several reasons.

FbF schemes require a thorough risk assessment to determine the potential impacts of a disaster. Risk information, including historical data and vulnerability assessment, is essential for accurately assessing the level of risk a community faces. This assessment guides the design of the FbF scheme determining the pay-outs and thresholds for the activation of the mechanism, similar to how parametric insurance works.

Risk information is also essential to better target the dissemination of finances through the territory, prioritizing interventions according to the location of vulnerable groups and their expected numbers. Ideally, the risk scenario would assist understanding when to scale operations up or down according to changing risk levels.

Furthermore, risk information can support beneficiaries in spending the resources effectively (e.g. on food, clean water, or other essential services that the risk scenario might highlight as priority challenges for that territorial context).

Effective FbF schemes involve engaging with local communities. Risk information helps in community sensitization and preparedness activities. When communities are aware of the impending risks and understand the importance of EA, they are more likely to cooperate and take measures to protect themselves.

Having access to risk information helps in accountability and transparency. When decisions are based on credible forecasts and risk assessments, it is easier to justify actions and demonstrate that resources were allocated appropriately.

In conclusion, risk information is the cornerstone of a successful FbF scheme. It enables timely and informed decision-making, cost-effective resource allocation, community engagement, and a proactive approach to disaster management.

For more in-depth guidance on the above issues, consult:

- Forecast-based Financing Practitioners Manual (https://manual.forecasr-based-financing.org)
- https://www.anticipation-hub.org/learn/methodology

Box 12: How to incorporate ILK into preparedness and response planning?
Local and indigenous people generate considerable knowledge and practices on disaster preparedness over time (Dekens, 2007). Based on a Kenyan case study, the inclusion of such risk knowledge in disaster P&R planning is necessary to implement relevant and effective EWS (such as livestock, farm or food management options, or evacuation) and reduce future disaster impacts on vulnerable communities (Mitheu et al., 2023b). It can also ensure that P&R activities become more equitable and socially just, from both procedural and judicial aspects ((Van Den Homberg and Sadik Trogrlic, Robert, 2023)). While many actors are responsible for P&R actions, the involvement of communities most affected by hazards is critical as they provide locally contextualised information that can help develop tailored and targeted AA (Mitheu et al., 2023a). Indeed, EWS should consider the needs of all, and that vulnerability and socio-economic contexts significantly influence people's capacity to prepare and act early (Akerkar et al., 2020). EWS designs should therefore ensure that all disaster actors and communities-at-risk have sufficient knowledge and capacity to respond to EW messages; this can be achieved by assessing the barriers and opportunities in using EW information among affected communities (Mitheu et al., 2022). The following community engagement processes have been identified to ensure the inclusion of ILK into P&R planning.

INVOLVE

- involve local community in assessing the underlying causes of changing risks (e.g. deforestation, demographic trends, agriculture practices)
- use local knowledge to identify EA and ensure they are appropriate (technically, socially and culturally) to the local context (Fakhruddin et al., 2015). Communities have specific knowledge on local socio-economic contexts, as well as different needs and coping capacities, as illustrated in a case study from Ethiopia (Mitheu et al., 2023c)

COLLABORATE
Collaborate in designing adapted EA solutions, ensuring that they address local needs and priorities (e.g. defining the best evacuation route, temporary shelters types). Designs on EA should include ILK

on context-specific factors that could influence the implementation of the action, including gender and diversity dimensions.

For example, a project from the American Red Cross focussed on extending an EWS to refugee settlements of Cox's Bazar, Bangladesh.[60] They ensured these at-risk communities were effectively prepared and able to respond to cyclone-associated risks through strengthening knowledge and coping capacities, community involvement and collaboration to include anthropogenic and cultural perspectives in disaster preparedness activities.

EMPOWER
Empower the community to implement the preparedness, EA or response plan, and allow communities to give feedback in a timely manner:

- participation in P&R exercises and activities can empower communities to train others on the use of local knowledge during search and rescue exercises. For example, the Nepal Red Cross Society organised community-based risk management training in 20 districts, including traditional ways of building rafts from banana trees to evacuate people. This saved lives in Jhapa district during the 2017 Flooding (IFRC, 2021)
- learn from experts and community sharing experiences and knowledge in stocking food and basic life supports

The inclusion of such knowledge, combined with disaster awareness and management campaigns, facilitates the engagement of the community in preparing to respond to emergency conditions.
Villagers discussing dyke design and construction with consultants in GVH Nafafa in Malawi (Van Den Homberg and Sadik Trogrlic, Robert, 2023)

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ANNEX
List of global and open-source datasets for risk data

Annex - List of global and open-source datasets for risk data

Below is a non-exhaustive list of risk-related free and open-source datasets, that are commonly used for producing risk information that inform EWS. The Review of Lindersson et al., 2020 provides additional references specific to floods and droughts.

General risk data	
Risk data library (GFDRR and WB)	https://riskdatalibrary.org/ and https://datacatalog.worldbank.org/search/collections/rdl
Community-level disaster risk data (GNDR)	https://www.gndr.org/impact/views-from-the-frontline/explore-the-data/

Historical Impacts data	
Desinventar (UNDRR), multi-hazards, national	https://www.desinventar.net/DesInventar/thematic_def.jsp
EMDAT	https://www.emdat.be/
GDACS	https://www.gdacs.org/Alerts/default.aspx
Floodlist	https://floodlist.com/
Emergency appeal, post disaster need assessments and disaster impact and need assessment reports	https://www.ifrc.org/emergencies/all https://go.ifrc.org/

Hazard data	
Earthquakes	https://www.usgs.gov/programs/earthquake-hazards
Environmental data	https://www.ncei.noaa.gov/
IRI Climate society	https://iridl.ldeo.columbia.edu/
HydroShed (hydrological database)	https://www.hydrosheds.org/products/hydrosheds
Satellite precipitation	https://www.gloh2o.org/mswep/ https://sharaku.eorc.jaxa.jp/GSMaP/
Land Products from NASA MODIS sensor (imaging spectroradiometer)	https://modis.gsfc.nasa.gov/tools/
SoilGrid (Global Soil characteristic)	https://soilgrids.org/

Exposure data	
OpenStreetMap (OSM)	https://openstreetmap.org
Humanitarian data Exchange (HDX- UNOCHA) National and global datasets	https://data.humdata.org/
Displacement	https://environmentalmigration.iom.int/developing-indicators-displacement-disaster-risk-reduction
Population	https://sedac.ciesin.columbia.edu/data/collection/gpw-v4 https://hub.worldpop.org/geodata/ https://human-settlement.emergency.copernicus.eu/copernicus.php
FAOSTAT, food and agriculture data	https://www.fao.org/faostat/en/#home
The Global Land Cover-SHARE (GLC-SHARE)	https://data.apps.fao.org/catalog/dataset/global-land-cover-share-database

Vulnerability data	
Poverty and vulnerability indexes	https://www.ciesin.columbia.edu/sub_guide.html

Note

1 https://www.undrr.org/drr-glossary/terminology

2 https://library.wmo.int/viewer/58209/download?file=Executive_Action_Plan_en.pdf&type=pdf&navigator=1

3 https://www.desinventar.net/DesInventar/

4 https://www.emdat.be/

5 https://www.munichre.com/en/solutions/for-industry-clients/natcatservice.html

6 https://www.sigma-explorer.com

7 https://floodlist.com/

8 https://reliefweb.int/disasters

9 https://go.ifrc.org/

10 https://recovery.preventionweb.net/build-back-better/post-disaster-needs-assessments/

11 https://www.undrr.org/building-risk-knowledge/disaster-losses-and-damages-tracking-system-dldt

12 https://www.undrr.org/disaster-losses-and-damages-tracking-system

13 https://www.undrr.org/news/disaster-forensics-learning-past-build-resilient-future#:~:text=The%20Forensic%20Investigations%20of%20Disasters,of%20disaster%20risk%20reduction%20plans

14 https://www.undrr.org/publication/hazard-definition-and-classification-review-technical-report

15 https://www.undrr.org/publication/hazard-information-profiles-hips

16 https://www.planet.com/pulse/ihme-microsoft-and-planet-collaborate-to-map-climate-vulnerable-populations-in-unprecedented-detail/

17 https://human-settlement.emergency.copernicus.eu/copernicus.php

18 https://www.unescap.org/sites/default/d8files/event-documents/Factsheet_DRSF.pdf

19 https://www.mistralportal.it/

20 https://www.ogc.org/about-ogc/domains/eranddm/

21 Risk data open standard: https://www.rms.com/risk-data-open-standard

22 https://rix.undrr.org/

23 https://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2-os.html

24 UNESCO's Local and Indigenous Knowledge Systems programme (LINKS): https://en.unesco.org/links

25 https://futureclimateafrica.org/coproduction-manual/book/text/02.html#22-co-production-of-weather-and-climate-services

26 https://www.ifrcvca.org/_files/ugd/7baf5b_bb97b862b57c4c33b02d6e8ac9b44dc7.pdf

27 https://docs.google.com/viewerng/viewer?url=https://nrctoolboxstrg.blob.core.windows.net/nrc-toolbox-docs/6%255CAT.5.3%2520Social%2520Cultural%2520Influence%2520Analysis%2520Tool%2520-%2520Key%2520Informant%2520Interview.docx

28 https://www.ifad.org/documents/38714170/39144386/PM_web.pdf/7c1eda69-8205-4c31-8912-3c25d6f90055

29 https://www.hotosm.org/resources/participatory-mapping-toolkit/

30 https://www.ifrcvca.org/

31 https://unfccc.int/ttclear/tec

32 https://earthobservations.org/index.php

33 https://unfccc.int/news/powering-climate-action-through-earth-observations-technology

34 https://emergency.copernicus.eu/
35 https://anticipatory-action-toolkit.unocha.org/
36 https://www.fao.org/3/cb7145en/cb7145en.pdf
37 https://www.ifrcvca.org/
38 https://www.pprdeast3.eu/
39 Adapted from UNDRR 2023: Words Into Action: A Guide To Multi-Hazard Early Warning Systems
40 https://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_combinedDroughtIndicator.pdf
41 https://www.avalanches.org/standards/avalanche-danger-scale/
42 https://effis.jrc.ec.europa.eu/reports-and-publications/annual-fire-reports
43 Numerical Weather Prediction (NWP) computer models process current weather observations to forecast future weather. Output is based on current weather observations, which are assimilated into the model's framework and used to produce predictions for temperature, precipitation, and hundreds of other meteorological elements from the oceans to the top of the atmosphere (https://www.ncei.noaa.gov/products/weather-climate-models/numerical-weather-prediction).
44 https://www.globalfloods.eu/
45 https://reliefweb.int/report/ecuador/ecuador-extreme-rainfall-related-el-ni-o-phenomenon-early-action-protocol-summary
46 https://glam.nasaharvest.org/
47 https://earth-observation-risk-toolkit-undrr.hub.arcgis.com/pages/drought-early-warning-in-uganda
48 https://www.weathersa.co.za/home/warnings
49 https://reliefweb.int/report/papua-new-guinea/early-warning-system-drought-implemented-png-crews
50 https://www.metmalawi.gov.mw/
51 https://signature.bmkg.go.id/
52 Rossi, L., Wens, M., De Moel, H., Cotti, D., Sabino Siemons, A., Toreti, A., Maetens, W., Masante, D., Van Loon, A., Hagenlocher, M., Rudari, R., Naumann, G., Meroni, M., Avanzi, F., Isabellon, M. and Barbosa, P., European Drought Risk Atlas, Publications Office of the European Union, Luxembourg, 2023, doi: 10.2760/33211, JRC135215.
53 https://www.climatecentre.org/scrollies/netherlands-red-cross/uganda/
54 https://www.510.global/effectiveness-of-drought-warning-communication-dissemination-in-malawi/
55 https://communityengagementhub.org/wp-content/uploads/sites/2/2021/12/TOOL-19.-Communications-methods-matrix.pdf
56 https://urida.co.za/
57 EA is defined as a set of actions 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 (REAP, 2022). Within the Handbook, 'EA' and 'AA' are used as synonyms.
58 https://www.climatecentre.org/3962/optimizing-protocols-for-early-action-in-ethiopia/
59 https://www.anticipation-hub.org/
60 https://globalcompactrefugees.org/good-practices/expanding-early-warning-refugee-settlements-coxs-bazar

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